CHAPTER IX

USE OF GYPSUM IN PORTLAND CEMENT

Gypsum, either calcined or crude is universally used as the Purpose retarding element in Portland cement. Cement should not develop its initial set in less than 45 minutes, nor its final set in less than ten hours.[154]

The sulphur trioxide (SO_3) is the active agent in the gypsum which renders it valuable as cement retarder. According to generally accepted conclusions, high alumina cements require more SO_3 to make them usable during the hot humid season than the low alumina and high iron-oxide cements; and further, the finer a cement is ground the more SO_3 is required to prevent it from setting too quickly.[155]

If sulphur trioxide is present in considerable quantities the Limits strength of the cement is weakened. Standard specification limit the SO_3 in Portland cement to 2 per cent.

Crude gypsum is generally used, on account of its cheapness as compared with calcined gypsum. The SO_3 content of the Forms used gypsum is generally specified in cement mill contracts. It is common practice to specify gypsum containing 42 per cent SO_3, though mineral carrying only 35 per cent SO_3 is at times used. When crude gypsum is used it is added to the clinker and ground with it.

Some cement chemists prefer calcined gypsum even though the cost per ton is twice that of the crude mineral. For this purpose the calcined gypsum is finely ground. It is added to the finished cement in very carefully measured quantities and is thoroughly mixed to insure uniform set.

Anhydrous gypsum contains a higher per cent of SO_3 than is found in gypsum proper. Some chemists have no objection to Anhydrite the use of anhydrite as cement retarder, while some actually prefer it, as a ton of anhydrite contains more SO_3 than a ton of gypsum. Other cement chemists are not satisfied with the results that they have secured with anhydrite.

154A. S. T. M. Standards, 1918, p. 504.

155P. H. Bates, Paper at A. S. T. M. meeting June 22, 1915.

The SO_3 content of the gypsum used in Portland cement must be fairly constant, or uneven set in the cement results. It seems probable that where trouble has resulted from the use of anhydrite, the cause is often to be found in the fact that the percentage of SO_3 was not uniform, rather than to the nature of the anhydrite itself. Anhydrite almost invariably occurs mixed with gypsum, and if it is used some care must be taken to see that the gypsum and anhydrite are so mixed by mechanical processes, that the SO_3 content is uniform throughout the entire mass.

Uniformity essential

Experiments now being carried on by various cement companies, co-operating with Committee C-11 of the American Society for Testing Materials seem to indicate that clinker of a high alumina content and relatively low lime cannot be sufficiently retarded by the use of pure anhydrite.

Anhydrite and High Alumina Clinker

Inasmuch as the magnesia (MgO) content of Portland cement is restricted to 5 per cent, gypsum for cement mill use should not contain any considerable amount of dolomite. This is a matter of no great importance, however, as both gypsum and anhydrite are seldom so intimately associated with dolomite as to make its presence in the gypsum a hazard.

Statistics given in chapter XXII show how extensive are the requirements of the cement industry. While the increase in the manufacture of Portland cement will hardly be as rapid during the next decade as in the ten years just past, there will be a steady expansion of the industry.

CHAPTER X

GYPSUM IN AGRICULTURE

HISTORICAL

USE IN EUROPE

The history of gypsum as a fertilizer dates back a little more than 150 years. The earliest use of gypsum in agriculture probably occurred in Wurtemberg, in southern Germany, but the first information published in regard to it came from the Economic Society of Berne, Switzerland.[156] Memoires de Societe Economique de Berne, in 1768, contain the first account of the use of gypsum on the farm. In response to a request for essays on the general subject "Description of the Different Kinds of Earth and Methods for Mixing Them to Render the Soil Fertile", Rev. J. F. Mayer of Kupferzell in Wurtemberg submitted a paper which was awarded first prize by the Society. This paper had in the form of an appendix a brief note on gypsum as a fertilizer which attracted great attention and led the Society to ask for more information, and in complying with this request Mayer stated:

Rev. J. F. Mayer's statement

"It is only two years since one has entertained the thought that a stone of which little account was taken, was nevertheless well suited to attract to itself the oil and salt of the air, and consequently suitable to be placed on the meadows and to enrich them. When it is found crude, it is reduced to powder, and after it is crushed it is placed on the meadows or upon sterile soils of whatever nature they may be. Over one acre one scatters eight fri (a measure 13 inches in diameter and 8 inches high) and this fertilizer furnishes the best forage and the best clover one can imagine. It has greater effect if calcined, but the best effect is obtained by adding to it two fri of wood ashes and eight handsful of salt, and the whole soaked in a half pail of manure water. Let these materials be well mixed, then let them lie eight days, after which having stirred them, one may spread them on the soils to be fertilized. Our people profit by it continually and the experience for two years has justified the first trials. As soon as

156According to Grimsley, in Geol. Survey of Michigan, Vol. IX, p. 194. Grimsley acknowledges his indebtedness to Prof. Chuard of Lussanne, Switzerland, who placed in his hands a number of his papers on agricultural gypsum.

one is quite convinced, and one cannot conceive it otherwise, that all plants are composed of salt, oil, and earth, one will be as easily persuaded that gypsum flour scattered over wheat, oats, barley, and vegetables, ought to produce the same effect. The experiment has already been tried."

The society of Berne decided to have these experiments repeated at a number of places, and the results of further experimentation conducted under its guidance were published in a memoir in 1771. In this memoir are important papers by N. H. Kirchbergner and M. Tschiffeli.

Kirchbergner's paper

Kirchbergner describes his experiments with clover, lucerne (alfalfa) and radishes and expresses his surprise at the marvelous results that he obtained with gypsum.

Tschiffeli's paper

Tschiffeli obtained results similar to Kirchbergner and like him found that legumes profited most from applications of gypsum. He further noted that, on wheat becoming weak in its growth at the first of June, gypsum applied liberally at a dry time resulted, after the first rain, in an almost miraculous growth and a good harvest.

USE IN AMERICA

In early American history Judge Richard Peters of Philadelphia and John Binns of Loudon county, Virginia, were staunch champions of gypsum as a fertilizer. Their names are perhaps not as well known in this connection as those of Benjamin Franklin, Robert Livingston and Edward Ruffin.

Judge Peters

Judge Peters' book seems to have been published in 1796 in response to a request from Washington for a statement of his experiments and experiences along this line. A second and revised edition was later published by Smith and Harris in Philadelphia.

The following interesting paragraphs appear therein:

"The prejudices for and against this manure are equally violant. In Germany, where this fossil has been longest known and used, opinions have been very opposite, and many of them very absurd and ridiculous. Witchcraft has been charged on those who used the plaister, but it has been said by some wonderfully wise people there, that it produced or attracted thunder and lightning. Petty princes made edicts against it, urged by the bigotry of its opponents and the unfounded German adage, "That it makes rich fathers and poor children". Peasants have however sown the plaister on their fields in the night.

"It is a capricious and whimsical substance. I have known it to produce no effect for four years, and then throw up a most astonishing vegetation. In field now in clover, I perceive it most luxuriant, where Indian corn hills were plaistered with no effect on the corn, four or five years ago. This is one among many instances I have had in my own fields, and have heard from other farmers of similar effects. May not this be accounted for by supposing that the operative principal in the plaister was an overcharge for the fermentable substances then in the earth, and that did not find enough of these substances to operate on till the time when it produced the vegetation here mentioned. According to these notions we may perhaps understand why all these manures which undergo the quickest decompositions, ought to be oftener applied than some others, which, not being susceptible, but of a very slow decomposition, such as chalk, lime, burnt and pounded bones, gyps, impart, during several years, the soil with prolific quality. I had not seen this essay when I gave an account of my experience of the plaister. But I am much confirmed, in some of my conjectures, since reading this production; and particularly in my opinion, that the plaister operates most powerfully, when in connection with animal or vegetable putrified or putrifying substances.

"Whatever be the cause, dew will remain on a part of a grass field plaistered, an hour or two in a morning, after all moisture is evaporated from the part of the same field not plaistered. I have also frequently seen this effect in my garden beds, which, if plaistered, will retain moisture in the driest season, when there is not the least appearance of it in those beds, whereon no plaister was strewed."

Professor Crocker, in an historical sketch on gypsum as a fertilizer summarizes Peters' book as follows:

Synopsis of Peters' book

"Peters, as did several of those filling out the questionnaire, started with worn out lands and brought them to a high state of fertility by the use of gypsum in combination with stable or green manure. Peters especially found this combination desirable, speaking of the gypsum and manure as mutually supplementary. Peters says, "I have heard of none who have been more successful in the plaster system than Mr. Price and Mr. West. They have brought old worn out land to a remarkable degree of fertility and profit by combining the plaster with other manures. The gypsum was, however, the principal agent. As to the results in general my experience and theirs agree; but I think that I have proved that dung and plaster mutually assist each other." The greatest effect was found on leguminous crops, especially red clover. The yield of the latter was often increased two or three fold. Gypsum also proved beneficial for flax, hemp, rape and other farm crops as well as garden plants and trees. It proved quite as beneficial on limed as on unlimed soil and on old as well as newer soils. American plasters were found as good as imported plasters. From his experience and questionnaire Peters concludes that plaster is of value on many types of soil but gives little if any response on heavy clays."

Judge Peters gives in his book a series of questions that he addressed to an intelligent farmer whose interest in gypsum had come to his notice, and a portion of this catechism is given below:

"Query 1st. How long have you used the plaister?

Answer. About eleven years, without disappointment in its effects.

Query 2d. What state was your land in when you began the use of it?

Answer. My land chiefly when I began to apply it, though naturally of the first quality, had been nearly a century under bad management, and tired down. I ploughed up about five or six acres, and dressed it with a rich earth about old buildings that grass had grown over, and rotted it down in itself, and applied about thirty loads to the acre, sowed it with winter barley, the spring following with clover, the next spring with Plaister of Paris; its product in grass was allowed to be equal to any that had anywhere been seen. I mowed it two summers, and have grazed it ever since, and the sod is now in good perfection. I redressed it last summer with plaister, and its stimulation very good: the sod is green grass, white clover with a mixture of red. This piece with a number of others, laid down in grass with different kinds of manure, and plaistered, will now feed as many cattle as acres, and from the effects of their droppings may be kept up continually. I have continued the application of plaister every year from my first using of it to the present, and its most beneficial use is on grass, if rightly managed on the previous dressing of other manure and its preparation; all which will require a system in itself to describe at large.

Peters' questions and answers

Query 3d. What quantity per acre have you generally used?

Answer. The quantity of plaister per acre, four and a half bushels, and the redressing about three bushels; but I would not recommend a second application when land has been mowed five or six years, without a light dressing of other manure.

Query 4th. What soils are the most proper for this manure?

Answer. The soils most proper for the plaister are warm, kind loamy ones; the land is generally deemed good wheat land; that will sink the water quick in winter, not too level, and land moderately hilly. Land that takes lime well, will the plaister.

Query 5th. Have you repeated the application of it with or without ploughing, at what intervals, and with what effect?

Answer. The repeated application of it has a good effect as I have mentioned above. It follows lime equal to any manure.

Query 6th. In consequence do you find that it renders the earth sterile after its useful effects are gone?

Answer. It does create something of sterility in five or six years by mowing; then it may, as above mentioned, be lightly dressed by dung or compost; about twelve loads to the acre, will make a new footing for the plaister. This quantity will promote a wheat crop.

Query 7th. To what products can it best be applied—grain and what kinds—grass and what kinds?

Answer. It is best adapted to grass and every kind of summer grain.

Query 8th. When is the best time to scatter it?

Answer. The time to strew it is in the spring, when vegetation is fairly abroad.''

John A. Binns

John A. Binns, in 1804, wrote a treatise on practical farming[157] and devoted nearly one-half of the book to a discussion of gypsum.

Professor Crocker thus sums up Binns' book:

''The following is a quotation from the preface of Binns' little book: 'Having been been frequently requested by several of my friends and acquaintainces as well as sundry persons from a distance to publish my experiences in farming generally, and more especially on the use of plaster of Paris; (the use of which has made my farm, from that of being tired down, or the natural soil entirely worn out, a rich and fruitful one) I have been induced to present them with the following pamphlet.' He speaks of raising the fertility of his first farm to a high level by the use of gypsum and later buying a second farm of exhausted fertility on which his neighbors said he would starve. This in turn was raised to a high state of productiveness by the same means. In time he induced his neighbors to use gypsum with the result that in a few years they doubled their corn yield and increased their wheat yield three to four fold. He speaks of the number and size of stacks

157Published by John B. Colvin, Fredericktown, Md., 1803. 2d edition published by S. Pleasants, Richmond, Va., 1804, 83 pp., 35 devoted to gypsum.

being greatly increased and the grain in greater proportion. The granaries and mills of the community were glutted and threshing greatly delayed due to big yields. He states that if the use of land plaster continues for a few years the uplands of Loudon county will be as good as, or superior to, any river bottom for grain, hemp and tobacco and far better for clover.

"Binns' favorite way of applying the plaster was to roll the moistened seed in it before sowing. He supplemented this with applications placed on the hill or sown broadcast on the crop in the early spring with a total application scarcely exceeding two bushel to the acre per year. Plaster proved to be especially beneficial to the clovers; but it also greatly benefitted corn, wheat, rye, and blue grass. From his report one cannot determine whether the benefit on the non-legumes is due to direct action of gypsum or due to the increase of nitrogen in the soil by the greater growth of the legumes in the rotation. He emphasizes the fact that gypsum greatly reduces the ravages of the fly on wheat.

"Peters emphasizes the use of green manures and stable manures with gypsum, but Binns does not mention this although later in his book he does discuss the use of other manures. One can hardly explain his results and those of other farmers of Loudon county except by assuming the accumulation of organic matter and nitrogen on the farms due to the marked effect of gypsum on the growth of clovers in the rotation. This nitrogen and organic matter must of course find its way back to the soil as stable or green manure along with root residues if it is to accumulate on the land.

"Binns' explanation of the method of action of gypsum was fatal to a system of permanent fertility for he assumed that gypsum contained all the virtues of any manure. At best it increases the supply of only three essential elements, calcium and sulphur directly and nitrogen indirectly by favoring the growth of legumes. While it may increase the solubility of potash and perhaps other nutrients it will not increase their amount in the soil. Such a system of fertility must in time fail for it will not care for the general shortage of phosphorus and the occasional shortage of potassium."

Benjamin Franklin

Franklin's keen interest in every phase of scientific thought and experiment is shown by his investigation of gypsum, and perhaps the most familiar anecdote in connection with the early history of gypsum is the story of the field of clover where Franklin sowed with gypsum the words LAND PLASTER USED HERE, with the striking result that this clover grew so much ranker and greener than the rest, that the words could be easily read from distant points.

Washington's particular contribution to this subject is found in the fact that he induced Peters to write and publish his experiences. Washington tried gypsum at Mount Vernon only once. The results were not very remarkable, and this is not strange since the crop to which application was made was oats, a crop that does not especially respond to a sulphur fertilizer.

George Washington

Charles F. Grece recorded his observation in the United States and Canada in 1819[158] in the Quarterly Review and speaks as follows:

Charles F. Grece

"This valuable manure, almost unknown though very easy to obtain, merits the attention of every farmer. There is scarcely a farm in the provinces but it might be applied to with advantage. The practice of nine years on the following soils and crops may suffice to prove its quality. On a piece of poor yellow loam I tried three grain crops without success, with the last which followed a hoe I laid it down with barley and the return was little more than the seed. The grass seed took very well. In the month of May of the following year I strewed powder of plaster at the rate of one minot and one pack to the arpent (acre). In July the piece of land being mowed the quantity of the grass was so great that it was not possible to find room to dry it on the land where it grew. The product was five large loads of hay to the arpent. It continued good for five years. I tried plaster on cabbages and turnips, but did not perceive any good effects. From the frequent trials of this manure on various soils it is evident that it is applicable to both light and strong soils for top dressing of succulent plants."

Edmund Ruffin, in his essay on Calcareous Manures,[159] speaks of gypsum as follows:

Ruffin

"I do not pretend to explain the mode of operation by which gypsum produces its almost magic benefits; it would be equally hopeless and ridiculous for one having so little knowledge of successful practice, to attempt an explanation, in which so many good chemists and agriculturalists both scientific and practical

158Vol. XXIII, pp. 147-150. 1820. Quoted by Grimsley in Geol. Survey of Michigan, Vol. IX, p. 196.

159Edmund Ruffin, An Essay on Calcareous Manures, XII, 242, 1832. J. W. Campbell, Petersburg, Va.

have failed. There is no operation in nature less understood, or of which the cause, or agent, seems so totally disproportioned to the effect, as the enormous increase of vegetable growth from a very small quantity of gypsum in circumstances favorable to its action. All other known manures, whatever may be the nature of their action, require to be applied in quantities very far exceeding any bulk of crop expected from their use. But one bushel of gypsum spread over an acre of land fit for its action, may add more than twenty times its own weight to a single crop of clover.''

USE OF GYPSUM IN ENGLAND

Fothergill

In 1808 Dr. A. Fothergill of Philadelphia reported to the Board of Agriculture of Great Britain on the use of gypsum as a fertilizer in the United States. He stated that at that time Philadelphia alone imported from France and Nova Scotia each year 12,000 tons, and that in addition much American gypsum was used in the region adjacent to Philadelphia.

Smithe

Smithe of Tunstall, Kent, England, wrote a prize essay, about 1805, setting out his experiments with gypsum. His findings, as summarized in a statement by Professor Crocker are strikingly in line with recent reports from the Oregon Experiment Station.

''Smithe, as did the American users, found it especially effective with leguminous forage crops,—sainfoin, clovers and alfalfa. He reports that the total value of crops of sainfoin was increased 45 per cent by the use of gypsum; cow-grass, 14 per cent; Dutch clover, 330 per cent; and red clover 237 per cent. Similarly the value of the seed was increased 300 per cent for Dutch clover and 325 per cent for red clover. Applications of gypsum after the first cutting of clover hay increased the seed of the second crop three fold. Smithe found that gypsum had little direct effect on the cereal crops. Indirectly, however it seemed to benefit the grain very materially. As he puts it the more clover was forced by the addition of gypsum the better the grain crop following the clover. In one case he got 86 per cent increase in wheat following gypsumed clover. This may be largely due to increased nitrogen fixation by the clover.

''Smithe applied about six bushels to the acre when seeding to the legume and followed with much lighter applications every second or third year afterwards. He recommends application in April or May, but gets very good results with seed production in clover, as mentioned above, by applying after the first crop is cut. Like most of the experiences with gypsum up to this time, he found that the greatest effect often appeared the second or third year after the application. This may be why Binns got such good results by rolling the seeds in the gypsum before planting. Such treatment insures close contact with the first roots put out by the plant. This delayed effect is still more marked with the very slightly soluble raw rock phosphates. Insoluble fertilizers in general should be mixed with the soil as thoroughly as possible by cultivation and otherwise to insure early maximum contact with the roots. In his answers to the questions of Sir John Sinclair, Smithe mentions seventeen users of gypsum to confirm his experiences. It seems that the use of gypsum as a fertilizer spread and became popular in the region of Tunstall, Kent, England, as it did about Binns' home in Loudon county, Virginia."

Johnson, in addition to a prize essay on the subject has an article "Gypsum as a Manure" in his encyclopedia of agri-
Johnson culture which was published in 1842. Professor Crocker reviews Johnson's essay as follows:

"The following quotation is from Cuthbert Johnson's prize essay on Gypsum. 'There is perhaps no artificial manure so decided in its effect upon some soils, so readily obtainable by the farmer and so plentiful in this country (England) as gypsum. Its mode of action, too, is easily understood, for it acts as a direct food for some plants, is not what is sometimes called a stimulant.' He goes on to say that there are only five cultivated crops that contain gypsum in any sensible quantities and for which it is consequently a choice food; lucern, sainfoin, red clover, rye, grass and turnips. Gypsum as a top dressing helps these. He speaks of other crops that do not contain a trace of calcium sulphate and that farmers find are not helped by applications of gypsum. Johnson was probably more nearly right than most later writers in speaking of its main function as a "direct food", although he was wrong, due to crude chemical methods of the time, in assuming the absence of calcium sulphate from most plants. He also did not know a thing discovered much later, that sulphur is a building material for several essential organic compounds of plants and calcium for at least one. Besides calcium has other indispensable functions inside and outside the plant. Johnson also mentions the experiments of various farmers, largely confirmatory of the results of Mr. Smithe."

The fact stands out in bold relief before the reader of these pages recording early experimentation with gypsum that the crops which gave a remarkable response to gypsum fertilizer, were clover, alfalfa, and legumes in general; together with cabbage, radishes, turnips, and other members of the mustard family. Potatoes and onions also responded moderately.

The fact that the scientific explanation for these results was not known makes the uniformity of results all the more striking.

When, about ten years ago, agricultural chemists checked on Wolff's analyses of plant seeds, leaves and stems, and discovered that, through using faulty methods he had overlooked most of the sulphur present in plants, the real explanation of the value of gypsum in agriculture was discovered and correct conclusions were promptly drawn.

Wolff's erroneous analyses

In the interval various theories were advanced to account for the efficacy of gypsum, some of which have merit.

In his Chemistry of Agriculture,[160] Storer called attention to the fact that all lime compounds, including gypsum, have a tendency to flocculate loose soils; that is, to collect the loose particles and give the soil more body. With a tough clay soil they have the opposite effect and break up such soils into finer particles.

Storer's theories

GYPSUM AS AN INDIRECT FERTILIZER

In addition to the physical benefit derived from gypsum, Storer pointed out—and leading agricultural chemists since his time have confirmed his conclusions—that gypsum decomposes the double silicates in the earth, and puts in soluble form the potash bound up in these silicates. Storer expressed the chemical reaction in the following form:

$$\left.\begin{array}{l} Al_2O_3 \\ CaO \\ K_2O \\ H_2O \end{array}\right\} \text{x } SiO_2 \text{ plus } CaOSO_3 \text{ equal} \ldots\ldots \left\{\begin{array}{l} Al_2O_3 \\ CaO \\ CaO \\ H_2O \end{array}\right\} \text{x } SiO_2 \text{ plus } K_2OSO_3$$

The favorable action of gypsum on legumes was accounted for by the fact that they are heavy users of potash, and gypsum renders potash available.

As is generally known there are enormous stores of potash

[160]Volume I, pp. 206-216, 1887.

present in most American soils, extremely sandy soils being about the only exception. This potash is much more abundant in the layer from twelve to twenty inches deep than in the six or seven inches nearest the surface. As a result of forty-nine analyses of typical soils in the United States, Professor Chester[161] found for the first eight inches of soil 13,400 pounds of potash. Doctor Olive estimates that if this potash is made available the supply is sufficient for 1000 wheat crops, counting 13.7 pounds removed per acre by an average fourteen bushel crop.

Abundance of potash in most soils

GYPSUM AS A DIRECT FERTILIZER

Hart and Peterson's[162] investigations, published in Wisconsin in 1911, first paved the way for a complete and satisfactory explanation of the behavior of gypsum when used as a fertilizer. They called attention to the errors in Wolff's analyses, and proved conclusively that many important crops consume as much sulphur as phosphate.

Wisconsin Bulletin 14

The authors sum up the results of their investigations in the following manner:

"The sulphur content of a number of our common farm products has been determined and in agreement with other investigations the quantity is much larger than found by Wolff in the ash from such products.

Wisconsin Bulletin No. 14 conclusions

"The amount of sulphur trioxide removed by crops is considerable, being equal in the case of average crops of cereal grains and straws to about two-thirds of the phosphorus pentoxide removed by these crops; the grasses of mixed meadow hay remove quite as much sulphur as phosphorus, while the legume hays may approach, and in the case of alfalfa, even exceed in this respect. Members of the Cruciferae, as the cabbage and turnip, are heavy sulphur-using crops and may remove two to three times as much sulphur trioxide as phosphorus pentoxide. An average acre crop of cabbage will remove about 100 pounds of sulphur trioxide.

"Normal soils are relatively poor in total sulphur trioxide; a limited number of analyses showed a percentage content of from 0.033 to 0.140; most of them contained less than 0.10 per cent. An acre foot will contain from 1,000 to 3,000 pounds

161Delaware Agr. Expt. Station, Bulletin 65, p. 51, 1904.
162Wisconsin Agr. Expt. Station Research Bulletin 14, 1-21, 1911.

of total sulphur trioxide. About the same quantity of phosphorus pentoxide will be found in an acre foot of normal soil. These results for sulphur trioxide are based on analyses made by the method of fusion with sodium peroxide. Determinations by extracting with hydrochloric acid or with nitric acid and bromine will not give the total sulphur content of soils.

Soils cropped for 50 or 60 years either unmanured or receiving but slight applications during that period have lost on the average 40 per cent of the sulphur trioxide originally present as determined by comparison with virgin soils.

"Where farm manure has been applied in regular and fairly liberal quantities the sulphur content of the soil has been maintained and even increased.

"The total sulphur trioxide precipitated at Madison, Wis., with the rain amounted in the five months of June to October, 1910, inclusive, to 11.7 pounds per acre. The annual amount may tentatively be placed at from 15 to 20 pounds.

"The losses of sulphur trioxide by drainage, based on the analysis of the drainage waters at Rothamsted, England, and on a yearly drainage of 10 inches, would amount to about 50 pounds per acre yearly.

"Even with much less loss by drainage it does not appear that the atmosphere can serve as a complete compensating factor for losses of sulphur trioxide which soils sustain through both cropping and drainage. The partial depletion of the sulphur of the soil by continued cropping without adequate fertilization is evidence in support of this view.

"From the data here presented it appears that for permanent and increased production of farm crops such systems of fertilization must be inaugurated as will supply to the soil from time to time, in addition to the elements now recognized as generally necessary,—namely, nitrogen and phosphorus,—a sufficient quantity of sulphur to meet the losses sustained by cropping and drainage.

"Such sources of sulphur are farm manures: the trade fertilizers, such as super-phosphate, ammonium sulphate and sulphate of potassium: and the socalled soil stimulant, gypsum or calcium sulphate."

Professor Shedd soon followed with two interesting bulletins[163] which confirmed for Kentucky soils the conclusions of

[163] Relation of Sulphur to Soil Fertility: Kentucky Agr. Expt. Station Bulletin 188, 595-630, 1914. The Sulphur Content of Some Typical Kentucky Soils: Kentucky Agr. Expt. Station Bulletin 174, pp. 269-306, 1913.

Shedd in Kentucky

the Wisconsin experiments. In his analysis of thirty-one samples of tobacco leaves he found that all but two contained more sulphur than phosphorus, and in some cases the sulphur was nearly double the amount of phosphorus.

Brown and Kellogg

In Iowa Brown and Kellogg found that there was nearly twice as much phosphorus as sulphur in the surface rocks of important areas and they came to the conclusion that "all systems of permanent agriculture in Iowa which[164] leave the sulphur out of account would be incomplete and inefficient."

Oregon Bulletin 163

In 1919 Reimer published a bulletin[165] giving the results of years of careful experimentation in Oregon, which proved conclusively that sulphur must be classed as an exceedingly important plant food, and showed that in many cases all or most of the benefit derived from acid phosphate could be secured by using gypsum, and a fifty per

FIG. 47.—Effect of agricultural gypsum on alfalfa in Oregon. Crop from test plots of equal size, the larger pile showing result of agricultural gypsum while the smaller was from plot receiving no sulphur fertilizer. From Oregon Station Bulletin 163, Courtesy SOUTHERN GYPSUM CO., INC.

cent saving be made. Most of the Oregon soils were found to be well supplied with phosphorus and deficient in sulphur. Agricultural gypsum therefore gave remarkable results, crops of alfalfa being increased from 200 to 500 per cent by the use of 200 pounds of gypsum to the acre. Figure 47 shows the effect of gypsum on alfalfa.

164Sulfofication in Soils: Iowa Agr. Expt. Station Bulletin 18, pp. 49-111, 1914. Also Iowa Acad. Science, Vol. XXI, p. 17.

165Oregon Agr. Col. Expt. Station Bulletin 163, 1919, Corvallis, Oregon.

Description of a typical test plot follows, with Reimer's explanation of the plot:

FERTILIZER APPLIED AND YIELDS PRODUCED

PHOENIX CITY ADOBE SOIL. PLOTS 2 BY 8 RODS.

FERTILIZER APPLIED MARCH 9, 1915.

Plot	Application		Fertilizing Constituents		Yield in pounds 1915	1916	1917	Total
		Lbs.		Lbs.				
1	Check				227	450	736	1413
2	Gypsum	59.5	Sulfur	10.00	369	826	936	2131
3	Double superphosphate	40	Sulfur	9.70	361	418	607	1387
			Phosphorus	7.40				
4	Superphosphate	82	Sulfur	10.00	348	728	860	1936
			Phosphorus	7.40				
5	Check				159	260	544	963
6	Sulfur	10	Sulfur	10.00	216	478	676	1370
7	Sulfur	30	Sulfur	30.00	253	422	668	1363
8	Check				294	192	480	896

"Check plot 1 borders on a stream and the soil of this plot is better than that of the other plots. This accounts for the larger yield of plot 1. It would probably be better to ignore this check plot entirely. The fertilizers containing sulfur again produced large increases in yield. The gypsum plot produced a larger yield than the superphosphate plot, and these two plots produced considerably more than the two plots which received flowers of sulfur. The small amount of sulfur in the double superphosphate, amounting to only 9.7 pounds an acre, produced a large increase in yield, especially the first and second seasons. This shows that only a very small amount of sulfur is necessary to produce material increases in yield. The effect of the double superphosphate was barely perceptible the third season of the experiment."

Quite a different type of soil was tested in the plot described below:

FERTILIZER APPLIED AND RESULTS ON BARRON COARSE SAND

PLOTS 2 BY 5 RODS. FERTILIZER APPLIED MARCH 12, 1915.

Plot	Application		Yield in Pounds 1915	1916	Total
		Lbs.	Lbs.	Lbs.	Lbs.
1	Gypsum	23.4	334	269	603
2	Check		158	149	307
3	Double superphosphate	16.5	265	228	493
4	Superphosphate	33.0	321	342	663
5	Check		194	162	356

"The gypsum, double superphosphate, and superphosphate produced very large increases in yield in this field. It is important to note that the small amount of sulfur in the double superphosphate, amounting to 5.7 pounds an acre, produced an increase of 186 pounds over the nearest check plot. It is also clear that this amount of sulfur is not sufficient to produce maximum yields on this soil, as shown by the larger increases produced by the larger amount of sulfur supplied to the gypsum and superphosphate plots."

Gypsum and nitrogen secreting bacteria

Professors Graves, Carter and others at the Utah Experiment Station have investigated the influence of gypsum and other salts on the production of nitrogen and on the growth of nitrogen fixing bacteria in the soil. They have found that gypsum greatly increases the growth of these helpful organisms. Of some twenty substances used in the tests gypsum was found most useful for increasing the nitrogen in the soil through bacterial activity, and the increase, as measured by their experiments, amounted to 97 per cent.

Gypsum fertilized alfalfa has greater feeding value

Gypsum increases the protein content in legume hays, alfalfa, clover and similar crops. Professor Peterson at Wisconsin found that land plaster more than doubled the protein in alfalfa. Reimer concluded that the feeding value of alfalfa hay from sulphur fertilized plots, without taking into consideration the increased yield, was sufficiently greater to pay for the fertilizer used.

Gypsum and root growth

Professor Reimer found that "the root system of alfalfa fertilized with gypsum and other sulphur fertilizers" is from two to three times as large as that of the unfertilized plants. The value of this larger root system is obvious.

St. John and Olson

In 1909 the Washington Agricultural Experiment Station began a study of Washington soils to determine the amount of sulphur present, and whether the beneficial results already recognized in that section of the United States as resulting from the use of agricultural gypsum, were due to its sulphur rather than its lime content. The results of their work are admirably presented in bulletin 165, of the Pullman Station.*

They consider that, "In a system of farming with legumes

* Bulletin 165, An Investigation of Sulphur as a Plant Food. State College of Washington, Agricultural Experiment Station, Pullman, Washington, May 1921.

included in the rotation, it has been evident that applications of gypsum have caused very profitable increases in alfalfa. This increased yield has been due to the supplying of sulphur which has been utilized by the legumes in comparatively large quantities and showing, therefore, that sulphur has been a limiting factor in the production of alfalfa. Cereals require small quantities of sulphur compared with the quantity utilized by legumes, and about one-half as much sulphur as phosphorus.

"With increased yields such as have been obtained with the

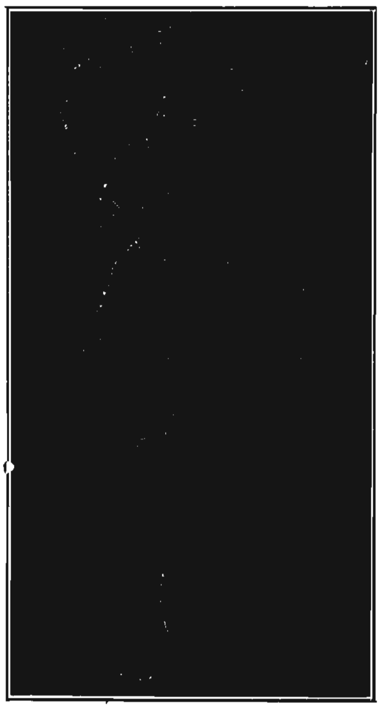

FIG. 48.—Alfalfa roots showing benefit of gypsum fertilization. Large plant with well branched root system from plot fertilized with gypsum which supplied sulphur at the rate of 100 pounds to the acre. The small plant with long slender unbranched root system was from test plot which received no gypsum. Oregon Agr. College Experiment Station Bulletin 163. Courtesy Southern Gypsum Co.

use of gypsum fertilizer, alfalfa growing has become more encouraging and may well be included in the rotation with cereals. On farms where alfalfa has been grown, it has been noted that better yields of wheat have been obtained and the wheat has been found to be of better milling quality. The soil has been rendered better physically and better water absorption and retention have been procured. The annual growing of cereals on land which has been in alfalfa, in place of the two crops in three years or one crop every two years as with the fallow system, has to be considered as an indirect benefit due to the growing of a legume such as alfalfa.

"QUALITY OF ALFALFA AND CROPS FOLLOWING: The darker green color noted in the alfalfa grown on the gypsum treated plots is also observed in the cured hay when compared with hay obtained from adjoining untreated plots.

FIG. 49.—Field showing effect of agricultural gypsum on clover. The dark streaks on each side show the heavy growth of the clover where gypsum was applied. On the light streak where no gypsum was applied the growth was very scant. From U. S. Department of Agriculture, Bureau Plant Industry, circular 22. Courtesy Southern Gypsum Co.

This difference in color adds to its merchantable value, and generally the highest colored hays are sold for the best price.

"The protein content of alfalfa grown on gypsum and acid phosphate treated land has been found to be higher than that in alfalfa obtained from adjoining untreated plots. The protein found in the alfalfa obtained from the gypsum treated plots was 30 per cent and that from the acid phosphate treated land was 17 per cent higher than that found in the alfalfa grown on the check plots. Similar relations have been found in farmers' lots of alfalfa. Land which has been in alfalfa has been improved both physically and chemically."

A PERMANENT AND ECONOMICAL SYSTEM OF SOIL FERTILITY

Nitrogen, one of the most important, and certainly the most expensive form of plant food to purchase in chemical form, is effectively and cheaply supplied to the soil indirectly by the use of gypsum.

Nitrogen

The legumes, as is generally known, are the hosts of nitrogen-secreting bacteria, and the legumes respond tremendously to a sulphur fertilizer like gypsum. Moreover the gypsum has a very stimulating effect on the nitrogen-gathering or nodule-forming bacteria of red clover roots, as shown by Pitz of Wisconsin[166] and others. Figure 49 shows the results of using gypsum on clover land.

Potash

Potash, which is abundant in most soils, and which, in insoluble form is present even in the first six inches of surface soil equal to the needs of hundreds of years, is made soluble without waste in sufficient quantities by the reaction of gypsum on the potash silicates. This action is assisted by turning under a green crop occasionally.

Phosphate

Many soils are deficient in phosphate and this deficiency may be supplied most cheaply by the use of raw rock phosphate. The solubility of raw rock phosphate has been called in question by the champions of the more expensive acid phosphate. If the rock phosphate is finely ground, however, and as offered to the trade at present its mechanical condition is excellent, and especially if it is turned under with a green crop, like clover or beans, there is sufficient ground for believing it abundantly soluble. Indeed the Illinois system of agriculture as advocated by Hopkins[167] and as successfully practiced throughout that state, shows that rock phosphate is sufficiently soluble even though the precautions suggested above are not carefully observed.

Sulphur

The sulphur essential to the legumes which are the source of the nitrogen supply, and which contributes direct plant food to numerous crops, is best and most cheaply furnished by gypsum. Figure 50 shows the results of tests in use of sulphates on clover and rape.

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166 Effect of Elemental Sulphur and of Calcium Sulphate on certain of the Higher and Lower forms of Plant Life. Jour. Agr. Research, Vol. 16, pp. 771-780, 1916.

167 Soil Fertility and Permanent Agriculture. Ginn & Co.

Acid phosphate is expensive as compared with gypsum and raw rock phosphate.

Raw sulphur is effective, but it rapidly sours the soil and this tendency must be constantly checked by the use of lime.

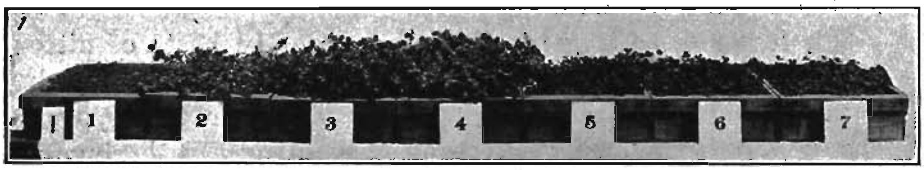


FIG. 50.—Clover showing effect of gypsum and other sulphates on growth, fertilized as follows: 1, check, 2, Nitrogen, Phosphate, Potash. 3, Nitrogen, Phosphate, Potash plus Sodium Sulphate. 4, Nitrogen, Phosphate, Potash plus Gypsum. 5, Sodium Sulphate only. 6, Gypsum only. 7, Sulphur. From Hart and Tottingham.

The sulphur must first be transferred into lime sulphate by chemical reaction in the soil, whereas gypsum, a neutral salt, is itself lime sulphate.

Except for garden plots and truck farms where the large returns per acre justify expensive mixed fertilizers, it is in the interests of economy and efficiency to fertilize through legumes, together with the natural rock fertilizers suitably ground; gypsum and rock phosphates.

Lime is essential also to keep the soil in an alkaline condition, which makes it congenial to most crops.[168]

Experiments by the United States Department of Agriculture show that gypsum has given remarkable increases in the yield of cotton.[169]

Gypsum as cotton fertilizer

The results are shown in the table given below. The following were the costs per ton of fertilizer used:

Nitrate of soda	$50.00
Sulphate of ammonia	62.00
Acid phosphate	14.00
Ground bone	26.00
Rock phosphate	9.00
Floats	8.00
Basic slag	12.50
Sulphate of potash	60.00
Bone black	22.00
Wood ashes	5.00
Gypsum	8.00
Marl	.50
Lime	6.00

168For a synopsis of recent literature on gypsum as a fertilizer see special Bibliography covering Gypsum in Agriculture.

169U. S. Dept. of Agriculture, Bureau of Soils, Bulletin 62, p. 10.

The value of cotton in the table was taken at ten cents a pound. The test plots were usually one-tenth of an acre, and were distributed through North Carolina, South Carolina, Louisiana, Georgia, Mississippi, Alabama, Arkansas, and Texas. The greater part of the work was done between 1888 and 1893. The proportion of cases of success to cases of failure (number of tests over 110) was as ten to one.

RESULTS OF FERTILITY TESTS WITH COTTON SOILS

Kind of Fertilizer Used	Total Area	Fertilizers per Acre		Average Crop Increase per Acre		Average Gain per Acre
		Used	Cost			
		Pounds	Dollars	Pounds	Dollars	Dollars
Nitrate of Soda	73	160	4.00	64.0	6.40	2.40
Sulphate of Ammonia	17	128	3.97	58.2	5.82	1.85
Acid Phosphate	181	286	1.90	69.8	6.98	5.08
Ground bone	14	279	3.63	92.8	9.28	5.65
Rock phosphate	6	706	3.18	4.0	.40	3.58
Floats	25	201	.80	16.7	1.67	.80
Basic slag	4	230	1.42	1.0	.10	1.52
Boneblack	3	500	5.50	132.7	13.27	7.77
Muriate of potash	36	98	2.16	34.5	3.45	1.29
Sulphate of potash	6	112	3.36	21.2	2.12	1.24
Kainit	161	292	1.75	32.3	3.23	1.48
Wood ashes	3	1,667	4.17	68.0	6.80	2.63
Cotton-seed-hull-ashes	12	271	4.61	41.6	4.16	.45
Lime	3	1,333	4.00	33.3	3.33	.67
Marl	3	900	.23	19.0	1.90	1.67
GYPSUM	11	195	.78	197.4	19.74	18.96
Salt	1	200	.80	8.0	.08	.88
TOTAL	559	[illegible]	2.33	54.0	5.40	3.07

On page 13 of the same bulletin is the following table:

Kind of Fertilizer Used	Total Area	Fertilizers per Acre		Average Crop Increase per Acre		Gain per Acre
		Used	Cost			
		Pounds	Dollars	Pounds	Dollars	Dollars
Cotton-seed meal Kainit GYPSUM	4	(260) (347) (210)	6.17	233.0	23.30	17.13

The investigations of Kearney and Cameron[170] show that

[170] Some Mutual Relations Between Alkali Soils and Vegetation: U. S. Dept. Agriculture Bulletin 71.

gypsum counteracts in a wonderful way the injurious effects of certain salts that are present in many soils. It is a veritable specific for black alkali, caused by the presence of sodium carbonate, as has been already pointed out. Magnesium sulphate, magnesium chloride, sodium sulphate, and sodium chloride are injurious to many important plants. In the presence of gypsum the endurable amount of these substances may be increased many times.

Neutralizing injurious salts

Kearney and Harter[171] experimented further and found that gypsum neutralizes the poisonous effects of salts. In the case of common salt or sodium chloride the resistance of the plant was increased as follows:

Lupine (white)	5 to 10 times
Wheat	5 to 10 times
Oats	9 times
Cotton (G. barbadense)	32 times
Beet	8 times

Similar beneficial results were secured with sugar cane in Hawaii. The use of gypsum to neutralize objectionable salts increased the yield of sugar 46 per cent.[172]

Hawaiian sugar

Remarkable results have been secured by the Cuban Agricultural Experiment Station.[173] The data given below were compiled by Dr. Mario Calvino.

171 Bulletin of Plant Industry, U. S. Dept. of Agr., No. 113.

172 Experiment Station Hawaiian Sugar Planters Assn., Bulletin 11.

173 Review of Agriculture: Commerce and Labor Official Organ. February, 1921, Havana.

TABLE NO. I

	Plot A Test Plot	(Quantities are per Caballeria) Plot B	Plot C
Fertilizer used:			
Waste matter (*cachazas*)	....	26,840 Klgs.	26,840 Klgs.
Ashes	....	13,420 Klgs.	13,420 Klgs.
Calcium sulphate (gypsum)	....	....	5,368 Klgs.
Value of the fertilizer: Waste matter	....	$134.20	$134.20
Ashes	....	134.20	134.20
Gypsum	....	....	107.36
Total	....	$268.40	$375.76
Yield (*arrobas*)	63,784	94,000	177,952
Difference of yield as compared with the test plot (*arrobas*)	....	30,216	114,168
Value of this difference, figuring 100 *arrobas* of sugar cane at $7.50	....	$2,266.20	$8,562.60
Net gain, deducting the cost of the fertilizers	....	$1,997.80	$8,186.84
Difference of yield, comparing the plot which was treated with gypsum with the plot which was not (*arrobas*)	....	....	83,952
Value of this difference, figuring 100 *arrobas* of sugar cane at $7.50	....	....	$6,296.40
Net gain, deducting the cost of the gypsum	....	....	$6,189.04

NOTES:—The capital of $268.40 invested in waste matter and ashes produced in about 14 months $1,997.80 more than the test plot, or 744 per cent.

The capital of $375.96 invested in waste matter, ashes and calcium sulphate (gypsum), produced in about 14 months $8,186.84 more than the test plot, or 2,177 per cent.

The capital of $107.37 invested in gypsum produced in about 14 months $6,189.04 more than the plot fertilized with waste matter and ashes only, or 5,764 per cent.

(A caballeria equals approximately 33.33 acres).

(An arroba equals approximately 25.4 pounds).

Gypsum as manure preservative

Ground gypsum when sprinkled over stable manure, changes the volatile ammonium carbonate into the non-volatile ammonium sulphate. In this way it preserves the valuable nitrogen compounds which are otherwise lost. Gypsum also aids in checking the decomposition of the organic materials and humus in the manure piles. From two to four pounds of gypsum may be used with profit daily for each head of stock.

Anhydrite can be used satisfactorily for agricultural gypsum provided it is very finely ground. This finer grinding is necessary on account of the fact that it is less soluble than gypsum. It is higher in sulphate and if its limited solubility is overcome by fine grinding it can be used without hesitation in making agricultural gypsum.

CHAPTER XI

OTHER USES FOR RAW GYPSUM

In addition to the use of gypsum in agriculture, in the manufacture of Portland cement and calcined plasters, there are a number of places in the arts where gypsum plays an important part.

Very white gypsum which has been ground and bolted through a 200 mesh screen is sold as a filler for paper and paint under the name of terra alba. In the making of paper its function is to close the pores and permit of a hard finish.

Terra Alba

In certain processes gypsum is added as flux to galena concentrate. In Germany it is used similarly in the concentration of lead-copper matte in reverberatory furnaces. Large quantities are required in the smelting of certain nickel ores in New Caledonia. The gypsum in this case furnishes the sulphur necessary for collecting the metal into a matte and also acts as a base to counteract and slag the siliceous gangue.[174]

Flux

Finely ground raw gypsum as well as calcined gypsum is used to dilute arsenic poisons that are employed in combating insects. Hundreds of tons of gypsum are used annually for this purpose. A large percentage of this amount is used in fighting potato bugs. The following experiment was one of a series tried by the Department of Agriculture in their endeavor to find suitable methods to control this pest.

Insecticides

"*Experiment No. 6*—This plat was treated with a mixture of Paris green and land plaster at the rate of 1 pound of Paris green to 50 pounds of plaster, the mixture being put in a coarse burlap bag and sifted over the plants by a negro laborer in the usual plantation manner, the amount of dust used being at the rate of 320 pounds per acre. The wind prevailing at the time carried a large part of the dust from the plat as it was applied, but the portion remaining was sufficient to thoroughly destroy the larvae by forty-eight hours afterwards. This mixture killed 90 per cent of the larvae during the first twenty-four hours, and is very effective in controlling the potato beetle."[175]

174 Stone, Bureau of Mines, Technical Paper No. 155, p. 38.

175 U. S. Dept. of Agriculture, Bureau of Entomology, Bulletin 82, Part 1, p. 5.

The mineralogical term alabaster is applied to pure white, semi-transparent gypsum which is used for statuary and vases.

Alabaster Its softness renders it easier to work than marble but the same property renders it less durable.

The common school crayon known as chalk is made from

Crayons finely ground uncalcined gypsum. The gypsum, with a suitable binder, is molded under pressure.

Numerous patents have been issued to cover processes of hardening gypsum blocks till they equal marble. Some ambi-

Imitation marble tious attempts have been made to establish a gypsum industry along this line. The processes are often successful but inasmuch as not one of the numerous attempts has survived under actual business conditions, it may be assumed that the cost of the processes is too great to permit of competition with marble and similar natural stones.[176]

Numerous patents have been issued for extracting sulphuric acid from gypsum and during the war it is stated that Ger-

Sulphuric acid many depended largely on gypsum for her supply of this essential. Our own country during the last months of the war took initial steps, at Grand Rapids, toward securing sulphuric acid from this source.

When calcium sulphate is treated in an open tube it decomposes at 1200° C., the products being CaO and SO_3[177]. When it is mixed with molecular proportions of silica the temperature of dissociation is 1005° C. While these temperatures are high they are within the range of those used for Portland cement and the process apparently has commercial possibilities. Certain patents issued in connection with these processes are described in the annual report of the Iowa Geological Survey for 1901 (Vol. XII, pp. 155-156) and others are reviewed in Bulletin No. 7 of the Department of Chemistry of South Australia (pp. 155-157).

Raw gypsum is used in the manufacture of rubber goods, and

Miscellaneous uses phonograph records. With other substances it enters largely into the composition of certain kinds of buttons. It plays a useful part in certain methods for filtering oils.

176For description of some processes see Geol. Survey of Michigan, Vol. IX, p. 206.

177H. O. Hoffman, Journal Society of Chemical Industry, p. 333, 1912.

POSSIBLE FUTURE USES

Dry spray

Considerable attention has been called to the possibility of widely extending the use of dry spray for orchard use and for fighting boll weevil. Finely ground gypsum seems to be an admirable filler for this purpose. The readiness with which it can be ground to pass 200 mesh, and the fact that it is not injurious to eyes, lungs or skin, are important properties to consider in this connection.

CHAPTER XII

CHEMICAL CHARACTERISTICS OF CALCINED GYPSUM

As set out in chapter I there are two natural forms of calcium sulphate, the hydrated form with chemical formula $CaSO_4$ $2H_2O$, correctly called gypsum, and the anhydrous variety $CaSO_4$ known as anhydrite.

Natural forms

Extensive beds of gypsum exist in our own country and elsewhere, free from anhydrite. Anhydrite also is found occasionally that is free from the water of crystallization which characterizes gypsum. As a rule, however, anhydrite shows on careful analysis, some water of crystallization, and this chemical test, easily confirmed by microscopic examination, establishes the fact that there is present in each case an intergrowth of the two minerals.

When gypsum is subjected to heat, a variety of chemical forms may result depending on the temperature to which the gypsum is exposed and the duration of the exposure.

Artificial forms

For over a century the various substances resulting from the partial or total dehydration of gypsum have been the subject of chemical study and a considerable volume of technical literature has grown up around them. Davis[178] in 1907, said that in spite of the work of such well known chemists as Lavoisier, Marignac, Le Catalier, Van't Hoff, and others, the confusion that exists on this subject is without parallel in inorganic chemistry. In 1916 L. A. Keene[179] was obliged to reiterate this statement, although in the meantime important articles on the subject had been published by Desch, Blake, Hursh, Rohland and Glasenapp.

Existing confusion

Inasmuch as progress in the technology of gypsum plasters is largely dependent on a correct understanding of the chemical characteristics of calcined gypsum it is essential that any treatise on gypsum that aims to serve the industry, must present all of the information available on this subject.

Importance of thorough investigation

178Journal Society Chemical Industry 1907, p. 727.
179Journal Physical Chemistry 1916, p. 701.

It must be kept in mind that certain physical characteristics of plaster, and notably plasticity, are as essential as tensile strength. Plasticity, as well as tensile strength, is dependent on the conditions that govern the calcining process. Only recently have attempts been made to consider and measure plasticity scientifically, and nothing has been published which sets forth the reasons for the relationship between plasticity and calcining temperature.

Chemists overlook physical properties of plaster

HISTORICAL SKETCH

Our knowledge of the chemical characteristics of gypsum dates back to the work of Lavoisier in 1765. He determined its solubility; that the mineral was a chemical salt; the nature of the acid and the base; and the presence of the water of crystallization. He called attention to the fact that overburned gypsum will not set in water, and that the setting of plaster of Paris is a simple process of crystallization, in which process the plaster of Paris builds into its structure the water of which it had been robbed by heat.[180]

Lavoisier

Payen in 1830[181] published a paper giving results of experimental work which amplified somewhat the earlier work of Lavoisier. He found that gypsum began to calcine at a temperature of 80° C. (187° F.) in a current of dry air, and the process continued rapidly as the temperature was raised. He noted that gypsum calcined at 200° C. (392° F.) hydrated slowly, and that gypsum calcined at 300°-400° C. (572°-752° F.) loses the power of taking on water of crystallization.

Payen

Berthier in 1840 demonstrated that the commercial plaster of Paris of his day contained from 3 to 8 per cent of water, and this corrected an error of Lavoisier who had reported that all of the water of crystallization was driven off in the calcining process.

Berthier

In 1883 Le Chatelier[182] published the results of investigations which were of great practical importance. He noted that the plaster of Paris of his day contained some 7 per cent of water, and that the decomposition of gypsum in the cal-

180Acad. des Science, Compt. Rend., Paris, 1765.
181Chimie Industrielle 1830.
182Acad. des Sci., Compt. Rend., 1883.

cining process took place in two very distinct periods of time.

Le Chatelier He treated a measured quantity of gypsum gradually in a paraffin bath, recording the temperature every five minutes. He found that the temperature did not rise uniformly, but that there were two periods at which it remained nearly stationary. After rising rapidly to 110° C. (227° F.) it then rose more slowly to 120° C. (248° F.), stood stationary for some time at 128° C. (262° F.) then went on more rapidly to 140° C. (284° F.), from this point the temperature moved slowly to 163° C. (325° F.) where there was a second stop, which was not as long as the first. W. A. Davis plotted the curve shown in figure 51 from these experiments, using the time as abscissa and the temperature as ordinates.

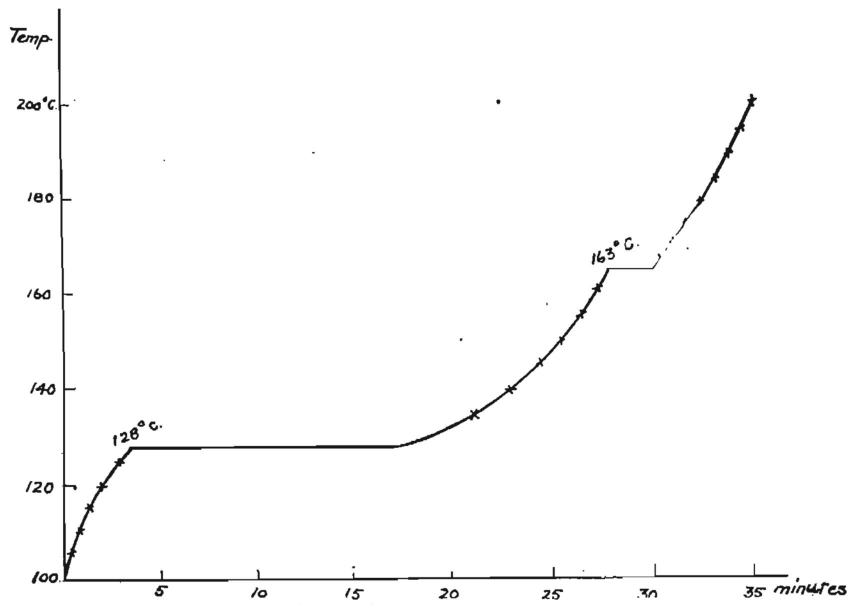


FIG. 51.—Temperature gradient for the decomposition of gypsum. Courtesy New York Geological Survey.

Le Chatelier concluded "that these two halts in the rise of the thermometer were brought about by the absorption of heat which accompanied the elimination of the water. They indicate the existence of two hydrates having different temperatures of decomposition."

Further experimental work of Le Chatelier determined exactly the chemical formula of the half hydrate.

Glasenapp in 1908[183] classified gypsum plasters as follows:

Glasenapp's Classification		
Sets with water, owing to formation of crystals.	107°C (224°F) hemihydrate 107°C (224°F) to 170°C (338°F) mainly hemihydrate 170°C (338°F) to 200°C (392°F) more or less dehydrated hemihydrate. Sets rapidly with water to form the hemihydrate. (The soluble anhydrite of Van't Hoff and others. F. A. W.) 200°C (393°F) to 250°C (482°F) contains small quantity of H_2O, sets slowly, at first with formation of hemihydrate. 250°C (482°F), contains traces of H_2O, sets very slowly	Plaster of Paris
Set slightly or not at all[184]	400°C (752°F) to 700°C (1292°F) anhydrous gypsum, practically dead burned. 700°C (1292°F) to 800°C (1472°F) beginning of formation of flooring gypsum.	
Set slowly with water without alteration of form[184]	800°C (1472°F) flooring plaster with crystal form of the granular anhydrite. 900°C (1652°F) to 1000°C (1832°F) flooring gypsum with full development of granules. 1000°C (1832°F) to 1400°C (2552°F) flooring plaster with granules of increased size and hardness and rising content of basic sulphate.	

Calcined gypsum, when pure, and when composed entirely of hemihydrate ($CaSO_4 \frac{1}{2}H_2O$) consists of 93.8 per cent of calcium sulphate and 6.2 per cent water. As actually manufactured the hemihydrate forms the greater part of calcined gypsum, but mixed with it there may be small amounts of

1. raw gypsum.
2. soluble anhydrite, or No. 1 anhydrite.
3. dead burned gypsum, or No. 2 anhydrite.
4. natural anhydrite or No. 4 anhydrite.

Raw gypsum should not be present unless fast setting material is desired, for raw gypsum speeds the set and wall plaster made from calcined gypsum containing some raw material requires more retarder and is apt to be irregular in set.

"First settle" calcined gypsum

Calcined gypsum intended for use in wall plaster is calcined to a temperature of approximately 320° F. (160° C.). It has passed through the first boil which takes place at 262° F. (128° C.) and is just ready to enter the second boil which begins at 325° F. (163° C.) (See Fig. 51.) It contains a small amount of soluble anhydrite.

In addition to the hemihydrate, there are considerable quan-

183Journal Society Chemical Ind. 1908, p. 858.

184When treated with alum solution set owing to formation of crystals.

tities of soluble anhydrite, and some dead burned gypsum in second settle calcined gypsum. The nature of the second settle product is considered at length in chapter VI.

"Second settle" calcined gypsum

Soluble anhydrite was first recognized by Van't Hoff, who formed it directly by heating gypsum in a vacuum over sulphuric acid, without the intermediate formation of the hemihydrate. In the ordinary calcining processes hemihydrate is first formed and this is converted to soluble anhydrite on further heating.

Soluble anhydrite

Soluble anhydrite is very soluble in water and very unstable. It readily takes moisture from the atmosphere and returns to the hemihydrate. To determine its presence, material must be taken directly from the kettles as they are discharged, and kept in air tight containers till analyses can be made.

The nature of gypsum calcined at high temperatures is considered in chapter XIX.

THE SETTING OF CALCINED GYPSUM

The generally accepted theory to account for the set of gypsum plasters was first propounded by Le Chatelier. He pointed out that when water is added to calcined gypsum a certain portion of it promptly goes into solution. Gypsum itself is very soluble, and the hemihydrate is at least five times as soluble as gypsum. When water is added to calcined gypsum, therefore, it very quickly becomes supersaturated with reference to gypsum and crystals of that substance begin to form. Only a portion of the hemihydrate actually goes into solution. Other portions of the hemihydrate serve as nuclei about which the crystals of gypsum grow. These crystals interlock and the whole mass is firmly bound together by them. If too much water is added the spaces between the crystalline centres is so great that the interlocking is imperfect or completely prevented, and in consequence the plaster is weak or does not set up at all.

Setting of gypsum plaster

Grimsley[185] assumes that a certain amount of raw gypsum in the calcined gypsum is necessary to start the crystallization.

185Kansas Geol. Survey, Vol. V, p. 167.

Without question raw gypsum greatly accelerates the setting action, but microscopic examination of calcined gypsum shows that material free from raw gypsum sets satisfactorily for wall plaster purposes. Indeed the manufacturer of gypsum wall plasters is exceedingly careful to exclude every trace of raw gypsum from the calcined plaster that he uses for making wall plaster.

CHAPTER XIII

PHYSICAL PROPERTIES OF CALCINED GYPSUM[186]

In the strictest sense calcined gypsum is a fine powder, and its more important physical properties are its color, fineness, and weight.

It is the custom to ascribe to calcined gypsum the properties which it possesses when mixed with various degrees of water to form a paste, and in this form its more important properties are, its setting time; plasticity; and expansion.

It is customary also to speak of the properties of the hard masses resulting from the setting of calcined gypsum pastes as the properties of calcined gypsum. The more important of these properties are tensile, compressive, and adhesive strength; hardness; and conductivity of heat and sound.

In this chapter the properties of calcined gypsum will be considered in all three of these aspects. Before taking up the properties of calcined gypsum pastes and of the solids resulting from the setting up of these pastes it will be necessary to consider at some length the question of the consistency of these pastes since the physical properties of pastes and resulting solids vary with the percentages of water added to the calcined gypsum.

Color

The color of calcined gypsum is dependent on the color of the mineral used in its manufacture and on the fineness of grinding. Inasmuch as gypsum varies widely in color, there is a wide range in the color of the calcined product. Color is not an important property of gypsum that is used in making plaster for base coats, nor is it essential for many of the purposes for which it is used in the arts. A pure white gypsum is often desired for finishing plaster and for moulding plaster. Certain beds of Nova Scotia gypsum have been preferred for the manufacture of finishing plaster. During the world war, the United States

[186] It is understood that the term calcined gypsum is applied to gypsum calcined under 400° F. with the formation of the hemi-hydrate or soluble anhydrite; and that the terms hydraulic gypsum and Keene's cement are applied to the products of calcination at higher temperatures.

was thrown upon its own resources and the genuine merit of certain beds of gypsum located in the Western States was recognized. Calcined gypsum made from these gypsum beds has as light a color and is in every way as suitable for the highest grade of finishing plaster, as the imported article.

Fineness

The fineness of calcined gypsum is entirely a matter of grinding and the standards are largely determined by the demands of the trade. For certain purposes very finely ground material is desired. Fineness of grinding is discussed somewhat at length in chapter VIII which deals with the Technology of Calcined Gypsum.

Weight

The weight of calcined gypsum is largely dependent upon the fineness to which the material is ground. As set out in chapter I calcined gypsum, ground so that 90 per cent passes a 100 mesh screen, when loose weighs from fifty to sixty-five pounds per cubic foot, and when well shaken down or taken from bins where it has been stored for some time, from sixty-five to seventy-five pounds per cubic foot.

NORMAL CONSISTENCY

In order that the setting time and tensile strength of different calcined gypsums may be accurately compared, it is essential that the different specimens be mixed with water to the same consistency. If samples of calcined gypsum from each of the sixty-five mills in the United States are taken, it will be found that when like amounts of water are added, the consistency of the resulting pastes will differ more or less for every sample. In consequence of this fact it is generally felt that an accurate method for establishing a "normal" consistency is the most important step in the standardizing of methods for testing the strength and setting time of calcined gypsum.

German method for determining normal consistency

The German Gypsum Assn. some years ago adopted a rather simple, but not very accurate method, for bringing samples of calcined gypsum whose physical properties were to be compared, to a common, or normal consistency. Their directions are as follows: "Place in a glass vessel 100 cc. of water. To this water add gypsum by hand till it ceases to sink; that is, till the water surface disappears and a thin dry layer of gypsum remains visible for a period of 3 to 5 seconds. All of the gypsum necessary should be added in 1½ to 2 minutes. While adding the calcined gypsum neither the glass nor the paste should be touched, jarred, or stirred in any way. The glass containing the paste is now weighed and the ratio of the dry material to the water (100 cc.) is recorded as the normal consistency."

Determination of normal consistency at Iowa City

In connection with tensile strength tests conducted for this report by Messrs. Holt and Holmes, of the Department of Engineering, Iowa State University, the question of normal consistency was necessarily considered, and the following method was used: "In the determination of normal consistency 300 grams of plaster were poured

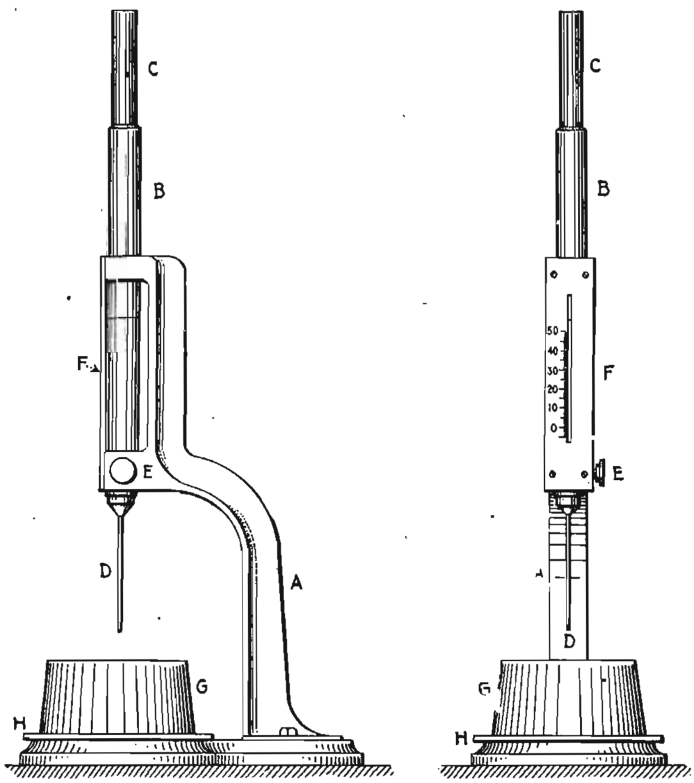


FIG. 52.—Vicat needle. Courtesy of American Society for Testing Materials.

upon a measured quantity of water, the mixture stirred to an even consistency, formed into a ball with the hands, and pressed by one hand into the larger end of the rubber ring (specified by the Committee on Uniform Tests of Cement of the

American Society of Civil Engineers) held in the other hand and through the ring so as to completely fill it with paste, leaving the surface flush at the larger end. The ring is then placed on its larger end on a glass plate, and the excess paste at the smaller end removed and the surface smoothed off with a trowel. The paste, confined in the ring, resting on the plate, was placed under the rod of the Vicat needle (see figure 52), the larger end of which was carefully brought in contact with the surface of the paste, the scale read, and the rod quickly released. The paste was assumed to be of normal consistency when the rod (or cylinder) settled to a point ten millimeters below the original surface in one minute after being released. In order to avoid inconsistent results from setting of the plaster the whole operation should be completed within three minutes from the time the calcined gypsum is put in the water. It was found that the method gave a very definite and positive method of determining normal consistency, in that the use of a quantity of water one per cent greater than that required for normal consistency permitted a settlement of the rod far exceeding ten millimeters; while the use of one per cent less than that required for normal consistency resulted in a settlement decidedly less than ten millimeters."

Samples of calcined gypsum tested in this manner for normal consistency gave the following results:

Sample	Trade Names	Per cent of water
A	Plaster of Paris, Ft. Dodge	58
B	Structolite	48
C	Moulding Plaster, Blue Rapids	55
D	Moulding Plaster, Blue Rapids	56.5
E	Moulding Plaster, Blue Rapids	52
F	Moulding Plaster, Blue Rapids	49
G	Moulding Plaster, Grand Rapids	40
H	Moulding Plaster, Grand Rapids	55
I	Stucco, Fort Dodge	56.5
J	Moulding Plaster, Fort Dodge	46.5
K	Dental Plaster, Fort Dodge	41
L	Plaster of Paris, Fort Dodge	56
M	Plaster of Paris, Fort Dodge	55
	Dental Plaster (unknown)	45.5

Southard viscosimeter

An apparatus for testing normal consistency has been devised by Mr. Geo. L. Southard and is known as the Southard viscosimeter. The instrument is shown in figure 53 and may be briefly described as follows:

The apparatus consists of a brass cylinder of 2-inch bore with a circular disk flange flush with its upper end. The screw actuating the piston is five-eighths inch in outside diameter, one-fourth inch pitch, right-hand square threads one-sixteenth inch deep. The top of the brass disk flange is etched with concentric circles which vary in diameter from 6 cm. up to 28 cm. by increments of 2 cm.

When in position for use the brass flange is to be maintained in a true horizontal position.

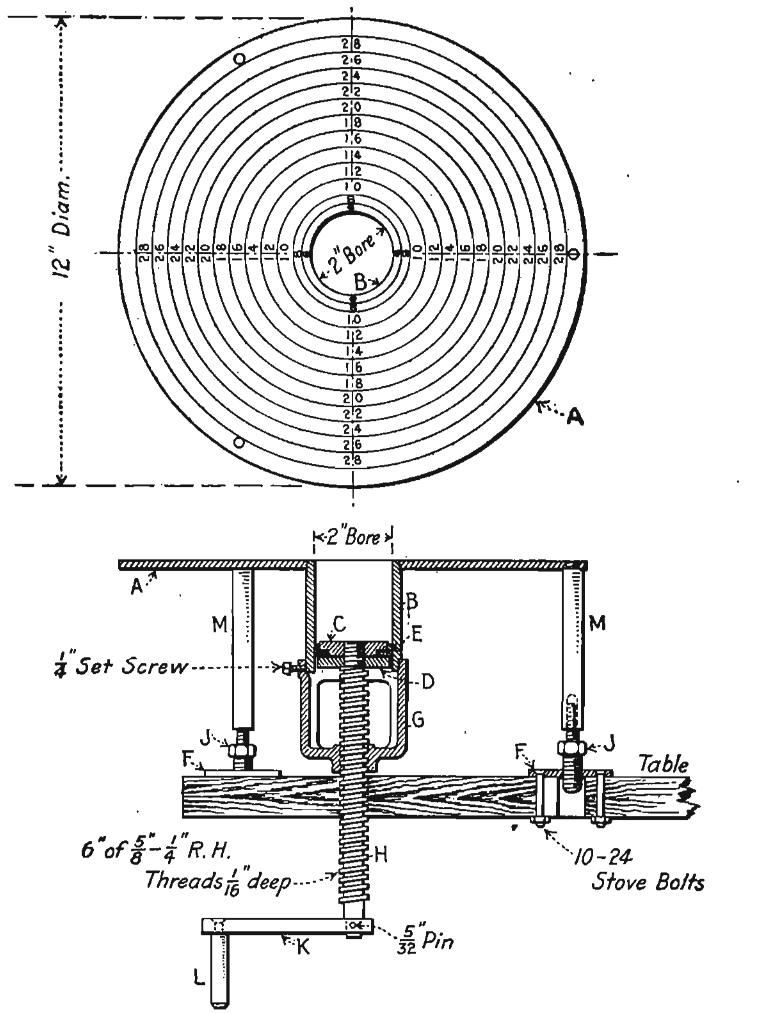
To prepare this viscosimeter for use see that the piston, cylinder walls and top of plate are clean. Then by turning the crank, bring the top of the piston exactly flush with the top of the plate. Then by reverse cranking make ten complete turns, which will lower the piston to a point 2½ inches below the top of the plate. Next proceed to prepare the sample of dry calcined gypsum, adding to it and mixing with it thoroughly in the dry state, 0.1 per cent of retarder. Then make a mixture of at least 300 grams total of this retarded calcined gypsum and water. Add the retarded calcined gypsum to the water, allowing it to soak two minutes. Then stir vigorously to an even fluidity for one minute. Then immediately pour this mixture into the well in the center of the plate of the viscosimeter, filling the well just flush with the top of the plate. Then immediately turn the crank at the bottom of the viscosimeter ten turns at the rate of one turn per second. The upward motion of the piston will cause the mixture to overflow into a circular patty, it being understood that the top face of the circular disk of the instrument is to be adjusted and maintained in a true horizontal plane. Next take the average of the quadrant readings on the concentric lines on top of the plate.

A mixture is of normal consistency if with this operation it gives a circular patty averaging 9.7 cm. in diameter. The normal consistency shall be expressed as the number of cubic centimeters of water required to be added to 100 grams of the plaster under test in order to make the mixture of normal consistency.

Field method for normal consistency

The committee of the American Society for Testing Materials, having in its charge gypsum and gypsum products, recommends the following simple method for determining normal consistency in the field, and reports that fairly accurate results are obtained thereby.

"The apparatus shall consist of a piece of brass tubing 2 inches in inside diameter and 4 inches long, and a piece of



A; 3/16" Hard Brass Plate Scale Disk.
B; 2" Ex. H. Seamless Brass Tube Cylinder.
C; Brass Piston Top.
D; " " Bottom.
E; Leather " Packing.
F; 3/16" x 1" Flat Bar Steel Support Plate.
G; Brass Cage (Open on two Sides).
H; ⅝" Hard Brass Piston Screw.
J; ½" Hex. Brass Support Stud.
K; ⅜" x ¾" C. R. S. Screw Lever.
L; ⅜" Diam. C. R. S. Lever Handle.
M; ½" Diam. C. R. S. Support Rod.

FIG. 53.—Southard Viscosimeter. Courtesy American Society for Testing Materials.

plate glass about 8 inches square. The brass tubing shall be cut off true and square at the ends, and to the exact length.

Thoroughly wet the cylinder and glass plate by immersion in clean water. Set the cylinder on end on top, and in the center of, the glass plate.

"Prepare a dry sample of calcined gypsum by adding to it and mixing thoroughly, in a dry state, 0.1 per cent of retarder by weight. Next make a mixture of this retarded calcined gypsum and water of sufficient quantity to slightly more than fill the cylinder. The mixture shall be made by adding the retarded calcined gypsum to the water, allowing it to soak for two minutes. Now stir vigorously to an even fluidity for one minute, and at once pour this mixture into the cylinder so as to completely fill it level with the top.

"Immediately raise the cylinder from the glass with a quick, straight and upward motion so as to withdraw it from the stucco mass within. This act will allow the stucco and water mixture to leave the cylinder, assuming a coneshaped circular patty upon the glass plate.

"The normal consistency is a mixture which will give a circular patty averaging 9.7 cm. in diameter, and shall be expressed as the number of cubic centimeters of water required to be added to 100 g. of the plaster under test in order to make the mixture of normal consistency."

SETTING TIME

Definition

The period required for calcined gypsum to harden is called its setting time. For practical purposes two stages in the hardening process are recognized and should be carefully distinguished.

Initial set

Calcined gypsum, after being mixed with water, can be manipulated freely for a certain period without reducing its ultimate tensile strength. When the point is reached where further manipulation measurably reduces the tensile strength it is said to have taken its initial set.

Final set

When the material has further hardened so that it cannot be worked conveniently with a trowel it has taken on its final set. The time of final set does not correspond with the point of maximum tensile strength, which is arrived at many days later.

Determination of setting time

Inasmuch as the value of calcined gypsum for many purposes is largely dependent on the length of time it can be conveniently manipulated the determination of final set is very important. The determination of initial set is of less importance, for practical tests show that the loss in tensile strength resulting from the manipulation of calcined gypsum plaster for some time after initial set has taken place, is not serious. In the case of gypsum wall plasters, initial set probably takes place in a majority of instances, before the plaster is applied to the wall. The strength method for determining initial set is exceedingly laborious, as a great many briquettes must be broken if accuracy is desired. The German Gypsum Association has adopted a simple empirical method, according to which the material is said to have taken on its initial set when a knife that is passed through it leaves a clean cut. The paste which has been mixed with water to normal consistency is poured on a glass plate and at frequent intervals a knife blade is passed through it. When the edges of the cut cease to flow together the initial set is recorded.[187]

Determining initial set

It is very desirable that a common standard for final set be agreed upon, so that comparisons may be accurately made. Many methods are in use which give widely divergent results. Mr. Emley has considered at some length the problems involved in determining the time of set of calcined gypsum and has suggested methods for use in determining final set. His paper is presented at length in appendix IV.[188] Extended experiments were conducted by Mr. Emley to determine the relative merits of the "Vicat needle", and the "rise of temperature" methods for determining final set.

Determination of final set

Heat is generated by the process of hydration which constitutes the setting process of calcined gypsum. Mr. Emley found that the point of maximum temperature occurred considerably after the gypsum had taken on its final set (defining final set as the time after the material is no longer workable). His conclusion from his experiments was (see appendix IV) that the measurement of the temperature rise is useless for determining the time of set.

Rise of temperature method

Mr. Emley's experiments led him to the conclusion that the use of the Vicat needle was the most satisfactory method of determining final set, and he outlines the following method of procedure: "Determine first the

Vicat needle method

187See Appendix IV for a more complete statement.

188Warren E. Emley, Measurement of the Time of Set of Calcined Gypsum: Transactions American Ceramic Society, Vol. XIX, 1917.

normal consistency using the Southard instrument, as recommended by Sub-Committee 4 of Committee C-11, A. S. T. M. Determine from this the amount of water which must be added to 100 grams of the sample to produce a paste of normal consistency. In a perfectly clean porcelain casserole, put three times this amount of distilled water, weigh out 300 grams of the sample and transfer to a clean sheet of glazed paper. Also provide a clean glass stirring rod about 1/8 in. diameter. When the second hand of a watch points to zero, transfer the sample from the paper to the casserole. This should be done as quickly as possible without splashing, and should not take more than two seconds. Let the plaster soak quietly until the second hand again reaches zero, when the mixture is to be stirred vigorously by means of the stirring rod for one minute, by which time the mass should be homogeneous.

"At the end of the second minute, this mixture should be poured into the mold for the Vicat needle. At one minute intervals, the needle is allowed to sink into the paste. Eventually there will be found a time when the needle will not penetrate clear to the bottom. The time elapsed between the time when the sample was added to the water and the time when the needle no longer penetrates to the bottom is recorded as the time of set.

"The sample, water, casserole, and mold shall be at a temperature of not less than 20° C., nor more than 25° C., at the beginning of the experment.

"The Vicat needle and the mold are described in the standard specifications for cement—1915 Yearbook, A. S. T. M., page 359. The mold is made of hard rubber, and it will be found difficult to remove all traces of set plaster from it without scraping, which might cause injury. To overcome this, the mold should be prepared for use by dipping it in melted paraffin. This will prevent adherence of the plaster to a great extent, and the mold can be cleaned thoroughly and easily by heating it very gently."

The German method

The method for determining final set adopted by the German Gypsum Association is wholly empirical. A paste made according to their established rules for normal consistency, is allowed to harden till pressure by the finger shows that the set has advanced considerably. From that time at intervals of one minute shavings about 2 mm. (about one-tenth of an inch) thick are cut off. When, with the knife blade moving fairly fast, the shavings come off grainy and brittle, the final set is said to have been reached.[189]

FACTORS GOVERNING TIME OF SET

The discussion of normal consistency, necessarily introduced before the consideration of setting time, has already brought out the fact that the amount of water used in mixing is an important factor in the setting time of calcined gypsum. Householder[190] sums up a series of experiments in the curve shown in figure 54. The time of

Setting time and consistency

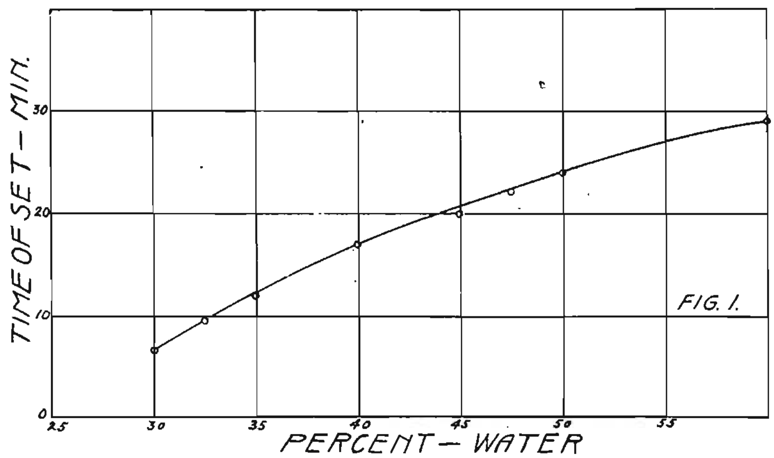


FIG. 54.—Diagram showing relationship between per cent of water used and setting time of calcined gypsum. Courtesy Journal of Ceramics.

set was determined by the methods proposed by Mr. Emley and quoted above.

Imperfectly calcined gypsum, that is, calcined gypsum containing some raw material, sets much faster than gypsum that has been properly carried to either the first or the second settle. Gypsum reground after calcining sets faster than material not reground, according to tests by Winterbottom.[191]

Calcining and set

The explanation probably lies in the fact that the tailings that are reground contain fragments that are not calcined to

[189]For a more complete statement including the German method of obtaining normal consistency, see appendix III.

[190]Some factors influencing the time of set of calcined gypsum. Paper given in full in appendix V.

[191]D. C. Winterbottom, Dept. of Chemistry, South Australia, Bulletin No. 7, p. 104.

the center, and the process of regrinding releases some raw material.

Certain impurities act as a retarder. This is notably true of colloidal clay that makes up 15 to 25 per cent of a calcined gypsum made from gypsite. The retarding effect of this clay is so great that very little retarder need be added for wall plaster purposes. Admixture of a sharp sand speeds the set of calcined gypsum, while a loamy sand may actually retard it.

Impurities and setting time

In general it may be said that substances that furnish nuclei about which the gypsum in solution can crystallize act as accelerators, and that materials that interfere with the interlocking of the growing crystals have a retarding influence. These matters are further considered in chapter XX on Retarders and Accelerators.

Agitation of calcined gypsum paste hastens its set. Householder has shown by diagram the accelerating effects of stirring and these diagrams are given in appendix V.

Stirring

PLASTICITY

In connection with calcined gypsum and similar substances, the word plasticity is given a meaning somewhat more restricted than in common usage. The dictionary defines plasticity as "that property of matter by virtue of which it can be molded into shape and will retain that shape". The lime section of the American Society for Testing Materials proposes that "Plasticity is that property of a material or combination of materials by virtue of which it deforms continuously and permanently during the application of force".

Definition

Plastering materials and clays, obviously, to be plastic must be combined with water, and their behavior when moving under pressure will indicate their plasticity.

A calcined gypsum paste is highly plastic if, when forced through an orifice, it presents a continuous, clean, unbroken surface. A plastic plaster is neither sticky nor sandy. It feels soft and velvety and a trowel passes over it as over an oiled surface.

The ability to take on and hold water in the face of the absorptive competition of the background is an essential characteristic of a plastic plaster.

The plasticity of plasters made from calcined gypsum is a highly important property, and the subject will be considered further in chapter XV where gypsum plasters are considered.

The question of plasticity is presented further and in an instructive way in appendix VII where the specifications for the Emley patent for making plastic gypsum are set forth.

Hardness Surfaces made from ordinary gypsum plasters used neat or with suitable sand not in excess of two parts by weight to one of plaster, are abundantly hard for all the usual structural demands. Until recently the hard surface given by gypsum plasters has been somewhat reduced by the necessity of mixing hydrated lime with the finish coat to secure the necessary plasticity. With the new processes for making plastic gypsum, however, a pure gypsum finish becomes possible. Where surfaces of unusual hardness are required Keenes cement, a standard gypsum product, may be used. Special processes for hardening gypsum surfaces are described in chapter XXI.

Compressive strength The compressive strength of calcined gypsum depends upon the amount of water used in mixing; the temperature of calcination; the dryness of the material; and the purity of the material.

Second settle calcined gypsum (gypsum calcined at 385° F.) gives a block of higher compressive strength than first settle calcined gypsum. When mixed with water to normal consistency its compressive strength is about 2000 pounds per square inch. The compressive strength of first settle material is about one-half as great. This subject is considered somewhat at length in connection with structural gypsum in chapter XVIII.

Heat conductivity Gypsum is a poor conductor of heat. This important property adds to its value in every one of the many forms in which it is used as a building material. While its low conductivity is a valuable characteristic of gypsum plasters, it is an even more important property of gypsum blocks and boards. This property makes it a remarkably good material for use in roofs and floors.

"Compared with other commonly used fireproof materials, a gypsum roof construction 3 inches in thickness will save about 125 sq. ft. of radiation (or 290 lineal feet of 1¼ inch pipe) or from three to four tons of coal for heating per year, for each 1,000 sq. ft. of roof area so covered. These figures are based upon test information submitted by Prof. G. F. Gebhardt, Armour Institute of Technology, and Prof. R. C. Carpenter, Cornell University. Professor Gebhardt's tests give the following in terms of B.T.U. transmitted per hour per degree difference in temperature through different thicknesses of gypsum and concrete.[192]

	B. T. U.	
Thickness—Inches	Gypsum	Concrete
0.250	.667	.780
0.500	.575	.770
0.750	.503	.757
0.875	.476	.750
1.000	.455	.745
2.000	.314	.706
3.000	.242	.670
4.000	.196	.635"

Gypsum posseses a peculiar virtue as an insulating material for protecting columns and beams of wood or metal from the high temperatures that develop during a conflagration. This property grows out of the fact that the gypsum must be deprived of its water of crystallization before its temperature can be made to rise above that required for its dehydration, 105° C. (221° F.). In figures 55 and 56 it has been proven on a large scale as well as in laboratory tests, that a protective coat of two inches of gypsum will protect steel against the temperatures that develop in severe conflagrations.

Commenting on the experiments of which the diagrams shown as figures 55 and 56 are a partial illustration, Hull[193] says:

"It is found that the length of time required to reach 600° C. at depths of 1½ and 2½ inches does not vary greatly in the clay and concrete specimens. This is not remarkable when it is considered that in materials of high conductivity, heat is more free to pass on to the interior, whereas, in materials of low conductivity it "banks-up" near the exposed surface. It is seen, however, that the denser clays, and the gravel and cinder concretes, make comparatively poor showings in this

192Marani, Blue Book, Gypsum Industries Association.

193Hull, W. A., Comparison of Heat-Insulating Properties of Materials used in Fire Resistive Construction: Proceedings American Society for Testing Materials, Vol. XVII, Part II, 1917.

respect, and that the limestone concretes make a slightly better showing than the other concretes. The gypsums are found to be distinctly better than the clays and concretes in this respect."

In another series of experiments Hull[194] demonstrated the insulating effect of gypsum on concrete columns. He says:

"In order to determine the effect of additional insulation on a square gravel concrete column, one of these, No. 27, was

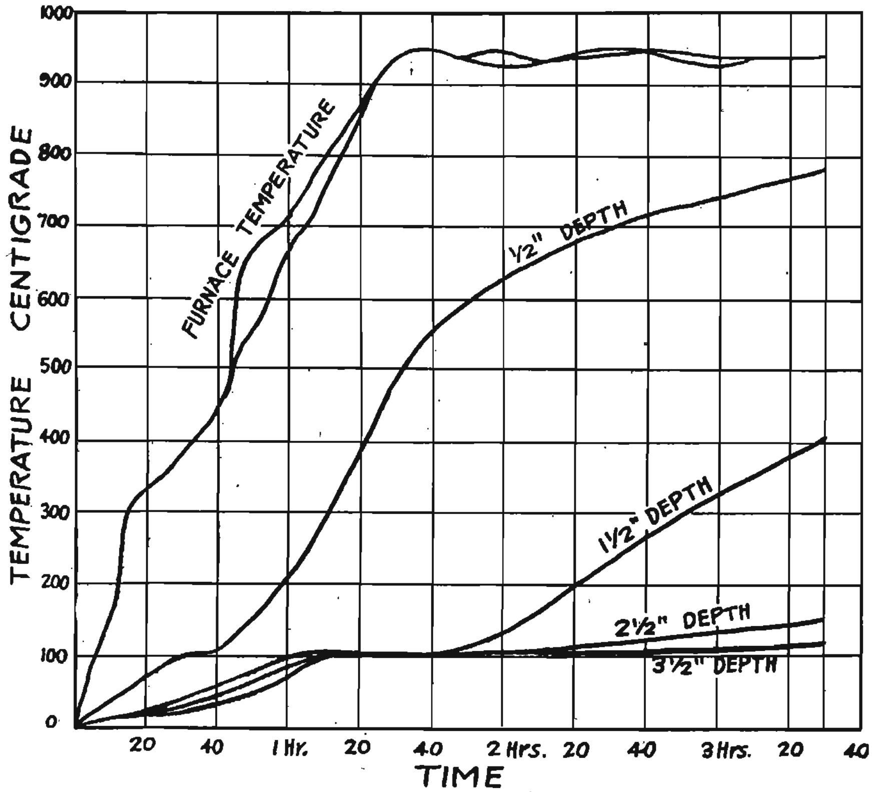


FIG. 55.—Diagram illustrating slow increase in temperature in protective coating of calcined gypsum, covering steel pillar. This is to be compared with figure 56 which gives temperature rise in pebble concrete under similar conditions. After Hull, Bureau of Standards.

plastered with 1 inch of a gypsum plaster, known as wood fibre plaster. This material contains no sand but has a wood filler. It was selected for this purpose on the assumption that such a material would give better thermal protection than a gypsum plaster containing sand. This plaster was reinforced with light expanded metal of the same grade and applied in

[194]Hull, W. A., American Concrete Institute, Vol. XIV, 1918.

the same way as that used on the round columns referred to in the preceding paragraphs.

"It will be seen that the ultimate strength of this column, at the end of the four-hour fire test, was slightly more than three times the average strength of the two columns of the same kind which had no plaster. In this case, as in the preceding one, a comparison of the temperature attained in the plastered and in the unplastered columns shows the important thermal effect of the additional insulation. In the unplastered square

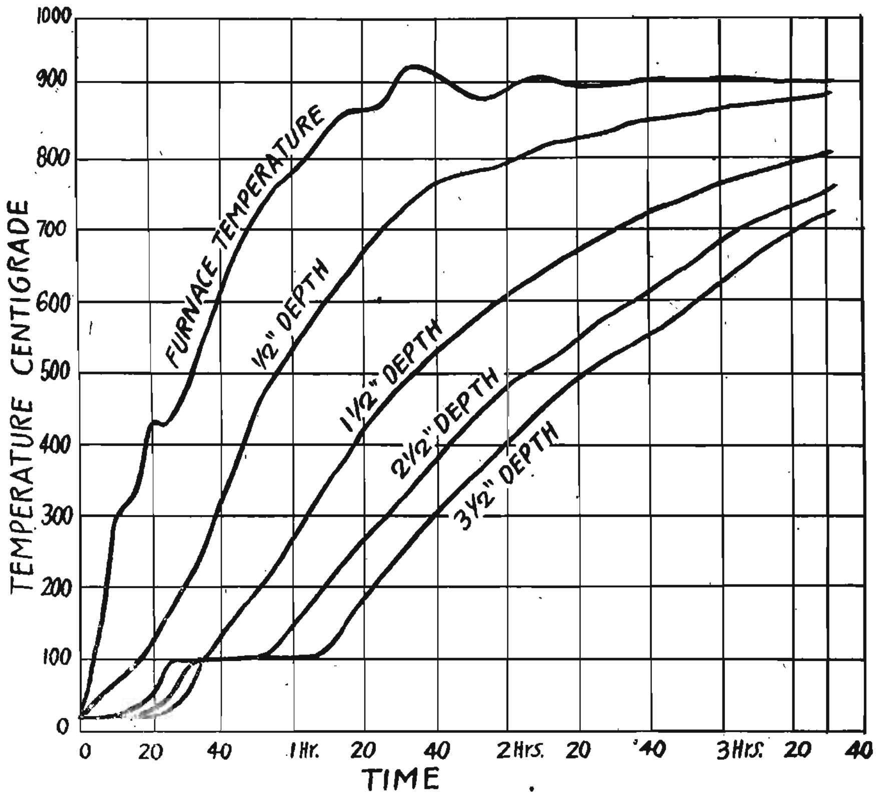


FIG. 56.—Diagram illustrating increase in temperature in pebble concrete. Shown for purpose of comparing with figure 55. After Hull, Bureau of Standards.

columns, a relatively small part of the protective covering spalled off in the fire test and the lower temperature attained at the center of the plastered column is to be credited largely to the thermal insulation of the plaster."

Gypsum products are unique in their lightness, a property which they enjoy without sacrifice of other essential characteristics required of a high grade, fire resisting building material.

A finished wall or partition of gypsum is 38 per cent lighter than a similar wall of the lightest competitive material.[195]

Structural gypsum weights 6½ pounds per square foot for each inch of thickness. This is about one-half the weight of average concrete.

This lightness means, in building construction, a saving in concrete and steel in footings and supporting members and a saving in labor required for erection.

TENSILE STRENGTH

The tensile strength of calcined gypsum is an expression of its ability to withstand a direct pulling strain. The instruments used in testing tensile strength are the same that are employed for this purpose in testing Portland cement, and

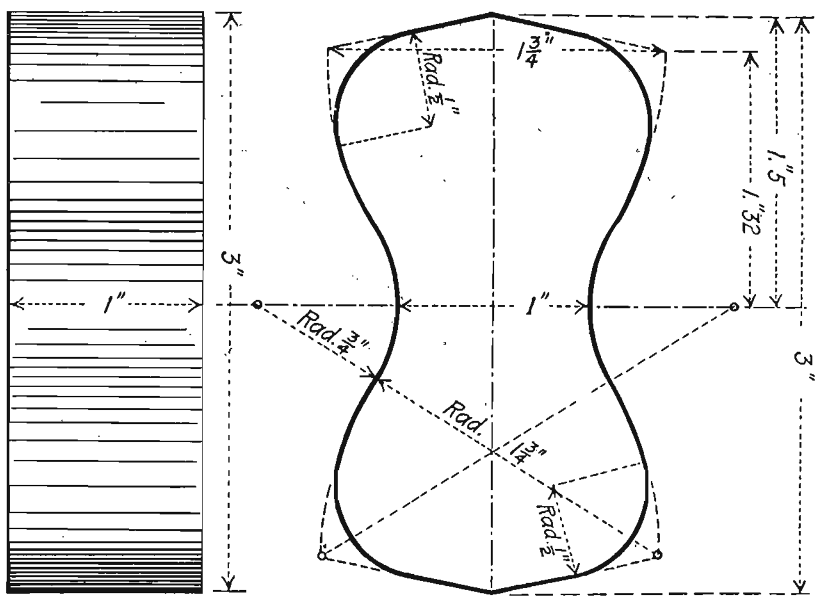


FIG. 57.—Standard Briquette used in testing tensile strength of calcined gypsum. Courtesy American Society for Testing Materials.

there are several standard machines on the market. Figure 57 shows the details for a briquette and figure 58 shows a gang mold in which briquettes are made.

The tensile strength of calcined gypsum varies with the

[195]Marani, in Blue Book, Gypsum Industries Association.

amount of water used in mixing; the age of the briquettes; the purity of the mineral used; the fineness of grinding; and the extent to which the calcined gypsum has been exposed to moisture before mixing. Other accidental factors sometimes interfere with a correct calculation of tensile strength. Flaws or blow holes of course cause weakness. If the briquettes are dried at too high temperatures, or freeze before becoming dry, they are weakened.

Dependent on various conditions

Preliminary to the devising of a method of determining

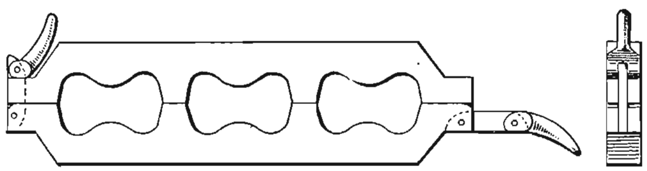


FIG. 58.—Gang mold for making briquettes. Courtesy of American Society for Testing Materials.

normal consistency a series of tensile strength tests were run at the laboratory of the State University of Iowa and varying percentages of water were used in mixing the calcined gypsum. On this point the report of Messrs. Holt and Holmes reads as follows:

"From each sample five briquettes were made with each of the following percentages of water: 35, 40, 50, 60, 70, and 80, by weight. 35 and 80 were chosen as the limiting percentages because 35 per cent gave, with most of the samples, a mix somewhat drier than it is practicable to handle; and 80 per cent gave a mix which in some cases was so wet that water drained from the moulds, causing shrinkage of the briquettes. These briquettes were tested at the age of seven days. The results of the tests are summarized in the following table, each number stated being the average of the strengths of five briquettes:

SAMPLE	35 PER CENT	40 PER CENT	50 PER CENT	60 PER CENT	70 PER CENT	80 PER CENT
A	251	242	278	177	158	191
B	177	258	235	172	142	101
C	197	189	174	146	120	105
D	145	139	194	169	162	142
E	190	180	160	142	109	84
F	184	207	174	215	146	100
G	141	197	161	148	123	112

Sample	35 Per cent	40 Per cent	50 Per cent	60 Per cent	70 Per cent	80 Per cent
H	257	263	275	228	185	173
I	221	179	208	129	139	136
J	229	243	206	145	128	114
K	249	223	209	151	123	113
L	182	153	145	131	111	90
M	197	162	135	113	119	87
X	494	449	373	350	261	200
	3114	3084	2927	2416	2026	1748
Average	222	220	209	173	145	125

"Comparing the results shown in this table with those which follow under the heading "Tensile Strength", it will be noticed that these tests of seven-day briquettes show strengths much lower than those there stated. The reason for this is that the briquettes for these preliminary tests, with the exceptions of those from Sample "X", were stored in a too closely confined space, where the moisture produced by evaporation so retarded the setting of the plaster and softened it as to prevent the briquettes from attaining the strength shown by those properly stored. It was assumed, however—and the validity of the assumption was shown by later tests—that since all these briquettes were (with the exception noted above) made and stored under the same conditions they would furnish a fair comparison of the results to be obtained by use of the different percentages of water.

"From this summary it is seen that the drier the mix the stronger the briquettes. There is, however, only a slight difference in strength between the 35 per cent and the 40 per cent briquettes."

Tests made at Ames for the Iowa Geological Survey in 1902 showed that for calcined gypsum as then ground and calcined (second settle) maximum tensile strength was secured with 30 to 35 per cent of water.

In connection with its report on Webster county the Iowa Geological Survey[196] published the results of laboratory work by Marston which included tensile strength tests of numerous samples of calcined gypsum, the briquettes being broken at intervals of 1, 7, 28, and 220 days.

Age of briquettes

Typical briquettes made from Ft. Dodge material as well as from calcined gypsum from Texas and Kansas are tabulated below.

[196] Iowa Geol. Survey, Vol. XII, p. 228.

	Strength per square inch after			
	1 Day	7 Days	28 Days	220 Days
A	226	204	329	274
B	219	188	379	288
C	211	184	375	335
D	131	170	483	386
E	192	224	348	359
F	107	128	333	193
G	227	236	468	405
H	181	195	465	283

Messrs. Holmes and Holt report on carefully made tests for tensile strength of calcined gypsum as follows[197]:

"The method of mixing the plaster and water to form a paste from which to make the briquettes was the same as that used whenever plaster and water were mixed for any of the tests, and was as follows:

"The measured quantity of water was placed in the mixing dish, which had previously been wiped clean and dry. The plaster, which had been passed through a number 20 sieve, was turned into the water and the mixture stirred with a spoon to an even consistency. The paste was then placed in the moulds as quickly as possible, pressed in firmly with the thumbs, and the surface smoothed off with a trowel. It was found in many cases that the surface could be made smoother by allowing the paste to set up somewhat before removing the excess, when the latter could be shaved off with a trowel.

"As soon as the briquettes were set sufficiently to permit, they were removed from the moulds and stored on shelves in such a manner that there was free circulation of air around and between them. It was found that the storage of specimens in a confined space or in contact with each other caused an appreciable softening, supposedly from dampness produced by evaporation, and a resultant decrease in strength.

"At the proper age the briquettes were broken in an Olsen cement testing machine, provided with A. S. C. E. standard roller clips as specified for cement testing. It was found that a large percentage of the breaks occurred where the rollers of the clips gripped the briquettes, and not in the one-square-inch cross section. The gypsum briquette is softer than one of cement or cement mortar and the rollers cut into it, causing the "clip break". This would seem to indicate a need of a clip of different design for gypsum briquette testing.

"The results of the tension tests of neat plaster (or gypsum)

197The samples are the same that are referred to on pages 295 and 296 by the same letters.

briquettes are summarized in the following tables. As in the similar tables previously given, each number represents, in pounds, the average of the strengths of five briquettes."

Sample	24 Hours			7 Days		
	35 Per cent	Normal Consist'cy	80 Per cent	35 Per cent	Normal Consist'cy	80 Per cent
A	176	175	104	439	322	235
B	264	247	128	359	406	245
C	225	185	112	422	355	236
D	163	173	147	163	379	278
E	187	173	104	460	363	124
F	241	212	124	457	386	239
G	204	269	159	343	502	......
H	178	219	157	200	391	274
I	201	142	95	409	322	216
J	202	258	114	472	422	234
K	278	270	104	495	459	218
L	220	162	97	321	349	211
M	216	139	94	392	358	248
X	317	239	121	469	400	229

Sample	28 Days			12 Weeks					
	35 Pct.	N. C.	80 Pct.	35 Pct.	40 Pct.	50 Pct.	60 Pct.	70 Pct.	80 Pct.
A	469	308	228	386	419	345	314	278	231
B	528	424	223	499	479	383	314	257	247
C	517	370	212	530	435	416	351	262	205
D	425	384	268	460	433	386	323	244	197
E	439	350	205	475	454	378	311	231	199
F	488	414	238	480	498	323	305	248	199
G	392	438	372	377	435	331	292	272	237
H	272	375	240	168	516	409	380	294	235
I	501	326	201	465	414	337	271	213	165
J	464	383	229	503	447	380	307	263	217
K	480	418	199	491	453	378	333	245	209
L	468	326	200	415	444	371	289	269	217
M	466	313	204	441	444	307	289	209	156
X	475	396	218	487	497	381	332	230	198

Numerous tests have demonstrated that the strength of calcined gypsum is not lessened with time, if the calcined gypsum is kept perfectly free from moisture. Under ordinary conditions, however, some moisture is absorbed by the calcined gypsum, and there is a tendency in material that has been stored for some time toward fast setting, as well as a slight loss in strength.

Tensile strength and age of the calcined gypsum

Tensile strength and age of briquettes

It has been noted that briquettes made from calcined gypsum reach their maximum strength in about thirty days and then recede slightly. Their strength becomes stationary after twelve months, and averages three-fourths the strength shown at thirty days.

Additional data on compressive and tensile strength are given in appendix I where a paper by Emley and Faxon reviewing work done at the Bureau of Standards is presented.

Adhesion

The only adhesion tests that have been reported were made by Marston for the Iowa Geological Survey, in 1901, and published, with other tests of calcined gypsum, in connection with the report on Webster county.[198] As they are of considerable interest they are repeated here.

	Strength per Sq. In. after		
Kind	1 day	7 days	28 days
Fort Dodge "Stucco"		87	133
Fort Dodge "Stucco"		45	115

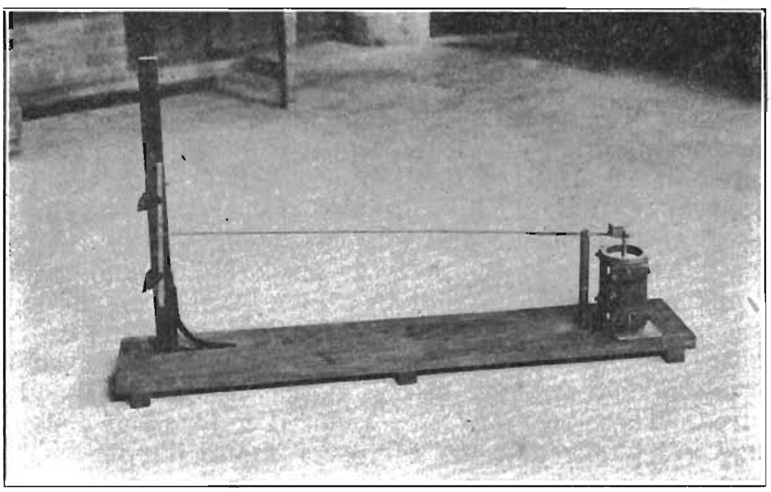


Fig. 59.—Instrument devised by Department of Engineering, University of Iowa, for testing expansion of calcined gypsum while setting.

Expansion and contraction

Tests to demonstrate change in volume in calcined gypsum while setting, were made at Iowa City by Messrs. Holt and Holmes and their report follows. The let-

198Iowa Geol. Survey, Vol. XII, 1901, pp. 224-225.

ters refer to samples of the same material described on page 298.

"For determining the percentage change in volume of the plaster while setting the apparatus shown in the accompanying cut (figure 59) was used. It consists essentially of a cast-iron cylinder, open at both ends and of known capacity, in which the paste under test is held. For convenience in removing the set plaster this cylinder was made in two halves, held firmly together by four bolts. During the test, the cylinder, containing the paste, rests on a glass plate. On the surface of the paste rests a disk, or piston, one-eighth inch smaller in diameter than the interior diameter of the cylinder. This piston is attached to the shorter end of a lever, the longer end of which terminates in a pointer which moves over a scale graduated to hundredths of an inch. The length of the longer lever arm being ten times that of the shorter, a movement of the pointer of 0.01 inch indicates a movement of the piston of 0.001 inch. The strength of the cast-iron cylinder is such that all change in volume is forced to take place in a vertical direction, causing a movement of the piston, which is magnified at the pointer by the ratio of the lever arms and is measured on the graduated scale. A light pressure of the piston on the paste is maintained by proper adjustment of a counter-weight.

Change in volume while setting

"In determining the change in volume, pastes of normal consistency were used. An amount of plaster sufficient to make the quantity of paste required to fill the cylinder to within half an inch of the top was mixed with the proper amount of water. The paste was placed in the cylinder a little at a time, each small quantity being lightly tamped in with a stick so as to compact the mass and remove air-holes. The piston was then brought to a firm bearing on the surface of the paste with the pointer against the scale, and an initial or zero reading made. Thereafter readings were made at intervals of five minutes, or less if the rapidity of the change required. These readings were reduced to terms of percentage change in volume and the curves of figure 60 plotted therefrom.

"Further tests were made with some of the samples to determine whether the change recorded was actually proportional to the volume of the mass under test. The tests were made exactly as above except that a cylinder of paste of one-half the height was used. The results obtained were, in quantity, almost exactly one-half those obtained from the full-sized cylinders, indicating the same percentage change."

Of the thirteen samples tested twelve show expansion and one shows contraction. This erratic sample (H) was taken from material supposed to be identical with C. Several of the samples show an initial contraction though an ultimate expansion.

Plasters made from calcined gypsum are remarkably good

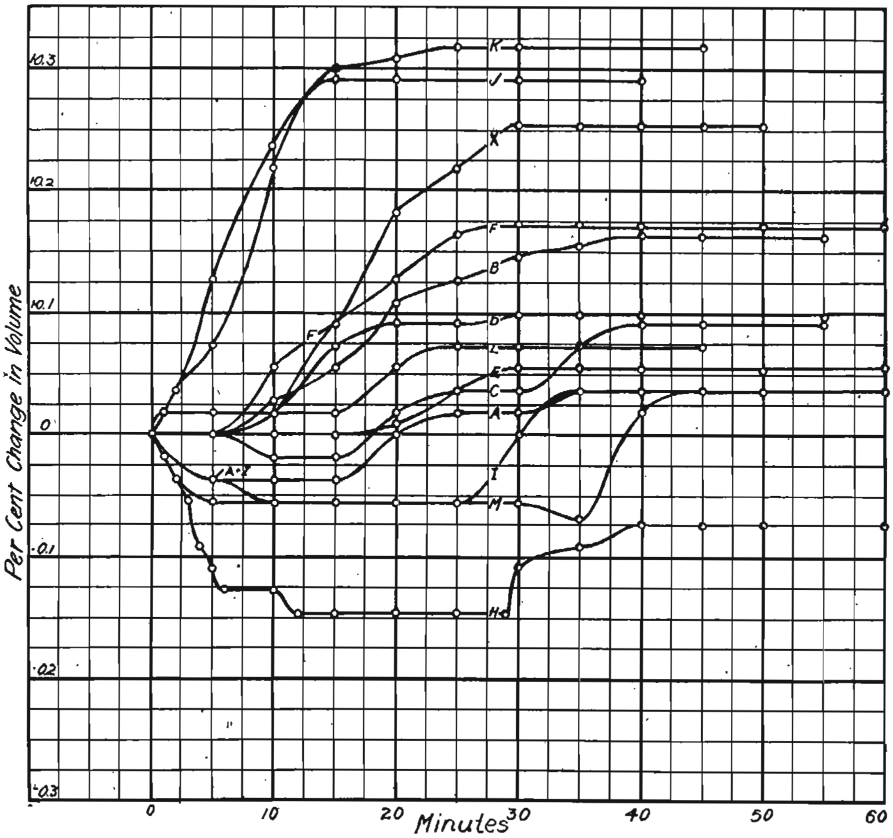


FIG. 60.—Diagram illustrating expansion of calcined gypsum while setting.

non-conductors of heat. This property makes them especially valuable for roof construction, where they serve to keep out exterior heat, and to retain heat generated within. Their fire resisting properties are of the highest value. Calcined gypsum will stand a long exposure to intense heat with little rise in temperature, due to the fact that its water of crystallization must be drawn off before it is possible for its temperature to rise above 360 to 400° F.

Conductivity, heat

This subject will be considered more fully in the chapters treating of structural gypsum, gypsum blocks, and wall plasters.

Advocates of lime plasters have frequently made the assertion that walls made of gypsum plasters do not deaden sound as effectively as does the material whose cause they champion. Their statements, however, do not seem to be borne out by careful tests. Inasmuch as these tests have been made in connection with gypsum plasters and plaster

Conductivity, sound

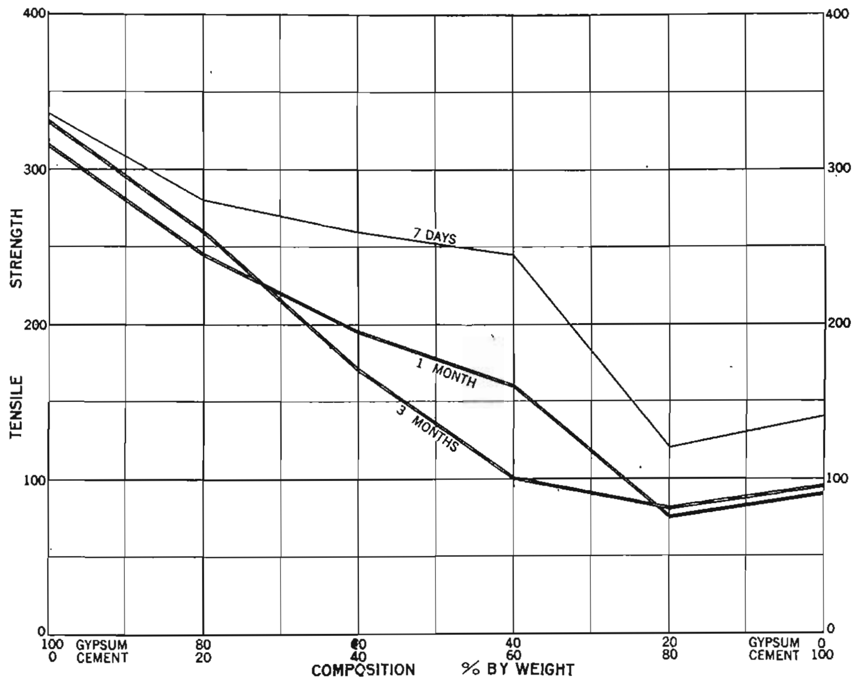


FIG. 61.—Diagram illustrating the tensile strength of mixtures of calcined gypsum and Portland cement in varying proportions. Courtesy of Bureau of Standards.

block the question of sound conductivity will be reserved for later chapters.

GYPSUM AND PORTLAND CEMENT

Some interesting tests of the tensile strength of gypsum and Portland cement were recently made by the Bureau of Standards and the results are shown in the curve given in figure 61. With this diagram the Bureau of Standards submits the following letter of explanation:

Tensile strengths

DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
WASHINGTON

July 10, 1920.

Dr. F. A. Wilder,
Southern Gypsum Company,
North Holston, Va.

(Subject: Curve for publication)

Dear Sir:

Complying with your request of the 30th, we take pleasure in enclosing herewith curves showing tensile strength of various proportions of gypsum and Portland cement. You are authorized to use these curves in your forthcoming monograph provided that they are accompanied by a qualifying statement which is also enclosed. It is understood that you will give due credit to the Bureau.

Respectfully,
S. W. STRATTON,
Director

"The tensile strengths of mixtures of gypsum and Portland cement are illustrated by the accompanying curve. It is to be noted that this curve shows the briquettes made of neat cement are weaker than those made of neat gypsum. While this statement can hardly be vouched for as a general conclusion, being based on only one series of experiments, it does not seem so improbable when all of the factors are taken into consideration. The consistency used is the standard prescribed for testing gypsum (9.7 by the Southard viscosimeter). Material of this consistency can be readily poured, and the mixtures were thus much wetter than is usual in tests of Portland cement. The briquettes were removed from the molds as soon as they were hard enough to handle, and immediately exposed to the air in the room for storage. This too is opposed to the usual practice of storing cement briquettes in a damp closet or under water. These two factors make the cement appear unusually weak, but the strengths found may possibly approach more nearly to those actually attained in practice than would have been the case, had the cement been tested in the usual way."

CHAPTER XIV

USES OF CALCINED GYPSUM

Calcined gypsum is often called stucco. The whiter varieties are called, in connection with certain trades, plaster of Paris.

The most important use for calcined gypsum is found in the manufacture of interior plasters. Perhaps four-fifths of all the gypsum calcined in America is used for plastering purposes. Gypsum plasters possess important advantages in this connection over other materials. First, their great hardness is an important and valuable characteristic. Almost as important is the fact that they set up in a few hours and the work of carpenters and finishers follows closely after the plasterers. Their period of drying is limited to a few days and this is of great importance, since certain kinds of mortar require weeks to dry out, and the house is untenable during this long period or is occupied at a positive risk to health.

Interior plasters

The nature of gypsum wall plasters and rules for their manipulation are considered in chapter XV.

Some Portland cement chemists prefer calcined gypsum to raw gypsum for retarding the set of their product. Calcined gypsum of course has a higher content of SO_3 and consequently less of it is required to produce the desired retarding effect. The mill price, however, is usually twice that of raw gypsum while the amount needed is only a few per cent less. Where excessive freight rates are involved in getting the raw gypsum to the cement mill, there might be economy in using the calcined product. The reason for its use in preference to raw gypsum, however, must be found in something besides economy, for mills that use calcined gypsum are not, as a rule, handicapped by high freight rates on gypsum. The reason for its use apparently lies in the belief that a more uniform product is secured.

For cement retarder

When calcined gypsum is used in retarding cement it is mixed carefully with the cement just before packing.

Gypsum blocks

Considerable quantities of calcined gypsum are used in making gypsum blocks for use in constructing partitions and roofs. Blocks and roof panels are considered at length in chapter XVI.

Plaster boards

The use of calcined gypsum in the making of plaster boards is increasing rapidly. These boards are of two types, one intended to take the place of lath and the first coat of plaster, and to be plastered over; while the other, after nailing to the studs, gives a finished wall when nailheads and cracks are covered by wooden strips or otherwise concealed. This type is called "wall board" to distinguish it from "plaster board", which is intended for a plaster base. These articles are considered at some length in chapter XVII.

Poured gypsum roof and floor

In chapter XVIII an interesting and important type of roof construction is discussed. This is the poured gypsum roof and floor. As is there pointed out the material used for these purposes in America must not be confused with hydraulic gypsum which is extensively used for flooring in Europe.

Plate glass industry

Many thousands of tons of calcined gypsum are used annually in connection with the plate glass industry. The glass is embedded in gypsum paste preparatory to polishing, and is held by a gypsum matrix during the polishing process.

The strength required for this purpose is not great and the set gypsum is crushed, ground and recalcined. Some fresh mineral is added each time, however, to give greater life to the plaster.

For plate glass purposes, material free from grit is required and this is secured by using gypsum of great purity, or by exceedingly fine grinding.

Insulation

Mixed with asbestos, calcined gypsum is extensively used as a pipe and boiler covering. It is used to fill the space between the walls of fire proof filing cabinets and safes.

A patent has recently been issued for a process of insulation with calcined gypsum, which consists of the addition when dry of chemicals which give off gas in the presence of water. The gas bubbles develop a spongy texture favorable for insulation.

Considerable quantities of calcined gypsum are required for pottery and terra cotta molds. This gypsum is usually calcined to the second settle, is short working and dense. Up to 1916 most of the potteries insisted on having material made from Nova Scotia gypsum, but when this supply was cut off by the war, it was found that some beds of domestic gypsum gave equally good results.

Pottery molds

The use of plaster of Paris for making casts and for reproducing works of art, ancient and modern, is familiar to all. Relief maps and scientific models are made of the same material.

Statuary

Plaster casts are commonly used for holding broken limbs in place while the bone is knitting. During the war hundreds of tons of domestic plaster of Paris were used in making orthopedic bandages. Open mesh bandages are passed through a tray containing plaster till the meshes of the fibre are filled. They are then rolled while dry and laid away for use.

Surgical uses

When applied the rolls are soaked in water ten minutes and then unrolled and wound firmly about the injured limb till a closely knit strong splint is produced.

Marble columns, wainscoatings and balusters are made by treating gypsum with various chemicals which harden and color it till it is very difficult to distinguish from marble. The methods used are presented in chapter XXI.

Scagliola

An exceedingly fine, fast setting plaster is used in making dental molds.

Dental plaster

Plaster of Paris, finely ground and properly colored is sold in small and large packages for tinting interior walls and ceilings. It is said that forty tints can be made from three colors, red, white, and blue, by mixing with the white plaster. Five pounds of the powder will cover fifty square yards of wall surface.

Cold water paints

In temporary exposition buildings plaster of Paris mixed with excelsior and known as "staff" is employed in large quantities. The surfaces of the great buildings at the fairs of Chicago and St. Louis were covered with staff and the striking statuary groups were built up out of the same material. Nearly 30,000 tons of calcined gypsum

Exterior stuccoes

were used by a somewhat different process, for exterior plastering at the Panama-Pacific Exposition.[199]

Miscellaneous

Calcined gypsum is used in marble setting, in making corn cob pipes, in the heads of matches, in taxidermy and for imbedding fragile material for transportation. It furnishes the mold in which rubber stamps are cast, and is used for some sorts of metal casting.

199For a full statement see Wall Surfaces of Panama-Pacific Exposition, by A. W. Markwart, Rock Products and Building Materials, Nov. 22, 1918.

CHAPTER XV

COMPOSITION AND PROPERTIES OF GYPSUM PLASTERS;[200] THEIR MANIPULATION AND SPECIFICATIONS FOR THEIR USE.

The composition of gypsum plasters differs somewhat, to make them fit for different purposes and varying conditions. Kinds The base for all gypsum plasters is, of course, calcined gypsum. Various substances are added to this base, and the following types of gypsum plasters are developed:

Neat gypsum plaster, often, but unfortunately, called cement plaster.
Gypsum wood fibre plaster.
Ready mixed gypsum plasters.

All of these plasters contain retarder and fibre of some sort.[201]

NEAT GYPSUM PLASTER

Neat gypsum plaster is intended for mixing with sand at the point where it is applied to the wall. Ordinarily it contains at least 85 per cent of calcined gypsum, the remainder being hydrated lime, ground clay, asbestos, retarder and fibre. From four to six pounds of goat or cattle hair is used in each ton of plaster. In addition some manufacturers use one or two pounds of manila or sisal fibre. The purpose of the fibre is to hold the plaster together while it is being applied and to prevent it from dripping from the keys that are formed behind the lath. The addition of other ingredients is for the purpose of plasticity, which aids in applying the plaster. The fibre does not add measurably to the ultimate strength of the plaster and is not needed for this purpose. The ingredients added to give plasticity are used sparingly, so that the tensile strength and hardness are not impaired.

Composition of neat gypsum plaster

Nature and purpose of fibre

Purpose of other ingredients

The amount of sand that may be mixed with neat gypsum

200Hydraulic or slow setting gypsum plaster and Keene's cement are treated in Chapter XIX.

201For the nature of retarders see Chapter XX.

plaster depends upon the quality of the sand and the nature of the background. Standard specifications adopted some years ago by the plaster manufacturers association stated that six, ten-quart buckets of clean sharp sand might be used with a sack (100 pounds) of plaster for a lath background. This represents proportions of two to one by weight. For brick, gypsum block or terra cotta side walls, the proportions of sand may be increased to three to one.

Proper amounts of sand

Loamy sand, while making a plaster that works nicely, will give a soft wall if used in the quantities permissible for a sharp, silica sand.

Suitable sand

The best sand consists of a mixture of moderately coarse and moderately fine grains. A good plastering sand is one which when dry will pass an eight mesh sieve and 80 per cent will be retained in a forty-eight mesh sieve.

Cement plasters are retarded to give from two to six hours working time. Some local sands seriously affect the set of plasters, some accelerating and some retarding them. Clean, sharp sand, and particularly sand having a trace of salt, will accelerate the plaster, while a muddy or loamy sand acts as a retarder. In a similar manner the water used in mixing may disturb setting conditions. It is sometimes necessary to specially retard plasters at the mill for certain markets, by using more or less than standard amounts of retarder, to meet local conditions.

Setting time

Gypsum plasters may be applied to the background selected in three coats; in two coats; or in a single coat.

Coatings

The best grade of work is three coat work. These three coats or layers are called:

First or scratch coat
Second or browning coat
Third or finish coat.

The scratch coat is made somewhat richer than the second or browning coat and should not contain more than two parts sand by weight. This gives a strong key and a better bond than will be possible if more sand is used.

Composition of scratch coat

If good sand is available three parts to one of plaster, by weight, may be used for the second or browning coat.

Composition of browning coat

Where a trowel or smooth finish is desired, a mixture of lime putty and calcined gypsum is used, the proportions varying with the season of the year. Standard proportions are 75 per cent by volume of lime putty to 25 per cent by volume of calcined plaster.

Composition of trowel finish

A sand or rough finish is composed of the following by volume:

Sand finish

Lime putty	1 part
Sand	3 parts

These ingredients are thoroughly mixed. Before applying mix six to nine parts of this mixture with one part of calcined gypsum.

GYPSUM WOOD FIBRE PLASTERS

Wood fibre plasters contain at least 80 per cent by weight of calcined gypsum, and not less than 1 per cent of a non-staining shredded wood. The remainder may be composed of hydrated lime, ground clay, asbestos, sand, or substance of a similar nature; and retarder. From thirty to forty pounds of shredded poplar, linn, willow, or buckeye wood are used to the ton of plaster.

Composition

Wood fibre plasters are intended for use where sand is scarce or expensive, or where unusual toughness and a measure of flexibility is desired. They are intended to be used without admixture of sand and are especially convenient for patch work.

Since they are prepared for use without sand, less retarder may be used than for those kinds intended for use with sand, since most sand has an accelerating influence on gypsum plasters. Ordinarily four or five pounds of commercial retarder to the ton will keep the plaster in proper working condition for two hours, which gives ample time for mixing and applying.

READY MIXED GYPSUM PLASTERS

Considerable quantities of plaster are shipped from some gypsum mills with sand already added. In some of the larger cities mixing plants take the calcined gypsum in car lots and mix it with sand for the local trade. It is not economical to ship sanded plasters any considerable distance, for if local sands are not suitable for mixing, it is generally cheaper to use wood fibre plasters.

TENSILE STRENGTH

Methods of testing

The apparatus and technique for testing gypsum plasters are the same that are employed in testing calcined gypsum, and they have been described in chapter XIV.

The same factors control the tensile strength of gypsum plasters that control the strength of calcined gypsum, and additional factors are found, of course, in the ingredients added to calcined gypsum for wall plaster purposes.

Effect of retarder on strength

Inasmuch as retarder must be added to calcined gypsum in the manufacture of all sorts of gypsum plasters, its effect upon tensile strength is of more than ordinary interest and has been carefully studied. Inasmuch as the common commercial retarders hold back the set of the plaster by forming a film between the gypsum crystals growing[202] around nuclei from gypsum in solution it is apparent that retarders may have a tendency to cut down tensile strength. Ample tests show, however, that the tensile strength of plasters is not materially reduced by retarders, till the amount of retarder used reaches seventeen or eighteen pounds to the ton of plaster. Conditions which call for use of more than fifteen pounds of retarder to the ton of plaster are very unusual and in general terms it may be said that in the ordinary manufacture of gypsum plasters, the retarder used does not reduce its strength.

Effect of other ingredients on strength

Ingredients added to increase plasticity and improve working qualities generally have less bonding value than the calcined gypsum, and therefore tend to some extent to reduce tensile strength. This is true of clays, kaolins and hydrated lime.

Sand, of course, is mixed with plasters in quantities sufficient to reduce the strength of the mixed goods materially below that of neat plasters.

Tensile strength tests on sanded plasters were made at

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202 See Chapter XX for the theory of retarders.

Ames[203] in 1901, the material used being secured in Kansas, and from the Fort Dodge district. The results were as follows:

	Proportion	Strength		
		1 day	7 days	4 weeks
Average of 15 tensile tests (Kansas plaster)	1:1	87	320	368
Average of 15 tensile tests (Kansas plaster)	1:2	55	203	212
Average of 15 tensile tests (Kansas plaster)	1:3	35	148	145
Average of 15 tensile tests (Ft. Dodge)	1:1	104	303	362
Average of 15 tensile tests (Ft. Dodge)	1:2	61	233	242
Average of 15 tensile tests (Ft. Dodge)	1:3	39	132	139

Remarkably high tensile strengths are reported by Grimsley as the result of tests made at Washburn College.[204]

As to the consistency used in these tests, Mr. Grimsley says that "the proportion of water varied somewhat with the plaster used in the experiments. In the Kansas plasters for a stiff mixture, the water percentage varied from 26.3 per cent to 40 per cent for neat briquettes, and in sand mixtures (2 to 1) the water percentage varied from 12 to 14, and proportions were about the same in the Michigan plasters.

"The briquettes for the long time test were set on edge on glass and kept in a room of fairly uniform temperature till broken. The sand used was ordinary Kansas river sand screened through a sieve (No. 20) of 400 meshes and held on a screen (No. 40) of 1600 mesh, and carefully dried."

The results given below are the average of three to five briquettes:

203Iowa Geol. Survey, Vol. XII, pp. 224-235, 1901.
204Geol. Survey of Michigan, Vol. IX, pp. 166-169, 1903-4.

KIND	PROPORTION	24 HRS.	1 WK.	1 MO.	6 MOS.	1 YR.
Kansas	Neat	255	386	553	430	370
Oklahoma	Neat	229	460	525	543	441
Kansas	1:2	117	351	375	364	278
Oklahoma	1:2	91	318	410	366	293
Grand Rapids	Neat	366	429	461	426	
Grand Rapids	1:2	125	412	302	344	

Messrs. Holt and Holmes, at Iowa City,[205] determined the tensile strength of calcined gypsum when mixed with three parts of sand. Inasmuch as the material was not ibred or retarded it was not, strictly speaking, gypsum plaster. The results, however, are probably correct for a 1:3 plaster mixture, for the fibre and retarder do not measurably affect the tensile strength of the plaster.

Iowa City tests

"Another series of tension tests was made to determine the best percentage of water to use in making 1:3 mortar briquettes. From each of six samples five briquettes were made with each of the following percentages of water: 25 per cent of the normal consistency determined for the given sample (same amount of water that would have been used for the plaster without the sand), 30 per cent, 35 per cent and 40 per cent or normal consistency. These briquettes were broken at the age of seven days. The results of the tests are summarized in the following table, each number stated being the average of the strengths of five briquettes.

SAMPLE	PERCENTAGE OF NORMAL CONSISTENCY OF PLASTER			
	25	30	35	40
B	249	328	280	272
D	189	253	238	240
F	152	225	249	258
I	154	187	197	182
J	182	281	252	255
X	218	261	304	222
	1144	1535	1520	1429
Average	191	256	253	238

"From this summary it is seen that 30 per cent of the normal consistency of the plaster gave the best results, and this con-

205For full report see page 295.

sistency was adopted for use with all other mortar briquettes made.

"*Tensile Strength.*—1:3 Mortar. The method of mixing the material for the mortar briquettes was the same as that used for the neat briquettes, except that the weighed quantities of plaster and standard Ottawa sand were thoroughly mixed dry before being put into the water.

"The method of placing the mortar in the moulds, the storage, and the method of breaking were the same as for the neat briquettes.

"The results of the tests are summarized below:

Sample	All of Normal Consistency	
	7 Days	28 Days
A	......	195
B	328	266
C	......	......
D	189	227
E	......	217
F	152	247
G	......	141
H	......	301
I	154	197
J	182	264
K	......	190
L	......	196
M	......	179
X	218	256"

Plaster for scratch coat mixed two parts of sand by weight to one part plaster should have a tensile strength of not less than 100 pounds to the square inch. Most gypsum plasters sanded in these proportions have a tensile strength of 200 to 300 pounds.

Minimum tensile strength

Plaster for browning coat in which three parts of sand to one of plaster, by weight, may be used should have a tensile strength of not less than 75 pounds. This figure is easily exceeded by all standard makes of gypsum plasters.

Neat gypsum plasters have a compressive strength ranging from 1000 to 1700 pounds per square inch. In a general way the compressive strength of gypsum plasters varies with their tensile strength, but the variation is somewhat irregular.

Compression

Adhesion tests for gypsum plasters, conducted in the same manner as were the adhesion tests for calcined gypsum described in chapter XIV, were carried on at Ames in 1901, with results as shown below:

Adhesion

KIND	PROPORTION	1 DAY	1 WEEK	4 WEEKS
Ft. Dodge	1:1	33	93	51
Ft. Dodge	1:2	21	31	54
Ft. Dodge	1:3	6	10	20
Kansas	1:1	27	58	48
Kansas	1:2	16	16	21
Kansas	1:3	....	....	7

BASE OR BACKGROUNDS FOR GYPSUM PLASTERS[206]

GROUNDS

Method of Setting Grounds

Wood lath

"For wood lath, the total nominal thickness including lath and plaster shall be 7/8 inch for three-coat dry-scratched or set-scratched work, and 3/4 inch for two-coat work.

Wire or metal lath

"For wire or metal lath, the total nominal thickness including lath and plaster shall be 7/8 inch for three-coat dry-scratch or set-scratch work.

Gypsum plaster board

"For gypsum plaster boards, the total nominal thickness including boards and plaster shall be 7/8 inch for three-coat dry-scratch or set-scratch work. In no case shall the thickness of the plaster on the surface of the boards be less than 1/2 inch.

Gypsum plaster blocks

"For gypsum plaster blocks, the grounds shall be set 3/8 inch in thickness.

Brick

"For brick, terra-cotta and cement walls, the grounds shall be set 5/8 inch in thickness.

APPLICATION

Three-Coat Work, Dry-Scratch

Three-coat work, dry-scratch

"Three-coat work, dry-scratch plaster, when used on wood lath, wire or metal lath, brick, terra-cotta, masonry, gypsum plaster blocks, or plaster boards, shall be applied as specified below:

First coat

"Apply first or scratch coat (with hair or fibre) well rubbed in, and scratch well with ordinary plasterer's scratcher and allow to become "bone dry" before applying second coat.

206The paragraphs under the headings Base or Backgrounds; grounds; applications; General Precautions; Work and Workmanship, were prepared by Sub-Committee 2 of Committee C-11 of the American Society for Testing Material, Mr. D. L. Haigh, chairman, but were not published in the report of that committee, due to the Society's general ruling against prescribing methods for applying and erecting materials.

"Apply second or browning coat (with or without hair or fibre), using enough to fill out to the grounds and to make walls straight and plumb. Rod and darby to a rough surface making angles and corners true, and allow to become "bone dry" before applying third or finishing coat.

Second coat

Note.—The first or scratch coat may be used as a second or browning coat and this custom is generally followed particularly in country work, as it avoids the necessity of shipping more than one material.

"If trowel or smooth finish is to be used, apply trowel or smooth finish and trowel to a smooth hard finish, free from trowel or brush marks or other imperfections.

Third coat

"If sand float or rough finish is to be used, apply sand float or a rough finish and bring to an even granular sand-float finish, free from cat-faces or other imperfections.

Note.—For first-class work, minimizing cracking, staining and other imperfections, three-coat dry-scratch work gives the best results.

Only three-coat, dry-scratch work should be used on metal lath. It is not advisable to apply the second coat on metal lath until the first coat has become thoroughly dry.

Three-Coat Work, Set-Scratch

"Three-coat work, set-scratch plaster, when used on wood lath, brick, terra-cotta, masonry, gypsum plaster blocks, or plaster boards, but not on the wire or metal lath, shall be applied as specified below:

Three-coat work set-scratch

"Apply first or scratch coat (with hair or fibre) and follow as soon as this sets firmly with second coat.

First coat

"Apply second or browning coat (with or without hair or fibre) using enough to fill out to grounds and to make walls straight and plumb. Rod and darby to a rough surface, making the angles and corners true, and allow to become thoroughly set for third or finishing coat.

Second coat

(a) "If trowel or smooth finish is to be used, apply trowel or smooth finish and trowel to a smooth hard finish, free from trowel or brush marks or other imperfections.

Third coat

(b) "If sand float or rough finish is to be used, apply sand float or rough finish and bring to an even granular sand-float finish, free from cat-faces or other imperfections.

Note.—Three-coat set-scratch work is more liable to have cracks and show staining from wood lath, but in so far as strength is concerned it is equally as good as three-coat, dry-scratch work.

Two-Coat Work

"Two-coat work, when used on wood lath, brick, terra-cotta, masonry, gypsum plaster blocks or plaster boards, but not on wire or metal lath, shall be applied as specified below:

Two-coat work

First coat

"Apply first or scratch coat (with hair or fibre), using enough to fill out to grounds. Rod and darby to straighten, and allow to become "bone dry" before applying second or finishing coat.

Second coat

(a) "If trowel or smooth finish is to be used, apply trowel or smooth finish and trowel to a smooth hard finish, free from trowel or brush marks or other imperfections.

(b) "If sand float or rough finish is to be used, apply sand float or rough finish and bring to an even granular sand-float finish, free from cat-faces or other imperfections.

Molded Work

Molded work

(a) "*Solid Cornices and Molding.*—All solid cornices and molding shall be blocked out with browning or second base coat of gypsum plaster to within ¼ inch of the finished surface and allowed to set for finishing coat. The finished moldings shall be run and composed of lime putty with calcined gypsum added at the building by the mechanic, in the proper proportion to secure a good working material and a satisfactory hard finish.

(b) "*Furred and Lathed Cornices.*—To all furred and lathed cornices the scratch coat of gypsum plaster shall be applied and scratched and allowed to set thoroughly. It shall then be blocked out with browning or second gypsum plaster to within ¼ inch of the finished surface, and allowed to set for the finishing coat. The finished moldings shall be composed of lime putty with calcined gypsum added at the building by the mechanic, in the proper proportion to secure a good working material and a satisfactory hard finish.

Note.—In all run-work moldings applied over furred or lathed surfaces, the finished surface should be not less than one inch from the furring.

Ornamental Work

Ornamental work

"All ornamental plastering in the form of molding or case pieces of varying design to be placed on cornices or moldings in place, shall be thoroughly keyed and securely fastened to the prepared surfaces of cornices or moldings. There are many acceptable methods employed to fasten or key the ornamental molded pieces to the surfaces but special care should be exercised to secure a proper key in attaching solid moldings to the prepared surfaces.

Finish Coats

Finish coats

"The finish coats shall be run to guide lines and made straight, level and plumb, with all arrises true and sharp.

(a) "Trowel-finish coats shall not be over ⅛ inch thick, and shall be troweled down true and smoothed with metal trowels and water brush to a polish free from defects and brush marks.

(b) "Sand-float finish coat shall be floated true with cork float to a sand finish free from defects.

Interior, Wire or Metal Lath and Furring

"Studs, joists, rafters, furring and similar support shall be spaced not to exceed 16 inches on centers. Where greater spacing of supports is necessary special types of ribbed lath, or special supporting construction, shall be provided.

Supports

"Place the metal lath horizontal upon the supporting members, securing same with staples spaced not over 8 inches apart and driven home. Or, the supporting members may be furred out with three-sixteenths inch round rods secured with staples spaced not to exceed 8 inches, and the metal lath applied as hereinbefore stated.

Setting

"The metal lath sheets shall be lapped not less than ½ inch, end to end. All metal lath and furring shall be wired with tie wires not less than once between adjacent supports. Sheets shall be started not less than 4 inches from corners and shall be bent around the corners in such manner that no joints shall occur at any corner. Lath upon ceilings shall be bent down to extend not less than 4 inches upon all wall surfaces.

Lapping and wiring

"Staples used for securing metal lath or furring shall be not less than 1-inch No. 12 gage. Staples used for securing three-sixteenths inch furring rods shall be not less than 1½ inch No. 12 gage. All wiring used between supports shall be done with not less than No. 18 gage tie wire.

Staples and tie wires

Gypsum Plaster Board

"Studs, joists, rafters, furring and similar supports shall be accurately spaced 12, 16 or 18 inches on centers, and shall be in proper alignment. The standard spacing of 16 inches is recommended.

Supports

"All boards shall be spaced ¼ to ⅜ inch apart on all sides.

Spacing

"Lay boards parallel to the run of the supports. Horizontal joints on walls, and joints at right angles to ceiling joists, shall be broken at each board by starting each alternate tier with a half or a quarter sheet. On wood stud partitions, vertical joints shall not occur on the same studs on both sides of the partition.

Setting

"To cut plaster board to suit requirements, score both sides and break against a straight edge. If sawing is preferred, provide firm platform, support board close to where cut is made, and saw.

Cutting

"Plaster boards shall be nailed directly to the supports. Nails shall be spaced not to exceed 6 inches on centers for walls and 4 inches on centers for ceilings. First nail entire middle of board, then follow by nailing all outer edges. No portion of any plaster board shall have less than a ¾ inch bearing upon the supports to which it is nailed.

Nailing

"The nails used shall be 1¼ inches No. 11½ gage wire nails with flat heads of not less than ⅜ inch.

Nails

"Grounds shall be secured by nailing through the plaster boards to the supporting members, and shall not be less than ⅞ inch in nominal thickness. This thickness includes the thickness of the ⅜ inch plaster board.

Grounds

"Do not sprinkle or wet gypsum plaster boards before the application of plaster.

Precaution

Gypsum Wall Boards

"Studs, joists, rafters, furring and similar supports shall be accurately spaced 12, 16, 18 or 24 inches on centers and shall be in proper alignment. The standard spacing of 16 inches is recommended.

Supports

"Gypsum wall boards shall be closely butted at all joints and corners or shall be spaced not less than ¼ inch where joint filler is to be used. In butt-joint work provision shall be made for boards to overlap the full thickness of the board at all internal and external angles.

Spacing

"Lay boards parallel to the run of the supports. Provide headers for nailing at all ends of wall boards; every joint and edge shall be supported by a firm backing to nail to. Ceilings shall be covered first and all ceiling boards shall lap beyond the face of the wall boards the full thickness of the board.

Setting

"To cut wall boards to suit requirements, score both sides and break against a straight edge. If sawing is preferred, provide firm platform, support board close to where cut is made, and saw from face side of the board always.

Cutting

"Wall boards shall be nailed directly to the supports. Nails shall be spaced not to exceed 3 inches at all edges and 9 inches elsewhere. Where joints are to be covered with battens the nailing may be spaced not to exceed 6 inches at all points. First nail entire middle of board, then follow by nailing all outer edges. Wall boards shall have a bearing of not less than ¾ inch upon all supports to which they are nailed. Nails securing the edges shall be driven ⅜ inch from the edge of the board.

Nailing

"The nails used shall be 3 penny, common or fine wire flat-head nails.

Nails

"Grounds are not necessary. Headers or plates shall be placed between studs behind the wall boards in order to provide a backing and nailing surface to secure base boards, chair rails, moldings and similar interior finishes.

Grounds

GENERAL PRECAUTIONS

"Precaution should be taken to see that all materials are mixed in clean, tight boxes, with clean, fresh water, and that all tools are kept clean. If a machine mixer is used it should be properly cleaned at frequent intervals.

Mixing boxes and tools

"All material shall be applied before it has commenced to set. Re-tempered material shall not be used.

"In the use of neat material which requires sand to be added, the neat material and sand shall not be mixed and allowed to stand before the addition of the water.

Mixing

"The temperature of all buildings being plastered during cold weather shall be kept above freezing during the time of plastering. Extreme forced heat shall be avoided.

Heat

Note.—In cold weather it is always better to have all or part of the permanent heating system in operation before starting to plaster. Avoid the use of salamanders, coke pots or other temporary heating appliances or local drying, to keep the plastered surfaces free from coal-smoke stains.

"While plastering, windows shall be in place, or other closures provided, as a protection against strong winds, and that ventilation may be controlled. Openings shall be kept sufficiently open to allow the escape of dampness. Drying and ventilation is governed by the time of year and weather conditions.

Drying and ventilating

"Gypsum plaster shall not be subjected to freezing temperature weather within 36 hours after application. If frost should get into any coat of plaster, the coat shall be free from frost and in good condition before application of the next coat.

Frost

WORK AND WORKMANSHIP

"The contractor shall furnish all material and labor for the completion of the plaster work, as hereinafter specified.

Work included

"All surfaces of walls, columns, piers, partitions and ceilings (including all furred and lathed surfaces), and in all interior exposed surfaces, terra-cotta, gypsum plaster blocks, gypsum plaster boards, hollow brick, rough brick and concrete, throughout shall be plastered as specified under "Application".

Distribution

"All plastering throughout the building shall be carried down to the floor, unless otherwise specified by the architect.

Workmanship

"The contractor shall do all necessary jobbing and patching after other mechanics, and finish up after them, at any and all times as required by the architects.

Jobbing and patching

"It shall be the duty of the contractor to properly protect all work, and he shall be liable for damage done to the same and have it properly repaired or replaced as the architect may direct.

Protection of work

"The contractor shall remove all refuse at any and all times, as directed by the architect, and have the entire building, including glass, clean at completion."

Refuse

CHAPTER XVI

GYPSUM BLOCKS FOR FLOORS, WALLS, AND ROOFS

In this chapter it will be understood that the term plaster block is applied to a construction unit made of calcined gypsum, which is delivered to the job ready for erection. It is a factory made article, in distinction from slabs or blocks poured at the point of erection. Blocks so made are considered under Structural Gypsum in chapter XVIII.

Definition

Gypsum blocks were introduced in Europe and particularly in Germany, during the latter part of the last century. The industry as it was developed in Germany in 1902 was described in an appendix to the report on Webster county, published by the Iowa Geological Survey, in volume XII.

Historical

About the year 1900 American manufacturers in the vicinity of New York City, stimulated by small importations of gypsum blocks from Germany, which were well received by the building trade, began the manufacture of blocks in America. By the year 1904 the American gypsum block industry was on a sound footing, as shown by the elaborate display of gypsum blocks at the St. Louis exposition in that year, and the interest on the part of the building trade in these exhibits.

Gypsum blocks consist of not less than 95 per cent gypsum by weight, and 5 per cent or less of nonstaining wood fibre. First settled calcined gypsum is used ordinarily in their manufacture.

Composition of

Gypsum blocks as used in nonbearing partitions are best known to the building trade. Closely related to the partition block is the furring block, which is merely a partition block split through the center.

Types of

Gypsum blocks, generally reinforced, are used in roof construction. These blocks may be made at the factory, or poured on the job. The larger and heavier units are generally used, and as these are usually poured on the job, gypsum roof blocks will be considered under Structural Gypsum in chapter XVIII.

GYPSUM PARTITION BLOCKS

Structure, size and weight

Gypsum partition blocks are either solid or partly hollow, depending on their thickness and the load they are intended to carry. Sizes from two and one-half to five inches may have single rows of core holes. The six and eight inch sizes have two rows of core holes. Sizes and weights are shown in the table below.

SIZES AND WEIGHTS OF STANDARD GYPSUM TILE

Size	Ceiling height feet	Weight tile per sq. ft., lbs.	Weight mortar in joints per sq. ft., lbs.	Weight plaster 1 side per sq. ft., lbs.	Total weight plastered 1 side per sq. ft., lbs.	Weight plaster 2 sides per sq. ft., lbs.	Total weight plastered 2 sides per sq. ft., lbs.
1½ inch split 1½″ by 12″ by 30″	Furring	4.5	1	3	7.5	6	10.5
2 inch split 2″ by 12″ by 30″	Furring	6	1	3	9	6	12
2 inch solid 2″ by 12″ by 30″	10	9	1	3	9	6	15
3 inch hollow 3″ by 12″ by 30″	13	10	1.2	3	13	6	16
3 inch solid 3″ by 12″ by 30″	15	12.5	1.2	3	15.5	6	18.5
4 inch hollow 4″ by 12″ by 30″	17	12	1.63	3	15	6	18
5 inch hollow 5″ by 12″ by 30″	25	15	2.04	3	18	6	21
6 inch hollow 6″ by 12″ by 30″	28	17	2.45	3	20	6	23
8 inch hollow 8″ by 12″ by 30″	40	23	3.26	3	26	6	29

Manufacturing methods

Gypsum partition blocks are either hand molded or machine made. The hand molded block is equal in quality to the machine made article. Economies growing out of the application of elaborate machinery to the manufacture of gypsum blocks have not been very great, and in consequence the machinery used is relatively simple.

Hand made blocks are molded on rubber mats. A frame with height equal to the thickness of the block desired is used to hold the plaster mixture. Calcined plaster which has been mixed with fibre and water till it has the consistency of thick soup, is poured into the frame, which is so constructed that it can be easily detached from the contents of the frame as soon as it has set. The calcined plaster is not retarded and the hardened block can be removed from the frame a few moments after pouring.

Machines for making blocks are all elaborations of the simple principles illustrated in the cut below.

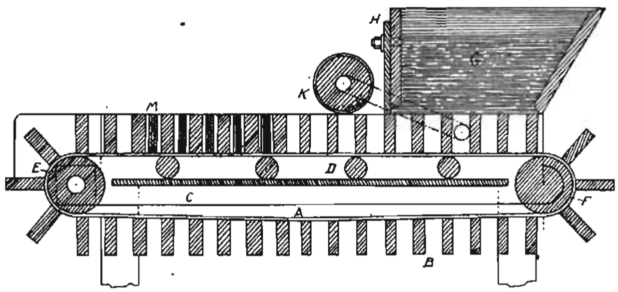

FIG. 62.—Diagram illustrating one of the methods of making gypsum blocks by machinery.

Wooden cores, tapered so that they may more easily be removed after the block hardens, are inserted in the frame before the calcined gypsum paste is poured. When hollow blocks are made various mechanical appliances may be used to force out these cores after the block has hardened.

In the case of gypsum boards considerable care must be taken in the mixing of the paste, for the intergrowth of crystals into the chip board seems to take place most efficiently during the earliest stages, and "peelers" may result if mechanical mixing is carried too far. In the making of gypsum blocks it is not necessary to exercise the same degree of care in the mixing, but crystallization, which is accelerated by agitation, must not go too far in the hopper or the block will lack strength. Hand made blocks often have a greater crushing strength than machine made blocks for this reason.

Mixing

Fire Protection.—Gypsum block has received the full approval of the Underwriters laboratories for use in nonbearing partitions, stairways and elevator enclosures in fireproof building construction. Tests conducted at Armour Institute of Technology show that gypsum blocks have 40 per cent greater resistance to heat conduction than other

Advantages of gypsum blocks

standard materials tested.[207] Figure 63 shows the use of gypsum blocks for this purpose.

An important fire proofing feature is their freedom from

FIG. 63.—Gypsum blocks used as fireproofing. Courtesy of V. G. Marani.

expansion and contraction during great changes in temperature. The Bureau of Standards has found that:

"The contraction of a block under load is about one-thousandth of an inch per two pounds per square inch load. This is when the block is tested on edge which is the usual method of laying it, and applies to loads from zero to seventy pounds per square inch. The expansion with heat is about .00001 inches per degree Fah. This applies to temperatures from 32° to 100° Fah. For higher temperatures the expansion is considerably greater. The change in moisture content from bone dry to saturated is accompanied by an expansion of one-thousandth of an inch per inch."

Light Weight.—Gypsum blocks are from 30 to 35 per cent lighter per square foot than any other structural material of a

[207] Marani in Buildings and Building Management, April, 1919.

similar nature and of equal thickness. This greatly reduces the load on columns, girders and all supporting members, and permits the use of steel with less cross section. The Statler Hotel, Cleveland, for instance, required 450,000 square feet of partitions. By using gypsum blocks a saving of 2,418 tons in dead weight was made.[207]

Noncondutor of Sound.—Tests described in chapter XVII show that gypsum blocks are 60 per cent more effective as a nonconductor of sound than other types of standard partition material.

Economy.—As has been noted gypsum blocks permit economy in connection with steel supporting members. Time and labor are saved through rapid construction made possible by the large units used. The surface presented by a finished partition of gypsum blocks is much truer than that offered by other tile surfaces, and a saving of 10 to 25 per cent in plaster is effected in consequence.

In remodeling a building where gypsum block partitions are used the cost is relatively small. A carpenter's saw may be used to cut through the partitions, and a large percentage of the gypsum blocks themselves can be salvaged.

"*Strength*[208]—The Chicago Board of Fire Underwriters' test of June 22, 1910, made at the Chicago laboratories, on 18 full-size three inch gypsum partition tile, selected at random from 50 samples, showed an average crushing strength of 12,603 pounds to the tile, or over an average area of 90.2 square inches. The average crushing strength was 139.7 pounds. As the weight of this tile is about 0.28 pound per square inch on bedding surface, a nonbearing partition of gypsum would have to be about 500 feet high before it would crush of its own weight."

The following specifications are generally agreed on by manufacturers of gypsum blocks:

Specifications for setting gypsum blocks

Partitions shall be set in at least ½ inch bed of mortar and started on the tile or concrete floor which shall first be swept clean.

208Marani, V. G., in Rock Products and Building Materials, Dec. 22, 1919, p. 48.

Blocks shall be set plumb and straight with joints broken regularly. All joints shall be at least ½ inch thick. The top course of blocks shall be securely wedged to the ceiling with mortar.

Reinforcement over openings.—Where the rough bricks do not extend to the ceiling the partitions over all openings three feet or less in width shall have reinforcement consisting of a strip of metal lath three inches, four inches, or six inches in width, depending on the thickness of the block, laid in the first horizontal mortar joint above the opening. This lath shall extend at least six inches beyond each side of the opening and be well imbedded in mortar.

For openings three feet or more in width, two or more blocks shall be laid end to end and a half inch rod laid in the lower core hole, and this core hole shall then be filled solidly with plaster and allowed to set thoroughly before being placed in the wall.

Mortar.—All blocks shall be laid up in gypsum mortar containing not more than three parts of sand by weight to one part of gypsum plaster. Do not use Portland cement or lime plaster.

Underwriters specifications.—In approving of gypsum block for fireproof buildings in July, 1916, the Underwriters Laboratories laid down the following specification:

"Partitions built of these blocks shall have the blocks set on noncombustible foundations and laid with staggered joints in properly tempered gypsum plaster containing not to exceed three parts of sand, and shall be coated on each side with the same material, fibred with hair or wood, at least ½ inch in thickness and are standard for use as nonbearing corridor and room partitions in office buildings, hotels, apartments and buildings of like class of fire-resisting construction, and acceptable for use at enclosures to vertical communications in such buildings where standard enclosures are not required, and when the partition heights do not exceed the following:

Nominal or Trade Size of Block	Maximum Height of Non-Bearing Partition
2 inch, solid	10 feet
2½ inch, cored	10 feet
3 inch, cored	13 feet
4 inch, cored	17 feet
5 inch, cored	20 feet
6 inch, cored	30 feet
8 inch, cored	40 feet

GYPSUM FURRING BLOCKS

Gypsum furring blocks are generally made by sawing four inch blocks the long way. The hollow space prevents dampness. They are held in place by metal ties inserted in the wall every twelve inches.

FIG. 64.—Sawing a four inch block for furring. Courtesy Beaver Board Co.

For free standing furring two inch hollow blocks are commonly used, which are attached to the wall by anchors or ties. The furring is laid up in mortar like that specified for gypsum blocks. Figure 64 illustrates the use of four inch block for furring by sawing it longitudinally.

CHAPTER XVII

GYPSUM PLASTER BOARD AND GYPSUM WALL BOARD

GYPSUM PLASTER BOARD

Gypsum plaster board consists of two or more layers of fibrous binding material and one or more layers of gypsum. It is used chiefly as a base coat for plaster and in this capacity takes the place of lath and the first coat of plaster.

Definitions

Gypsum wall board is an incombustible material which gives a finished surface for interior walls, partitions and ceilings. It consists of two outside layers of fibrous binding material and a core of gypsum which may contain a small amount of filler.

While plaster boards differ slightly as placed on the market by different manufacturers, the following specifications, prepared in 1919 by a committee of the Gypsum Industries Association for the Building Material Division of the War Industries Board, present fairly the nature of plaster board:

Composition

"The fibrous binder shall consist of two outer layers of chip board of the following specifications:

Two ply board

(a) "*Caliper.*—Each ply of chip board shall caliper not less than .025 inch—subject to manufacturer's normal variation of not more than 10 per cent, excepting in cases of boards where the chip board on plastering side is keyed on by means of a mechanical bond when chip board of not less than .020 inch may be used—subject to manufacturer's normal variation of not more than 10 per cent.

(b) "*Finish.*—The finish of the chip board may be plain chip, filled news, or any finish of equal strength.

(c) "*Weight.*—One thousand square feet of chip board shall weigh not less than the following:

.020 Chip Paper Minimum weight 60 lbs.
.025 Chip Paper Minimum weight 75 lbs.

(d) "*Strength.*—The puncture test (Mullen test) shall not be less than 50 per cent (Mullen test points) of the weight per thousand square feet.

"The fibrous binder shall consist of two outer plies (and may contain one or more inner plies) of wool felt interposed and cemented together with a core or cores of gypsum.

Two, three and four ply boards

(a) "*Caliper of Felt.*—Outer layers to be not less than No. 18 felt (18 lbs. per 480 sq. ft.), inner layers not less than No. 15 felt (15 lbs.per 480 sq. ft.). Manufacturer's variation in paper of not more than 10 per cent shall be permissible.

"*Core of all Boards.*—The core shall consist of calcined gypsum mixed with water to handling consistency, to which may be added not to exceed 10 per cent by weight of sawdust or other fibre, intimately mixed with the calcined gypsum.

"*Dimensions of Finished Boards.*—Standard boards shall be

32 inch by 36 inch or
24 inch by 32 inch.

"Boards may be ¼ inch undersize to allow for structural variations and to provide for a plastering key. Provided however that not to exceed 5 per cent what is known as ½ and ¼ boards (of same quality as full sized boards) accumulated in manufacture may be included in each shipment.

"*Thickness of Board.*—The boards shall be not less than ⅜ inch in thickness. This thickness shall be determined as follows: 32 boards when piled flat shall measure not less than 12 inches.

"*Plaster Board Less Than ⅜ Inch in Thickness.*—¼ inch and five-sixteenths inch boards are produced by board manufacturers and are only recommended in cases where economy is of greater importance than the more perfect fire protection afforded by use of the thicker board.

"*Weights of Boards.*—One thousand square feet of ⅜ inch board shall weigh not less than 1700 pounds.

"*Finished Product.*—The finished boards shall comply with the following: (a) the edges shall be folded, molded, cut or perforated-break. (b) The core shall be of sufficient thickness throughout the board to make the product conform to specifications. (c) The finished product shall present a suitable surface for plastering and when shipped from the manufacturer's plant shall be free from cracks or breaks except that 2 per cent shipment may consist of boards with breaks not exceeding one-half of 1 per cent of the total area of a single board.

'*Physical Characteristics.*—The boards when shipped must be dry, true and straight excepting that boards with not more than two inch warp may be shipped. The chip board binder must adhere firmly to the core."

A remarkable bond between the fibrous binder and the calcined gypsum develops during the hardening of the gypsum.

Impregnation of binding material

A certain amount of the saturated gypsum solution penetrates the fibre and crystals form which penetrate the fibre and interlock with the material in the gypsum layers.

The same conditions develop when plaster is applied to gypsum plaster board, and a fine bond, more reliable even

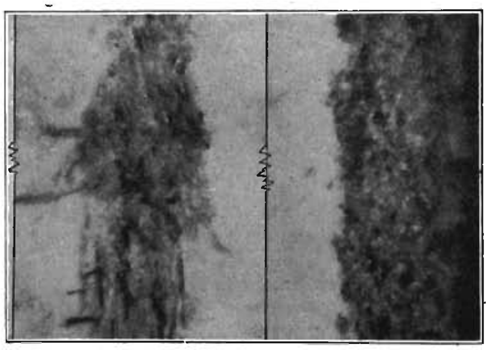

FIG. 65.—Cross section of plaster board magnified to show the penetration of the pulp board by the gypsum. Courtesy of United States Gypsum Co.

than the keys formed when lath are used, results. Figure 65 shows cross section of gypsum plaster board magnified to reveal this impregnation.

Marani[209] describes tests made to determine the adhesion of plaster to gypsum plaster board. As shown in figure 66 an average sample of plaster board was covered with gypsum

Adhesion of plaster to plaster board

plaster in which hooks for attaching a weight were cast. By ordinary testing methods the weight attached to these hooks was gradually increased till the point of rupture was reached. The material tested and the results obtained are more fully described as follows:

Gypsum plaster board lath	⅜ inch thick
Area of plaster board lath (5 inches by 4 inches)	20 sq. inches
Area of plaster coat (3 7/16 inches by 2 11/16 inches)	9.19 sq. inches
Thickness of plaster coat	½ inch
Total load to produce parting of plaster coat from plaster board	115½ lbs.
Total load at rupture, per square inch	12.57 lbs.
Factor of safety, assuming weight of ½ inch plaster coat at 3 pounds per square foot (approximate)	600

"The gypsum plaster board of this test consisted of two

209Marani, V. G., Construction, Sept. 1916, pp. 161-164.

layers smooth chip binder and one intermediate layer of gypsum, making up the full thickness of the board. The rupture was in the parting of the smooth chip binder itself, the plaster board and plaster coat remaining uninjured."

Gypsum plaster boards are approved on a parity with metal

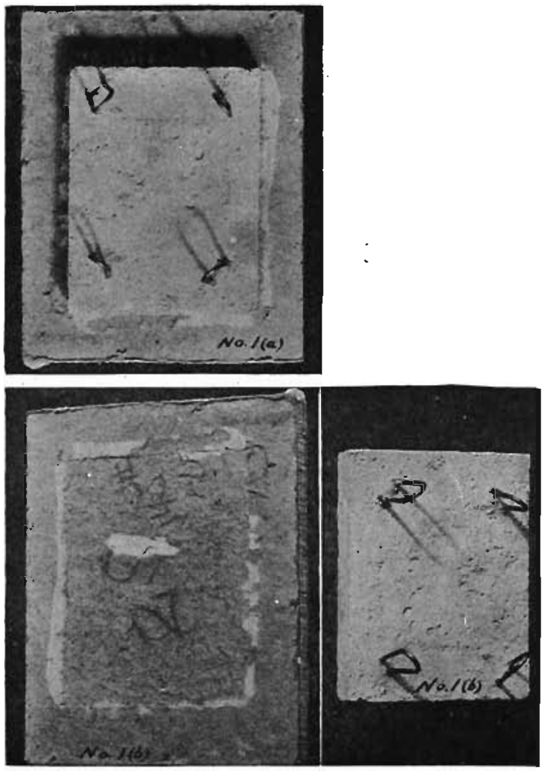

FIG. 66.—Photograph showing method of preparing specimen of plaster board for the adhesion tests described in the test. No. I (a) specimen before weights were attached. No. I (b) after bond between plaster and board was broken. Courtesy U. S. Gypsum Co.

lath in most large cities, and such approval is set out in the provisions of the building codes of the National Board of Fire Underwriters in 1915 and 1916. As a fire resistive material gypsum plaster board is recommended by:

Fire resisting properties

Construction Division of the Army.
The U. S. Bureau of Mines.
National Board of Fire Underwriters' Codes.
New York State Department of Labor.

Industrial Commission, Ohio.
Building Department, Milwaukee, Wisconsin.
Building Department, Cincinnati, Ohio.
Building Department, New York City.
Building Department, Chicago, Illinois.
Chicago Board of Underwriters.
New England Fire Insurance Exchange.
Kansas State Architects Specifications.
New York State Architects Specifications.

The fire test described below was conducted by the Building Department of the City of Detroit on January 2, 1920:[210]

"The furnace consisted of a small enclosure of fire brick with an opening on the top capable of testing samples about 10x10 feet in position as for ceiling construction.

"Temperature. The temperature was maintained, as nearly as possible, at 1700 degrees Fah. and was recorded by electric pyrometer readings.

"Samples. Plaster board, 10 by 10 feet, ¼ inch thick and plastered with about ⅜ inch of sanded gypsum plaster in the proportions of about 1 part of gypsum plaster to 2½ parts fine sand by volume. These proportions were determined by crumbling and washing a portion of the plaster, allowing it to settle in a test tube in water. On the top of the unexposed face of the sample (the face not exposed to the furnace fire) there was placed a piece of 2 by 4 inches studding.

SAMPLE NO. 1

TIME	DEGREES FAH.	REMARKS
1:47 P. M.	1650	Test started
1:58 P. M.	1700	
2:03 P. M.	1700	Unexposed face of board hot to the touch
2:06 P. M.	1700	Paper on unexposed face begins to char
2:11 P. M.	1610	Wood, 2" by 4" on unexposed face begins to char
2:47 P. M.	1700	
3:02 P. M.	1700	Board begins to check
3:17 P. M.	1700	Signs of failure
3:31 P. M.	1700	Test stopped

210Reported by V. G. Marani, who was present as representative of the Gypsum Industries Association.

SAMPLE NO. 2

Time	Degrees Fah.	Remarks
3:32 P. M.	1700	
3:54 P. M.	1700	Unexposed face of board hot to the touch
3:56 P. M.	1700	Paper on unexposed face begins to char
3:59 P. M.	1700	Temperature on unexposed face about 440 degrees Fah.
4:04 P. M.	1700	Board begins to check
4:18 P. M.	1700	Wood, 2″ by 4″, on unexposed face begins to char
4:20 P. M.	1700	Test stopped

Gypsum plaster board is valuable as a sound deadener. Professor P. D. Woolworth[211] of Lewis Institute, Chicago, in tests made in 1914, found that a plaster board containing four laminations of fibrous binding material was 3½ times more sound proof than wood lath plastered to the same standard grounds as was the plaster board.

Sound tests

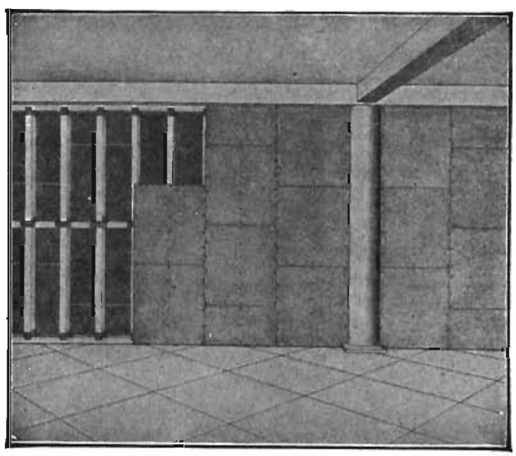

FIG. 67.—Placing plaster board on gypsinite studding. Courtesy Oklahoma Geological Survey.

More recent tests by Professor Watson, show that gypsum boards and plasters are remarkable for their ability to prevent the transmission of sound through partitions. Watson's tables show that as sound absorbers gypsum boards and gypsum plasters are slightly more effective than lime plasters, and make plain the fact that to prevent reflected sound carpets

211Marani, in Construction, Sept., 1916, p. 165.

and tapestries must be employed. His conclusions lead decisively to the fact that gypsum boards and plasters are desirable materials from the standpoint of acoustics.

Directions for application

Studding and Joists.—Set studding and joists straight and true, 16 inches from center to center.

Spacing of Boards.—Boards must be spaced not less than ¼ inch apart at all horizontal or other joints which do not come on studs or joists. See figure 67 for method of application.

All vertical or other joints coming on the studs or joists may be butted tight, or spaced not to exceed ⅜ of an inch apart.

Nailing.—Place the branded side of board against the face of the support. Nail the boards directly to studding, furring or joists. Nail center of boards first, then the outer edges.

The nails used, to be 1¼ inch, 11½ gauge, seven-sixteenths inch head wire nails, spaced not more than four inches apart with each nail head driven home firm and tight.

Joints must be broken at right angles with the nail studs and the ceiling joists, which shall be accomplished by starting every other course with a half board.

Perpendicular joints on the opposite side of partitions must not occur on the same stud as on first side, but shall come on the next stud.

Cutting.—Boards to be cut to size with a saw, or scored both sides and broken across a straight edge.

Grounds.—Grounds shall be ⅞ inch in thickness. Wherever practical, the grounds shall be placed on the face of the plaster board and securely nailed to the studs through the board.

Grounds shall be applied directly to the surface of the board after the board is in place.

Grounds shall be nailed to the studs or joists through the boards, and shall be not less than ⅞ inch in thickness which shall include the thickness of the ⅜ inch plaster board.

MORTAR.—To be any "Standard" brand of gypsum cement plaster, gypsum wood fibre plaster, or gypsum sanded wall plaster.

Mixing.—Gypsum cement plaster shall be mixed with dry clean sharp sand screened through a six mesh screen (avoid quicksand) in the proportions of not more than two parts of sand to not less than one part of gypsum by weight.

Gypsum wood fibre plaster may be used with the addition of water only, or mixed with equal parts by weight of dry, clean, sharp sand, screened through a six mesh screen (avoid quicksand).

Gypsum sanded wall plaster shall be used with the addition of water only.

To mix gypsum plasters with sand, place in raised end of mortar box, first a layer of sand, then a layer of plaster. Hoe dry from raised end of mortar box to the other, then back again, working sand and plaster thoroughly together until the mortar is of uniform color. Put water in lower end of the box and hoe the plaster into the water, mixing thoroughly to proper consistency for application.

Gypsum wall plasters which do not require the admixture of sand on the job, shall be mixed by placing the plaster in the raised end of the mortar box, hoeing it into the water in the lower end of the box, mixing thoroughly to proper consistency for application.

Note.—In ordering gypsum sanded wall plaster, specify that it is for use on gypsum plaster board.

Application.—Do not wet plaster boards before applying the mortar.

First work plaster well into joints, forming perfect keys, and follow immediately with base coat, filling out to grounds. Darby to a straight and even surface. To receive the finish coat, darby lightly, and leave surface rough, and use water sparingly.

FINISHING COATS.—To be any "Standard" brand of "Lime putty gauged with gypsum", "prepared white trowel finish" or "gypsum sand float finish".

Mixing.—Lime Putty Gauged with Gypsum (plaster of Paris), shall be prepared (as in general practice) by making a two foot ring of lime putty, height of ring to be about six inches. Fill in center of ring with water to a depth of about four inches. Sift gypsum finishing plaster (plaster of Paris) into the water, allow to settle a few minutes, mix to creamy consistency and then mix the lime putty and plaster to a uniform paste.

The mixture should be composed of three parts of lime putty to one part of gypsum finishing plaster (plaster of Paris) by volume.

Prepared white trowel finish and gypsum sand float finish shall be used with the addition of water only, and shall be mixed in a suitable mortar box used exclusively for this purpose.

Place material in raised end of mortar box with water in lower end. Hoe the material into the water, allowing it to soak without further hoeing for at least ten minutes, then mix thoroughly to a smooth and even consistency.

Application.—All finishing coats shall be not less than ⅛ inch in thickness, shall be run to guide lines and made straight and level and plumb, with all arrises true and sharp.

Gypsum prepared white trowel finish shall be applied to a thoroughly dry base coat, and shall be applied in three coats. First coat shall completely cover the surface using material as thin as possible, grinding it thoroughly into the base coat. Allow this coat to draw for a few moments to avoid blistering. Second coat shall be applied perfectly level, and the thin coat shall be applied with material as thin as can be handled to fill in cat faces and imperfections.

After the finish has drawn a few moments, trowel it to a smooth surface, brushing lightly with a damp brush.

Gypsum sand float finish shall be applied after the base coat

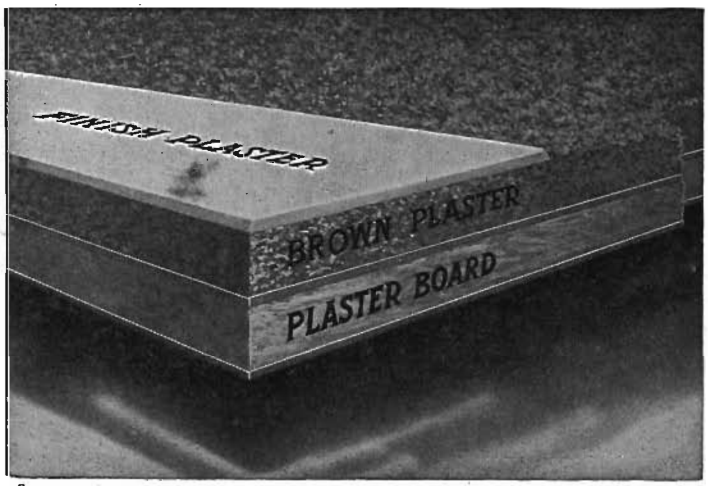

FIG. 68.—Plaster board and plaster coatings. Courtesy Beaver Board Co.

has set firm and hard, but while still green, and within twelve hours after the base coat is applied, lay on with trowel, using cork, carpet or felt float, working the material to a smooth surface free from cat faces, defects and brush marks. For floating, use as little water as possible, applying same with a damp brush.

Lime putty finish shall be applied in the usual manner, troweled down perfectly true, with metal trowel and water brush to a smooth surface free from defects and brush marks. Figure 68 gives a cross section of plaster board covered with standard plaster coatings and figure 69 illustrates the use of plaster boards on ceilings together with gypsum block partitions.

GYPSUM WALL BOARD

Gypsum wall board is an incombustible material for interior walls, ceilings, and partitions, consisting of two layers of fibrous binding material on the outside of a core of gypsum. In distinction from plaster board, gypsum wall board furnishes a finished surface, and is not intended to serve as a

Definition

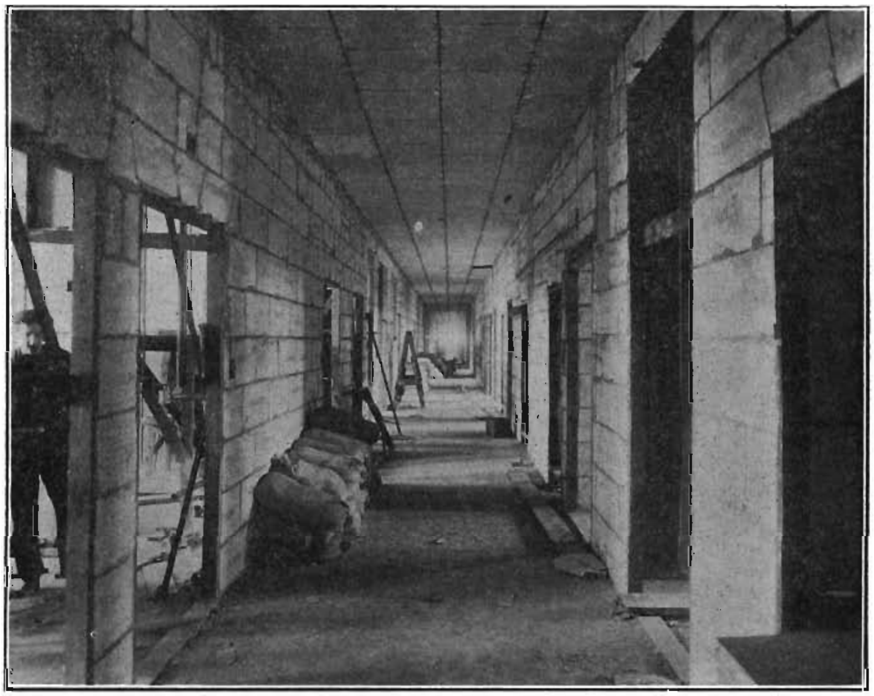

FIG. 69.—Plaster board ceilings and gypsum block partitions. U. S. Government Hospital, Maywood, Ill. Courtesy V. G. Marani.

base for plaster. A sectional view of wall board is presented in figure 70.

The following specifications[212] show the nature of gypsum wall board, as well as the various materials entering into its composition.

Nature of wall boards

"*FIBROUS BINDER.*—The fibrous binder shall consist of two outer layers of chip board of the following specifications:

Caliper.—Each ply of chip board shall caliper not less

212Prepared for the Building Materials Division of the War Industries Board, by the War Service Committee of the Gypsum Industries Association, O. M. Knode, Chairman.

than .030 inches—subject to manufacturer's normal variations of not more than 10 per cent.

Finish.—The finish of the chip board may be plain chip, filled news, or any finish of equal strength.

Weight.—One thousand square feet of chip board shall weigh not less than 90 lbs.

Strength of Binders.—The puncture test (Mullen test) shall be not less than 50 per cent (Mullen test points) of the weight per thousand square feet.

Core of Boards.—The core shall consist of calcined gypsum mixed with water to handling consistency, to which may be added not to exceed 10 per cent by weight of sawdust or other fibre intimately mixed.

Dimension of Finished Boards.—Length, 3 feet and 4 feet

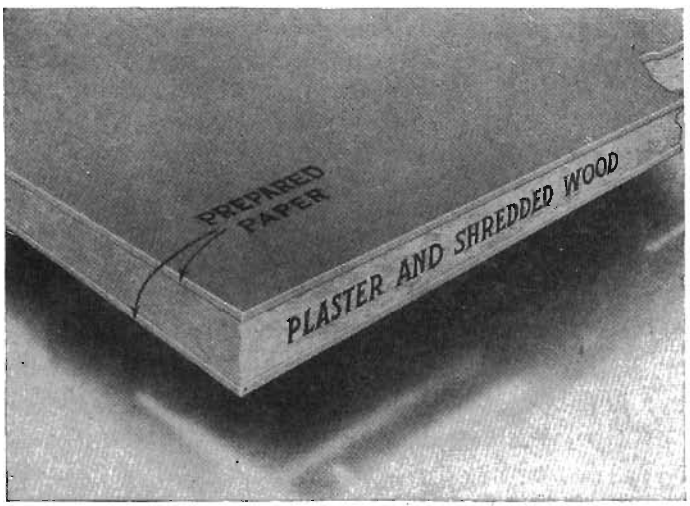

FIG. 70.—Section of gypsum wall board. Courtesy of Beaver Board Co.

with nominal width of 32 inches; length, 8 feet, 9 feet and 10 feet with nominal width of 32 and 48 inches.

In the process of manufacture boards 4 feet, 5 feet, 6 feet, and 7 feet in lengths, by 32 inches and 48 inches are produced in limited quantities.

Boards may be ¼ inch under-size in the narrow dimension to allow for structural variations and unequal stud spacing.

Thickness of Boards.—Boards shall be not less than ⅜ inch in thickness. This thickness shall be determined as follows: 32 boards when piled flat shall measure not less than 12 inches. In determining the thickness in the above method, no boards shall vary more than three sixty-fourths of an inch over or under size.

Weight of Boards.—One thousand square feet of 3/8 inch in thickness Wall Board shall weigh not less than 1700 lbs.

Wall boards less than 3/8 inch in thickness, namely 1/4 inch and five-sixteenths inch are produced by manufacturers and are recommended only in cases where economy is of greater importance than the more perfect fire protection afforded by use of the thicker board.

Finished Product.—

Edges.—The edges shall be folded, molded, cut or perforated-break.

Core.—The core shall be of sufficient thickness throughout the board to make the product conform to these specifications.

Surface.—The exposed or outer face of boards shall present a surface suitable for use with, or without, additional decoration. When shipped from the manufacturer's plant all boards shall be free from cracks or breaks.

Physical Characteristics.—The board when shipped must be dry, true and straight, excepting that boards with not more than two inch warp may be shipped. The chip board binder must adhere firmly to the core.

Advantages of gypsum wall board

Gypsum wall board is the only form of wall board on the market that has fire resisting features. Its value in this connection is recognized by the underwriters. Gypsum wall board itself will not burn even at high temperatures and is capable of withstanding great heat for a long period of time without breaking down. It thus presents an effective barrier to the spreading of fire.

Gypsum wall board does not shrink, expand, warp or buckle, and for all situations where a type of construction more flexible than a plastered surface is desired, it offers greater advantages than any other form of construction material. It may be applied and decorated in the same way that any of the numerous forms of wall boards are treated.

MANUFACTURE OF GYPSUM PLASTER BOARD AND WALL BOARD

The methods used in manufacturing gypsum plaster board and wall board are quite similar. Since wall board gives a finished surface, while plaster board is covered with plaster, it is essential that wall board be uniform in thickness and attractive in color. These properties are not so essential in plaster board. It is necessary to have thickness sufficient for strength, but the fact that some plaster boards are somewhat thicker than others does no harm.

A satisfactory bond between paper and gypsum matrix is the great essential in both types of boards. As has been stated, while the gypsum core or matrix is setting there is an actual growth of gypsum crystals within the fibre of the chip board, due to the penetration of the chip board by water saturated with gypsum. The chip board must not be sized enough to prevent moderately prompt water penetration. On the other hand if the chip board takes up water too quickly it loses its stability and tends to wrinkle.

Bond between chip board and the gypsum

The chip board is delivered in large rolls and the gypsum paste, made by mixing slightly accelerated calcined gypsum and water either on the lower sheet of chip board or in a mixer, is spread out between the layers of paper as the plastic mass passes between rollers. The edges are either molded, trimmed with saws or made true by folding the edge of the lower sheet of the chip board under the edge of the upper sheet.

The edge

The plaster board is allowed to run out on a traveling belt till the plaster has set sufficiently to make it possible to handle the boards without breaking. It is then either cut into appropriate lengths by knives or saws, or perforated so that the sheet can be broken to size.

After the plaster in the board has hardened so that the board may be handled conveniently the boards are placed in a dryer and subjected to moderate heat, to remove the surplus water in the chip board. The temperature must not reach a point which would deprive the gypsum of any of its water of crystallization. Steam radiators are commonly used to furnish the heat, though in some instances carefully regulated direct heat obtained by burning coke in a furnace attached to the dryer, is employed.

Drying

CHAPTER XVIII

STRUCTURAL GYPSUM

When gypsum is used in roofs, floors and pillars, it is often spoken of as structural gypsum.[213] For these purposes the compressive strength of gypsum, which is relatively unimportant in connection to its other uses, becomes a matter of prime importance. That gypsum possesses a compressive strength which makes it useful in floor and roof construction has been recognized only in recent years. The other properties of gypsum which make it an admirable material for roofs and floors were better known.

Definition

Nature of structural gypsum

The compressive strength of gypsum depends upon the amount of water used in mixing; the method of calcining; the dryness of the material and the purity of the mineral.

Mr. Willis A. Slater, in the Laboratory of Applied Mechanics, University of Illinois, carried out an elaborate series of tests in accordance with a comprehensive plan, and worked out formulae for the guidance of engineers who use gypsum for structural purposes.[214]

Professor Slater's summary of his tests follows:

(1) "The rate of drying of gypsum after setting took place was nearly constant until about 87 per cent of the excess water had been evaporated. For 6x12-in. cylinders this required about 20 days. Evaporation of the remaining 13 per cent required about 20 days more. This was at ordinary temperatures and humidities. With the temperature raised to 100 degrees F. and relative humidity at about 0.50, the drying time was reduced to 7 days or less for complete dryness.

(2) "The weight of hydrated first settle gypsum per cubic foot was about the same as that of hydrated second settle gypsum. The weight of dry hydrated gypsum decreased with an increase in the amount of water used in mixing. The calcined gypsum required was about five-sixths of the weight of the dry hydrated gypsum resulting, regardless of the amount of water used in mixing.

(3) "The attainment of the maximum compressive strength

213Gypsum calcined at high temperatures for flooring is considered in Chapter XIX.

214W. A. Slater and J. J. Whitacre, Tests of Plain and Reinforced gypsum specimens: Journal of the Western Society of Engineers, Vol. XXIV, No. 7, September, 1919.

of gypsum appears to depend upon the amount of drying out rather than upon the age. Increase in strength with age is apparently due to increased drying with age. Small specimens (3x6-in. cylinders) dried at 100° F. showed a temporarily high strength as soon as they were dry. This strength soon fell to about the same as that of specimens dried at ordinary temperatures or of larger specimens dried at the same temperature. The permanent strength of second settle dry specimens made from gypsum mixed at standard consistency and having 0.1 per cent retarder seemed to be about 1900 to 2000 pounds per square inch, whether dried at 100° or 70°, regardless of the size of the specimen.

(4) "When mixed without retarder at standard consistency the strength of the first settle gypsum when dry was about two-thirds that of second settle gypsum, whether the storage was at 70° or at 100° F.

(5) "The compressive strength fell off regularly and rapidly with an increase in the percentage of water used in mixing. For second settle gypsum, 100 per cent dry using 0.1 per cent retarder, the range in strength found was from 2400 to 400 lb. per sq. in. when the water varied from 35 per cent to 53 per cent.

"For first settle gypsum about 50 per cent dry, using no retarder, the range in strength was from 760 lb. per sq. in. to 140 lb. per sq. in. when the water varied from 35 to 60 per cent.

Slater's tests

"A portion of the difference in strength between the second settle and first settle gypsum is undoubtedly due to the fact that the first settle gypsum was only about 50 per cent dry.

(6) "Under certain conditions the use of retarder caused a decrease in the strength of the gypsum. For the conditions most likely to be met in practice the use of not more than 0.1 per cent retarder is likely to cause only a slight loss but under certain storage conditions it may even cause an increase in the strength.

(7) "The tensile strength of gypsum seems to be from, say 300 to 800 lb. per sq. in. The earlier beam tests indicated that no cracks occurred in the gypsum until the stress in the reinforcement was very high. This was, to a certain extent, true for the later beams, but was less marked than in the earlier investigations. The combination of a high tensile strength with a low modulus of elasticity would be expected to bring about this kind of a result. A part of the difference in behavior may be due to the fact that the earlier beams were not as dry at the time of testing as were the later ones.

(8) "Only a small amount of exposure of dry hydrated

gypsum to very moist air was sufficient to reduce the strength of gypsum considerably—but additional exposure even to the extent of soaking the specimen in water had relatively slight effect on the strength.

(9) "The use of hydrated lime up to about 4 per cent of the weight of the gypsum caused a marked decrease in the

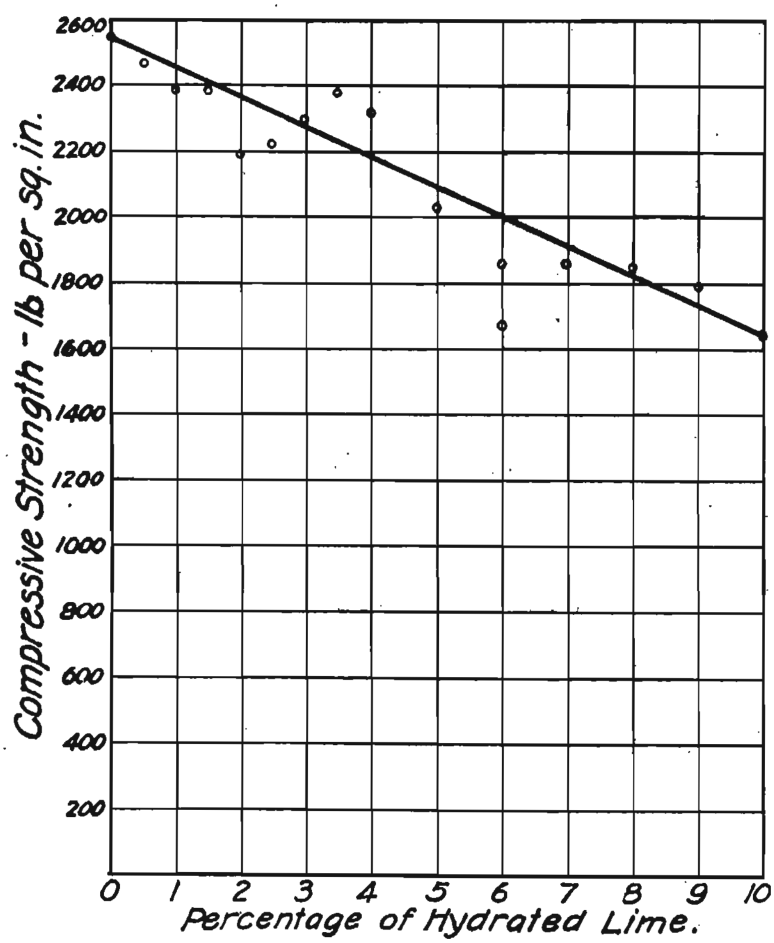

FIG. 71.—Effect of addition of hydrated lime on compressive strength of calcined gypsum. Courtesy of Society of Western Engineers.

amount of corrosion of the imbedded bar and in the bond strength with steel bars. With larger amounts of lime there was little additional effect on either the bond strength or the amount of corrosion.

"The tests indicated a loss of about 3½ per cent of the compressive strength of the gypsum for each one per cent of hydrated lime used. This is true up to ten per cent of the total weight of lime and gypsum. Ten per cent was the largest amount of lime used. Results of the tests are shown graphically in figure 71.

(10) "Corrosion of the reinforcement in roofing tiles which had been in use for four years was negligible where the gypsum had been kept reasonably dry. Where the gypsum had been continually saturated for a considerable time the corrosion was important.

(11) "Second settle gypsum from various mills showed a good degree of uniformity in compressive strength.

(12) The tests of the T-beams indicate that the same principles which are used in the design of reinforced concrete beams are applicable to the design of reinforced gypsum beams.

(13) "Under conditions comparable with those which existed in these tests and where stripping and bond failure are eliminated failure by diagonal tension in beams without web reinforcement does not seem likely to occur when the shearing stress is 80 lb. per sq. in. or less.

(14) "Anchorage of reinforcing bars by means of semicircular hooks at the ends was fully as effective as the use of plates attached to the ends of the bars for anchorage.

(15) "In a test made to determine the effectiveness of anchorage the end plate came into action early in the test. Shortly after the beginning of the test the proportional part of the total tension carried by bond began to decrease and the proportion carried by anchorage increased until at about two-thirds of the maximum load slightly more than one-half of the total tension was resisted by bearing against the anchor plate. From then until failure the proportion carried by bond was nearly constant. It is possible that under some conditions a larger proportion would have to be carried by the anchor plate. The largest average bond stress found for this beam was about 120 lb. per sq. in. and this occurred at the maximum load.

(16) "An upward deflection amounting usually to about 3-16 in. and in certain cases to as much as $\frac{1}{4}$ in. was found in the beams previous to testing them. An expansion of the gypsum during the setting or drying process took place and the restraint of this expansion on the reinforced side of the beam seems to be responsible for the upward deflection. It was ascertained that the most of the expansion occurred soon after the first set had taken place and at the end of 24 hours the expansion generally was larger than at any time later."

A valuable report on Design of Reinforced Gypsum Beams, by Professor Slater, appears as appendix VIII.

First settle gypsum has been used successfully for roofs and floors though its compressive strength is not equal to the second settle product.

Gypsum carrying impurities sufficient to affect its compressive strength may be used for flooring and roofing provided the cross section of the slab is figured somewhat more liberally, to allow for any difference in strength. For any rock gypsum now in commercial use the increase in the section required to balance such impurity would be small.

Advantages of structural gypsum

Conductivity.—As gypsum is an exceedingly poor conductor of heat, it has an important advantage over other substances used in making roofs and floors. A gypsum roof slab as ordinarily made shows a heat loss per square foot per hour, for each degree difference in temperature of .4 B. T. U. as compared with 1.2 B. T. U. loss for an equal thickness of cinder concrete and 2.0 B. T. U. loss for an equal thickness of stone concrete. These figures justify the statement that where a gypsum roof is used instead of cinder concrete, between latitudes thirty-nine and forty-two there is a saving of 10 per cent in the initial cost of the heating plant, and a saving of 20 to 25 per cent in the cost of fuel. These savings are of course greater if comparison is made with stone concrete, and are still greater as compared with clay tile.

These figures showing relative nonconductivity are as favorable to gypsum if summer conditions, instead of winter conditions, are under consideration. The gypsum roof is cool, and lofts may be used with comfort where gypsum is the roofing material which would be intolerable otherwise.

Gypsum roofs are free from condensation or ''sweating'', which is an important consideration in industrial buildings where the air is moist from any cause.

Fire Resistance.—Because gypsum is a poor conductor of heat, gypsum roofs and floors are remarkably resistant to fires. This has been considered to some extent in chapter XVII.

An important fact that deserves special mention is found in the protection given by gypsum roofs and floors to the structural steel that carries the weight of the building. At a temperature of only 800° F. steel loses 10 per cent of its strength, and at 1700° F. it loses 50 per cent of its strength. It is exceedingly important, therefore, that in fireproof buildings, where the contents of the building may create high temperatures, the steel be given ample protection.

Lightness.—Gypsum roofs and floors are lighter than any other form of fireproof construction. Certain types of poured roof do not weigh over twelve pounds per square foot for average purlin spacing, ready for finish or water proof surfacing. A four inch poured slab weighs but sixteen pounds per square foot. Precast roof blocks have the following weights:

Type	Length, Inches	Thickness, Inches	Width, Inches	Weight per Square Foot, Lbs.
Solid	30	3	12	13
Hollow	30	4	12	14
Slabs	48 to 72	5	15	14 to 16

The thirty inch blocks, either solid or hollow, are set in T iron sub-purlins and save 40 per cent in steel over clay block tile construction.

Elasticity.—Gypsum roofs and floors are more elastic than concrete structures and the vibrations from machinery or other causes do not develop cracks which are often troublesome where a less resilient construction material is used.

Nonconductor of Sound.—Tests quoted in chapter XVII verify the statement that gypsum floors are excellent nonconductors of sound. For this reason gypsum floors are especially commended for hotels, apartment houses and educational institutions.

Rapidity of Construction.—The rapidity with which gypsum sets makes rapid construction possible. The forms or centers from poured units can be removed in twenty or thirty minutes. In the case of a poured roof or floor the resulting surface is sufficiently strong to be used at once and within an hour provides a working floor that may be safely used under the loads for which it was designed. In the case of precast gypsum roof blocks, on account of the large size of the unit and its lightness, construction is rapid.

In the case of poured floors and roofs the gypsum generates considerable heat while setting and it is possible to proceed

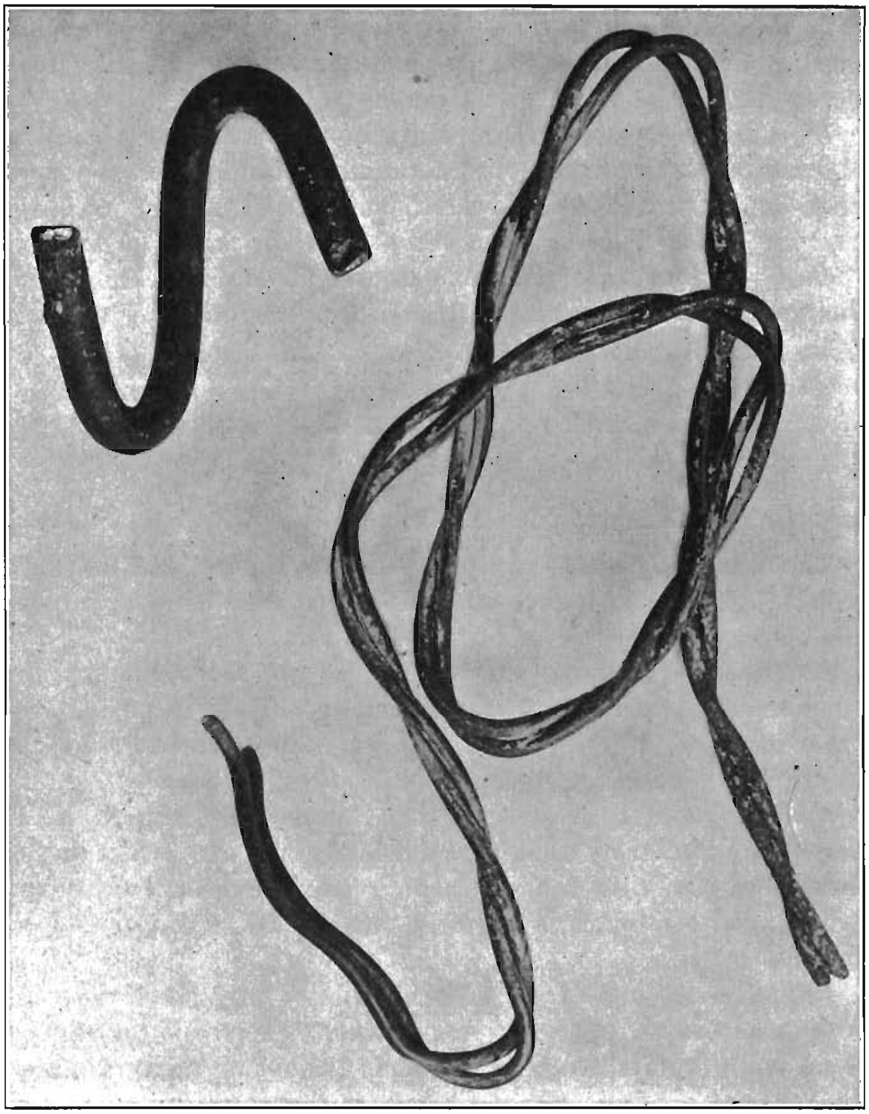

FIG. 72.—Showing excellent condition of steel reinforcing imbedded in calcined gypsum for fifteen years. Hammerstein Theater. Courtesy V. G. Marani.

with the work even when temperatures are considerably below freezing.

Strength.—As has been shown in the paragraph on compressive strength and as is more fully set out in appendix VIII where the computations of Professor Slater are given at length, gypsum can be easily and amply reinforced to give the strength desired for any roof and floor construction. Where roof slabs or blocks, either precast or poured on the job, are used ample strength for all needs is easily secured.

Durability.—The steel reinforcement used in structural gypsum is remarkably free from corrosion. Wires which have been imbedded in gypsum for fifteen years have been examined repeatedly and, aside from a thin film of initial rust that always forms when a wet substance touches metal, the steel is as bright as when installed.

Mr. Marani[215] describes an interesting investigation of the gypsum floor in Hammerstein's Theater as follows:

"In the year 1911 the sub-committee on engineering subjects of the Joint Committee of City Departments of New York City, while investigating the subject of corrosion, caused the cutting into of a gypsum floor slab in the roofing and upper floor system of Hammerstein's Victoria Theater, Seventh Avenue and Forty-second street, New York City, for the purpose of examining the imbedded steel. Both the twisted wire cables and the I beams showed only initial rusting and that the rusting had not progressed, the committee being favorably impressed with the condition of the steel.

"Subsequently in the summer of 1915, this theater building was torn down. "S" hooks, which were used as anchors for the reinforcing cables, though not previously coated in any manner, showed no signs of progressive corrosion, the same being true of the galvanized, twisted cables. The accompanying illustration (figure 72) shows this hook and a section of the cables as they were taken from the building. (This matter will be found carefully set forth in an affidavit made by Samuel G. Webb, and registered Bronx County, No. 4, Bronx Register, No. 606. Certificate filed in New York County, No. 11, New York Register, No. 6036.)

GYPSUM ROOF CONSTRUCTION

Historical

Gypsum has been used as a roofing material in America since 1898. Sufficient time has elapsed, therefore, to demonstrate its durability. The list of important office buildings in New York City, covered with gypsum roofs, in-

215Marani, in Construction, September, 1916.

cludes a fair percentage of the more important structures in that city, while the number of gypsum roofs on industrial, apartment and office buildings in that city runs into the hundreds.

Canada seems to have been a particularly favorable field for the installation of gypsum roofs, probably on account of the fact that they can be poured, or put in place in freezing weather, and under conditions that make the use of concrete impossible.

In Europe gypsum roof and floor work is of an altogether different nature, as gypsum calcined at high temperatures, as described in chapter XIX is employed entirely for these purposes.

Types

Gypsum roofs are of two types; the poured roof, and the roof slab. Although advocates of each type claim for it superior advantages local conditions will probably decide the question when choice must be made between them. Both systems adequately meet all requirements for fire protection, durability and economy.

The poured roof

The principle involved in the poured roof is that of the suspension bridge. Steel cables properly paced, carry the entire load with an ample margin for safety, to which factor of safety may be added the compressive strength of the gypsum roof deck.

Cables composed of galvanized wires are carried over the tops of the beams or purlins and are secured to purlins or walls by strong hooks, bars, or anchors. The cables are laid parallel to one another and at intervals of from one to three inches, varying according to spans and loads. The cables pass under an iron bar midway between the purlins which causes a uniform deflection in the cables. Forms are placed about an inch below the round iron bar which crosses the center of the cables. When the gypsum paste is poured on this form till it stands about one-half inch above the tops of the purlins, the slab has a thickness of about three inches.

The gypsum paste consists of calcined gypsum and water, with planer shavings or shredded wood, preferably of some non-staining sort. The percentage of water used in mixing is a highly important factor, for, as has already been shown, the compressive strength of the slab depends upon this, more than upon any other single factor. Over the gypsum slab a layer of ordinary slag roofing is commonly poured. A variety of water proof compounds may be substituted for the slag cement any of which will successfully keep water from the gypsum slab, which is essential.

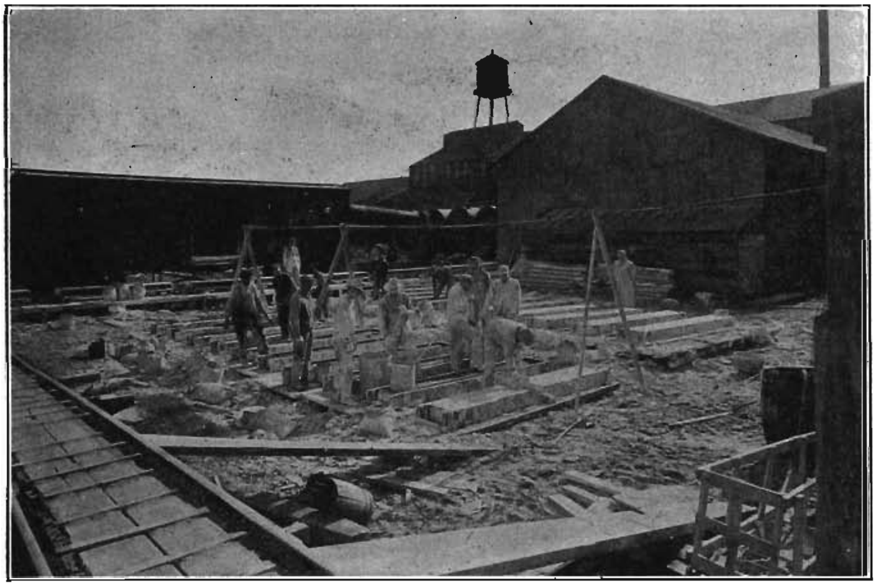

FIG. 73.—Making large roof tile on the job. Courtesy V. G. Marani.

The government in awarding contract for the navy yard at Norfolk made a thorough investigation of the poured gypsum roof and its report[216] is very favorable to this type of construction. This report is reproduced as appendix VI and to this the reader is referred for much valuable information.

Roof Block Construction.—Factory made blocks, reinforced, but otherwise like gypsum partition blocks are used in roof construction. The tendency, however, is to use larger units, moulded on the job, such as blocks ten feet long which extend from truss to truss and eliminate the T irons ordinarily used in roof construction. Figure 73 shows how these units are made and figures 74 and 75 illustrate the method of laying and surfacing a tile roof. Tests of these blocks made twenty-

216Bulletin 25, Public Works of the Navy, Washington, 1917.

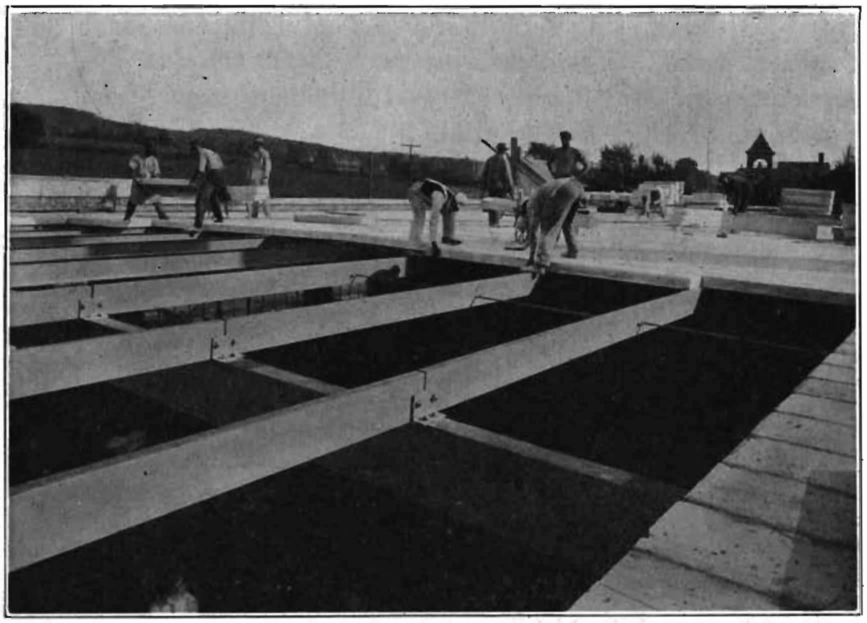

FIG. 74.—Laying precast gypsum roof tile on purlins. Courtesy United States Gypsum Co.

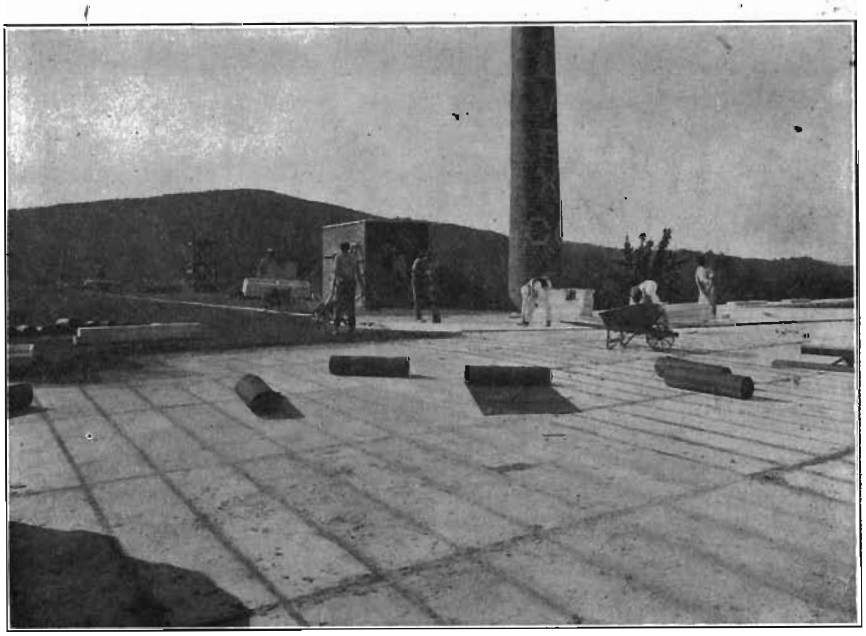

FIG. 75.—Surfacing a gypsum tile roof. Courtesy United States Gypsum Co.

four hours after pouring showed them to be capable of carrying a uniformly distributed load of two hundred pounds per square foot.

GYPSUM FLOORS

The same types of construction used for roofs are appropriate for floors in fireproof buildings. In addition to these a gypsum floor tile or filler for use in reinforced concrete floor construction is popular. These floor tile or domes are light, and permit of long floor spans. They have solid ends which

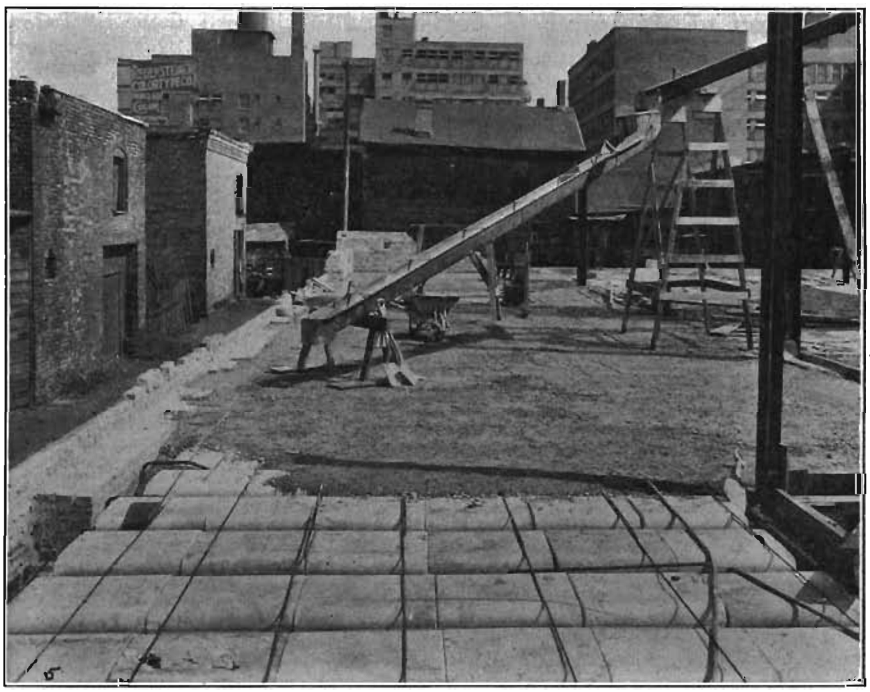

FIG. 76.—Gypsum floor tile showing conduits, and surfacing of same with concrete. Castle Hotel, Omaha. Courtesy V. G. Marani.

reduce the loss of concrete at the joints when concrete is poured. The bottom of these tile makes an excellent surface for the plaster of the ceiling formed by the floor.

Floor tile of this type are spaced twenty-four inches on centers and are about one-half the weight of clay tile. They are illustrated in figure 76.

CHAPTER XIX

HYDRAULIC GYPSUM AND KEENE'S CEMENT

An English term is needed to cover gypsum which has been calcined at high temperatures and in consequence has not merely been dehydrated but has lost a portion of its sulphur through oxidation.

Definition

Calcined gypsum is a term that may well be confined to gypsum calcined at moderate temperatures, and which retains a portion of its water of crystallization or so quickly takes on water from the atmosphere (as in the case of soluble anhydrite) that it is in the hemi-hydrate form when it reaches the market. It then becomes a synonym for stucco and plaster of Paris.

Dead burned gypsum is a term which satisfactorily covers gypsums dehydrated between the temperature used in making calcined gypsum (400° F. or 190° C.) and the temperature at which partial oxidation takes place (1652° F. or 900° C.).

The German "Estrich"

In Germany the term Estrich (which means flooring) is applied to gypsums calcined at the temperatures last named, because it possesses properties which make it peculiarly valuable for flooring purposes.

Inasmuch as ordinary calcined gypsum is used extensively and successfully in America as a flooring material, it does not seem wise to use the term "flooring" as the descriptive adjective which designates the gypsum product resulting from high temperature calcination.

The term hydraulic gypsum has been used to describe this product, and inasmuch as it correctly describes one of its important attributes and is free from confusing associations it is recommended for use in this connection.

How calcined

Hydraulic gypsum is calcined by heating lump gypsum in an oxidizing flame to a temperature of 900° C. (1652° F.) to 1300° C. (2372° F.). The gypsum at these temperatures is at a red heat. Higher temperatures are in no way harmful and produce a somewhat better product, but they are expensive and hard to attain.

Glasenapp[217] made a series of microscopic studies of gypsum calcined at various temperatures up to 900° C. and beyond, and found that the structure that definitely characterizes hydraulic gypsum does not develop until 900° C. is reached. These studies coincide with pyrometric tests which show that the minimum furnace heat required for the manufacture of hydraulic gypsum is about 900° C. When burned at higher temperatures the gypsum sets harder and more quickly, both desirable properties.

Glasenapp[218] states that anhydrite may be used successfully as raw material for the manufacture of hydraulic gypsum provided it is heated to sufficiently high temperatures (1400° C. and above).

Hydraulic gypsum from anhydrite

Next to the point as to the proper temperature required for burning hydraulic gypsum, it is necessary to stress the fact that it must be burned under oxidizing conditions. In other words, the heat must be applied in such a way that, during the later stages of the burning process, an excess of free oxygen is present. Some of this oxygen will, at the high temperature prevailing, combine with a portion of the sulphur present as calcium sulphate ($CaSO_4$) and go off with the furnace gases as SO_2. There will be left in consequence a certain amount of calcium oxide (CaO), ranging from 4 to 10 per cent.

Chemical nature of hydraulic gypsum.

Glasenapp[219] gives the following table which shows the increase in the amount of calcium oxide present in hydraulic gypsum, with increase of the temperature used in burning.

Temperature in Centigrade	$CaSO_4$	CaO
800	96.93	2.73
1100	95.88	3.58
1400	88.20	11.40

If the gypsum is left at 1400° C. for a considerable time the percentage of calcium oxide will be considerably in excess of the figure given above.

217 Glasenapp, M., Plaster, Overburnt Gypsum and Hydraulic Gypsum. Translated by Dr. W. Michaelis, Jr. Cement and Eng. News.

218 Bericht uber die XVI Haupt Versammlung des Deutschen Gipsverein, Ann. 2, Marz. 1914, p. 110.

219 The Manufacture of Hydraulic Gypsum and other Gypsum Products. Translated by Michaelis, p. 29.

The hardening of hydraulic gypsum is not due, primarily, to the growth of gypsum crystals from solution, as is the case with calcined gypsum. According to Glasenapp[220] "hydraulic gypsum hydrates principally without changing its form, without crystallizing because it is unable to form an over-saturated solution. This explains the necessity of densifying the mortar during the early stages of its hardening,

Theory of set

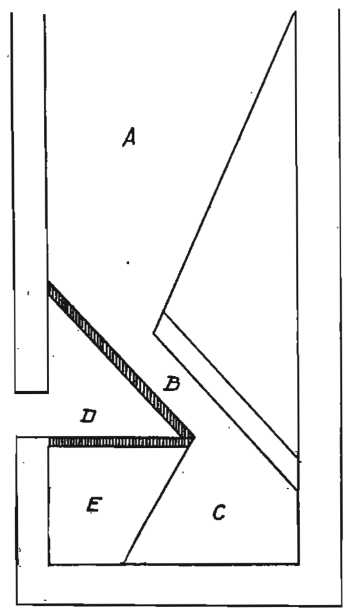

FIG. 77.—Diagram showing arrangement of kiln for burning hydraulic gypsum.

by tamping it. The particles are thus forced together more closely". The hydration apparently causes a growth and expansion of the particles till one particle adheres to its neighbor by a sort of concretional growth, quite different from the structure of interlocking crystals. The calcium oxide also slowly takes on carbon dioxide and sets after the manner of burnt lime.

Hydraulic gypsum is produced extensively in Germany. It is there burned in a simple kiln not unlike the old style kiln. Lump mineral is dumped into the top of the kiln (figures 77 and 78), and is exposed to intense heat generated in the fire box. The red hot mineral is, from time

Burning of hydraulic gypsum

220The Manufacture of Hydraulic Gypsum, p. 36.

to time, drawn out from the bottom of the kiln, where it is thoroughly exposed to the oxygen of the air. After the kiln has become thoroughly heated the carbon is completely oxidized and there is no smoke. The operation is continuous, or

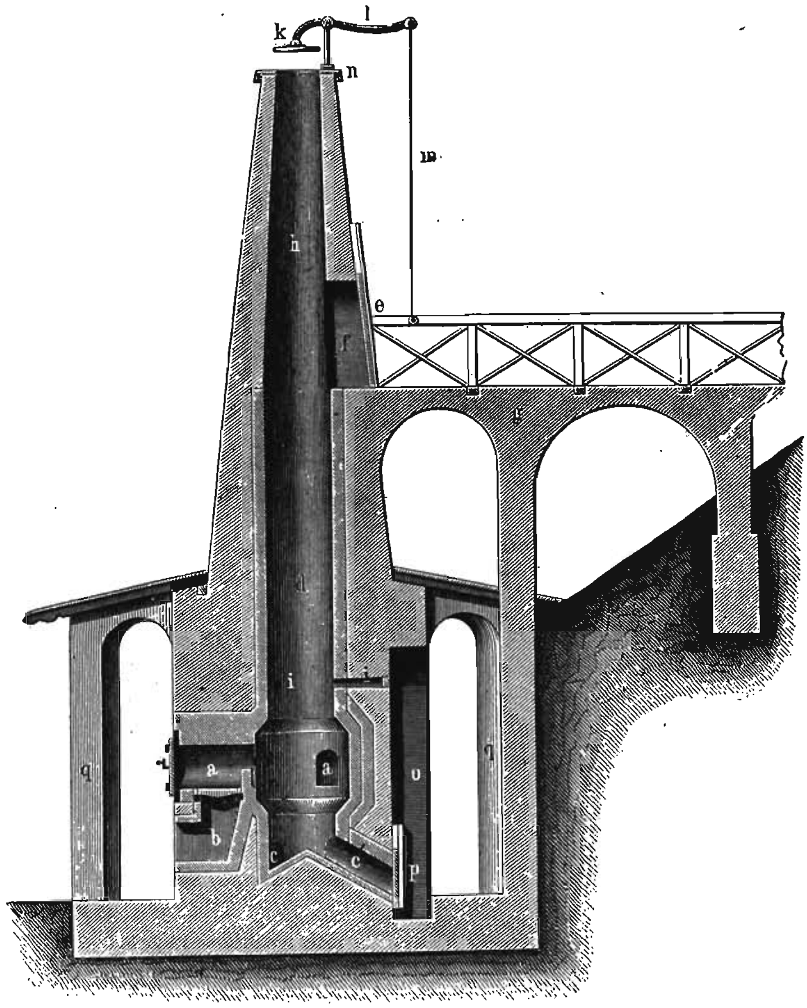

FIG. 78.—Cross section of one type of kiln for burning hydraulic gypsum (Estrick). After Von Waldegg.

intermittent, as best suits the convenience of the operator in drawing out the heated mineral.

The whole process is extremely simple and no delicate control of temperature is necessary.

As in lime kiln practice it is not practical to burn the fines because they choke the draft in the kiln. In Germany the fines are used for calcined gypsum or for agriculture and the lump is reserved for burning in the hydraulic gypsum kiln.

Grinding

After burning, hydraulic gypsum is coarsely ground as it gives the best results when only a small percentage of the whole passes the hundred mesh sieve.

PROPERTIES AND MANIPULATION OF HYDRAULIC GYPSUM

The following is a free translation of a pamphlet published in 1914 by the German Gypsum Association[221] and the illustrations are taken from the same source.

Properties of hydraulic gypsum

Specific gravity

"As already mentioned above hydraulic (flooring) gypsum is a highly calcined gypsum, that is, the gypsum rock is heated to a bright heat, say from 800° to 1000° C., in kilns of various construction. Burning at high temperatures results in the slow setting of the water-gypsum paste which, on completion of the setting stage, shows a very great hardness. After setting, hydraulic (flooring) gypsum resists an occasional exposure to moisture, and the specific gravity is greater than that of ordinary calcined gypsum. Hydraulic gypsum weighs from 900 to 1200 grams per liter, while calcined gypsum weighs from 650 to 850 grams per liter.

"Since calcined gypsum must be manipulated in a manner altogether different from hydraulic gypsum, it is clear at once that failures are bound to result if these varieties of plaster are mistaken for each other or are used in the wrong place.

ADVANTAGES OF HYDRAULIC GYPSUM FLOOR

Fire protection

"A floor made of hydraulic gypsum has remarkable advantages over other floor compositions. Due to the absence of joints in the one piece gypsum floor many a destructive fire is prevented. If a fire starts on a given floor the gypsum floors prevent its spreading upward or downward, and in addition protect the lower floors against the destroying action of water.

A non-conductor

"The one piece gypsum floor does not readily deteriorate owing to its hardness. It is cool in summer and warm in winter. Vermin like moths and mice cannot find a shelter in it and being free from joints and cracks it does not furnish a gathering place for dust. Gypsum floors are highly suitable for houses and hotels. In these places the

221Die Verwendung Von Estrichgips im Bauwesen, und seine richtige verarbeitungsweise. Verlag den Tonindustrie—Zeitung. Berlin, IV. W. 21.

floors will be covered with rugs or linoleum. Gypsum floors possess a considerable amount of elasticity and walking on them is noiseless. The penetration of dust and bacteria is impossible and in consequence gypsum floors are excellent for hospitals, schools and public buildings.

"In the laying of gypsum plaster floors it must be borne in mind that considerable experience is required in order to secure the best results. In all cases it is recommended that the gypsum flooring be handled as a distinct and separate item in the contract and that the gypsum flooring be not tied in with other plaster and stucco work.

"As a rule it is the custom of the flooring-plaster manufacturers to have the casting of plaster floors done by special workmen skilled in this line of work or else to sublet it to contractors who specialize on the laying of gypsum floors and consequently are in position to execute the work properly.

"In the laying of gypsum floors care must be taken to secure a proper background. A wooden base will prove satisfactory provided it is covered with asphalt paper or something of a similar nature; or with a layer of dampened gravel sand or coal ashes, at least 3 cm. (1.2 inches) thick. Before the plaster is poured the dampened underlayer must be levelled and rammed tight. If the gypsum floor is to be poured upon concrete or brick these must be wet down well, for otherwise the water needed for the hardening of the gypsum floor will be too rapidly absorbed by the dry background and the floor will lack hardness.

Application of floor gypsum

"As in the case of cement floors or any composition floor, the rooms where gypsum floors have been laid should be protected from draughts and low temperatures.

"Usually there is spread upon the underlayer a top layer of flooring plaster from 3 to 5 cm. (1.2 to 2 inches) in thickness. In the construction of a gypsum floor hydraulic gypsum should always be used and never the ordinary calcined gypsum. The latter will fail utterly to meet the requirements as to hardness and too much stress cannot be laid on the necessity of avoiding all confusion in regard to the kind of gypsum plaster suitable for flooring.

"As in the case of other cast-floor materials, the mixing of the gypsum plaster requires the attention of a careful workman. The best mixing box consists of a rectangular box of sheet iron, about 1.5 m. (4.5 feet) long and .7 m. (2.5 feet) high. This should be well braced with bar or angle iron and provided with handles.

"In a box of this size thorough mixing is possible, whereas in a smaller box it is difficult. The box is first filled with water and the gypsum plaster is slowly added till it stands above the level of the water. It is best to shake the shovel steadily, letting the dry plaster slowly spill into the water. After a while, when the water has soaked the plaster mass thoroughly, it is thoroughly stirred and worked, and no lumps should be allowed to form. The ordinary beater used in slaking lime is used for

FIG. 79.—Mixing the hydraulic gypsum.

mixing the gypsum plaster with water. For large rooms it is well to have two mixing boxes, a fresh batch being mixed in one while the contents of the other is being poured.

"Figure 79 shows at the right a surface bounded by lath and covered with dampened sand, which is to be covered with flooring plaster. The sand layer is well sprinkled with water, brought to level and tamped. At the left of figure 79 the preparation of the plaster is shown. From a bag held open by one of the workmen the other takes the plaster with a shovel and shovels it into the box of a wheelbarrow which is used here as a mixing receptacle and is half filled with water. The shovel is constantly agitated as can be clearly seen in the picture. A still better method consists in taking the plaster from the bag by hand and in letting it run through the fingers under constant agitation of the hand.

"While the plaster paste is being spread on the floor it is necessary that the material in the mixing box be stirred frequently. If this is not done the water will separate from the mortar, and it may happen that the water content of the first third of the batch will be normal, the second third deficient in water; while the last third will contain too much water. Under these circumstances the floor does not set or harden properly.

"The pouring requires a sufficiently dampened underlayer as otherwise the flooring plaster loses its moisture too rapidly and does not attain the desired hardness. Care also must be taken to make the sand layer, which has been tamped with the rammer, as level as possible and to avoid deep depressions therein. This is necessary in order to obtain a layer of plaster of uniform thickness, which, on being struck after hardening, will emit a uniform sound throughout the entire surface. A well constructed floor emits a clear sound after setting, the height of the sound being indicative of its hardness. If the sound indicates a hollow space this means that, at this point, the plaster has not been tamped enough or is not flush with the underlayer.

"The plaster is generally poured with an ordinary sheet bucket. High-grade flooring plaster should remain soft hours and hours, during which time part of the water first sweats out at the surface and is afterward again slowly absorbed. The pasty mortar is spread on the underlayer in a uniform thickness of 3 to 5 cm. (1.2 to 2 inches) after which it is straightened out.

FIG. 80.—Pouring the hydraulic gypsum.

"Spreading is effected by means of an ordinary straightedge, which, in order to increase its durability, is reinforced with a galvanized iron sheet along one edge. After some experience the workman learns to spread the plaster with the aid of a single template, on the outer edge of the area to be covered, and relies on the free edge of the freshly poured plaster for the inner edge. It is good practice to provide the outer edge of the first coat portion with indentations in order to effect a better junction of the sections. Figure 80 illustrates this method of procedure.

"Figure 80 shows how the plaster mortar is poured from a bucket by one of the workmen and how it is spread out with a trowel by another.

"Figure 81 illustrates the leveling of the mortar with a straight edge. The straight edge in this case rests on both sides on templates and is drawn to and fro till a level surface is secured.

"After the plaster floor has become hard enough so that only a slight impression is left on making an imprint with the thumb, the operation of tamping the plaster layer is started. During this operation the workman stands on a plank in order

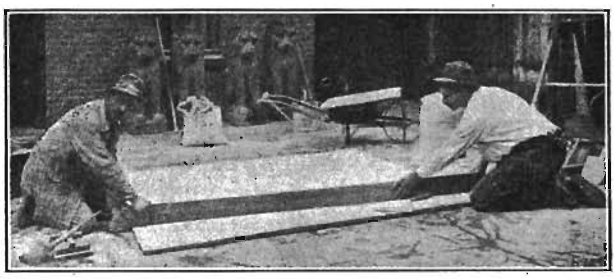

FIG. 81.—Bringing hydraulic gypsum to a true surface.

not to injure the still unhardened floor. Various sorts of rammers or iron tamps are used. The most suitable form consists of a long plate provided with an upright plate which enables the workman to tamp the floor without having to bend down too much. The floor is tamped as long as water appears on

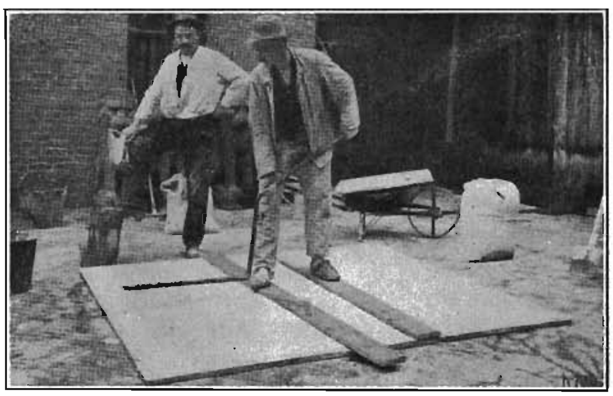

FIG. 82.—Tamping the hydraulic gypsum floor.

its surface. After this the tamped surface is rubbed with an ordinary rubbing board and then smoothed down with a flexible steel trowel. After these operations the floor is left untouched for a time and protected from drying too rapidly. When the weather is unusually dry and the outside temperature high the floor should be sprinkled with pure water from a watering can once or twice at intervals of two or three days. Draughts should be avoided and to this end windows and doors should be kept closed.

"Figure 82 shows how the cast floor is tamped after the flooring plaster has passed through the first hardening stages. The workman is standing on two boards in order not to damage the still fresh plaster.

"Figure 83 shows the smoothing down of the tamping operation with rubbing board and trowel. The workman is shown holding in the left hand the rubbing board by means of which

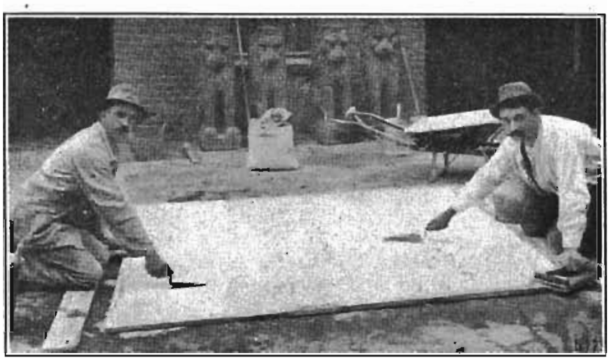

FIG. 83.—Smoothing hydraulic gypsum floor with trowels.

the first smoothing is accomplished. The steel trowel in his right hand is used for giving the finishing touch.

"After all of these operations have been completed, the floor is left untouched for some days as it attains to maximum hardness only after ten to fourteen days.

"If for reasons of economy other material is mixed with the flooring plaster these admixtures should not amount to more than one-third of the volume of the plaster. For this purpose clean sharp sand may be added, or calcined, preferably ground and weathered slag. The mixing of these ingredients must be thorough to insure uniform hardness. Generally it is preferable to use pure flooring plaster. If other material is to be added the contractor should consult the manufacturer of the flooring plaster and secure his advice as to the nature of the material that may best be added under existing conditions.

"The process described above may be called the casting process. Another method has of late been used which we shall call the ramming method.

"In the ramming method one volume of flooring plaster is intimately mixed while dry with one to two parts by volume of sharp sand or suitable slag. Then the mass is uniformly dampened by sprinkling while it is being turned with a shovel, like cement concrete. By this method much less water is used than is required in the casting process. The underlayer must be moistened. In case the underlayer is of a sort that strongly absorbs water (dry cement concrete, plaster floor, etc.) more water should be used in the mixing. The mortar is spread out like cement concrete in a layer of 3 to 4 cm. (1.2 to 1.6 inches) and thoroughly tamped till water appears on the surface.

"In order to smooth down the surface the concrete plaster is coated with dry flooring plaster by means of a screen, im-

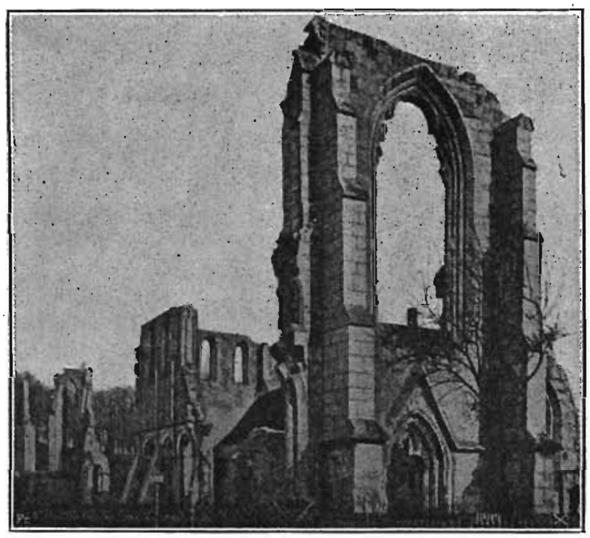

FIG. 84.—Medieval cloister of Walkenreed. The walls were laid in hydraulic gypsum mortar. After Von Waldegg.

mediately after the completion of the tamping operation, after which it is rubbed down to a smooth finish.

"A floor made in this way will harden and dry rapidly. After two or three days it is ready to support the weight of a person walking on it. It is a good plan to cover the surface with moistened sawdust for one or two days more in order to prevent too rapid drying.

"The advantage of the tamping process lies in the fact that little water is required, which favors the rapid drying and hardening of the floors, and eliminates the danger of cracks from air draughts. (If hydraulic gypsum ever becomes popular in America as a flooring material this process undoubtedly will be used as it permits the use of concrete mixers and gives a floor that can be used two or three weeks sooner than is possible by the "casting process". F. A. W.)

"The floor should not be covered with linoleum for six or eight weeks in order that it may completely harden. Bubbles are also apt to form under the linoleum which will injure the fabric.

"In case the plaster floor is to be used without a linoleum cover the best procedure is to soak it with linseed oil, after which it may be given a coating of oil-paint after the manner of an ordinary wooden floor. It will be found that the floor maintains its good condition for years without showing appreciable signs of wear.

"A floor made strictly according to these rules will never expand, nor will it develop cracks. It will always be solid, warm, and show a high resistance to wear.

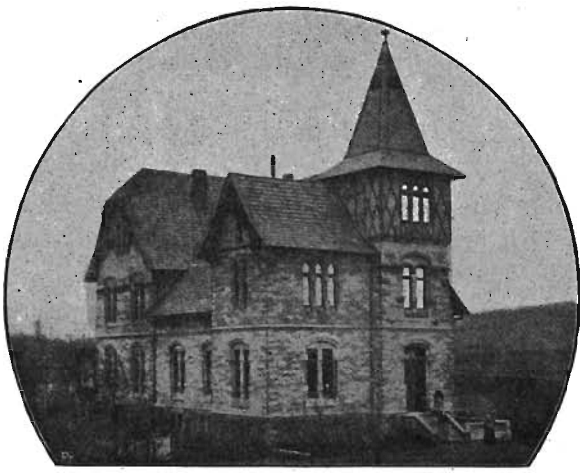

FIG. 85.—Modern German building in which hydraulic gypsum was used for floors and as mortar for walls. After Von Waldegg.

"The good properties of the cast plaster floor are more and more being recognized by architects and contractors. As shown by the long list of notable buildings appended to this pamphlet, it enjoys a wide reputation in all parts of the country. (Figures 84 and 85 afford illustrations of the use of estrich gypsum in ancient and modern buildings. F. A. W.)

"In order to illustrate the manipulation of flooring plaster with the greatest clearness the figures have been taken in open outside places as interior illumination would have been difficult. The floor section as shown in the picture is bounded by lath bars and should be considered as merely a sample. In closed rooms the plaster floor is laid by starting in one of the corners."

KEENE'S CEMENT

Composition

Keene's cement consists of "dead burned gypsum" (that is gypsum heated to 500° to 600° C. or 900° to 1100° F.) to which the property of quick setting is restored by the use of certain salts which act as positive catalysers. Authorities differ somewhat in their description of this material and it is probable that the treatment given to gypsum under this name is not always the same. According to E. C. Eckel[222] Keene's cement is made by calcining lump gypsum to a red heat; treated with a 10 per cent solution of alum; reburned to a dull red heat and then ground. Redgrave and Spachman[223] describe the process similarly stating also that borax may be used instead of alum. Strictly speaking, however, when borax is used the term Parian cement should be applied to the product.

American

R. W. Stone[224] says that it is reported that most of the producers of so-called Keene's cement in this country calcine lump gypsum in stationary kilns, grind it to a very fine powder, and add a small amount of powdered borax and other chemicals. The mixture is not recalcined and is marketed as American Keene's Cement. Mixtures of aluminum sulphate and sodium sulphate are doubtless employed to give the burned gypsum proper setting properties.

English

Keene's cement as originally made in England,[225] was produced by burning lump gypsum at a temperature only high enough to produce the hemi-hydrate ($2CaSO_4,H_2O$), soaking the lumps in a solution of alum, aluminum sulphate or borax, and recalcining at 500° C. (932° F.), after which the lumps were ground. Instead of lumps, ordinary finely ground calcined gypsum may be used. In this case the calcined gypsum is mixed with the alum solution and the hardened masses are broken up and burned on a vertical or a rotary kiln at temperatures from 900° to 1400° F.

A patent issued to John C. Best in 1919, and owned by Best

222Eckel, E. C., Cements, Lime and Plasters, 1st ed., p. 77, 1905.

223Redgrave, G. R., and Spachman, Calcareous Cements, 2d ed., p. 273, 1905.

224Stone, R. W., Gypsum Products, their Preparation and Uses: Technical paper 155, Bureau of Mines, p. 47.

225Encyclopedia Brittanica, 11th ed., Vol. 5, p. 658.

Brothers, Keene's Cement Company, Medicine Lodge, Kansas, covers the following methods:

"The market product known as the superfine grade of Keene's cement and generally used for the manufacture of artificial marble or scagliola has heretofore been produced in the following manner:

"A standard grade of Keene's cement is mixed with water, permitted to set, being at that time molded into blocks of suitable size. These blocks are then recalcined substantially as was the original gypsum. After this second calcination the blocks are crushed and ground to produce the superfine product.

"I have discovered that this same product may be more simply and cheaply prepared by initially burning the gypsum at a temperature higher than would ordinarily be employed for the production of a standard grade of Keene's cement. I prefer to carry out this burning or calcining operation in a rotary internally-fired kiln of the type used in the Portland cement industries, conducting the process so as to obtain a temperature of 1200° to 1400° F. of the burnt product issuing from the nose-ring of the kiln. The time of passage of the material through the kiln under these temperature conditions should be approximately one hour.

"As an accelerator, catalyst or setting agent for this material I employ a neutral salt, such as neutral potassium sulphate, in the proportion of 1 per cent by weight. The entire product should be ground to 150 mesh.

"This product prepared in this manner is very slow setting, has no effect upon colors, takes a very high polish, and is perfectly suited for the uses to which the superfine grade of Keene's cement is put, that is particularly for artificial marble or scagliola."

Rotary kilns

In a patent issued on March 8, 1921, to William Hoskens and by him consigned to Best Brothers, there are described[226] certain difficulties which developed in the use of a rotary kiln growing out of the presence of small quantities of lime carbonate in the gypsum. The product swelled in the mold, was deficient in tensile strength and density, and markedly porous. These difficulties, it is claimed, may be overcome by any one of three methods:

"1. By the addition to the burnt product of a quantity of

226Rock Products, Vol. XXIV, No. 9, pp. 36-37, April 23, 1921.

hydrate of lime, for example, 0.2 to 0.5 per cent, although any proportion greater than this may be used.

"2. By the use of a setting agent more strongly acid than the potash-alum which is commonly employed; for example, by the use of potash sulphate, containing 0.25 per cent free acid.

"3. By grinding the burnt product to an unusually fine state of subdivision, for example, 150 mesh.

"Based upon the foregoing, it is my conclusion that in the calcining of the gypsum in the manner described, the lime content thereof suffers a peculiar modification, which I assume to be surface calcination, perhaps accompanied by surface sintering, fluxing, or fusing, these results being explainable by reason of the very high flame temperature in the kiln and the opportunity which is necessarily given for overburning of the surfaces of the particles.

"It is my belief that by reason of this surface modification of the lime content of the burnt product, the acid constituent of the setting agent, as for example, potash-alum, reacts with the calcium compounds much more slowly than would normally be the case, so that the reaction is still incomplete and carbon-dioxide is still being liberated when the material has set so far as to prevent its escape. By virtue of this continuing reaction during the period of setting, the cement is therefore caused to puff and become porous. As before stated, this difficulty may be entirely overcome by speeding up the reaction of the acid constitutent of the setting agent with the lime content of the cement, which acceleration may be accomplished in any one of the three ways mentioned. The action being properly accelerated, the evolution of carbon dioxide ceases while the cement remains so nearly fluid as to permit the free escape of the liberated gas.

"By the process described I am therefore able to produce from gypsum a dehydrated product suitable for use in the production of Keene's cement by a rotary kiln calcining method, which is highly desirable from an economic standpoint and superior to the stationary kiln method heretofore required."

According to Von Waldegg[227] the solution commonly used in making Keene's cement (which is also known as marble cement, MacLean's cement, alum cement, and in France as Cement Anglais) consists of seventy-seven to eighty-three grams of potash alum to a liter of water. Hot water is generally used as the solubility of alum is greatly increased thereby.

227Der Gips, by Edmund Heisinger von Waldegg, p. 240, Leipsig, 1906.

In addition to its greater hardness Keene's cement is valued because it takes a high polish, and will to some extent withstand exposure to the elements.

Properties of Keene's cement

Parian cement is made like Keene's cement and differs only in the fact that a borax solution is used instead of alum. In making the solution ninety-one grams of borax are used for each liter of water.

Parian cement

Mack's cement consists of hydraulic gypsum to which 0.4 per cent of sodium sulphate (Na_2SO_4) or potassium sulphate (K_2SO_4) has been added. This cement is unusually hard and durable, sets quickly and bonds well with the background to which it is applied.

Mack's cement

CHAPTER XX.

RETARDERS AND ACCELERATORS

RETARDERS

A great many substances have been used to retard the set of calcined gypsum and of gypsum plasters. Any material that will temporarily interfere with the growth and interlocking of the gypsum crystals as they form from solution; or will take up temporarily part of the water and later release it; will act as a retarder.

Clay as retarder

The setting time of calcined gypsum is lengthened by the presence of clay. Colloidal clays in particular act as effective retarders. Gypsite plasters, which contain from 10 to 20 per cent of clay, require little in the way of additional retarder.

Organic matter

The ancients used dried blood to retard the set of calcined gypsum. Sugars and syrups in small quantities may be used in an emergency. Pulverized glue is an effective retarder. Two pounds of glue may be dissolved in forty gallons of water. Use this glue-water in proportions so that three ounces of glue are added to one hundred pounds of plaster, if an hour of additional setting time is desired. As an emergency retarder citric acid may be similarly used.

Standard retarders

Commercial retarders for gypsum plasters are manufactured by several companies. The ingredients used and the method of preparation are generally the same. The raw materials consist of cheap hair or leather scraps; caustic soda, and lime.

Amount of retarder used

The amount of standard retarder used in different kinds of gypsum plasters may vary from one to fifteen pounds per ton of plaster. Gypsite plasters require very little retarder other than the colloidal clay that is present in the raw mineral. Wood fiber plasters for use without sand require only three or four pounds of retarder; while plasters intended to be mixed with three parts of sharp sand, for use on brick or terra cotta, may require eight or ten pounds of retarder.

Plasters intended for mixing by machine are retarded heavier than other plasters, for it is difficult to keep the mixer clean, and additional retarder is required to overcome the accelerating effect of particles of set plaster.

Chemical action of all sorts is hastened by heat, and the set of calcined gypsum is hastened somewhat when the material and water are warm. On the other hand, the retarder dissolves more completely and its action is more effective when water and plaster are warm. In consequence less retarder may be used during the summer months. Some care is necessary during these months, for if the plaster is over retarded, in warm weather dry-outs will result, due to atmospheric absorption of the water in the plaster before crystallization has taken place.

Retarder and the seasons

Over retarded plasters may be treated with any of the accelerators described in later paragraphs in this chapter and brought to proper setting time. If they have been spread on the wall before their tendency to slow set is discovered, they will set up perfectly if kept moist with spray pump or brush. A weak solution of zinc sulphate,—three or four ounces to a pail of water,—applied with a spray or brush will remedy soft spots due to premature drying.

Treatment of over retarded plaster

The effect of retarders on the strength of plasters has been considered in chapter XV.

ACCELERATORS

Substances which will serve as nuclei about which crystallization may start will speed the set of gypsum plasters. Certain other substances also hasten crystallization directly.

Nature of accelerators

Raw gypsum is a powerful accelerator but it is not recommended for this purpose, for its effect in other ways is generally regarded as unsatisfactory. Calcined gypsum which has set up and after drying has been ground, is the form of accelerator usually furnished by gypsum producers. Eight or ten ounces of this material, to the 100 pound sack of plaster will speed the set about an hour. This accelerator should be dry mixed through the plaster and sand.

Raw gypsum as accelerator

Dried mortar

Three ounces of zinc sulphate dissolved in water will speed the set of a 100 pound bag of ordinary plaster about an hour.

Zinc sulphate Dissolve about two pounds of commercial zinc sulphate in an ordinary fifty gallon barrel of water, and mix this with the water used in gauging the plaster; the same solution applied with a spray pump or brush is useful in bringing back normal hardness to plaster that has dried out before setting.

Alum Alum may be used as an accelerator in the same manner recommended for zinc sulphate. Slightly more alum will be required to the bag of plaster to produce the same degree of acceleration.

Portland cement and lime A few pounds of Portland cement or hydrated lime may be added to each sack of plaster as an emergency accelerator.

Effect of accelerators in plaster Any of the accelerators that have been mentioned when used in the limited quantities required for the purpose of acceleration, will not injure the quality of the plaster. The accelerator manufactured by the plaster producers is the most convenient form for use, but it is not always to be found in the dealer's stock as calls for accelerator are not frequent.

CHAPTER XXI.

THE HARDENING AND COLORING OF GYPSUM AND CALCINED GYPSUM

Various methods have been used to raise the hardness of gypsum. Many of these methods are successful from a technical point of view and works of art made from gypsum have been given the hardness of marble. The impulse to efforts along this line has grown out of the fact that gypsum is relatively soft and in its natural state can be carved easily. Its crystalline structure is beautiful and in some localities the coloring and the banding of the mineral are very pleasing. After it has been given the form desired, it can be hardened so that it is as durable as marble. The hardening processes at the same time generally reduce the solubility of the gypsum. The processes generally involve partial or complete dehydration of the gypsum and its immersion in the hardening substance. United States patent 549,151 may be cited as an example.

Hardening gypsum

"This invention relates in part to processes for treating gypsum rock to impart to it a hardness and polish resembling marble; but my object is to produce a product not only superior to marble in hardness and fineness of surface, grain and luster, but resembling in colors and in general appearance the different varieties of chalcedony, such as onyx, agate, etc. To this end the crude gypsum rock is first shaped in any desired form and configuration by carving, sawing, planing, etc., and this is then freed from the water constituting one of its constitutent elements, next colored in accordance with the desired effect and then it is treated to the action of hardening chemical solutions, all as more particularly set forth below. Beautiful onyx, agate, etc., effects can be produced, in accordance with the tastes and desires, in statuary, furniture ornamentations, and the like, and in finishing of rooms, using the material in lieu of marble or woodwork. By my treatment the colors are made to appear as if a constitutent part or element of the rock in its native condition and formation, and the condition of the product, as stated, is superior in hardness and finish to either marble or chalcedony.

"To carry my process into effect, the gypsum rock from the mines, having been given the desired configuration, as stated, is submitted to the drying action of hot air for twelve hours (more or less) until all the moisture has been eliminated. The material is now calcium sulphate, porous from surface to center, and capable of absorbing sufficient chemical solution to produce the desired effect of the rock and colors. To the surface of the dehydrated rock is now applied the mineral colors—such as, for an illustration, solution of copper nitrate and aqua ammonium, or a solution of a sulphate of iron, nitric acid, and potassium sulpho-cyanide or other mineral colors. After coloring, the rock is immersed in a solution of aluminium sulphate ($Al_2(SO_4)_3$) for about fifteen hours or until the pores of the rock are completely filled. The material is then removed and exposed to the open air for a few hours at a low temperature and then polished."

Hardening calcined gypsum

Where just enough water is added to calcined gypsum, (most conveniently in the form of steam) to meet the demands for chemical combination, and the moist mass is submitted to hydrostatic pressure, the resulting mass is unusually hard and dense. In Germany forms so made are used in connection with the molding of roof tile and similar articles.[228]

Surface hardening

Where very hard waterproof surfaces are desired surfaces and objects made of calcined gypsum may be washed with linseed oil, paraffin, stearic acid, or combinations of these. The surfaces to be hardened are carefully dried and warmed and then immersed or otherwise covered for three or four minutes in melted paraffin or stearic acid. When paraffin is applied it should be heated to 60° C. (140° F.) while stearic acid should be heated to 85° C. (185° F.). The surface should then be rubbed with a soft brush or flannel.

Various substances may be mixed with calcined gypsum to give it greater hardness. For this purpose calcined borax (fifty parts of calcined gypsum to one of borax) was one of the first substances used.

Hardening by mixing chemicals

Oxides of magnesium, aluminum or zinc, mixed with a thin solution of phosphoric acid are said to impart to calcined gypsum great hardness and a porcelain-like polish.[229]

228Von Waldegg, Der Gips, p. 388.
229Von Waldegg, Der Gips, p. 364.

One hundred parts of calcined gypsum may be mixed with twenty parts of magnesite. Gypsum paste is made by adding water in the usual proportions and the objects made therefrom are soaked in a solution of zinc sulphate. Iron sulphate may be used instead if a golden brown color is desired.

The German texts (see bibliography) may be consulted for a great variety of formulae for hardening objects made from gypsum, as well as for processes by which gypsum surfaces may be rendered impervious to water. Von Waldegg in addition gives methods for coloring gypsum objects and for cleaning gypsum plaster surfaces.

Coloring wall plasters

Emley and Faxon have devised methods for coloring wall plasters by staining the wood fibre that is often used in them.[230] As stated by them "the process consists briefly of dyeing the fibre the desired color with analine dyes, mixing it with the other ingredients, applying the plaster to the wall in the usual way, and then, after the plaster has set, removing its surface in such a way as to expose the colored fibre." For a more detailed statement of methods of procedure, the reader is referred to the text of the government report.

230Bureau of Standards, Technologic Paper No. 181.

CHAPTER XXII.

STATISTICS

Gypsum mined in the United States in 1920 totaled 3,130,305 short tons. The highest previous record was in 1916, when the mine output reached 2,757,730 tons. The gain, therefore, over any previous year was considerable. Compared with 1919 the increase was more than 700,000 tons. All the more important producing states showed gains in output. Gains were general for all forms of gypsum products.

CRUDE GYPSUM MINED IN THE UNITED STATES (*a*)*

STATE	1918 Quantity Mined (Short Tons)	1919 Quantity Mined (Short Tons)	1920 Quantity Mined (Short Tons)	1921 Quantity Mined (Short Tons)
Iowa	327,927	421,279	571,895	350,247
Kansas	54,958	78,479	130,044	92,526
Michigan	286,768	339,125	382,212	408,224
New York	531,038	591,153	780,295	712,665
Ohio	199,456	251,259	277,899	363,905
Oklahoma	126,208	114,313	135,279	209,201
Texas	157,388	176,607	220,157	232,806
Wyoming	41,877	51,079	57,732	38,927
Nevada	(*c*)	91,756	143,929	178,275
Other States (b)	331,395	305,113	429,700	464,208
	2,057,015	2,420,163	3,129,142	3,050,984

(*a*) R. W. Stone, U. S. Geol. Surv. (*b*) Includes Arizona, California, Colorado, Montana, New Mexico, Oregon, South Dakota, Utah, Virginia. (*c*) Included with "Other States."

CRUDE GYPSUM MINED IN THE UNITED STATES (*a*)*

(Tons of 2000 lbs.)

1885	90,405	1897	288,982	1909	2,252,785
1886	95,250	1898	291,638	1910	2,379,057
1887	95,000	1899	486,235	1911	2,323,970
1888	110,000	1900	594,462	1912	2,500,757
1889	267,769	1901	633,791	1913	2,599,506
1890	182,995	1902	816,478	1914	2,476,465
1891	208,126	1903	1,041,704	1915	2,447,611
1892	256,259	1904	940,917	1916	2,756,630
1893	253,615	1905	1,043,202	1917	2,696,226
1894	239,312	1906	1,540,585	1918	2,057,015
1895	265,503	1907	1,751,748	1919	2,420,163
1896	224,254	1908	1,721,829	1920	3,129,142
				1921	3,050,984

(*a*) Statistics of the U. S. Geol. Surv.

TOTAL VALUE OF CRUDE AND CALCINED GYPSUM

1908	$4,075,824	1913	$6,774,822	1918	$11,470,854
1909	5,906,738	1914	6,895,989	1919	15,727,907
1910	6,523,029	1915	6,596,893	1920	24,542,512
1912	6,563,908	1917	11,116,452	1920	24,533,065
1911	6,462,035	1916	7,959,032	1921	23,700,290

*From Mineral Industry, Vol. 29, p. 340.

Named in the order of tonnage produced the leading states rank as follows: New York, Iowa, Michigan, Ohio, Texas, Virginia, Nevada, Oklahoma, Kansas. The same order will hold for values, with the possibility that Virginia and Texas might exchange places. Virginia's position is not set out by itself in the federal statistics in view of the fact that there are only two producers in the State. The output of each of these plants is considerably above that of the average, taking the gypsum mills of the country as a whole.

*Gypsum produced and sold in the United States, 1920 and 1921, by States.**

STATE	Number of plants reporting	Total quantity mined (short tons)	Sold without calcining				Sold calcined		Total value
			Agricultural gypsum		For Portland cement, paint, and other purposes				
			Quantity (short tons)	Value	Quantity (short tons)	Value	Quantity (short tons)	Value	
1920									
Iowa	6	571,895	41,404	$161,838	69,435	$252,593	321,400	$4,008,534	$4,422,965
Kansas	3	130,044	(*a*)	(*a*)	(*a*)	(*a*)	78,347	864,334	968,298
Michigan	6	382,212	12,092	54,050	61,750	214,918	261,499	3,252,060	3,521,028
Nevada	4	143,929	(*a*)	(*a*)	13,043	32,123	105,280	1,036,158	1,100,261
New York	8	780,295	15,510	67,862	255,567	919,641	387,856	5,451,426	6,438,929
Ohio	3	277,899	(*a*)	(*a*)	8,474	35,707	220,903	2,122,223	2,161,038
Oklahoma	4	135,279	(*a*)	(*a*)	(*a*)	(*a*)	69,924	772,749	816,768
Texas	5	220,157	(*a*)	(*a*)	16,900	47,961	164,956	1,391,382	1,439,491
Wyoming	4	57,732	(*a*)	(*a*)	(*a*)	(*a*)	43,384	410,599	410,724
Other States [b]	18	429,700	*c* 38,437	*c* 274,175	*c* 136,648	*c* 504,327	250,935	2,658,405	3,253,563
	61	3,129,142	107,443	557,925	561,817	2,007,270	1,904,484	21,967,870	24,533,065
1921									
Iowa	6	350,247	26,364	98,311	58,293	135,727	216,930	2,688,662	2,922,700
Kansas	3	92,526	(*a*)	(*a*)	28,566	89,792	50,663	574,601	665,164
Michigan	5	408,224	26,558	98,139	84,119	271,046	240,648	2,942,911	3,312,096
Nevada	4	178,275	(*a*)	(*a*)	15,558	45,477	132,837	1,471,960	1,533,037
New York	9	712,665	20,081	84,283	186,223	610,235	418,695	5,715,703	6,410,221
Ohio	3	363,905	2,645	13,493	4,344	15,179	263,879	3,163,265	3,191,937
Oklahoma	3	209,201	(*a*)	(*a*)	72,087	238,494	99,923	1,046,844	1,289,226
Texas	4	232,806	(*a*)	(*a*)	10,709	33,068	183,159	1,732,463	1,765,600
Wyoming	5	36,927	....	....	(*a*)	(*a*)	24,244	222,960	224,258
Other States[b]	20	464,208	*c*29,318	*c*196,676	*c*78,079	*c*336,091	165,873	1,874,910	2,386,051
	62	3,050,984	104,966	490,902	537,978	1,775,109	1,796,851	21,434,279	23,700,290

[a] Included under "Other States."
[b] Alaska, Arizona, California, Colorado, Montana, New Mexico, Oregon, South Dakota, Utah, and Virginia. Includes also a small quantity sold by warehouses and not elsewhere accounted for.
c This figure includes also output of States entered as "([a])" above.
*Cottrell, K. W., U. S. Geol. Survey, Mineral Resources of the U. S., 1921, pt. II, p. 90.

*Gypsum produced and sold in the United States, 1916–1921, by uses.**

Year	Sold without calcining											
	For Portland cement			As agricultural gypsum			For other purposes			Total		
	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton
1916	[a] 454,112	[a] $607,995	$1.34	81,879	$167,136	$2.04	[a] 11,128	[a] $15,299	$1.37	547,119	$790,430	$1.44
1917	[a] 526,881	[a] 867,123	1.65	84,366	230,808	2.74	[a] 12,748	[a] 26,439	2.07	623,995	1,124,370	1.80
1918	[a] 403,635	[a] 974,283	2.41	64,571	255,716	3.96	[a] 1,986	[a] 6,553	3.30	470,192	1,236,552	2.63
1919	[a] 470,267	[a] 1,332,637	2.83	39,978	185,566	4.64	([a])	([a])	....	510,245	1,518,203	2.98
1920	541,901	1,941,057	3.58	107,443	557,925	5.19	19,916	66,213	3.32	669,260	2,565,195	3.83
1921	[a] 537,978	[a] 1,775,109	3.30	104,966	490,902	4.67	([a])	([a])	....	642,944	2,266,011	3.52

Year	Sold calcined														
	As plaster of Paris, wall plaster, Keenes cement, etc.			For dental plaster			To glass factories			As boards, tile, and blocks, and for other purposes			Total		
	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton	Quantity (short tons)	Value	Average price per ton
1916	1,677,081	$6,884,960	$4.11	661	$8,766	$13.26	11,537	$28,839	$2.50	116,535	$246,037	$2.11	1,805,814	$7,168,602	$3.97
1917	1,531,535	8,873,176	5.79	991	7,672	7.74	13,808	72,558	5.25	131,056	1,038,676	7.93	1,677,390	9,992,082	5.96
1918	1,174,359	8,483,633	7.22	([b])	([b])	....	13,567	84,928	6.26	[b] 140,343	[b] 1,665,741	11.88	1,328,269	10,234,302	7.70
1919	1,393,141	11,809,624	8.48	([b])	([b])	....	14,677	96,561	6.58	[b] 188,202	[b] 2,303,519	12.24	1,596,020	14,209,704	8.90
1920	1,578,360	15,723,372	9.96	1,731	27,440	15.85	15,637	125,441	8.02	308,756	6,091,617	19.73	1,904,484	21,967,870	11.53
1921	[c] 1,603,844	15,870,289	9.89	([c])	([c])	....	([c])	([c])	....	193,077	5,563,990	28.82	1,796,851	21,434,279	11.93

[a] A small quantity of paint material and of gypsum sold for other purposes included with gypsum sold for Portland cement.
[b] Some dental plaster included with boards, tile, etc.
[c] Dental plaster and plaster sold to glass factories included with plaster of Paris, etc.
* U. S. Geol. Survey, Mineral Resources of the United States.

PRODUCTION OF GYPSUM IN IOWA

	Short Tons	Value
1889	21,789	$ 55,250
1890	20,900	47,350
1891	31,385	58,095
1892	12,000	28,500
1893	21,447	55,538
1894	17,906	44,700
1895	25,700	36,600
1896	18,631	34,020
1897	29,430	64,900
1898	24,733	45,819
1899	75,574	296,220
1900	184,600	561,588
1901	125,000	562,500

PRODUCTION OF GYPSUM IN IOWA—Continued

Year	Crude Gypsum Mined	Sold Crude				Sold Calcined				Total Sold		No. Producers Reporting	Year
		To cement mills etc.		As land plaster		As Hard Wall Plaster		As Plaster of Paris, Stucco, Boards, etc.					
	Tons	Tons	Value	Tons	Value	Tons	Value	Tons	Value	Tons	Value		
1902	143,632	600	$ 900	2,000	$ 3,000	100,314	$ 290,242	17,865	$ 43,593	120,779	$ 337,735		1902
1903	166,713	703	1,534	2,098	9,227	87,397	411,503	30,306	100,744	120,504	523,008	8	1903
1904	145,359	2,013	4,223	933	1,816	94,811	399,281	19,540	64,112	117,297	469,432		1904
1905	179,016	4,867	9,357	2,723	2,723	119,252	558,992	4,566	17,983	131,408	589,055	6	1905
1906	286,857	9,862	15,414	3,751	6,922	146,526	551,162	Included in Hard wall plaster		160,139	573,498	8	1906
1907	251,874	17,272	24,837	1,562	4,278	153,965	656,268	9,000	45,000	181,799	730,383	7	1907
								Plaster Paris incl. in wall plaster					
1908	240,270	19,816	27,061	1,128	2,087	158,043	535,540	Plaster Paris incl. in wall plaster		179,987	564,688	7	1908
1909	319,577	18,452	11,466	9,676	14,633	188,389	629,503	Plaster Paris incl. in wall plaster			655,602	6	1909
1910	322,713	31,532	38,683	6,159	8,312	202,131	816,989	28,801	79,865	267,623	943,849	6	1910
1911	354,204	11,032	14,465	incl. under cement mills		195,274	777,095	34,616	80,192	240,922	871,752	6	1911
1912	411,186	42,443	40,824	incl. under cement mills		223,756	708,198	49,360	96,606	315,559	845,628	6	1912
1913	456,031	43,300	35,285	8,757	10,266	252,719	942,198	80,636	170,190	385,414	1,157,939	5	1913
1914	480,404	52,934	45,566	12,251	14,920	265,619	1,109,570	69,446	151,401	400,250	1,321,457	5	1914
1915	495,860	59,823	48,508	12,086	11,422	256,063	1,057,546	78,994	160,652	406,966	1,278,128	5	1915
1916	522,293	47,923	40,869	12,923	18,428	373,416	1,437,498	Included in Wall plaster		434,262	1,496,795	5	1916
1917	461,864	50,818	80,488	14,194	30,253	323,987	1,700,691	Included in Wall plaster		388,999	1,811,432	5	1917
1918	327,927	47,173	122,325	10,546	37,823	159,322	1,225,924	58,846	560,342	275,897	1,946,414	5	1918
1919	421,279	66,619	222,672	2,405	8,760	208,829	1,754,815	55,827	651,197	333,680	2,634,444	6	1919
1920	571,895	69,435	252,593	41,404	161,838	219,107	2,328,744	102,293	1,679,790	432,239	4,422,965	6	1920
1921	350,247	58,293	135,727	26,364	98,311	133,717	1,346,452	83,213	1,342,210	301,587	2,922,700	7	1921

PRODUCTION OF CRUDE GYPSUM IN THE PRINCIPAL COUNTRIES (a)*

(In metric tons)

Year	Algeria (b)	Canada (g)	France (b)	Germany (c) Baden	Germany (c) Bavaria	Greece	India	United Kingdom	United States
1903	41,550	285,242	1,998,804	29,423	30,894	94	(d)	223,426	945,286
1904	48,375	309,133	1,957,802	26,984	22,766	393	3,937	237,749	853,546
1905	34,743	395,341	1,378,145	28,823	46,247	185	4,877	259,596	982,625
1906	27,950	378,904	1,377,429	25,643	50,763	70	(e) 5,000	228,627	1,397,480
1907	26,400	431,286	1,316,567	29,153	48,975	70	(e) 5,000	239,285	1,564,061
1908	25,500	346,436	1,750,562	35,217	51,314	Nil.	(e) 5,000	231,980	1,694,155
1909	36,250	398,290	1,655,672	36,621	51,630	191	17,588	242,832	f) 2,042,286
1910	60,625	481,941	1,980,804	41,078	54,397	249	13,759	259,648	f) 2,158,756
1911	61,502	470,381	2,110,520	42,408	60,390	1,263	11,115	281,111	f) 2,112,770
1912	54,414	524,892	2,150,900	51,777	57,114	127	21,383	247,724	f) 2,269,296
1913	50,413	577,442	1,726,379	49,767	....	2,245	25,362	242,341	f) 2,357,752
1914	....	463,375	....	....	32,993	639	22,639	269,637	f) 2,247,246
1915	....	430,752	....	....	28,459	1,648	22,926	251,209	f) 2,220,458
1916	....	311,092	....	....	26,124	356	16,826	222,814	f) 2,500,815
1917	....	305,120	....	....	21,035	44	16,952	175,800	f) 2,446,016
1918	....	138,155	....	....	23,330	....	17,016	181,612	f) 1,865,622
1919	....	278,454	....	....	33,692	....	28,774	223,545	f) 2,223,547
1920	....	398,501	....	....	....	....	33,551	291,598	f) 2,838,758
1921	....	324,122	....	....	....	....	30,672	....	f) 2,768,588

(a) From official reports of the respective countries, except the statistics for the United States. (b) A part of the product is reported as plaster of Paris. In converting this into crude gypsum it has been assumed that the loss by calcination is 20 per cent. (c) Prussia is a large producer of gypsum, but there are no complete statistics available. The output in 1910 was 22,042 tons. (d) Statistics not available. (e) Estimated. (f) U. S. Geol. Surv. (g) Tonnage shipped.

* Mineral Industry, Vol. 29, p. 346.

APPENDIX I.

RESULTS OF TESTING GYPSUM PRODUCTS[231]

BY W. E. EMLEY AND C. F. FAXON[232]

In an effort to write standard specifications for gypsum, many difficulties have been encountered. Probably the greatest source of confusion was the attempt to adopt verbatim the standard methods of test which were in use in the examination of other similar materials. Experience showed the futility of this procedure, and finally compelled the invention of new methods of test, designed especially for gypsum. After considerable deliberation and experiment, a number of methods of test were finally agreed upon and adopted as tentative.[233]

It then developed that no one had had enough experience with these new methods to be able to predict what numerical results they would give. For example, take the tensile strength. This property of gypsum was pretty well known when measured by any one of several different methods. The method adopted, however, introduced certain innovations, so that no one could foretell just what tensile strength a given sample of material would have when tested by this new method.

Obviously some information about these numerical results was essential, in order that specifications could be intelligently written. It would be absurd to specify a tensile strength of 300 pounds per square inch, and then discover that either all or none of the gypsum on the market met the requirement.

Accordingly the Bureau of Standards undertook to test a number of commercial samples. This article is a compilation of the results obtained. The tests were carried out on 43 samples, made by three different manufacturers. Of these, 25 were shipped to us direct from the factory, packed in air-tight glass containers; 8 came direct from the factory, in the usual commercial package; and 10 were obtained from dealers.

While an attempt was made to follow the methods of test

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[231]Reprinted from the Journal of the American Ceramic Society, Vol. 3, No. 12, December, 1920.

[232]Published by permission of the Bureau of Standards.

[233]American Society for Testing Materials, C-26-19T.

cited above, certain changes and additions were found advisable and were accordingly made. A brief description of the methods is as follows:

1. *Chemical Analysis.*—Lime, sulphuric anhydride, carbon dioxide, and loss on ignition, were determined by the usual methods of chemical analysis.[234] These constitutents were then combined as follows: The amount of lime required to combine with the carbon dioxide was found by multiplying the per cent carbon dioxide by 56/44. The per cent lime present as carbonate was deducted from the total per cent lime. The per cent water was found by subtracting the per cent carbon dioxide from the per cent loss on ignition. From the figures for lime, sulphuric anhydride, and water, the maximum possible content of calcined gypsum ($CaSO_4.\frac{1}{2}H_2O$) was calculated, using the ratios 56:80:9. Usually two, and always one of these three ingredients was found to be in excess of these ratios. This was taken to indicate the presence of some foreign material, such as calcium hydroxide, magnesium sulphate, anhydrous calcium sulphate, etc.

2. *Normal Consistency.*—This is the number of cubic centimeters of water which must be added to 100 grams of dry material to produce a paste of standard "wetness." It was determined by means of the Southard viscosimeter,[235] the standard wetness being such that the final radius of the pat was 9.6 cms.

3. *Time of Set.*—This is measured by means of a Vicat needle, on material of normal consistency. It is the elapsed time from when the sample is added to the water to when the needle fails to penetrate to the bottom of the pat.

4. *Fineness.*—This is expressed as the per cent by weight of the material separated by six sieves of different meshes. The sieves used were the Nos. 8, 14, 28, 48, 100 and 200. In general, the material could be screened dry through Nos. 8 and 14, but had to be washed with kerosene in order to get clean separations on the finer sieves.

5. *Compressive Strength.*—Three cylinders, 2 inches in diameter by 4 inches high, were made of paste of normal con-

[234]Hillebrand, Analysis of Silicate and Carbonate Rocks: U. S. Geol. Survey Bull. 700.
[235]A. S. T. M., C26-19T.

sistency. They were removed from the molds as soon as they were hard enough to handle (1 to 24 hours), stored in the air in the room for one week, and tested. The results are expressed as pounds per square inch.

TABLE I

Lab. No.	Trade name of material	Class
1	Unretarded gauging plaster	Calcined gypsum only
2	Molding plaster	
10	Unretarded gauging plaster	
11	Molding plaster	
19	Unretarded gauging plaster	
20	Molding plaster	
26	Stucco	
28	Molding plaster	
29	Reground stucco	
31	Stucco	
32	Stucco	
34	Plaster of Paris F	
35	Plaster of Paris FFF	
37	Windsor cement FFF	
43	Potters plaster	
Ave.		
3	Retarded gauging plaster	Calcined gypsum plus retarder
4	Cement plaster, unsanded, not fibered	
12	Retarded gauging plaster	
13	Cement plaster, unsanded, not fibered	
21	Retarded gauging plaster	
22	Cement plaster, unsanded, not fibered	
38	Ready finish	
41	Superfine Windsor cement	
Ave.		
5	Cement plaster, unsanded, fibered	Calcined gypsum plus retarder plus fiber
16	Retarded fibered cement plaster	
23	Fibered cement plaster	
27	Fibered plaster	
33	Fibered plaster	
36	Windsor cement, neat	
Ave.		
6	Wood fiber plaster to be used with sand	Calcined gypsum plus retarder plus wood fiber
7	Wood fiber plaster	
14	Wood fiber plaster to be used with sand	
15	Retarded wood fiber plaster	
24	Wood fiber plaster to be used with sand	
25	Wood fiber cement	
30	Wood fiber plaster	
39	Windsor cement for concrete	
42	Wood fiber plaster	
Ave.		
9	Ready mixed brown coat	Calcined gypsum plus retarder plus sand
18	Ready mixed brown coat	
Ave.		
8	Ready mixed scratch coat	Calcined gypsum plus retarder plus fiber plus sand
17	Ready mixed scratch coat	
40	Brown mortar	
Ave.		

TABLE 2

	Chemical analysis					
	Found				Calculated	
Lab. No.	CaO	CO_2	SO_3	Loss on ignition	Calcined gypsum	Constituents in excess
1	37.60	4.21	48.73	10.40	83.50	$SO_3.H_2O$
2	37.20	4.22	49.00	10.70	82.40	$SO_3.H_2O$
10	34.80	12.53	36.80	16.20	48.77	$SO_3.H_2O$
11	35.28	11.00	38.55	16.40	55.10	$SO_3.H_2O$
19	38.12	0.56	53.50	8.00	97.02	$CaO.H_2O$
20	38.24	.74	53.64	8.00	86.60	$SO_3.H_2O$
26	38.20	.10	54.00	7.60	97.88	$CaO.H_2O$
29	35.80	2.40	47.80	9.20	84.83	$SO_3.H_2O$
31	37.44	0.60	51.90	7.90	94.07	$CaO.H_2O$
32	37.10	4.10	48.70	10.60	82.54	$SO_3.H_2O$
34	38.00	1.00	51.65	7.53	93.65	$CaO.H_2O$
35	38.26	0.62	53.70	6.91	97.10	$SO_3.H_2O$
37	38.13	.53	53.80	6.94	97.00	$SO_3.H_2O$
43	38.90	.70	53.60	7.55	97.15	$CaO.H_2O$
Ave.	37.41	2.89	49.98	9.44	87.02	
3	37.04	4.53	48.28	10.90	83.50	$SO_3.H_2O$
4	36.72	4.37	47.90	10.75	80.60	$SO_3.H_2O$
12	34.52	10.02	36.49	17.35	56.35	$SO_3.H_2O$
13	34.84	12.33	37.56	16.55	49.58	$SO_3.H_2O$
21	38.60	0.81	53.30	7.55	96.60	$CaO.H_2O$
22	38.28	.84	53.74	8.10	96.40	$SO_3.H_2O$
38	39.20	2.83	15.55	14.20	28.20	$CaO.H_2O$
41	35.72	15.20	35.90	20.05	42.38	$SO_3.H_2O$
Ave.	36.86	6.37	41.09	13.18	66.70	
5	36.96	4.73	47.83	11.15	80.20	$SO_3.H_2O$
16	35.00	12.16	37.90	17.15	50.56	$SO_3.H_2O$
23	36.88	0.68	52.30	7.35	93.30	$SO_3.H_2O$
27	38.24	.40	53.90	7.90	97.68	$SO_3.H_2O$
33	37.70	.10	53.40	7.80	96.79	$CaO.H_2O$
36	36.88	1.40	48.50	8.18	87.95	$CaO.H_2O$
Ave.	36.94	3.24	48.97	9.92	84.41	$CaO.H_2O$
6	36.92	4.36	48.52	10.70	81.20	$SO_3.H_2O$
7	37.00	4.41	48.59	10.50	81.25	$SO_3.H_2O$
14	34.96	12.64	37.32	17.35	48.86	$SO_3.H_2O$
15	35.12	11.90	38.10	17.40	51.70	$SO_3.H_2O$
24	38.20	0.74	53.64	7.90	96.47	$SO_3.H_2O$
25	38.08	.82	53.06	7.95	95.95	$SO_3.H_2O$
30	36.14	2.50	48.40	9.40	85.34	$SO_3.H_2O$
39	27.41	1.64	27.70	9.25	50.22	$CaO.H_2O$
42	35.40	1.31	46.40	8.60	84.10	$CaO.H_2O$
Ave.	35.47	4.48	44.64	11.01	75.01	$CaO.H_2O$
9	18.20	10.86	13.49	13.10	11.27	$SO_3.H_2O$
18	25.60	15.70	13.68	17.80	14.50	$SO_3.H_2O$
Ave.	21.90	13.28	13.58	15.45	12.88	
8	18.52	10.32	14.80	12.75	13.92	$SO_3.H_2O$
17	24.80	13.86	15.84	16.70	18.49	$SO_3.H_2O$
40	8.76	0.47	10.80	3.09	19.58	$CaO.H_2O$
Ave.	17.36	8.22	13.81	10.85	17.33	

TABLE 3

LAB. NO.	FINENESS On 8	8–14	14–28	28–48	48–100	100–200	THROUGH 200
1	....	0.1	0.1	0.9	3.9	15.4	79.6
2	....	......	.2	1.1	4.1	8.2	86.4
10	....	.1	.3	4.6	7.0	11.5	76.5
11	....	.1	.1	.3	0.7	6.8	92.0
19	....	.1	.3	3.0	24.0	26.7	45.9
20	....	......	.1	0.5	6.3	23.2	69.9
26	....	......	.3	4.0	15.6	29.7	50.4
28	....	......	.1	0.3	4.8	15.6	79.2
29	....	......	.7	3.8	8.5	20.3	66.7
31	....	......	.1	0.4	1.1	9.1	89.3
32	....	......	.2	1.3	3.1	8.2	87.2
34	0.3	0.7	2.5	8.8	16.4	11.1	60.2
35	....	......	......	0.2	9.3	13.4	77.1
37	....	......	......	.1	6.1	9.7	84.1
43	....	......	......	.3	4.9	13.2	81.6
Ave	0.0	0.1	0.3	2.0	7.7	14.5	75.1
3	....	......	0.2	0.9	3.1	10.7	85.1
4	....	......	.1	1.3	4.1	12.4	82.1
12	....	0.1	.3	4.1	8.9	8.8	77.8
13	....	......	.1	0.2	1.2	4.7	93.8
21	....	......	.2	2.5	18.0	28.7	50.6
22	....	......	.3	2.2	18.6	21.5	57.4
38	....	......	......	0.2	2.6	7.7	89.5
41	....	......	......	1.7	14.1	10.3	73.9
Ave	0.0	0.0	0.1	1.6	8.8	13.1	76.3
5	0.1	0.1	0.1	0.9	3.3	10.8	84.7
16	.1	.1	.1	.2	0.8	6.4	92.3
23	.1	.1	.2	1.7	14.8	21.9	61.2
27	....	......	.2	0.9	2.8	17.0	79.1
33	....	......	.3	1.5	4.8	28.7	64.7
36	0.1	0.4	2.3	13.5	16.8	9.6	57.4
Ave	.1	.1	0.5	3.1	7.2	15.9	73.2
6	0.5	0.4	0.5	1.7	3.8	9.7	83.4
7	.7	.3	.3	1.7	4.0	10.7	82.3
14	.4	.2	.4	4.0	8.9	11.0	75.1
15	.4	.2	.4	3.7	8.6	9.5	77.2
24	.8	.5	.6	2.7	17.5	19.3	58.6
25	.4	.1	.4	2.6	19.5	22.6	54.4
30	.1	.2	1.2	3.5	9.7	22.4	62.9
39	1.5	4.2	7.5	16.0	17.5	6.6	46.7
42	0.3	0.6	1.1	8.5	23.5	9.4	56.6
Ave	.6	.8	1.4	4.9	12.6	13.5	66.4
9	0.1	8.9	10.9	18.0	25.4	16.7	20.0
18	.8	21.2	21.6	10.8	11.4	3.8	30.4
Ave	.4	15.0	16.2	14.4	18.4	10.2	25.2
8	0.2	10.3	11.3	12.8	21.2	13.7	30.5
17	3.6	30.0	12.8	6.5	10.0	4.4	32.7
40	0.5	5.3	10.2	31.4	26.0	8.0	18.6
Ave	1.4	15.2	11.4	16.9	19.1	8.7	27.3

TABLE 4

Lab. No.	Compressive strength	Yield: Lbs. paste per cu. ft.	Yield: Lbs. dry material per cu. ft. paste	Yield: Lbs. set material per cu. ft.	Tensile strength	Normal consistency	Time of set
1	1460	106	64	76	254	66.1	21
2	1315	107	64	75	775	66.9	21
10	1700	113	77	88	333	46.6	12
11	1570	107	66	79	270	56.2	7
19	1105	101	58	68	244	73.2	11
20	1060	102	58	68	220	75.0	19
26	1550	113	74	82	413	53.0	14
28	1580	112	72	81	387	56.0	22
29	1956	114	77	89	357	48.0	16
31	1935	107	68	78	394	58.0	8
32	1875	110	72	83	444	51.8	12
34	2200	114	76	85	437	50.0	13
35	1630	111	69	79	280	60.2	9
37	2285	116	75	83	299	51.5	8:00
43	1720	92	57	78	270	61.0	9:00
Ave	1665	108	62	80	325	58.2	13:00
3	1295	107	65	77	273	64.3	53:00
4	925	105	63	74	236	66.0	11:56
12	1420	111	76	87	290	46.2	2:54
13	630	112	74	85	218	51.9	17:23
21	1280	103	62	73	272	65.4	1:58
22	1000	103	62	73	262	65.0	13:07
38	145	93	50	54	37	85.5	1:00
41	1400	120	83	87	129	44.6	5:37
Ave	1010	107	67	76	215	61.1	6:41
5	555	104	63	73	182	65.7	14:15
16	1100	110	73	80	254	51.2	25:24
23	1030	106	66	75	269	61.0	13:09
27	1730	107	69	81	379	55.5	6:34
33	1475	115	75	83	400	53.3	8:50
36	800	107	70	80	186	51.6	19:42
Ave	1115	108	69	79	278	56.4	14:39
6	835	103	62	73	222	65.4	18:35
7	670	103	62	74	195	66.3	6:17
14	785	108	73	86	223	47.1	11:26
15	885	109	75	87	259	45.7	6:20
24	960	99	61	73	228	63.0	10:30
25	910	101	60	71	232	67.4	12:24
30	1480	104	70	85	372	48.6	9:10
39	275	115	75	78	73	53.0	3:10
42	710	107	69	81	120	53.7	4:45
Ave	835	106	67	79	214	56.7	9:11
9	195	129	101	108	52	27.0	2:19
18	475	131	106	111	109	23.1	2:32
Ave	335	130	103	109	80	25.0	2:30
8	200	126	98	104	53	29.0	1:52
17	865	130	106	112	198	22.2	4:51
40	180	120	95	103	37	25.8	3:27
Ave	415	125	100	106	96	25.7	3:23

6. *Yield.*—The above cylinder molds were weighed empty, and immediately after filling. The cylinders were weighed just before they were tested. The amount of dry material in a given volume of paste was calculated from the figure for normal consistency. These data were used to calculate the weight per cubic foot of paste, the weight of dry material per cubic foot of paste, and the weight per cubic foot of set material.

7. *Tensile Strength.*—Three briquettes of the usual form

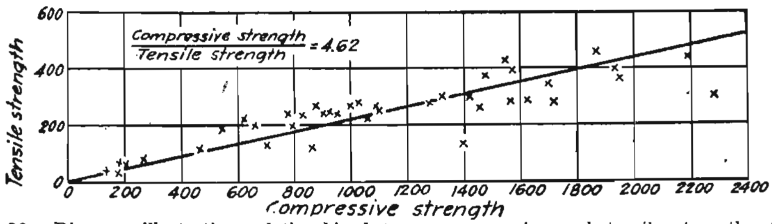


FIG. 86.—Diagram illustrating relationship between compressive and tensile strength of calcined gypsum.

were made of paste of normal consistency, stored in the same way as the compressive strength specimens, and tested when one week old. The results are expressed in pounds per square inch.

The results of all of these tests are given in the accompanying tables. Owing to the extremely confusing nomenclature, no attempt has been made to group the samples according to their

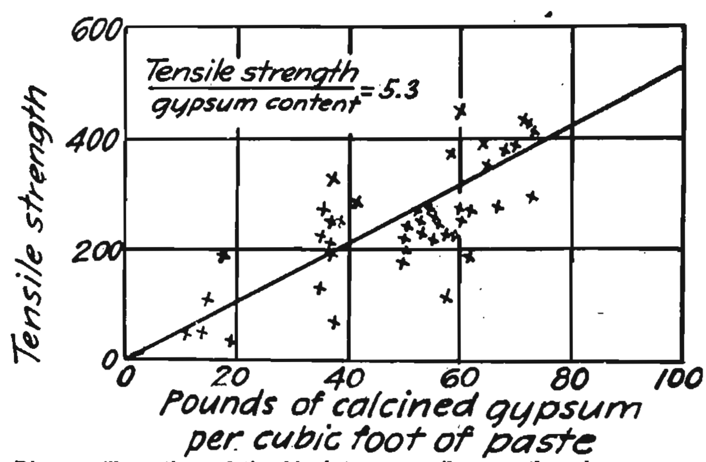


FIG 87. Diagram illustrating relationship between tensile strength and gypsum content.

trade names. They have been classified, instead, in accordance with their actual compositions.

Primarily, these data are intended to enable us to arrive at numerical values expressing the different properties of gypsum. These values are to be used in writing specifications for the material. Incidentally, the data may also be used in an attempt to correlate the various properties. Certain efforts along this line are indicated in figures 86 and 87, showing the relations between tensile strength and compressive strength, and tensile strength and gypsum content, respectively. Obviously the data permit and invite a great deal of this sort of calculation.

It seems that the present method of measuring time of set by means of the Vicat needle has been the subject of much criticism. To get more information on this point, the times

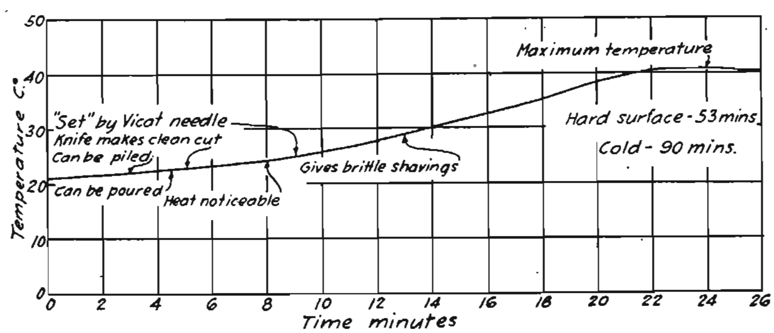


FIG. 88.—Diagram illustrating relationship between temperature and setting time of calcined gypsum.

of set of ten samples were measured by means of the temperature rise, and by direct observation. The results for one of these samples are given in figure 88. All of these results confirm those previously[236] obtained: that the temperature rise method is fundamentally unsound, and is misleading. The Vicat needle is endorsed. It gives results which are definite, which can be checked, and which indicate the time during which gypsum may be worked without injury.

The use of the Southard viscosimeter to measure normal consistency has also been criticized. The results obtained by means of this instrument are probably accurate within 1 per

236 Emley, Time of Set of Calcined Gypsum: Trans. Amer. Ceram. Soc., 19, p. 573, 1917.

cent, and can be readily checked by different observers. The machine is not portable, and its use is therefore confined to the laboratory. It was suggested that a cylinder mold two inches in diameter by four inches long could easily be carried in the pocket, and a "slump" test, using this mold, would measure consistency to a sufficient degree of accuracy. Accordingly, pastes of normal consistency (by the Southard viscosimeter) were made of 10 samples, and were tested by the slump method, using a two by four inch cylinder. It was found that the final diameter of the pat varied from 4¼ to 5½ inches for the different samples. It would seem, therefore, that the slump method is hardly accurate enough for a standard method, although it will probably give satisfaction when used for plant control.

We wish to acknowledge our obligations to Mr. H. A. Bright for the analytical work, and to Mr. L. A. Balser for assistance in making physical measurements.

BUREAU OF STANDARDS
WASHINGTON, D. C.

APPENDIX II

MICROSCOPIC EXAMINATION OF RAW OR CALCINED GYPSUM

BY DR. ESPER S. LARSEN[237]

Microscopic examination

13. The systematic microscopic examination of gypsum products offers no great difficulties to the specialist in petrography or microscopic mineralogy and any intelligent person could be taught certain routine tests that would apply to material whose constitutents are known and as few in number as are those in ordinary gypsum, just as a laboratory assistant can be taught to make simple chemical analyses. As in chemistry, such routine work should be controlled more or less by a trained microscopic mineralogist, as otherwise unexpected products or other difficulties may introduce serious errors in the results. The distinction under the microscope between substances depends on their optical and other crystallographic properties and accurate distinction requires skill if the substances have similar properties, and especially if they are in minute particles, or appear to have variable properties due to variable composition or submicroscopic inclusions. Ordinarily the microscope gives only qualitative results but rough quantitative estimates can usually be made very quickly, and for many determinations, as in the determination of anhydrite in gypsum, a fair quantitative estimate can be made. The greatest value of a microscopic examination is in checking the chemical analyses and in showing the state of combination of the radicals determined by chemical analyses.

Minerals in raw gypsum

14. The minerals most commonly found in raw gypsum are gypsum, quartz, anhydrite, calcite, and clay. In plaster of Paris calcined at about 170° C. the quartz and anhydrite remain unchanged as does the calcite for the most part, the clay loses some water and the gypsum changes to $CaSO_4.\frac{1}{2}H_2O$. If calcined at a higher temperature the gypsum changes

[237]Published by permission of the Director of the United States Geological Survey.

to insoluble anhydrite or soluble anhydrite and some lime and calcium hydroxide may be formed from the calcite and the clay may be dehydrated.

The more important properties that aid in determining the minerals follow:

Gypsum

15. Gypsum ($CaSO_4.2H_2O$) is found in grains or prismatic crystals. Artificial crystals and small natural crystals are commonly lathlike and elongated parallel to c and with the flat face (010). Gypsum can be scratched with the fingernail. It has a very perfect cleavage (010). The indices of refraction are $\alpha = 1.521$, $\beta = 1.523$ and $\gamma = 1.530$. The double refraction is 0.009. The optic character is positive and the axial angle is 58°. The mineral belongs to the monoclinic crystal system and the optic orientation is $Y = b$, $x - c = 37\frac{1}{2}°$. Hence grains or crystals lying on the cleavage face are parallel to the plane of the optic axis and show large extinction angles. The low hardness, very perfect cleavage, indices of refraction, rather low birefringence, and large extinction angles readily distinguish gypsum from all other compounds found in gypsum products.

Quartz

16. Quartz (SiO_2) is one of the common impurities in gypsum and occurs chiefly in grains. It is the only product common in gypsum that is harder than glass and its presence can be determined from the fact that if a powder containing quartz is rubbed between two fragments of glass it will be "gritty", and will scratch the glass. Quartz has no cleavage. It is uniaxial positive and has indices of refraction appreciably higher than those of gypsum and lower than those of anhydrite ($\omega = 1.544$, $\varepsilon = 1.533$). It is distinguished from the associated minerals by its hardness and lack of cleavage, its indices of refraction, and its uniaxial positive character.

Calcite

17. Calcite ($CaCO_3$) is common in raw gypsum and is in many cases present in minute crystals or grains scattered through the clay or the gypsum. Less commonly it is in large grains. It is harder than gypsum but can easily be scratched with a knife. It is characterized by very perfect cleavages ($10\bar{1}1$) which gives rhombic cleavage pieces. Microscopically it is characterized by its very strong birefringence ($\omega - \varepsilon = 0.172$) giving rise to a white of the higher order in-

terference color for grains of normal thickness and to bright colored specks for the minute crystals. The ω index of refraction, shown on every grain, is 1.658, while ε, shown only on grains lying parallel to the crystal axis c, is 1.486. Calcite can be distinguished from the associated minerals by its perfect cleavage, its high interference colors and the high value for the index of refraction.[238]

Anhydrite

18. Anhydrite ($CaSO_4$) is common in natural gypsum and is usually found in grains of considerable size. It has a hardness near that of calcite. It is orthorhombic in crystallization and has a very perfect cleavage parallel to (010), and less perfect parallel to (100); thus cleaving into rectangular parallelopipeds. Its indices of refraction are considerably higher than those of gypsum and quartz and $\alpha = 1.570$, $\beta = 1.576$, $\gamma = 1.614$. Its birefringence is 0.044, and it therefore gives bright interference colors. It is optically −, and 2V = 74°. The optic orientation is X = c, Y = b, Z = a, and all cleavage fragments give extinction parallel to the other cleavages. It is easily distinguished from the associated minerals by its cleavages, its indices of refraction, its bright interference colors, and its parallel extinction.

Clay

19. Clay is a term applied to a group of hydrous aluminum silicates of which kaolinite is the commonest. The clay minerals are either amorphous or occur in very fine grains collected into aggregates or scattered through gypsum. They nearly all have a cloudy or dirty appearance under the microscope. Their optical properties are variable and their study requires a skillful optical mineralogist. Kaolinite has indices of refraction $\alpha = 1.561$, $\beta = 1.563$, and $\gamma = 1.567$. The clay minerals can usually be distinguished by their finely crystalline character and cloudy appearance; such material is for the most part intimately mixed with quartz, calcite, and other minerals.

Products in plaster of Paris

20. Plaster of Paris is made up mostly of $CaSO_4.\frac{1}{2}H_2O$ with some soluble anhydrite, lime, calcium hydroxide, quartz, anhydrite, calcite, and clay.

[238] If calcite is imbedded in a liquid with an index of refraction of about 1.550, most grains when turned to extinction in one direction will show considerable relief (ω), but turned to the other extinction position will show little relief. Rare grains lying nearly parallel to the base will show lower interference colors and relief for all positions.

21. In ordinary plaster of Paris calcined at about 170° C. the gypsum grains have been dehydrated to $CaSO_4.\frac{1}{2}H_2O$ in an aggregate of very minute, fibrous crystallites which are intricately intergrown. These crystallites are in aggregates whose boundaries are those of the original gypsum crystals and the fibers tend to be orientated parallel to the crystallographic axis of the original gypsum. The mean index of refraction of the aggregate is about 1.54, which is a little higher than that of gypsum. The extinction is parallel and the elongation positive. The hemihydrate ($CaSO_4.\frac{1}{2}H_2O$) is characterized optically by its fibrous character, its parallel extinction, positive elongation, and mean index of refraction (1.54).

$CaSO_4\frac{1}{2}H_2O$

22. Soluble anhydrite ($CaSO_4$) forms by the dehydration of gypsum at a higher temperature than the hemihydrate. Like the hemihydrate it occurs in minute needles, intricately intergrown but its crystals show inclined extinction and have a mean index of refraction of 1.55. The double refraction is low, and the crystals give low order gray and white interference colors. Soluble anhydrite resembles the hemihydrate and insoluble anhydrite in its fibrous character but it has inclined extinction and a mean index of refraction of 1.55.

Soluble anhydrite

23. Insoluble anhydrite ($CaSO_4$) is found at temperatures between 200° to 500° C. It occurs as minute prisms, irregularly intergrown, thus resembling the hemihydrate and soluble anhydrite. Its optical properties are those of the mineral anhydrite with which it is probably identical. Just below the dissociation point the small needle crystallites reconsolidate, and the resulting crystal is comparatively large, agreeing with soluble anhydrite in all its optical properties. Insoluble anhydrite has a considerably higher mean index of refraction (1.587) than either $CaSO_4.\frac{1}{2}H_2O$ or soluble anhydrite.

Insoluble anhydrite

24. Lime (CaO) crystallizes in rounded, isotropic grains with a very high index of refraction (1.82) and is thus easily distinguished from all the other constituents.

Lime

25. Calcium hydroxide is probably amorphous and occurs in isotropic grains with an index of refraction of 1.58. Due to insufficient water during hydration, it may show a strained condition which manifests itself by very low

Calcium hydroxide

gray interference colors. Its index of refraction and isotropic character distinguish it and it is also recognized by White's calcium phenolate test.

Estimation of anhydrite

26. The quantitative estimation under the microscope of anhydrite in raw gypsum is especially important as the chemical analyses cannot be used to determine the amount of anhydrite, owing to the variable water content of natural gypsum and perhaps also of the clay minerals. The method recommended for this estimation will, therefore, be described in some detail and can be applied with slight modification for the estimation of other minerals.

Estimation by thin sections

27. The most accurate and probably the simplest method for determining anhydrite, or any other mineral that is in crystal grains of moderate size,—say over 0.1 mm. diameter—in a gypsum rock, is by grinding enough thin sections of the rock to represent a satisfactory sample and measuring the proportion of the mineral in the section by the Rosiwal method. Some of the objections to this method are:

Enough thin sections must be cut (from flat fragments about an inch square) to represent the material. This takes time and sections cost about 60 cents each.

Unless great care is exercised some of the harder minerals, such as quartz and anhydrite may tear out in grinding and lead to erroneous results.

Considerable skill is required to determine some of the mineral grains in the thin sections. The Rosiwal method is described in books on optical mineralogy.

Estimation of powder

28. A more practical method is to use a sample of the powder pulverized to about 100 to 200 mesh. The sample of the powder as charged to the kettles is satisfactory. The only equipment needed is a petrographic microscope, or even an ordinary microscope, a few object and cover glasses, and a liquid with an index of refraction of about 1.550.

Preparation of imbedding liquid

29. This liquid can be made by mixing by volume 77 parts of clove oil with 23 parts of cinnamic aldehyde. If kept in a carefully stoppered bottle this liquid will remain satisfactory for several years. Its index of refraction can be checked by immersing a little powdered quartz in

the liquid on a microscope slide and comparing the indices of refraction of the quartz and the liquid. To do this use a low power objective, shade one side of the field by sliding the finger or a card into the field below the substage condenser, or by tilting the mirror. The liquid has an index of refraction of about 1.550 if most of the quartz grains show a bright bluish white border on the shaded side of the field and a dark reddish gray border on the opposite side, while a few show rather dark blue on the shaded side and bright red on the opposite side. Its index is too high and more clove oil should be added if all the quartz grains show bright borders on the shaded side without much color. Its index is somewhat low and more cinnamic aldehyde should be added if most of the grains show a blue border on the shaded side and a red border on the bright side of the field. Its index is much too low if all the grains show dark borders on the shaded side of the field.

Estimation of anhydrite

30. To estimate the anhydrite, place a drop of the liquid (n equals 1.55) on an object glass, sprinkle from a knife blade a little of the sample in the drop of liquid and cover with a cover glass. Distribute the grains evenly by shifting the cover glass; place on the stage of the microscope fitted with a rather low power objective. The liquid should just fill the space between the two glasses, and the grains, as observed with the microscope should not be too close together. If they are packed closely together too much powder was used.

Shade one side of the field by sliding the finger or a card into the field beneath the substage condenser, or by tilting the mirror. All grains of gypsum will show a bright border on the shaded side of the field and a dark border on the bright side.[239] Quartz grains will show a faint bluish white to blue border on the shaded side. Clay will be in clouded aggregates which have dark grayish borders on the shaded side of the field and light grayish borders on the opposite side. Calcite grains can be distinguished by their strong birefringence, perfect cleavages, and by the fact that on revolving the stage of the microscope the grains nearly or quite disappear in some

239 With a strong condensing lens lowered below focus the borders will be reversed.

positions and stand out in marked relief in others. Most grains of anhydrite will show bright interference colors between crossed nicols and all will show a dark border toward the shaded side of the field and a bright border on the opposite side.

Each grain of anhydrite, and also of the other constituents can thus be quickly recognized and by counting grains and estimating sizes, remembering that a third dimension is normal to the microscope slide, an approximate determination of the proportion of anhydrite by volume can be made. To reduce to percentage by weight multiply by 1¼.

In practice it is usually true that the anhydrite grains are as large as the gypsum grains and there is no special tendency for the anhydrite to be either more or less abundant in the finer powder than in the coarse. This being true, the estimate is simplified from the fact that it is necessary only to consider the larger grains. To do this either ignore the fines in the microscope slide or, better, sift some of the sample in fine bolting cloth to get rid of the fines before mounting the sample. Sets of very small sieves can be purchased that are suitable for this purpose.

Accuracy of the method

31. The chief errors in the estimates are due to the difficulty in estimating sizes of grains, and the uncertainty in assuming that the proportion of anhydrite in the fines is the same as that in the coarser grains. Duplicate determinations should be made on different days by the same man checked to within ½ per cent for samples containing less than 5 per cent anhydrite and to within 1 per cent for samples with 10 per cent anhydrite. The actual accuracy of the determinations may be somewhat less.

Time required

32. In practice it is best to make measurements on several slides of the powder and to average the results. The time required to make a measurement is from a few minutes to an hour depending on the care taken and the number of slides examined.

More accurate modification

33. A more accurate estimate can be made by separating the anhydrite from a weighed amount of powder (1 to 10 g.) by a heavy solution weighing both the heavy and light portions of the powder and estimating the

anhydrite in both portions under the microscope as described in the preceding pages. If the separation has been carefully made the heavy portion should be made up chiefly of anhydrite. If any considerable amount of calcite is present it can be removed by hot dilute HCl. The light portion should contain very little anhydrite. Bromoform is about the most satisfactory heavy solution to use and if pure bromoform is found to be so heavy that anhydrite will not sink satisfactorily, its specific gravity can be reduced by adding a little carbon tetrachloride or benzol. On account of the large amount of fine material in the samples it is necessary to make a preliminary separation in a separatory funnel, drain off the heavy (settled) portion into another separatory funnel and to repeat the separation in both funnels by shaking the sample up in more liquid. Repeat the separation as many times as is necessary to get a clean separation. The use of heavy solutions in mineral separations is described in most text books on mineralogy and petrography.

This method should give more accurate results but it takes much more time.

APPENDIX III.

GERMAN METHODS OF TESTING GYPSUM

REGULATIONS FOR UNIFORM TESTING OF GYPSUM ADOPTED AT THE 13th ANNUAL MEETING OF THE GERMAN GYPSUM ASSOCIATION, (BERLIN NW. 21, DREYSESTRASSE 4) HELD FEBRUARY 15, 1911[240]

As a basis for the uniform testing of structural and stucco gypsum has been laid the determination of the following:

a) amount of "addition"
b) time of pouring
c) time of marking
d) fineness
e) tensile strength
f) bending strength

The amount of gypsum required for the above tests is from 4 to 5 kg., in accordance as the amount of gypsum used in making the pat is larger or smaller.

1. SCREENING

The gypsum to be tested is passed first through a sieve of 16 mesh per sq. cm., or 2mm. diameter of mesh, which causes the soft lumps, which often occur in gypsum, to break up, while the larger pieces of impurities are eliminated.

For this purpose it is most convenient to use a large sieve measuring 35x60x12 cm., as it allows not only the screening of the entire amount of the gypsum used for the test in one operation, but makes a thorough mixing of the material possible.

2. DETERMINATION OF THE AMOUNT OF "ADDITION"

By the "amount of addition" of gypsum is meant the amount of gypsum paste that can be poured.

For this determination is used a glass vessel of 60 mm. inside height, and 70 mm. inside diameter, which must be thoroughly dried for each test.

The weight of this glass is then carefully balanced off an

240Translated for Keystone Plaster Co., and presented by courtesy of H. L. Brown.

exact table scale, of 4 to 5 kg. capacity (shot is best used for this purpose); next 100 grams (cub. cm.) of pure water, 15° to 20° C., are poured in or weighed, in such manner that no drops should fall on the upper part of the surface of the vessel, as otherwise, when the gypsum is being added, it may stick to the wet places, which may lead to errors. It is therefore best to measure off or weigh the 100 grams. or cub. cm. of water in a separate glass.

The glass is now set on a paper washer. The time of starting the addition of the gypsum is carefully noted, and the gypsum is added by hand until it ceases to sink, that is until the water level disappears, and a thin dry layer of gypsum remains visible for a period of 3 to 5 seconds. The duration of addition should be of 1½ to 2 minutes. While gypsum is being added, neither the glass, nor the paste should be touched.

The glass vessel is now weighed with the water and gypsum, and, after the amount of the water added, viz. 100 grams, is subtracted, the amount of gypsum added is obtained, which is the *amount of addition.*

The gypsum paste obtained in the determination of the amount of addition, should not be used for further tests, i. e. for the determination of the pouring and marking time.

3. DETERMINATION OF THE TIME OF POURING

By "time of pouring" of gypsum is meant the period of time which elapses from the time of the addition of gypsum (see par. 2) to the instant when gypsum ceases to be fluid enough to pour. To determine the time of pouring a *new* paste is made in accordance with the data on the amount of addition determined in paragraph 2. For this purpose a rubber hemisphere is used 12 cm. in diameter, over which is laid a square zinc sheet (16x16 cm.) with a circular opening 10 cm. in diameter.

The beginning of the period of addition of gypsum is again carefully noted, and the amount of gypsum, previously weighed, is uniformly added by means of a spoon, in about 30 seconds. The gypsum which may have fallen on the zinc sheet is carefully swept off into the rubber half-ball. After the zinc sheet cover is taken off, the paste is carefully stirred with the spoon, which should result in the breaking up any lumps that might have formed. The paste is then poured out on a glass plate (15x15 cm.), and, by lightly shaking the latter, allowed to form into a cake 5 to 7 mm. thick and 10 to 12 cm. in diameter.

At intervals of ½ minute cuts through the gypsum paste are made with a pocket knife. The knife must be thoroughly cleaned after each cut both in this case and in the tests for marking. When the edges showing the path of the cut cease to flow together of themselves, the time of pouring is considered to be concluded. This instant is recorded.

4. DETERMINATION OF "MARKING TIME"

By "marking time" of gypsum is meant the period elapsing from the addition of gypsum to the water in making the paste to the instant when the gypsum loses the ability to be marked or finished. To determine the marking time, the cake made during the determination of the pouring time is used. As soon as it has been established by pressing the paste with the finger that the mass is near the "marking time", at intervals of 1 minute shavings about 2 mm. thick are cut off. When, with the knife blade moving fairly fast, the shaving comes off grainy and brittle, the marking time is considered to be over, and the instant is recorded.

5. DETERMINATION OF FINENESS

100 grams gypsum are weighed on a small lever scale and passed through a dry sieve having a surface of 600 by 350 mm. and 900 mesh per sq. cm., that is 0.22 mm. diameter of mesh, until no more gypsum dust can be seen on a piece of black glazed paper laid below. The residue remaining on the sieve is weighed. Since 100 grams were used, the weight of the residue gives the percentage direct. Finely ground gypsum leaves residue from 0 to 10 per cent. Moderately fine gypsum leaves a residue of 10 to 20 per cent. Coarsely ground material leaves a residue of 20 to 30 per cent.

6. DETERMINATION OF TENSILE STRENGTH

For the determination of tensile strength twelve test-pieces (5 sq. cm. crosssection of rupture) are cast. Groups of six pieces are tested, one after one day, and another after 28 days, for tensile strength on the machines generally used in testing cement.

Preparation of the test piece for the tensile strength test.— The gypsum paste required is prepared in accordance with the data on the amount of gypsum addition obtained in paragraph 2. The amount of paste required for six test-pieces is obtained by adding to 400 cub. cm. of water having a temperature of 15° to 20° C., a fourfold amount of addition, and thoroughly stirring the mixture until all the lumps are broken up. If, e. g., the amount of addition determined in paragraph 2 was 160 grams, then 4x160, or 640 grams are to be added to 400 cub. cm. of water.

This paste, *constantly stirred,* is rapidly poured into a mold covered by white vaseline or wiped with a cloth impregnated with oil, the paste overrunning each mold by about 5 mm.

In quick setting types, with a period of setting of 2 to 3 minutes, only three test-pieces can be cast at a time, a double amount of addition being used per 200 cub. cm. of water.

After the lapse of the "marking time", the overrunning part is carefully cut off by laying the knife specially used for this purpose flat on the mold, and removing the excess of material by a seesaw motion of the knife. The surface of the test-piece is smoothed over by stroking it with the knife, but without applying any pressure. After the setting of the gypsum (i. e., after about half an hour), the test-pieces are described so as to make their recognition later on possible, taken from the molds, weighed and placed on triangular strips in a closed dry room having a temperature of 60 to 70° F. (15 to 20° C.) until they are old enough to be tested.

The best thing to be used for this purpose is a drying stand. Care should be taken that on none of its sides does the stand approach the walls nearer than 20 to 30 cm., so that the test-pieces will be on all sides surrounded by air, and may dry uniformly.

In order to introduce a uniform notation, the following is proposed:

In the first instance each gypsum test receives a running number—No. 1, 2, 3, etc.

As all tests are made after one and twenty-eight days, the test pieces which are due for test after one day, are marked with A, and those due for test after twenty-eight days, with C, the notation B being reserved for the exceptional test-pieces tested after seven days. If pieces are to be tested after eighty-four days and more, they are to be marked with letters D, etc. For denoting individual test-pieces, a number is added to the letter, so that the six pieces due for tests after one day, will be marked as A_1, A_2, A_3, A_4, A_5, and A_6. If the running number of the gypsums tested is 70, then the complete notation of the test-pieces will be as follows:

1 Day	7 Days	28 Days	84 Days
$70A_1$	$70B_1$	$70C_1$	$70D_1$
$70A_2$	$70B_2$	$70C_2$	$70D_2$
$70A_3$	$70B_3$	$70C_3$	$70D_3$
$70A_4$	$70B_4$	$70C_4$	$70D_4$
$70A_5$	$70B_5$	$70C_5$	$70D_5$
$70A_6$	$70B_6$	$70C_6$	$70D_6$

This notation permits also one to recognize at once each test piece. For example, $35C_5$ will indicate that it is a test-piece No. 5 for gypsum No. 35, due for test in 28 days. By placing a fraction in front of the mark, the days of preparation of the test piece can be indicated. Thus, 7/4 70 A_1 shows that the test-piece was made on April 7 from gypsum No. 70, and shall be the first piece to be tested after one day.

7. DETERMINATION OF BENDING STRENGTH.

For the bending test twelve prisms, 16 cm. edge, and a square crosssection 4 by 4 cm., are prepared in a manner exactly similar to that of making the test-pieces for the tensile tests. Sets of six prisms each are tested, one after one day, and one after twenty-eight days. The test pieces are made in an iron mold divided into six parts, which can be easily taken apart, and is held by a single bolt. To make six test-pieces for the bending test, an elevenfold "amount of addition" is put into 1100 cub. cm. of water of 60 to 70° F. (15 to 20 deg. cent.). If, e.g., the "amount of addition" was found to be 150 grams, then 11 times 150, or 1650 grams are added to 1100 cub. cm. of water. The method of pouring is the same as that described in paragraph 6, but for finishing and smoothing the mold there is used a larger knife, 340 by 50 mm.

The test-pieces for the bending tests are marked also in the manner stated in paragraph 6, and placed on the same triangular strip drying stand.

For bending tests the Michaelis device is used (that is, the usual tensile test apparatus) which, instead of the usual grips, has on top a bow shaped piece with two edges 10 cm. apart, and below a little frame with a peg. The prisms are placed horizontally in the bow between the guides of the frame, and the iron peg of the lower frame is then set in. The bending tests are to be carried on in such a manner that the side of the prisms which was on top when it was made, that is, the side smoothed off, be on top in the bow. The weight of the cup and shot, multiplied by 11.7, gives the bending strength per sq. cm. Both in the tensile and bending tests the mathematical average of the six figures obtained in the series of six tests is taken (denoted by M, average, in German, *Mittel*).

In a letter from the Bureau of Standards the German method of testing gypsum for time of set is summed up as follows:

The German method of testing gypsum for time of set may be quoted from their specifications as follows:

First—It is necessary to determine the amount of addition, which corresponds to our normal consistency. This is done by placing in a glass vessel 100 cc. of water. The vessel recommended is 70 mm. inside diameter and 60 mm. high and should, of course, be thoroughly cleaned and weighed before each test. To this water gypsum is added by hand until it ceases to sink, that is, until the water level disappears and a thin dry layer of gypsum remains visible for a period of 3 to 5 seconds. All of the gypsum necessary should be added in about 1½ to 2 minutes. During the addition neither the glass nor the paste should be touched, jarred, or stirred in any way. The glass containing the paste is now weighed and the amount of dry material which has been added is calculated and reported. To determine the "time of pouring," corresponding perhaps, to initial set, it is necessary to make up a new paste using the proportions of gypsum and water as just determined. This paste is made up in a rubber hemisphere 12 centimeters in diameter, over which is laid a square zinc sheet 16 centimeters square with a circular opening 10 centimeters in diameter. The amount of gypsum, previously weighed, is added by means of a spoon in about 30 seconds. The gypsum which may have fallen on the zinc sheet is carefully swept off into the rubber half ball. After the sheet cover is taken off the paste is carefully stirred with the spoon to break up any lumps that might have formed. The paste is then poured out on a glass plate 15 centimeters square and by lightly shaking this the paste is allowed to form into a cake, 5 to 7 mm. thick and 10 to 12 centimeters in diameter. At intervals of ½ minute cuts through the paste are made with a pocket knife which must be thoroughly cleaned after each test. When the edges showing the path of the cut cease to flow together of themselves the time of pouring is considered to be concluded. Of course the first time reading is taken at the instant when the gypsum is added to the water. As soon as it has been established by pressing this cake of paste with the finger, that the mass is getting hard, at intervals of one minute, shavings about 2 mm. thick are cut off. When, with the knife blade moving fairly fast, the shavings come off grainy and brittle, the "marking time" is considered to be over.

APPENDIX IV

MEASUREMENT OF THE TIME OF SET OF CALCINED GYPSUM

BY WARREN E. EMLEY[241]

The time of set of calcined gypsum, or of a prepared wall plaster made therefrom is one of its most important properties. Pure $CaSO_4 \cdot \frac{1}{2} H_2O$ sets very rapidly. Commercially, however, the time of set is subject to variation, due to impurities in the gypsum, to the temperature of calcination or to the addition of retarder. Under these circumstances, it is impossible to use the time of set as a criterion by which to judge the purity or proper calcination of the material. The time of set of calcined gypsum is far more important: it is frequently the determining factor which governs the suitability of a given plaster for a given purpose. For example, a plaster should not begin to set too soon or its application would be a difficult matter; but having been applied, it should then set as rapidly as possible, in order not to delay the work. Obviously, any specification for calcined gypsum or wall plaster should cover the time of set. The writing of such specifications has been undertaken by Committee C-11 A. S. T. M., and as a necessary preliminary thereto, a standard method for measuring the time of set must be developed.

The time of set of any plaster is customarily divided into two periods, which may logically be differentiated as follows. For some time after the plaster has been mixed with water, it may be worked with impunity. Eventually, at the point of "initial set" it begins to harden. After this, any further working will destroy whatever bond has been formed, thus impairing the value of the finished product. Finally, the material will have undergone sufficient hardening so that it can no longer be worked, and is then said to have taken its "final set". With most plasters neither of these points is very sharply defined, so that it is deemed expedient to adopt some arbitrary means of determining them. For example, it would be

[241]Republished from Transactions American Ceramic Society, Vol. XIX, 1917.

very difficult to decide just when a sample of Portland cement had set sufficiently so that it could no longer be worked. We can, however, determine when a needle of given dimensions will not penetrate it, and arbitrarily state that this shall be called the time of final set. To be acceptable, any such empirical designation must fulfill three requirements: (1) It must conform pretty closely to what is generally conceded to be the time of set of the material from both a scientific and a practical viewpoint. (2) It should be simple, so that the test will not be too costly. (3) It must be universally adopted.

The mechanics of the setting of calcined gypsum is so well known that it needs no explanation here. One point, should, however, be called to your attention: the tremendous effect of small amounts of foreign material in the water and sand. If a contractor in a certain locality desires a plaster which will set on the wall in from four to six hours, the manufacturer may give him a calcined gypsum which when mixed neat with distilled water will set in forty minutes. The manufacturer must thus be familiar with the qualities of sand and water in his markets and allow for them. Obviously, such anomalous conditions are not conducive to free intercourse, because if the above contractor asked a manufacturer who was unacquainted with local conditions for a gypsum plaster which would set in four hours, the material received would probably not fulfill his requirements.

Many methods of measuring the time of set of calcined gypsum have been suggested, and most of them are in use, with the result that it is difficult to find any two people who agree as to the time of set of a given sample. Recently a sample of plaster was thoroughly mixed and divided into five parts, which were sent to five different manufacturers. Each one determined the time of set by the method he is accustomed to use. The results varied from 16 minutes to 93 minutes. It is for the purpose of learning, if possible, which of the methods is best adapted to this material, that the present work was undertaken.

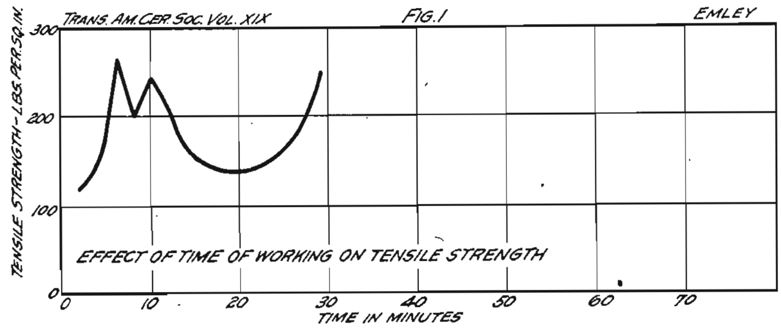
The methods in use may be grouped as follows: A—Methods based upon the measurement of the actual strength or hardness of the material at different time intervals. B—Methods based upon the measurement of some concurrent phenomenon such as the rise of temperature, or the expansion. C—Rule of thumb methods, which were originally devised for plant control, but have frequently found their way into specifications.

For the experimental work, a large sample of pottery plaster was mixed and stored in an airtight container until used. It was extremely lean and slow setting, and therefore very well adapted to the work. The experiments reported in a paper by Kerr[242] called attention to the necessity of using the same consistency throughout, if the results are to be at all comparable. Since the same quality of plaster was used for all experiments, uniform consistency could be obtained by keeping the proportions of water and plaster constant. It was decided to use a rather thin consistency so that small errors in weighing the materials would have no effect. The following procedure was maintained constant for all experiments: In a perfectly clean porcelain casserole, put 65 cc. of distilled water. At a definite noted time, which shall be designated hereafter as zero time, 100 grams of plaster was added to the water as quickly as possible. This was permitted to soak for one minute. Thus the sample was ready for use exactly two minutes after zero time. Extreme care was taken to see that all traces of set plasters were removed from the casserole and stirring rod after each experiment. The molds were cleaned thoroughly and then dipped in melted paraffine just before using. A stirring rod is to be preferred to a spatula or trowel for many reasons: its use precludes the possibility of chemical or electrical action; it is more easily kept clean; the plaster and water can be stirred into a homogeneous mass without the "working" effect which is necessarily attendant upon the use of a larger blade.

Under Group A, the first method to be examined is the strength measurement. This method is the only one which can be regarded as absolute rather than empirical. If a point of time can be found such that any further working of the sample beyond that point will cause a diminution of strength, that point is by definition the time of initial set. Unfortunately, the method is far too laborious, and the results too indefinite for general use, so that it is of value only for judging which

242Trans. Am. Cer. Soc. XVIII, 1916.

of the empirical methods comes nearest to the truth. The experiment was conducted as follows: A sample of plaster and water, mixed as above described, was permitted to stand



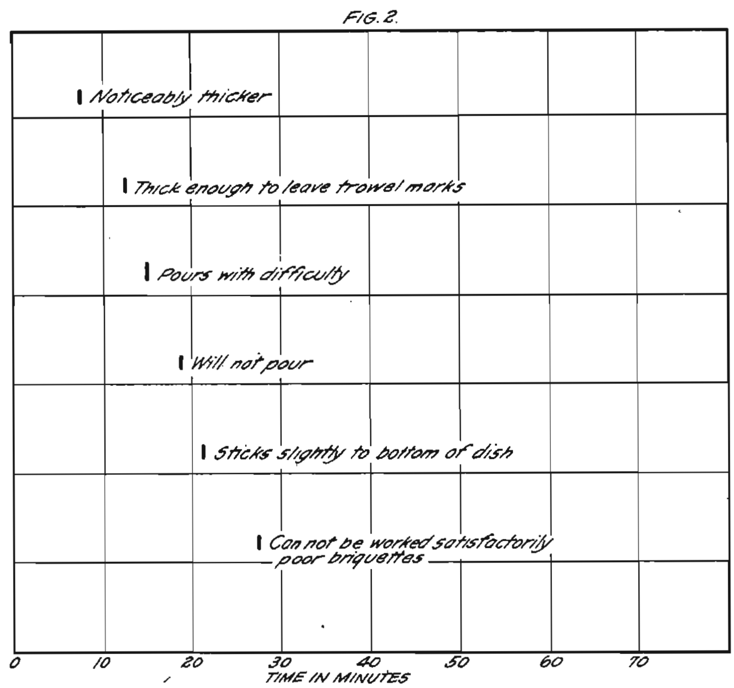
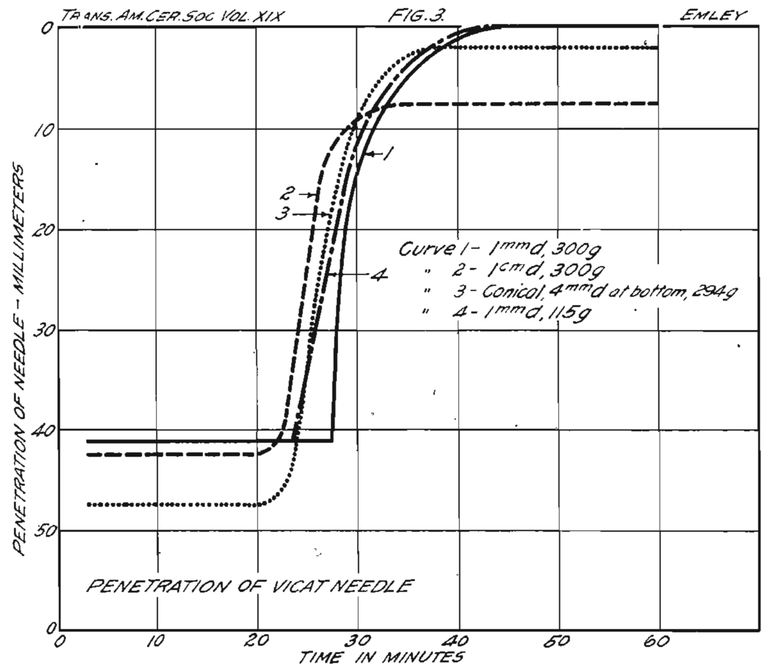


FIG. 89.—Effect of time of working on strength.
FIG. 90.—Stages in the setting of calcined gypsum with corresponding time intervals.

for X minutes. It was then reworked by mixing vigorously with a steel spatula, and cast into three briquettes. One hour after zero time, the briquettes were removed from the molds and put into a drying oven at 40° C. Twenty-four hours later, they were removed from the oven, and tested immediately. X was varied by one minute intervals from two minutes past zero time till the material was no longer workable. The results are shown in figure 89 and the remarks on the accompanying phenomena in figure 90. The immediate increase to a maximum is probably due to the thin consistency used; for the first four minutes, the plaster settled out of the mixture so rapidly that an undue proportion of it remained in the dish after the briquettes had been cast. This tendency becomes less marked as the plaster begins to thicken. For example, in the 5 minute sample the strengths of the three individual briquettes were 120, 206 and 317 pounds per square inch, indicating conclusively that the mixture was not homogeneous. The 9 minute sample showed strengths of 191, 212, 217, showing that the mixture had thickened sufficiently to keep the plaster from settling out. In view of these results, it is possible that the depression shown at eight minutes may be due to experimental error. The curve shows clearly that the time of initial set for this plaster is ten minutes, because if the sample is worked after this time, it loses strength. The time of final set is shown by figure 90 to be twenty-seven minutes. The plaster can be worked after this time but not satisfactorily; the briquettes made at twenty-eight and twenty-nine minutes had rough surfaces and were ragged and full of holes. Figure 89 shows that these last two samples were stronger than those preceding them. This is probably because the damp powders were packed into the molds with considerable force in an endeavor to make a presentable specimen.

The next four experiments were conducted to examine the "penetration method". The Vicat needle is 1 mm. in diameter, and weighs 300 grams. Curve 1 in figure 91 shows how far this needle will penetrate into the paste by its own weight after given intervals of time. It will be noted that this method shows no indication of any initial set at ten minutes. It shows very sharply and distinctly the point of final set at twenty-seven minutes. It shows also another rather indefinite point at about forty-five minutes, when the needle will make no impression on the surface of the plaster.

Curves 2, 3, and 4 in figure 91 were produced by changing the size, the shape, and the weight of the needle respectively. Apparently with these needles, the final set occurs in less time.



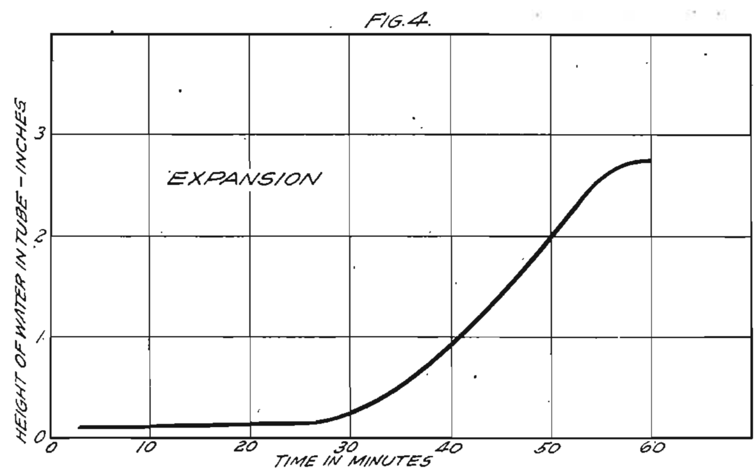


FIG. 91.—Diagram illustrating setting time of calcined gypsum.
FIG. 92.—Diagram illustrating rate of expansion of calcined gypsum while setting.

Figure 89 tells us that this is not so, and therefore the regulation Vicat needle (Curve 1, figure 91) is best adapted to the material. There is no indication of any initial set shown by any of them.

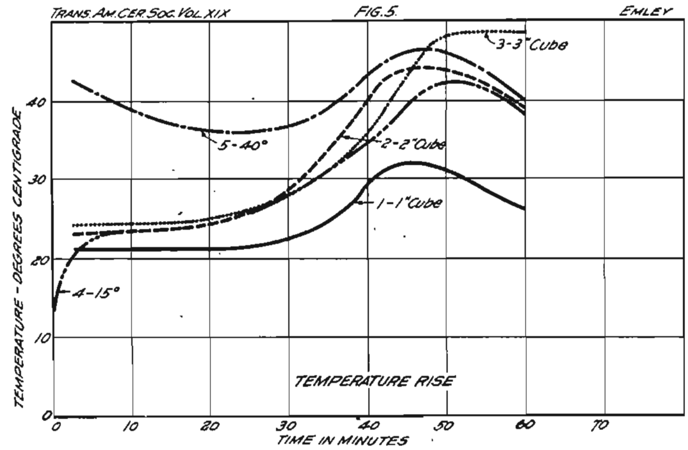
Under Group B there are two general methods, based upon expansion and temperature rise. We know that calcined gypsum expands as it sets, and a measure of the rate of expansion should therefore measure the rate of set. A thin walled rubber bulb was filled with water and placed in a small heavy metal can. The can was then filled with a sample of plaster and water mixed as above described. The cover was then screwed on until the plaster came out through two holes in it, so that the can was completely filled. Through one hole in the cover protruded the stem of the bulb, which was connected to a vertical glass tube. The other hole served to introduce a thermometer into the plaster. As the plaster expanded it squeezed the water out of the bulb and made it rise in the glass tube, where its height could be read. The thermometer was read simultaneously, and the height of the water corrected for the expansion due to heat. The final results are plotted in the curve, figure 92. This curve also shows no initial set. It shows the final set at twenty-seven minutes, but not so sharply and definitely as curve 3, figure 91.

Heat is generated by the chemical reaction which causes the set of gypsum. This causes the temperature of the mass to rise, and the rate of the rise of temperature should therefore be an indication of the rate of set. This method has been more widely used and more thoroughly investigated than any other, but it seems that one of the basic principles has been overlooked. The speed of any chemical reaction is either retarded or accelerated by an increase of temperature. Assuming that the method of manipulation is so refined as to prevent all loss of heat by radiation, then a large sample of plaster will generate more heat than a smaller one, but it will also have a larger quantity of material to heat. The final temperature will depend upon the balancing of these two factors. Without attempting to discuss whether a large sample will give a higher or lower temperature than a small one, we may be reasonably certain that the two temperatures will not be the same, even under ideal conditions. Practically, the sample is always subject to more or less loss of heat by radiation, so that the temperature as read really indicates the difference between the rate at which the heat is generated and the rate at which it is lost by radiation. Therefore the maximum temperature is a function of the shape and size of the specimen, the difference between the temperature of the specimen and that of the air and other similar factors which govern the radiation of heat. It is logical to assume that the absolute value of the temperature at any time will have some influence on the speed of the reaction, and therefore on the rate of set, at that time.

The curves 1, 2, and 3 of figure 93 show the effect of the size of the sample on the rate of temperature rise. They were made by inserting a thermometer in the center of a one inch, two inch, and three inch cube respectively. The molds were made of paraffined paper, and care was taken to keep the factors governing radiation as nearly constant as possible. It will be noted that curves 1 and 2 show maximum temperature at forty-five minutes, while the rate of set of the 3 inch cube is somewhat retarded. The size of the specimen evidently makes little difference, provided it is not too large. It is suggested that a good design would be a cylindrical specimen of such a size that the bulb of the thermometer would be equidistant from the surface. For example, if the bulb of the thermometer is ¾ in. long by ⅛ in. diameter, the specimen might be made 1¾ in. long by 1⅛ in. diameter, and then every point on the surface of the bulb would be just ½ in. from the surface of the specimen. A mold of this shape can be conveniently made by cutting a piece of paper of the required dimensions, dipping it in melted paraffin, rolling it to shape, and mounting it on paraffin on a glass plate.

Specimens of this shape were used in curves 4 and 5 in figure 93, which show the effect of variation of initial temperature.

Three points are to be noted from these five curves; (1) Initial set occurs before there is any noticeable rise of temperature. (2) At the time of final set, the temperature has begun to rise, but there is no sharp break in the curve to indicate a sudden change in the rate of reaction. (3) There is a well defined point of maximum temperature, which has frequently been called the time of set. If, however, we define final set as the time after which the material is no longer workable, this point of maximum temperature occurs consider-



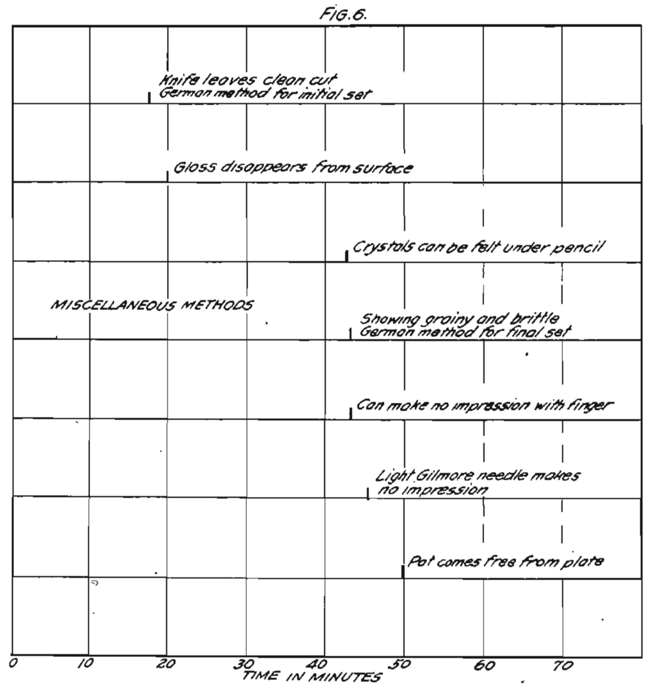


FIG. 93.—Curves illustrating temperature changes in calcined gypsum while setting.
FIG. 94. Diagram illustrating time intervals for initial and final set by various methods.

ably (with this plaster, eighteen minutes) later than the final set. It does not mark the completion of the chemical reaction, for we know that the specimen will continue to increase in strength for days. This point can be interpreted only as the time at which the reaction reaches its maximum velocity. The point is undoubtedly of scientific interest, but inasmuch as the plaster has long before ceased to be workable, it is difficult to see how this point can have any practical significance. Certainly it is a misuse of terms to call it the time of set.

Only one conclusion can be drawn from the above experiments: The measurement of the temperature rise is useless for determining the time of set.

In group C are included a number of empirical methods, the results of which are shown in figure 94. None of these requires any special explanation, except that the standard German method for measuring initial set is when the knife leaves a clean cut; and for the final set, when the shavings come off grainy and brittle. The number of methods in this group could be multiplied indefinitely, since almost everyone dealing with gypsum has a pet method of his own. The seven methods given were selected as being typical and since none of them shows the remotest connection with the time of set, either initial or final, it is hardly worth while to go further.

From the above discussion it seems reasonable to draw the following conclusions: (1) None of the methods examined is capable of indicating the initial set. (2) The ordinary Vicat needle, 1 mm. in diameter, weighing 300 grams, is eminently satisfactory for measuring the final set. (3) There is a third point, indicated by the temperature curves and by some of the methods in Group C., which is apparently the time of maximum velocity of setting. This point is of doubtful practical value.

Referring to figure 89, we find that when plaster is worked after it has taken its initial set, its strength is somewhat impaired. Fortunately, however, it does not seem possible to decrease the strength below ordinary practical requirements. That is, for most purposes for which gypsum is used, it could make little difference whether its tensile strength is 250 pounds per square inch or only 125. Indeed, experience leads one to believe that in most cases initial set has taken place before the application of the plaster has been completed. In other words, the working of a gypsum plaster makes no serious differences in its properties up to the time of final set when it can no longer be worked. From a practical view-point, therefore, the measurement of time of initial set is unnecessary, the final set only being of importance.

This interpretation of results may be objected to by one familiar with the testing of Portland cement. By such a one, the first break in curve 3, figure 91, would be taken as indicating the time of initial set, instead of the time of final set, as it has here been designated. In answer to this objection, it may be stated, first: The definition of either initial or final set, when measured by a penetration method, is purely empirical. There is, therefore, no particular reason for following the definitions adopted by the cement industry, when there is any advantage to be gained by deviating from them. Second; If it is accepted as logical that final set has occurred when it is no longer physically possible to work the material, then a comparison of figures 89, 90, and 91, will be convincing that the first break in curve 3, figure 91, corresponds to the time of final set.

Based on the above information, the following method is recommended for determining the time of set of calcined gypsum or of prepared plaster made therefrom. Determine first the normal consistency using the Southard instrument as recommended by Sub-committee 4 of Committee C-11, A. S. T. M. Determine from this the amount of water which must be added to 100 grams of the sample to produce a paste of normal consistency. In a perfectly clean porcelain casserole, put three times this amount of distilled water. Weigh out 300 grams of the sample and transfer to a clean sheet of glazed paper. Also provide a clean glass stirring rod about 1/8 in. diameter. When the second hand of a watch points to zero, transfer the sample from the paper to the casserole. This should be done as quickly as possible without splashing, and should not take more than two seconds. Let the plaster soak quietly until the second hand again reaches zero, when the mixture is to be stirred vigorously by means of the stirring rod for one minute, by which time the mass should be homogeneous.

At the end of the second minute, this mixture should be poured into the mold for the Vicat needle. At one minute intervals, the needle is allowed to sink into the paste. Eventually there will be found a time when the needle will not penetrate clear to the bottom. The time elapsed between the time when the sample was added to the water and the time when the needle no longer penetrates to the bottom is recorded as the time of set.

The sample, water, casserole, and mold shall be at a temperature of not less than 20° C., nor more than 25° C. at the beginning of the experiment.

The Vicat needle and the mold are described in the standard specifications for cement—1915 Yearbook, A.S.T.M., page 359. The mold is made of hard rubber, and it will be found difficult to remove all traces of set plaster from it without scraping, which might cause injury. To overcome this, the mold should be prepared for use by dipping it in melted paraffin. This will prevent adherence of the plaster to a great extent, and the mold can be cleaned thoroughly and easily by heating it very gently.

APPENDIX V

SOME FACTORS INFLUENCING THE TIME OF SET OF CALCINED GYPSUM[243]

BY F. F. HOUSEHOLDER[244]

Introduction.—The time of set of calcined gypsum is one of its very important properties. Several methods for its measurement have been suggested and the chief ones have been tested and rated according to their merits.[245] However, no data resulting from thorough work on the relation of the time of set to the other physical properties are available. Obviously, this relation will depend upon the purity of the gypsum from which the plaster is made, the temperature at which it is calcined, and the amount of retarder or accelerator added. Experience shows that it depends also upon the cleanliness of the boxes or vessels in which the plaster is mixed, and the purity of the water used.

This preliminary note describes some tests made in order to determine the effect of varying the consistency of the mixtures, the time of stirring, the rate of stirring, and the temperature of the water used in mixing, on the time of set of calcined gypsum. The tests reported — although they may be of some value in themselves — were made as a guide in outlining further and more extensive tests on the physical properties of gypsum.

Preparation of Samples.—The same grade of plaster was used (without the addition of any retarder or accelerator) throughout the whole series of tests. A sample of 300 g. was made up in each case in a clean casserole. Each sample was stirred by means of a small spatula which was kept well polished. The plaster was added to the water as rapidly as possible (four to five seconds) without splashing or wasting and was allowed to stand undisturbed for one minute. It was

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243By permission of the Director, Bureau of Standards.

244Republished from the Journal of the American Ceramic Society, Vol. I, No. 8, Aug., 1918, pp. 578-583.

245Emley, Trans. Am. Ceram. Soc. 19, 573-584.

then poured (or was stirred as the test demanded and then poured) into the standard mold of a Vicat[246] apparatus. The mold was thoroughly cleaned before each test and was covered with a very thin coating of oil. The time of set was determined, as suggested by Emley,[247] by means of the standard Vicat needle.

Effect of Per Cent Water Added.—To determine the effect of the amount of water used in mixing the plaster on the time of set, samples containing 30, 32½, 35, 37½, 40, 42½, 45, 47½. 50 and 60 per cent of water, respectively, were made up and tested. A large number of tests on each mixture were made and the average results at each percentage were plotted. In figure 95 is shown the variation in the time of set with the amount of water used in the mixture.

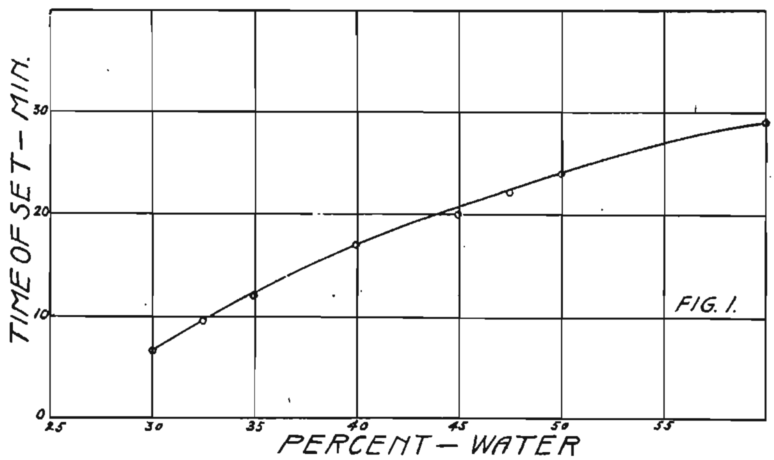

FIG. 95.—Diagram illustrating relationship between per cent of water used, and setting time of calcined gypsum.

The samples containing 30 per cent water were so stiff and viscous that much care and effort were required in introducing them into the mold. However, the time of set of the individual samples did not vary from the average by more than one-half minute. The sample containing 32½ per cent water was too viscous to mold satisfactorily, but gave fairly uniform values.

The curve (Fig. 95) shows a fairly uniform increase in the

246 1915 Year Book. ASTM., p. 359.

247 See page 578, Loc. cit., 19, 583-4.

time of set as the percentage of water was increased until about 45 per cent was reached. Thus the increase in time of set was less rapid — due to the fact that when the mixture was poured into the mold the plaster settled to the bottom and the excess water came to the top. A thin film of water came to the top of the 47½ per cent sample, and in the case of the 50 per cent sample, a layer of water 1-1.5 mm. deep formed, while with the 60 per cent sample, the water was 7 mm. deep at the top of the mold. Evidently, before any setting had taken

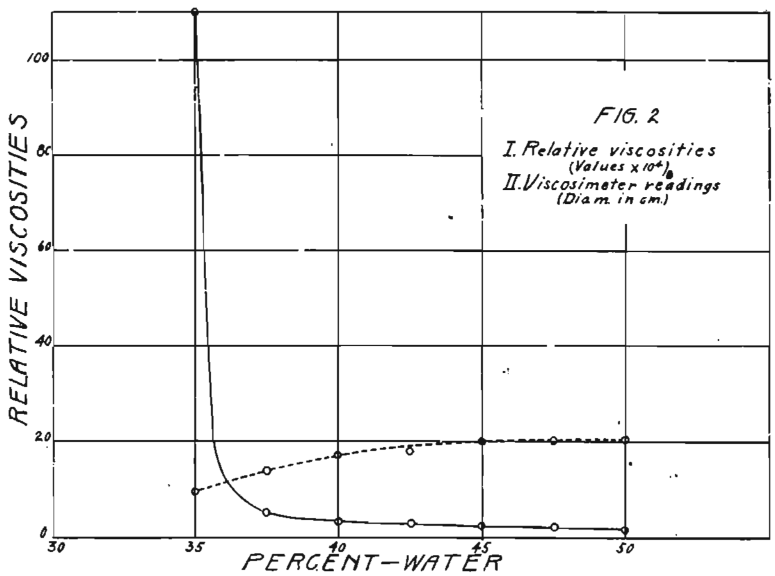

FIG. 96.—Described in text.

place, the mixture was reduced to about 47 or 48 per cent and the further retardation probably was due, in part at least, to the fact that the plaster was under water. Also, the layer of water at the top of the mold increased the penetrating ability of the needle. These samples did not harden at the top — not even after the pouring off of the water and their removal from the mold. A day or two later the top could be brushed away with the hand. Considering the samples containing from 30 to 45 per cent water, an increase in the time of set from 6.5 minutes to 20 minutes, or approximately 300 per cent, is noted, while in the 45 to 60 per cent samples it increases from 20 minutes to 29 minutes or approximately 50 per cent.

Viscosity Measurements.—The relative viscosities of each of the samples were determined by means of the Southard viscosimeter. The samples from 35 per cent up were placed in the viscosimeter and gave the results shown by the dotted curve (Fig. 96). Assuming that the "patties" were circular, the viscosity of a mixture would vary inversely as the square of the diameter of the "patty." The relative viscosities are shown by the solid curve (Fig. 96). A very marked decrease is noted between the water contents of 35 and 40 per cent but not much change is noted thereafter. The instrument used was not water tight and hence the 60 per cent sample was not tested. The shape of the viscosity curve would indicate that the viscosity very rapidly approaches that of water and prob-

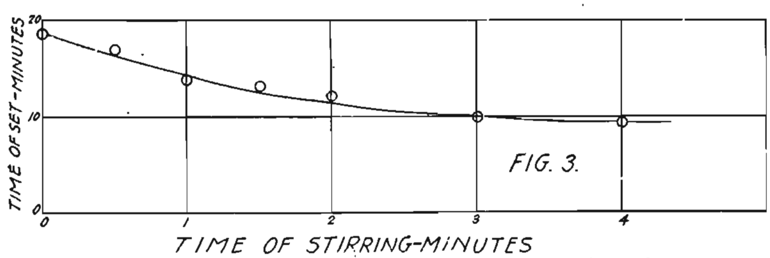

FIG. 97.—Diagram illustrating effect of stirring on time of set.

ably reaches it before it crosses the 100 per cent abscissa. Lack of data makes it unsafe to judge where the two curves meet.

No extensive work has been published on the properties of gypsum solutions, although investigations along this line may lead to a more satisfactory definition of normal consistency. The immediate results obtained here indicate that decreasing the viscosity increases the time of set, but that the relation between the two is not a simple function.

Effect of Stirring.—In determining the effect of continued stirring, the samples used were mixed with 40 per cent water and each was stirred with a small spatula at the rate of four strokes per second. The calcined gypsum was added to the water and the mixture allowed to stand one minute, as before. The first sample was then poured immediately into the mold and the time of set determined. Each of the others was stirred at the same rate for 0, 0.5, 1, 2, 3, and 4 minutes respectively, and then poured into the mold. In figure 97 are shown the results of the tests.

Continuous stirring for four minutes decreases the time of set from 18.5 minutes (with no stirring) to 9.5 minutes or to almost one-half. The general shape of the curve would indicate that the time of set would not be very greatly decreased by a continuation of the stirring.

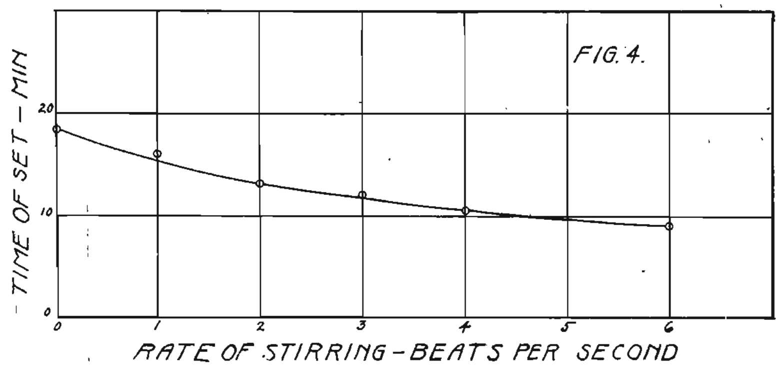

FIG. 98.—Diagram illustrating effect of rate of stirring on time of set.

In figure 98 is shown the effect of varying the speed of stirring of the same kind of samples on the time of set. The stirring was all done by hand and the speed varied from 0 to 6 strokes per second (each sample being stirred for one minute only).

Increased speed of stirring reduced the time of set. The shape of this curve is very similar to that of the curve shown in figure 97, although the decrease in the time of set is not so marked. The increased agitation of the mixture — either by increased stirring or by more rapid stirring — hastened the time of set. The first effect is probably to increase the rate at which the dry plaster takes up the water and goes into solution. The first crystal clusters formed are probably broken up and distributed throughout the mixture — thus becoming nuclei for further crystallization.

Effect of Temperature.—The effect of heating the water before mixing with the plaster was also tried out. The samples used for this purpose contained 40 per cent water and each was stirred at the same rate and for the same time as before. The data secured are less uniform than those secured in the foregoing experiments, but do not vary in any given direction. The conclusion reached is, that the temperature of the water has no appreciable effect on the time of set. The setting of calcined gypsum is always accompanied by the evolution of heat (pure $CaSO_4$ $\frac{1}{2}H_2O$ in forming $CaSO_4$ $2H_2O$ giving up about 3700 cal. per gram molecular weight). Heating would therefore tend to retard the process were it continued. On the other hand, the solubility of calcined gypsum tends to increase with a rise in temperature of the water — which probably would induce an acceleration of the process. Evidently from the results of this test, the two factors mentioned would about balance each other.

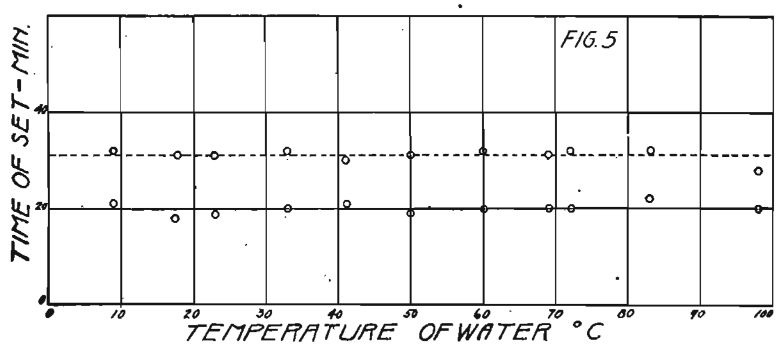

FIG. 99.—Diagram illustrating effect of temperature of water used in mixing on time of set. (Results would have been different had retarder been present in the calcined gypsum).

By the heavy curve (Fig. 99) is shown the time of set as determined by this test. The dotted curve shows the points at which the needle did not penetrate at all, or the time of hardening of the gypsum. The same regularity that is seen in the time of set is shown here.

CONCLUSIONS

(1) Increasing the proportions of water causes a decrease in viscosity, and an increase in the time of set of calcined gypsum.

(2) Vigorous and continued agitation, when mixing the calcined gypsum with the water, tends to decrease the time of set.

(3) The temperature of the water used in mixing has no influence on the time of set.

The above experiments were the outcome of the suggestions of Mr. C. A. Birdsley, Chief Engineer; P. H. Butler, Supt.; and J. A. Davis, of the Oakland Plant of the U. S. Gypsum Co. Acknowledgments are also due Mr. F. A. Kirkpatrick for many valuable suggestions in making the experiments.

APPENDIX VI.

GYPSUM COMPOSITION SLAB CONSTRUCTION FOR ROOFS AND FLOORS.[248]

The bureau has awarded contract No. 2264 for structural shop, navy yard, Norfolk, Va., on the basis of the roof slab being constructed of gypsum composition, because of the saving in weight of structural steel resulting from using a roof slab so much lighter than reinforced concrete, and also because of the anticipated saving from the reduction of heat losses through the relative nonconductivity of gypsum as against concrete. The unit cost of the gypsum slab complete for this project is 22.2 cents per square foot. In view of this being the first use of this material by the Bureau, the following report and record of test is published as being of particular interest to the corps.

REPORT ON INSPECTION OF INSTALLATION OF GYPSUM COMPOSITION SLAB CONSTRUCTION

(BY CIVIL ENGINEER GEORGE A. McKAY, U. S. NAVY)

As directed by Order No. 4234-93, dated September 13, 1916, I proceeded to Philadelphia and inspected installations of gypsum slab construction at the Midvale Steel Co.; Baldwin Locomotive Works, Eddystone; Remington Arms, Eddystone; Pennsylvania Ship Building Plant at Gloucester; and other installations.

The largest installation seen was at Eddystone, where there are built about 22 acres of roof covered with gypsum composition slabs. Certain of these slabs have been in use for as long as six years. All slabs inspected were installed in accordance with the table of spans, slab depths, and cable spacing, and represented standard construction of the Keystone Fireproofing Co. The superintendents of construction or their assistants at the different plants were interviewed, and all information gathered either by inspection or by interview was favorable.

248Republished from Bulletin 25, Public Works of the Navy, pp. 20-37. Washington, 1917.

Particular attention was given to the work being installed on ordnance machine shop No. 7 Midvale Steel Co. The roof slabs were three inches thick, spans six feet three inches, reinforcement consisting of two No. 11 wires three inches on centers, wires being held down in the center of the span by one 5/8-inch round bar. This slab is designed for thirty pounds live load. Beam lengths were seventeen feet six inches, and the end panels were stiffened with three 1½-inch pipe struts and the center panels were stiffened with one 1½-inch pipe strut. In the end two panels, there was a six by six inch gypsum beam, six feet three inches long installed for further stiffening of the end slabs. The gypsum composition used contained 15 per cent by weight of wood chips and heavy broken shavings. The bulk of this wood filler, however, was considerable, so that in appearance, there was apparently much more wood filler than gysum. The gypsum and wood chips were first mixed dry by hand turning, similar to hand concrete mixing, on the ground; were then loaded into sacks, raised to roof by elevator, and transported to the site of the work where the mixture of gypsum and wood chips was again mixed in a box, water being added at the same time. The mixture was then immediately shoveled on the forms and screeded to proper elevation.

The company's force consisted of a total of seventy-five men, which force laid 7,500 square feet per day. There were about twelve men dry mixing, two men on hoist, and eight men for wet mixing and screeding. The remaining men were employed placing reinforcement and forms, stripping forms, and on miscellaneous work. Within fifteen minutes after a slab was poured, it was possible to step on same without leaving a footprint. A slab which had been poured at 9 o'clock had the form stripped at 11 o'clock. Seventeen men were then put on this slab in a space about 8 by 6¼ feet, which represented a live load about double that for which the slab had been calculated. The slab adjacent to the one loaded was without load. No defection was noticeable to the eye, and there was no apparent injury to the construction. At the time this first load was applied, the gypsum slab was so soft that it could be slightly compressed under the pressure of the thumb. The gypsum slab construction is quite elastic, and when compared to concrete is comparatively soft under foot, particularly so until it has thoroughly dried out, which takes about three weeks' time.

Through the courtesy of Civil Engineer L. M. Cox, U. S. Navy, public works officer, arrangements were made to have one of his assistants inspect certain floor installations in New York. The report of this inspection as forwarded by Mr. Cox is attached hereto. The advantages of gypsum slab construction are:

(a) The light weight of slab, thereby reducing dead loads and decreasing cost of steel foundations and piles.

(b) Quick construction, as forms can be removed in less than 24 hours, and roof covering can be placed in advance of the time required on concrete slabs.

(c) The material being a nonconductor decreases heat losses through roof, reduces coal consumption required for heating, and is free from condensation on the underside of the slab.

(d) The material has successfully passed several fire tests conducted by the bureau of buildings, New York City, and the Columbia University fire testing station at Brooklyn.

(e) There was a noticeable absence of cracks on all installations inspected, which is undoubtedly due to the elasticity of the material.

(f) The cost of maintenance and repair is low. The slabs are easily cut out where changes and construction are necessary; nails can be driven in the slab at any time.

This construction has the disadvantage that it is impracticable for the contractors to obtain wood chips which are free from oak and chestnut; and where these occur in the wood filler, brown stains are developed on the underside of the slab. Asbestos filler has been used in an effort to avoid this stain, but asbestos has been found unfit because of a chemical action which takes place which results in a white salt developing on the underside of the slab, which is more objectionable than the stain for the average installation. The slab is very porous, absorbs moisture freely, and when used for roofs must be waterproofed. The compressive strength of gypsum is diminished when the slab is wet, but it regains its strength in large part when it is redried. It is not considered that the decrease in strength of the slab when wet is sufficient to materially affect the strength of the structure when slabs are used for light loads and short spans.

The installation of gypsum is approved by building inspectors of several cities, among them being the cities of New York, Philadelphia, and Baltimore.

Letters requesting information concerning gypsum-slab installation were sent to the following companies:

The American Locomotive Co.
Baldwin Locomotive Co.
Montreal Light, Heat & Power Co.
Garvin Machine Co.
Norfolk & Western Railway.
Southern Railway.
Ingersoll-Rand Co.
Mr. John T. Wilson, Contractor.
Clinton & Russell, Architects.

All replies received (seven in number) were favorable. Information was particularly requested as to the length of time the system had been used; whether any trouble had been experienced from cracks due to irregular loading or vibrations; as to any deterioration in the slab where same had been exposed to moisture or rain; as to the effectiveness of the slab in decreasing heat losses and in preventing condensation, and as to whether the installation had been entirely satisfactory.

The method used by the Keystone Fireproofing Co. in figuring strength of slab, while not approved, appears to be safe for ordinary installations. It is believed that a method of analysis similar to that used for reinforced concrete construction would give results which would conform more nearly to those which actually occur in the installation. Calculation on the latter basis for a roof of spans and loading as specified for the structural shop showed that the slab should be four inches thick instead of 3½ inches thick as recommended by the manufacturers. It is also believed that a change in the system of tying down reinforcing cables, using two ½-inch round bars spaced about one-quarter of the span apart to hold down the cables instead of a single ⅝-inch round bar placed in the center of the span, would result in a material improvement in their construction.

Gypsum composition slabs are recommended for roof construction such as will be needed for the structural shop at Norfolk and also for light floor construction where no concentrated loads occur. Gypsum slabs are not recommended for floors having heavy concentrated loads, or for wide spans, that is, eight feet or over in width, nor for office floors or roofs where stains on the underside would form a serious objection.

The manufacturers claim that after a gypsum slab has thoroughly dried out, the underside can be coated either with calcimine or with plaster, and that further stains will not occur. This, however, has not been confirmed, as the installations examined were not so coated. It is considered probable that if the underside of a gypsum slab was plastered and again became wet, stains would develop through the plaster or calcimine.

REPORT TO CIVIL ENGINEER L. M. COX, U. S. NAVY, ON EXAMINATION OF GYPSUM SLAB FLOORS

The St. Nicholas Skating Rink.—This building has been in service for twenty-three years. The main floor, supporting the ice tank, consists of Metropolitan system type B slabs supported on steel beams five feet eight inches center to center. The basement floor below is occupied by ice-making machinery and small ice tanks. The rink was not in operation at the time of my inspection. Nails, pipes, and pipe hangers attached to the ceiling were all badly rusted, indicating severe moisture conditions. The tank above is insulated from the floor slab by twelve inches or more of material. Part of the ceiling is plastered. The underside of the floor slab, where exposed, is hard and sound. There is no sign of tension cracks in the ceiling. There are three or four small spots of porous material over the pumps, the gypsum probably not having filled the form. In one such spot I picked off enough of the gypsum to expose six of the steel cables and part of the ⅝-inch holding-down rod. The cables were entirely free from rust; there was a slight coat of rust on the ⅝-inch rod. A piece of gypsum knocked off a beam haunch with chisel and hammer showed a clean break, and sound, hard material. There has been little or no deterioration in the floor slabs of this building.

The Garvin Machine Co.—This building was erected over twenty years ago. It is an eight-story building, the floors above the second being occupied by machine tools driven by belts from overhead shafting. There is some vibration from the machines, but it is not severe. The bureau of buildings permits a live load of 220 pounds per square foot on the floors, which are Metropolitan system type B slabs between steel beams seven feet three inches center to center. However, there were local loads, such as piles of shafting, which I estimated at 400 pounds per square foot, and instances were frequent in which a heavy machine next to an aisle caused one panel to be fully loaded and the adjacent one unloaded. The floor slabs are to all appearances as good as new. There is no sign anywhere of cracking, flaking, or softening of the gypsum. The second-floor ceiling is plastered, elsewhere the ceilings were painted with a wash of plaster or cement. At one point two panels have been cut out and replaced. This was necessitated by the spilling of sulphuric acid over the floor, penetrating the cinder concrete fill and the gypsum slab. Employees of the Garvin Machine Co. stated that no work had been done on the ceilings as a whole since the company has occupied the building — about twenty-two years — except painting the plastered ceiling on the second floor.

At the office of the Keystone Fireproofing Co. I saw pieces of floor slab and steel taken from the Hammerstein Theater when that building was torn down, and from the overhang of the Ingersoll-Rand Co. building in Phillipsburg, N. J. The fireproofing was hard and sound; the steel showed only a little corrosion. The Hammerstein Theater had been in place nineteen years; the Ingersoll-Rand Co. building eight or nine years.

From the information I obtained, it appears that no repair or maintenance is required for Metropolitan system slabs at least for twenty years or more. In regard to alterations, costs were not obtainable, but it is probable that the gypsum and wood-chip composition is very much cheaper to cut than concrete. On the other hand, fastening the cables to the floor beams in existing work may be difficult. At 42 Broadway, New

York, a new stair well was cut; the cables in the adjacent panel were left untied, reliance being placed on the bond between the steel and the gypsum. The floor is apparently safe, but this procedure is, in my opinion, poor practice. The system is inapplicable to stairways.

In regard to appearance, the ceilings of the Garvin Machine Co. finished with a wash coat, the exact nature of which could not be ascertained, were gray in color and reasonably smooth and entirely satisfactory for a building devoted to manufacture. The untreated ceiling of the St. Nicholas Rink refrigerating room could not be recommended except where appearance is of no consequence whatever.

ARTHUR KRAUS, *Draftsman.*

REPORT ON LOADING TEST OF METROPOLITAN COMPOSITION FLOOR MADE BY THE U. S. BUREAU OF STANDARDS, NOVEMBER 14, 1916, AT 17th AND E STS. N. W., WASHINGTON, D. C.

DESCRIPTION OF TEST FLOOR

1. *Design of Metropolitan Floor.*—The design of this type of floor is based primarily upon the employment of steel cables placed in tension in the form of a series of suspension members. These suspension strands are so placed between I-beam supports that when a superimposed load is placed on the floor surface the resultant stress is transmitted through the tension of the cables to the I-beams on each side of the floor panel. The composition of calcined gypsum and wood chips which forms the body of the floor is intended to be used in direct compression merely to transmit the superimposed load uniformly to the steel cables.

2. *Construction.*—The test floor was constructed October 20, 1916 (warm day, partly cloudy, mean temperature 72°F.), according to details shown on Exhibit No. 1, (figure 100), which details were followed closely. As shown on the above noted exhibit, the structure consisted of five spans of Metropolitan composition floor, eight feet wide, supported by six 12-inch, 28½ pound I-beams, which beams rested in two 8-inch brick walls, placed twenty feet between inside faces. The floor was constructed only eight feet wide, in order to permit of lateral observation of the behavior of the floor under the test loading.

The floor as constructed differed from the customary type of

Metropolitan floor construction, in that there were placed in each panel two 1¼-inch diameter iron pipes seven feet five inches long at the one-third points of the eight-foot floor sec-

EXHIBIT 1

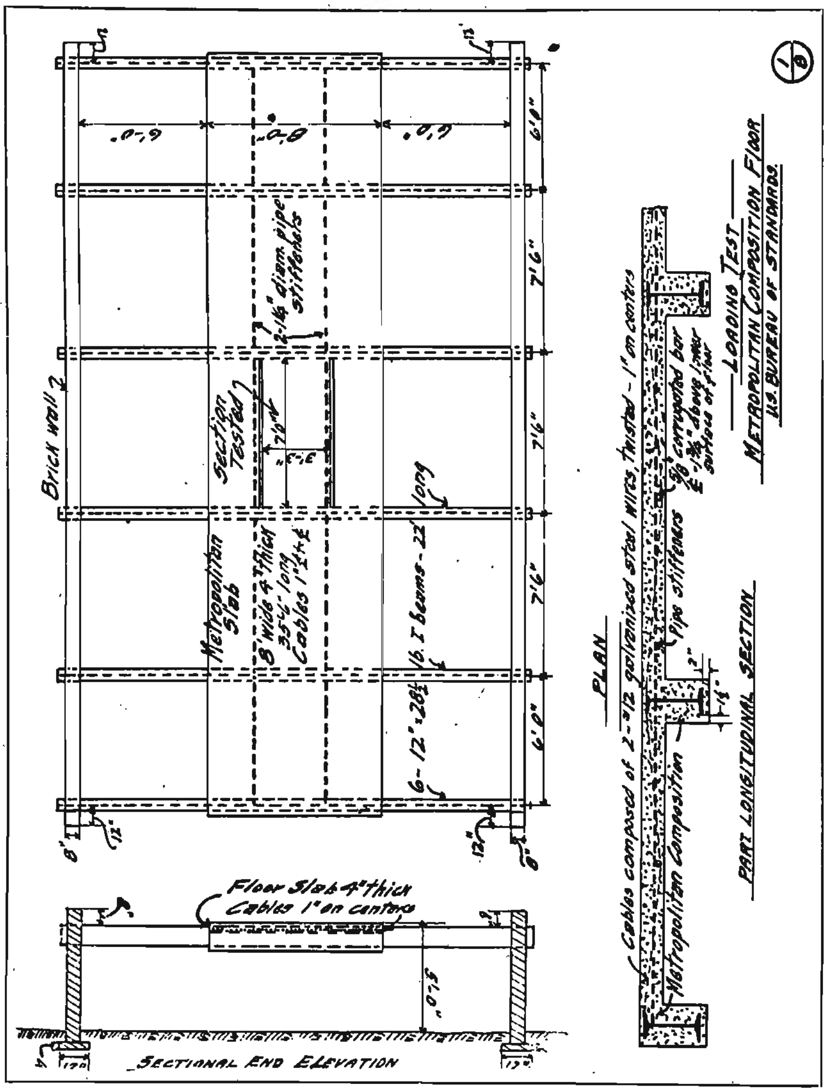

FIGURE 100

tion, parallel with the cables, normal to the webs of the I-beams, and on top of the transverse ⅝-inch rod. These pipes were installed to give stiffness to the I-beams, in order to counteract any overturning effect produced by the pull of the cables on the top flanges of the I-beams. The builders' statement was to the effect that in the customary type of construction these pipes are not used, since the floor, being continuous for the full distance between the brick walls, gives the necessary stiffening or strut action.

Another exception to the customary installation consisted in the inability to place the cross rods in each panel as low as usually specified. Corrugated rods were used in place of the specified 5-8-inch diameter round rods (not obtainable at the time), and the corrugations had a tendency to cut the tie wires with which the cross rods were to be held down until the composition was placed. As a result of this difficulty the cross rods were placed with centers from 1¼ to 1¾ inches above the under surface of the floor slab instead of the specified distance of 1 inch. This misplacement of the cross rods shortens the effective depth of the cables below their points of suspension over the I-beams, and the builders state that the allowable live load is dependent directly upon this effective depth, and that consequently the slab as built, with the cross rod 1¾ inches above the underside of the floor, would have an allowable load of about 133 pounds per square foot instead of the specified 150 pounds per square foot.

The construction of the floor consisted of three operations, viz:

(a) Constructing the haunches or beam covering. This was effected by building forms around the webs and bottom flanges of all the I-beams and filling the forms with Metropolitan composition of a mushy consistency. This operation was completed in an hour, from 11 A. M. to 12 M.

(b) Stretching the cables and inserting cross rods, from 1 to 2:30 P. M. The cables were first stretched taut over the tops of the I-beams, being secured by S hooks of ¼ inch round steel to the outer edge of the top flanges of the two outermost beams. The center cross rod was then placed in each panel and brought down by means of tie wires to deflect the cables uniformly.

(c) Placing floor composition. Forms were built between the beams four inches below the top flanges and the composition of gypsum and wood chips was placed in these forms in a mushy condition and brought to a level of about ¼-inch above the top beam flanges.

The composition in the south panel was placed from 2:40 to 2:57 P. M. The balance of the panels were filled with the composition at an average rate of twenty minutes each. At 3:15 P. M. the south panel was firm enough to sustain a man walking on the surface, and from 3:17 to 3:25 all form work was removed from this section. At 3:30 P. M. 12 men of an average weight of 170 pounds stood in the center of the south panel, thus subjecting it to a load of about 85 pounds per square foot. The forms were removed from all sections of the floor by 4:35 P. M.

3. *Size of Test Panel.*—The section of the floor which was loaded for test consisted of a strip three feet four inches wide along the longitudinal center line of the center span, thus giving a section 7 by 3.33 feet supported at two ends. This size section was chosen because of the size of iron ingots available for producing the load. The loading material consisted of cast iron elevator weights approximately four by six by thirty-nine inches in size. A slot was made about ¾ inch wide on each side of the test slab the full depth of the floor in order to free the slab from any side friction on the balance of the floor.

4. *Age and Seasoning of the Test Slab.*—The floor was loaded for test November 14, 1916, the floor when tested being then twenty-five days old. The floor was constructed in the open air and seasoned through a period of rather cool weather with light rains for three days previous to the test. Tar paper shelters were used to protect the floor from precipitation and for a period of 4½ days previous to the loading of the slab the floor was heated with two salamanders under the center span. These salamanders maintained a temperature of 120 degrees F. under the structure.

5. *Loading the Floor for Test.*—The iron ingots described above were placed on the test slab at right angles to the slab center line in layers of ten weights each, producing load increments of approximately eighty pounds per square foot. Approximately twenty-five minutes to an increment were consumed in placing the load on the floor. The individual ingots were weighed and their respective weights recorded. Care was

taken to leave space between adjacent weights in each layer to avoid any arching action in the load. Four load increments were placed on the slab, producing a total load of 322 pounds per square foot, which was a little in excess of twice the original computed allowable working live load. Deflection measurements were made on the slab and the two supporting I-beams for each increment of load. The total load was then removed and at the end of thirty-five minutes measurements were again made to determine the recovery of the slab and the various members. The floor was next loaded to 726 pounds per square foot and deflection measurements were again made. This load of approximately five times the allowable live load was left in place seventeen hours until the morning of November 15, at which time the fatigue of the floor was determined. In an endeavor to destroy the slab the loading was continued to 1,040 pounds per square foot, and the resulting deflections noted. The total load was finally removed and the recovery of the slab again determined.

6. *Instruments.*—Determinations were made of the deflection of the slab at its center point, the deflection of the supporting beams, the settlement of the brick walls, and the stretch produced in various steel cables, figures shown in Tables I, II and III, Exhibit 2 (figure 101).

The deflectometer used at the center of the slab (point G on Exhibit No. 3, figure 102) consisted of an Ames dial gauge working between two steel rods. The dial was suspended vertically by an adjustable and graduated steel rod from the under side of a two by eight inch timber placed edgewise horizontally five feet above the center of the test slab. This timber was supported by two A frames twenty feet apart. The piston of the gauge worked in contact with the upper end of a vertical steel rod fastened by means of a flanged socket to the upper surface of the test slab at its center point. The dial was placed in compression with no load on the slab and when the load increments caused the floor to deflect, the pressure on the gauge piston was gradually released and the lowering of the center point of the slab was indicated on the dial.

The deflection of the supporting beams at their middle points was determined by measuring with an inside micrometer caliper between the under side of the bottom beam flange and the end of a steel rod held vertically in a steel tripod resting on a concrete platform 30 inches square built temporarily on the ground. These measurement points are shown at B and E on Exhibit No. 3 (figure 102).

EXHIBIT 2

TABLE I.

Superimposed Load lbs. per sq. ft.	Mean Wall Settlement Inches	Mean Beam Deflection Inches at Middle		Deflection of Slab Inches at Center	
		Indicated	Net	Indicated	Net
80	0.004	0.028	0.024	0.205	0.177
161	0.012	0.074	0.062	0.455	0.381
241	—	—	—	0.787	—
322	0.030	0.166	0.136	1.051	0.885
00 (Load Removed)	0.000	0.000	0.000	0.199	0.199
322	0.032	0.168	0.136	1.100	0.964
483	0.035 *	0.248 *	0.213 *	1.959	1.711
645	0.040 *	0.328 *	0.288 *	2.964	2.636
726	0.043	0.371	0.328	3.790	3.419
726 (17 hours)		0.373		4.920	4.547
1040				5.750	
00				3.690	

TABLE II.

Load lbs./sq. ft.	Wall Settlement in Inches					Deflection of Beams Inches at Middle		
	A	C	D	F	Mean	B	E	Mean
80	0.006	0.006	0.005	0.000	0.004	0.026	0.029	0.028
161	0.014	0.014	0.012	0.006	0.012	0.076	0.072	0.074
322	0.028	0.031	0.029	0.031	0.030	0.172	0.159	0.166
00	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000
724	0.040	0.045	0.041	0.045	0.043	0.398	0.344	0.371

TABLE III

Stretch in Cables on Spans of 20 Inches

Load lbs./sq. ft.		Span Numbers								
		1	2	3	4	5	6	7	8	9
80	Inches	0.0006	0.0008	0.0000	0.0016	0.0012	0.0026	0.0033	0.0027	0.0051
	o/o	0.0030	0.0040	0.0000	0.0080	0.0060	0.0130	0.0165	0.0135	0.0255
161	Inches	0.0036	0.0053	0.0020	0.0059	0.0039	0.0051	0.0063	0.0045	0.0126
	o/o	0.0180	0.0265	0.0100	0.0295	0.0195	0.0255	0.0315	0.0225	0.0630
322	Inches	0.0135	0.0175	0.0106	0.0159	0.0122	0.0135	0.0149	0.0131	0.0269
	o/o	0.0675	0.0875	0.0530	0.0795	0.0610	0.0675	0.0745	0.0655	0.1345
00	Inches	0.0042	0.0053	0.0020	0.0026	0.0006	0.0067	0.0016	0.0022	0.0051
	o/o	0.0210	0.0265	0.0100	0.0130	0.0030	0.0335	0.0080	0.0110	0.0255

* Values interpolated from Curves I & II

—LOADING TEST—
METROPOLITAN COMPOSITION FLOOR
U.S. BUREAU OF STANDARDS

3/B

FIGURE 101

The same type instrument was used to determine the settlement of the brick walls, measurements being made between the upper end of a similar vertical steel rod and the under side of the bottom flange of the beam at a point five inches in front of the inside face of the brick wall in each case. These meas-

EXHIBIT 3

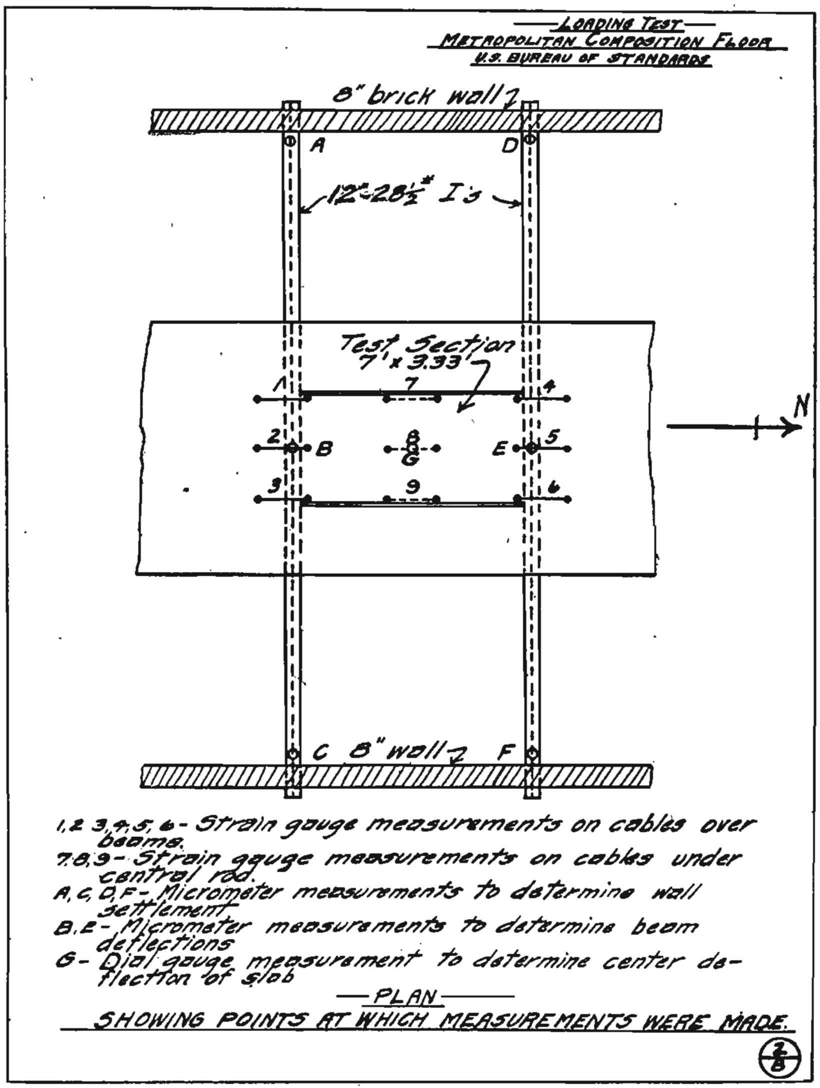

FIGURE 102

urement points are shown at A, C, D, and F on Exhibit No 3 (figure 102).

At points 1 to 9 inclusive, shown on Exhibit 3 (figure 102), determinations were made of the stretch produced in various cables. Holes were drilled in the composition to expose two points twenty inches apart on each of the cables measured. At

EXHIBIT 4.

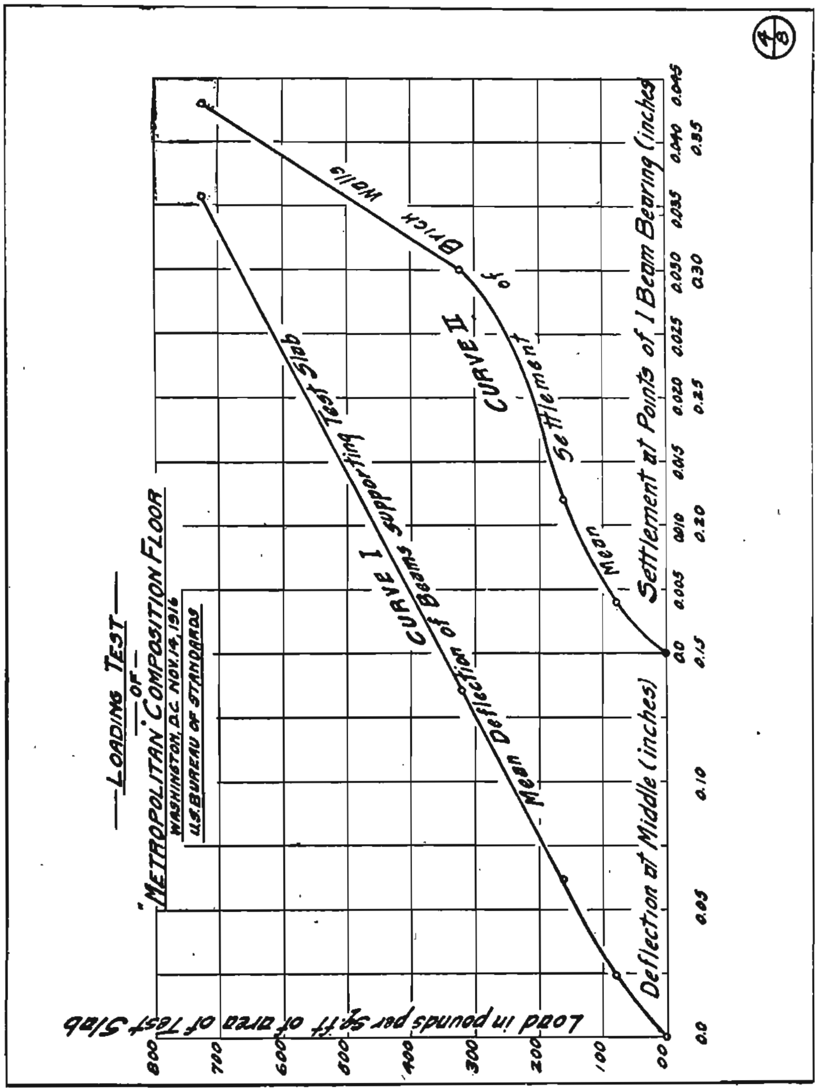

FIGURE 103

these exposed points double-screwed clips were attached to the cables. These clips were fitted with counter-sunk holes of size suitable to seat the points of a 20-inch Berry strain gauge, which instrument indicated the elongation between clips as the load was applied. These clips were so placed as to grip firmly both wires in each cable measured, thus assuring that the double wire acted as a unit.

EXHIBIT 5.

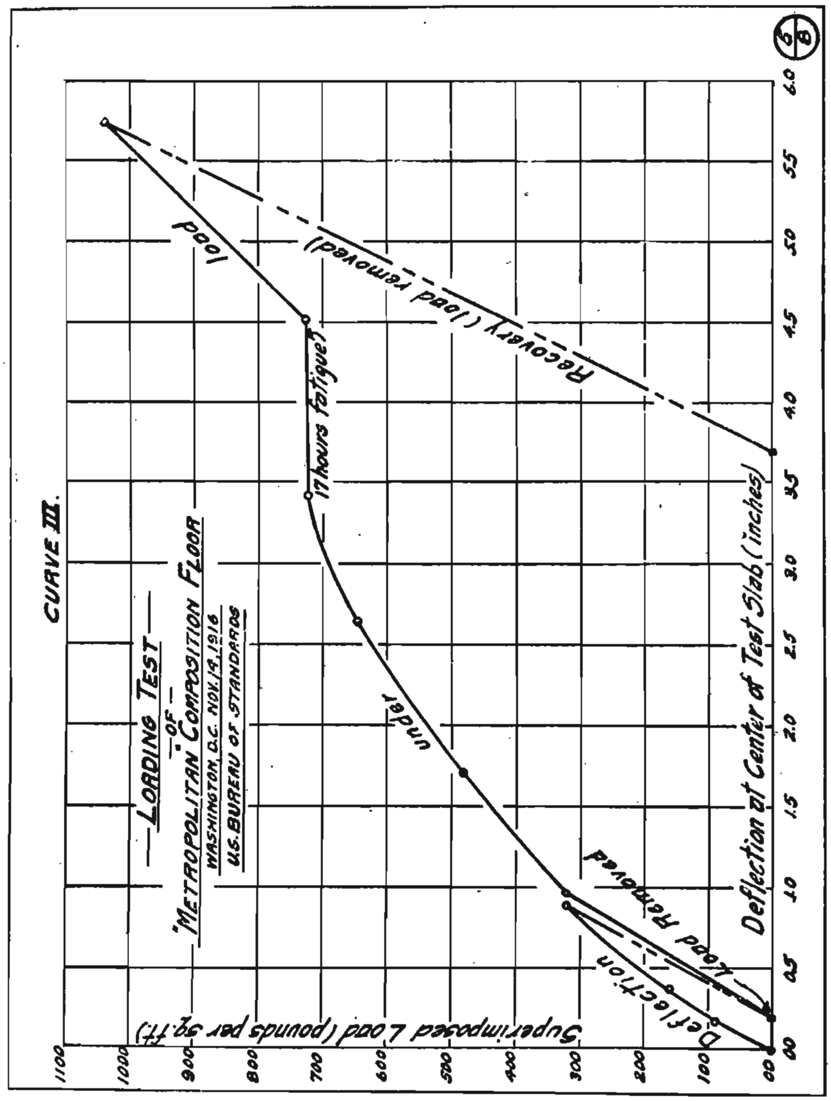

FIGURE 104

7. *Measurements of Deformation.*—As the various load increments were applied to the floor, determinations were made of the center deflection of the test slab, the middle deflection

of the two beams which supported the test section, the settlement of the brick walls at the points at which the supporting I-beams rested on the walls, and the elongation of the steel cables at nine points. The results of these measurements are shown in Tables I, II, and III, Exhibit 2 (figure 101).

In curves I and III, Exhibit 4 (figure 103), are plotted respectively the mean deflection of the supporting beams and the mean settlement of the brick walls. These values are used in making allowance for external influence in computing the net deflection of the floor from the values indicated by the deflectometer G.

The net deflection of the test slab is shown graphically in curve III, Exhibit 5 (figure 104). As indicated on this curve, at a load of 322 pounds per square foot, or somewhat more than double the allowable live load, the floor deflected 0.885 inch. When the load was removed and the floor allowed to stand free for thirty minutes, the floor returned to within 0.199 inch of its original unloaded position. Applying the load a second time caused a center deflection in the floor of 0.965 inch at a load of 322 pounds per square foot, which would seem to indicate a fatiguing action in the slab. With a load of 726 pounds per square foot, or approximately five times the allowable live load, the floor deflected 3.419 inches and leaving this load in place for seventeen hours caused a fatigue of 1.128 inches in the slab. Applying a load of 1,040 pounds per square foot deflected the floor 5.75 inches at the center. The steepness of curve III between these last two load points is probably attributable to the fact that at this stage of the loading the deflection of the floor was sufficient to lower the cables in the floor to a point where they were placed in practically direct tension and consequently the section of the curve mentioned above represents simply a tension deformation of the steel cables. When the total load was removed, the floor returned to a point 3.69 inches below its original unloaded position.

In curves IV (1 to 9), Exhibit 6 (figure 105), are shown the per cent elongation produced in the cables at six points spanning the supporting I-beams and at three points spanning the middle of the test slab. As shown on the curves, the stretch in the cables at the middle of the span was in general greater than at the points over the I-beams. This is especially noticeable in the early stages of loading.

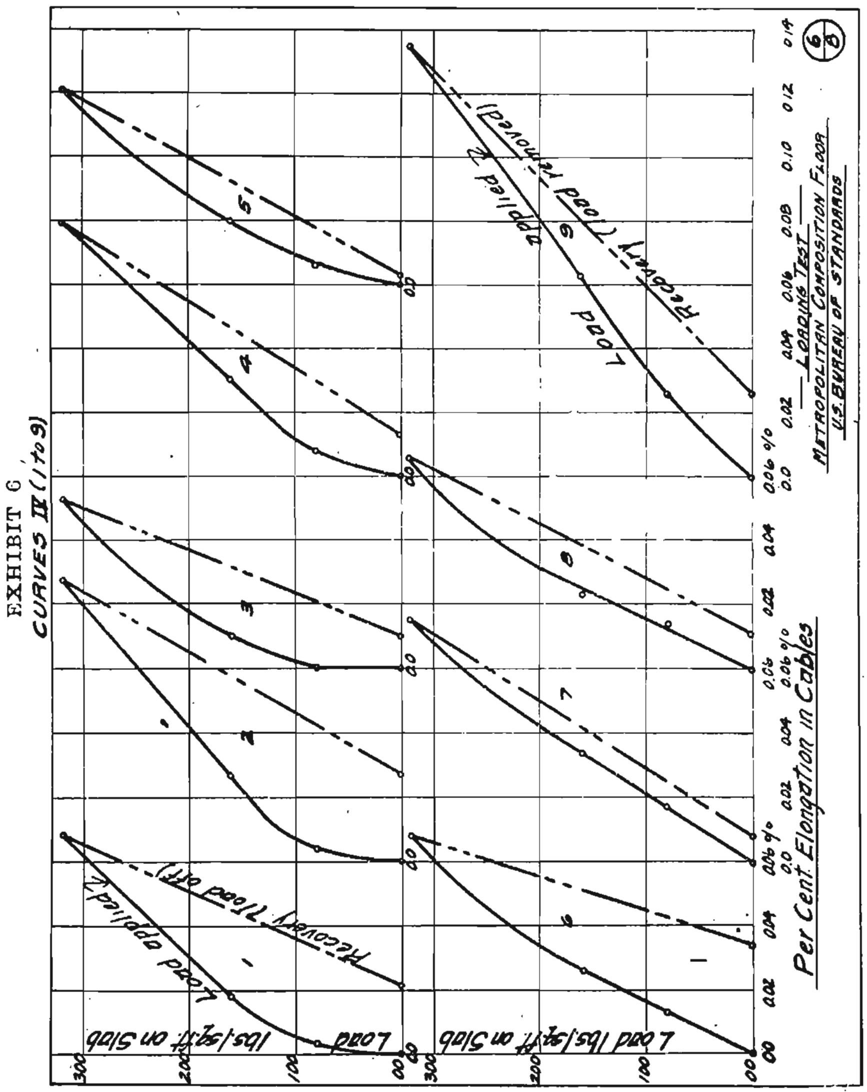

FIGURE 105

It could not be definitely ascertained as to whether spans 1, 7, and 4; 2, 8, and 5; and 3, 9, and 6 were in each case three spans on a common cable. However, these measurements were made on cables which were fairly representative of the wires at the three respective points. In curve 3 is a peculiarity in that no elongation was apparent for the first increment of

EXHIBIT 7

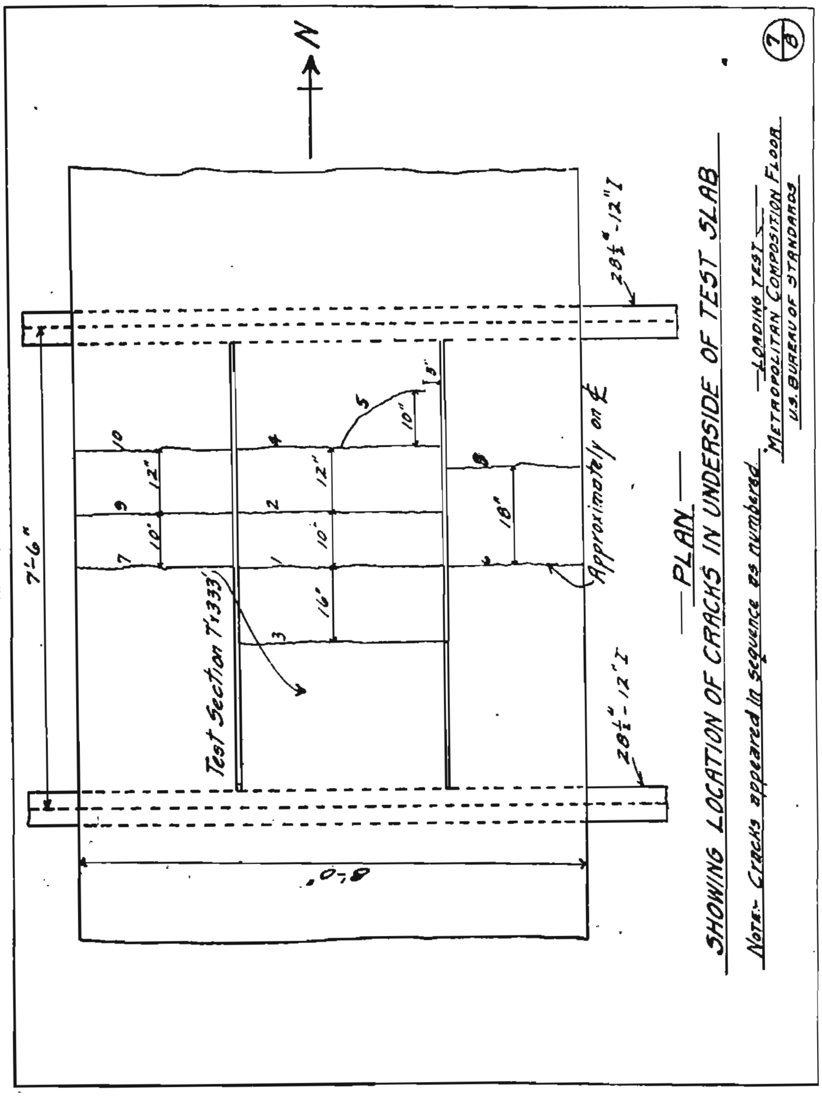

FIGURE 106

load. This may be due to the fact that some of the cables installed had slight irregularities or kinks in them. If this cable was in such a condition, it is evident that the kink would straighten out before direct tension would be noticeable in the span measurement.

8. *Observations.*—On Exhibit No. 7 (figure 106), are shown the location of cracks as they appeared in the underside of the floor. Cracks 1, 2, 3, 4 and 5 appeared as fine hair cracks at a load of 322 pounds per square foot. After the removal of this load the cracks closed and practically disappeared, showing considerable elasticity in the body of the floor. At a load of 726 pounds per square foot these three cracks opened about one-sixteenth inch, and cracks 6 and 7 appeared as fine lines on the surface. After seventeen hours cracks 6 and 7 had opened about one-eighth inch, 1 to 5 had opened about three-eighths inch, and cracks 8, 9, and 10 had formed one-sixteenth inch open. When the floor was loaded with 1,040 pounds per square foot cracks 1 to 5 opened to five-eighths inch and cracks 6 to 10 about three-eighths inch.

There was very little spalling of material from the underside of the floor, and most of the cracks formed practically parallel to the I-beams. Although cracks 6 to 10 were not in the actual test slab, they are of interest in that they show presence of a thrust action along the upper surface of the floor on both sides of the test section. This thrust was due to the overturning of the beams, as shown on Exhibit No. 8 (figure 107).

With the load of 726 pounds per square foot in place for thirty minutes an arching action commenced in the two panels adjacent to the test section, the panel on the south rising three-eighths inch at its center and the panel on the north rising three-fourths inch at its center. After seventeen hours these distances increased to three-fourths inch and two inches respectively. With the load of 1,040 pounds per square foot in place, these rises increased to 1¼ inches and 3⅛ inches, as shown on Exhibit No. 8 (figure 107). These measurements were made with a steel scale and not by means of a micrometer caliper. The extreme end panels showed no arching action, although there was a slight horizontal deflection of the outside I-beams. The four inner I-beams suffered a more perceptible horizontal deflection, the south beams deflecting less than those to the north. After the removal of the total load the four outermost I-beams returned to practically their original straight condition, but the two beams supporting the test slab suffered a permanent distortion.

EXHIBIT 8

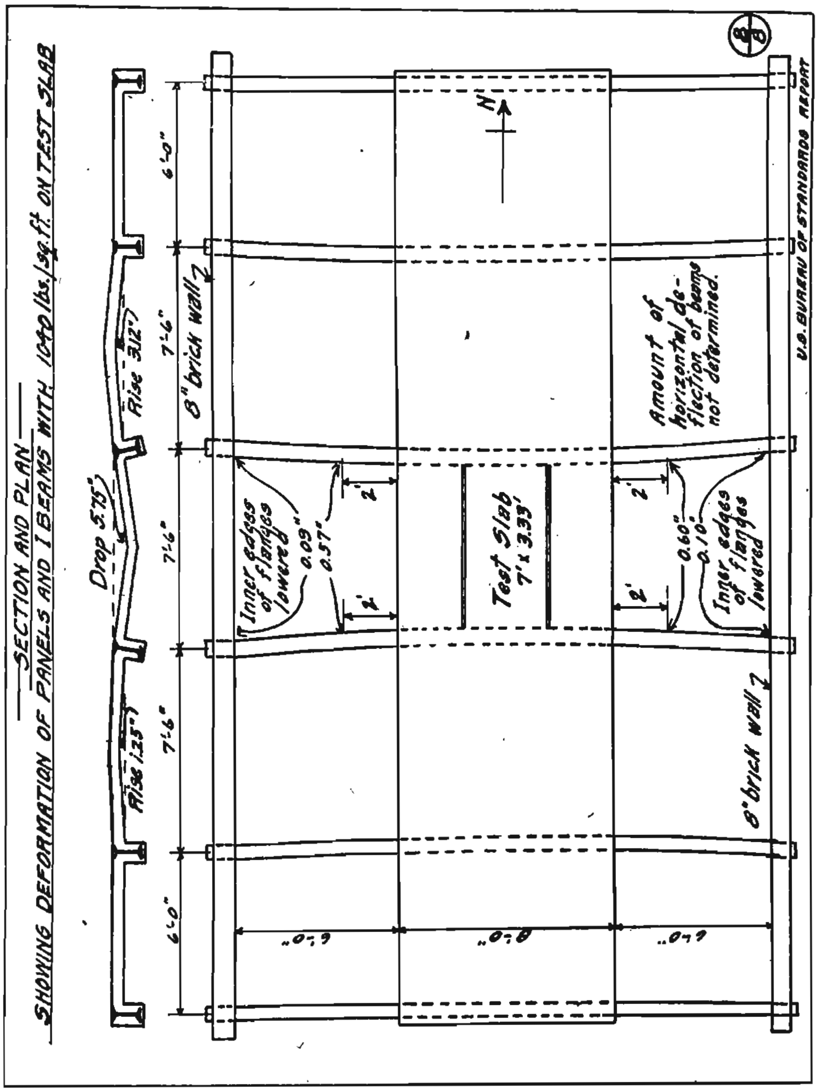

FIGURE 107

9. *Condition of Structure after Test.*—Two days after completion of the loading test sections thirty inches square were cut out from the center and ends of the test panel and from

the center of each of the other four panels. In the section taken from the test panel and the two adjacent panels there was no sign of the cables or cross rods having cut through the gypsum composition, the cross rods still being apparently the same distance above the bottom of the floor as when first measured, shortly after the floor was built. This was rather substantiated during the load test by the fact that when the cables in the panels adjacent to the test panel straightened horizontally under tension the slabs arched up, thus leaving the upper surface of the slabs in practically the same position relative to the cables and cross rods.

The cables in the various cut-out sections showed considerable rigidity or bond when jerked or shaken by means of a pair of pliers applied at alternate exposed sections three inches long, separated by sections three inches long, in which the cables were left covered with the composition. However, since, as noted above, there was an apparent horizontal tightening of the cables in the two slabs adjacent to the test panel there must have been a movement of the cables horizontally over the top flanges of the I-beams.

Laboratory tests are to be made of the ultimate crushing strength, the modulus of elasticity, and the bonding strength of the gypsum composition used in the floor.

Respectfully,

E. B. Rosa, *Acting Director.*

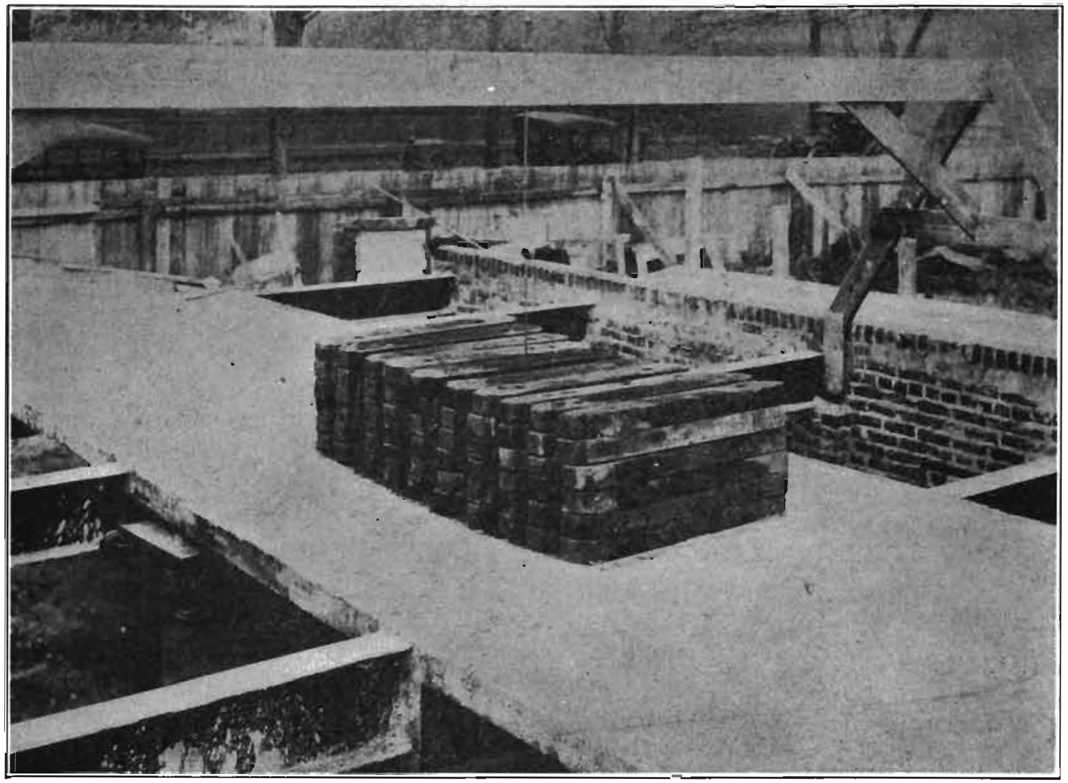

Photo showing the method of loading the gypsum roof in the tests described in text.

APPENDIX VII

EMLEY PATENT FOR PLASTIC GYPSUM
SPECIFICATIONS

To all whom it may concern:

Be it known that I, Warren E. Emley, a citizen of the United States, residing at Washington, in the District of Columbia, have invented new and useful improvements in the process of making plastic calcined gypsum, of which the following is a specification:

This application is filed under the Act of March 3, 1883, under the terms of which the applicant agrees that the invention described herein, if patented, may be used by the Government or any of its officers or employees in prosecution of work for the Government, or by any other person in the United States without the payment to him of any royalty thereon.

Calcined gypsum, or plaster of Paris, is a chemical compound of the formula $CaSO_4 . \frac{1}{2}H_2O$. It is of crystalline structure and sandy character. Because of this characteristic, calcined gypsum cannot be used alone for the white or finishing coat of plaster: the plasterer is not physically able to spread it. For the same reason, not more than two or three parts (by weight) of sand may be added to it in the preparation of the scratch or brown coats of plaster. This characteristic is described in the trade as "non-plastic".

It is quite possible to make a material sufficiently plastic for white coat work from calcined gypsum by the addition of other materials. It is known, for instance, that the addition of molasses, of certain other organic materials, or of loamy sand, will improve the plasticity of the calcined gypsum. In the 1919 Tentative Report on Gypsum Plasters, issued by the American Society for Testing Materials, it is stated that a neat gypsum plaster may contain up to 15 per cent of "hydrated lime, ground clay, asbestos, retarder, or fibre". In the 1920 report, this was changed to permit the addition of 15 per cent of "materials to control the working quality, setting time and fibering". It is general trade practice to add hydrated lime to calcined gypsum in the manufacture of neat gypsum plaster. In the 1919 report quoted above, it is recommended that plaster for white coat work be composed of 75 per cent lime putty and 25 per cent calcined gypsum. Practically all white coat plaster is composed of these two ingredients, although the proportions of them are variable.

If calcined gypsum is ground after calcination, one of two things may occur: If the grinding is not severe, the crystals will be reduced in size, but the sandy or non-plastic nature of the material will still remain. If the grinding is very severe, a chemical change can be made to occur, the water being actually ground out of the material. In actual practice, a buhr mill or tube mill is used for this grinding, and any water which is liberated is evaporated and carried off by the current of air passing through the mill. The resultant product is known as "soluble anhydrite". This is anhydrous calcium sulphate, but it differs from the naturally occurring anhydrite in that it has a great affinity for water. So great is this affinity that a few moments exposure to moist air is sufficient for it to recombine with enough water to change back to the original calcined gypsum. Because of this fact, and also because the soluble anhydrite is itself crystalline, the effect of this severe grinding is lost, and the product is still non-plastic. Commercial gypsum plasters consist mostly of calcined gypsum, with more or less soluble anhydrite and undecomposed gypsum.

I find that if calcined gypsum is ground severely so as to liberate the water, but in such a way that the water cannot escape, the resultant product has radically different properties. It is now plastic, rather than non-plastic. This can be proved by testing the material by means of the Carson blotter test as described in the Transactions of the National Lime Manufacturers Association, 1916, p. 175, or by means of a plasticimeter. It can be used alone as the white coat of plaster, and can be used with at least six parts (by weight) of sand for the scratch or brown coats. When compared with the original material, it will be found that it requires more water to mix it to a given consistency, that it sets more slowly, and that it will develop higher strength after setting. To use this material as a wall plaster, it will, of course, be necessary to retard it, using for this purpose the ordinary reagents which are used in the manufacture of wall plaster from calcined gypsum.

If it is not practicable to grind the calcined gypsum in such a way as to prevent evaporation of the liberated water, the same end can be attained by adding, either before or during the grinding, enough water to make up for the quantity evaporated, so that the final product will contain approximately one molecule of water to two molecules of calcium sulphate.

At a meeting of Committee C-7 on Lime, of the American Society for Testing Materials, held on January 12, 1821, directions were adopted for the use of the plasticimeter described in Bureau of Standards Technologic Paper No. 169, and for the calculation of "plasticity figures". It was also decided that a lime putty, to be satisfactory for finishing purposes (white-coat work) must have a plasticity figure of not less than 200.

This plastic calcined gypsum may be produced from substances other than calcined gypsum. The same end product will result if raw gypsum is ground in such a way that some, but not all, of its water is allowed to escape; or if the requisite proportion of water is ground into anhydrite, either soluble or natural.

Specifically, I find that if calcined gypsum is ground in a ball mill or similar sealed container, with such severity as to liberate the water of crystallization, the resultant product will be at least as plastic as "finishing" hydrated lime. This grinding may be either in addition to or in lieu of the usual grinding which is a part of the regular process of manufacture of calcined gypsum. The duration of the grinding, which determines the plasticity of the finished product, depends upon the quality (fineness) of the original material, and also upon the size of the mill. In a small laboratory mill, it required seven hours to produce one pound of material of the desired plasticity; in a larger mill, it required four hours for eighty pounds of material. I find that plastic calcined gypsum can be made by this method from calcined gypsum from any source, and that storage for four months does not cause any noticeable deterioration of its plasticity.

While it is true that in the academic sense all plastering materials, and even sand itself, have a measurable degree of plasticity, in the practical use of the word, a material is not considered plastic unless it has a certain minimum degree of plasticity. In the subjoined class the word "plastic" is taken to agree with the practical definition. That is to say, a material is plastic only when it can be used alone for the white coat of plaster. This degree of plasticity is readily ascertained by means of the Carson blotter test, or by means of the plasticimeter. When the latter instrument is used, the material is plastic only when the plasticity figure is greater than 200.

I claim:

1. The process of increasing the plasticity of calcined gypsum which comprises the grinding of the calcined gypsum and preventing evaporation of its water content.

2. The process of increasing the plasticity of calcined gypsum which comprises grinding the calcined gypsum in the presence of its water content.

3. The process of increasing the plasticity of calcined gypsum which comprises grinding the calcined gypsum to eliminate its water content only during the grinding operation.

4. The process of increasing the plasticity of calcined gypsum which consists in grinding the calcined gypsum to eliminate the water content during the grinding operation, preventing the escape of the said water content during the grinding step, and continuously keeping the above treated gypsum in contact with the water thus eliminated, ceasing the grinding operation, and permitting the water thus eliminated to be reabsorbed.

5. The process of increasing the plasticity of calcined gypsum which comprises grinding the calcined gypsum, with the addition, before the grinding operation, of enough water to make up for that lost by evaporation, during the grinding.

6. The process of increasing the plasticity of calcined gypsum which comprises grinding the calcined gypsum, with the addition, during the grinding operation, of enough water to make up for that lost by evaporation during the grinding.

7. A plastic calcined gypsum which is sufficiently plastic to be used without added ingredients for the white coat of plaster.

8. A plastic calcined gypsum which, when properly retarded, will give a plasticity figure of at least 200.

9. A plastic calcined gypsum having a plasticity figure of at least 200, the plasticity of which is not dependent upon the addition of any foreign material.

10. A plastic calcined gypsum having a plasticity figure of at least 200, the plasticity of which is not dependent upon the addition of lime.

In testimony whereof, witness my signature this day of February, 1921.

APPENDIX VIII.

TENTATIVE REPORT ON DESIGN OF REINFORCED GYPSUM BEAMS.[249]

The following recommendations are intended to apply to the design of simple beams of reinforced gypsum.[250]

It is assumed that:

1. The loads designed for are the weight of the structure and the static live loads.

2. The span length effective in causing moment is the distance between centers of supports.

3. Calculations will be made with reference to working stresses and safe loads for dry gypsum rather than with reference to ultimate strength and ultimate loads.

4. A plane section before bending remains plane after bending.

5. The modulus of elasticity of the gypsum is constant up to the ultimate load.

6. The ratio of the modulus of elasticity of steel to the modulus of elasticity of gypsum is 30.

7. In calculating the moment of resistance of beams the longitudinal tensile strength of the gypsum is neglected.

8. Initial stress in the reinforced gypsum due to the expansion or contraction of the gypsum is neglected. The cross-sectional area of gypsum effective in resisting the bearing pressure applied to it by the anchoring of the reinforcing bars is the projection of the anchor (either a hook or a plate) on a plane normal to the longitudinal axis of the beam.

It is recognized that the assumptions given are not entirely borne out by experimental data. They are given in the interest of simplicity and uniformity, and variations from exact condi-

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249Republished from
Proceedings of the American Society for Testing Materials,
Philadelphia, Penna.
Volume XIX, Part I, 1919.

250It is impossible within the scope of this report to give data on which the recommendations for design are based. The bibliography at the end of this report contains references to published literature supporting the report.

tions are taken into account in the selection of formulas and working stresses.

9. Reinforced gypsum as herein provided applies only to interior construction and to protected exterior construction.

10. Reinforced gypsum when used either in interior or protected exterior construction will be permitted to dry out as quickly as possible after hardening.

Tension and Compression.—The tensile stress in the reinforcement should not exceed 16,000 lb. per sq. in.[251].

The maximum compressive stress in a gypsum beam should not exceed 22 per cent of the ultimate compressive strength of the dry gypsum[252] to be used in the construction under consideration, when tested as a cylinder whose height is twice its diameter, and should not exceed 44 per cent of the ultimate strength of the gypsum when saturated[253] with water.

Modulus of Elasticity.—Results of tests indicate that the modulus of elasticity of dry gypsum is nearly constant up to the ultimate strength of the gypsum and that for saturated gypsum the stress-strain diagram approaches a parabola whose vertex is at the point representing the ultimate strength.

An approximate value of the modulus of elasticity for dry gypsum cast from a mixture of normal consistency is 1,000,000 lb. per sq. in.

Computations of stress in reinforced beams using such gypsum should be made on the basis of a ratio of $\frac{E_s}{E_g}=n=30$ for dry gypsum. No recommendation is made for beams using a gypsum mixture of other than "normal consistency." (See Tentative Methods for Tests of Gypsum and Gypsum Products).

Bond Strength, Bearing Strength, and Diagonal Tensile Strength.—Bond strength, bearing strength against anchor

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251This recommendation is the same as has been adopted by the Joint Committee on Concrete and Reinforced Concrete for tension in steel in reinforced-concrete beams. *Proceedings*, Am. Soc. Tst. Mats., Vol. XVII, Part I, pp. 202 ff. (1917).

252The term "dry gypsum" is used here to mean hydrated gypsum from which all water, except that which is combined as water of crystallization, has been evaporated. Drying the specimen to constant weight in air having a temperature of 70° F. and a relative humidity of 50 per cent will produce "dry gypsum." Committee C-11 will later prepare a specification to which reference will be made.

253The term "wet" or "saturated," as herein used, refers to hydrated gypsum which after being dried (as specified) has been immersed in water to complete saturation but not longer than one hour. (See Tentative Methods for Tests of Gypsum and Gypsum Products (Serial Designation: C 26–19 T) of the American Society for Testing Materials).

hooks or plates, and diagonal tensile strength of reinforced gypsum beams are so closely interrelated that they are discussed under one head.

Any provision which helps to prevent slipping of the reinforcing bars increases so markedly the diagonal tensile strength of a beam that mechanical anchorage at the ends of reinforcing bars should be used in all cases except those in which the bond stress and the diagonal tensile stress to be resisted are very small.

It may be assumed as a basis for design that when effective mechanical anchorage is furnished, the bond stress actually developed at any point along the bar is one-half of that computed on the basis of pure beam action, and that the remainder of the resistance is furnished by the truss action developed by anchoring the bars.

Test results on beams with anchored bars indicate that at the maximum load only about one-half of the tension in the reinforcing bars is developed by bond and that the remainder is developed by the anchorage of the bars.

It is recommended that the allowable working bond stress as computed by Eqs. 9 and 9 (*a*), given in percentage of the compressive strength of the hydrated gypsum to be used in the construction, be not more than 1 per cent in case mechanical anchorage is not furnished, nor more than 5 per cent in case mechanical anchorage, conforming with the requirements hereinafter stated, is furnished.

Test results indicate that truss action in the beam due to anchorage of the bars comes into existence early in the test. They indicate also that there is little difference in the effectiveness per square inch of the bearing area of the anchorage whether the anchorage be furnished in the form of U-hooks at the ends of bars or in the form of bearing plates rigidly attached at their centers to the reinforcing bars. Assuming that the effectiveness is the same for the two cases the average bearing unit pressure may be considered a measure of the value of the anchorage.

It is recommended that the allowable average bearing pressure to be used in determining the value of anchorage be taken as 40 per cent of the compressive strength of the dry hydrated gypsum to be used in the construction under consideration, or 80 per cent of the wet hydrated gypsum, and that Eqs. 10 or 11 be used for computing the bearing stress.

Test results have indicated a marked increase in the shearing strength of beams in which bars have been bent up for web reinforcement, over the strength of similar beams having no bars bent up.

It is recommended that the allowable working stress in shear, given in percentage of compressive strength of the dry hydrated gypsum to be used in the construction under consideration, be not more than 1.5 per cent for beams with no bent up bars but with or without mechanical anchorage at the ends of the bars, and 4 per cent for beams which have mechanical anchorage conforming to the recommendations in this report and which have bars bent up in conformity with the recommendations hereinafter specified.

In order that the working stresses in shear above named may be used in design:

(*a*) The angle Θ which the bent bar makes with the direction of the longitudinal axis of the beam should be not less than 18 nor more than 45 deg.;

(*b*) Except in cases of concentrated loading, one or more longitudinal reinforcing bars should be bent up at a section where the shearing unit stress is equal to or less than the allowable shearing stress for beams with no web reinforcement;

(*c*) In cases of concentrated loading where bending up of bars is necessary the distance between the load point and the first bend should not be greater than the depth of the beam, d;

(*d*) Proceeding from the point at which the first bar is bent up toward the end of the beam, other bars should be bent up at intervals not to exceed the distance s defined by Eq. 12.

(*e*) The distance from the last point of bending to the center of the support should be not greater than the distance s.

Between any section in the span and the section of zero shear the ratio of the total cross-sectional area of the bars bent up to the total cross-sectional area A_s should not exceed the value of $\frac{A_b}{A_s}$ given by Eq. 13 nor be less than the value given by Eq. 14.

One or more bars having a total cross-sectional area of not less than three-eighths of the total area, A_s, of the longitudinal reinforcement should extend throughout the length of the span in the bottom of the beam and these bars should have mechanical anchorage at their ends, except where the bond stress calculated by Eq. 9 is less than one per cent of the compressive strength of the gypsum.

The radius of bends except for U-hooks should be not less than $24a$.

The point of bending up is considered to be at the intersection of the axis of the inclined straight portion of the bar with the line parallel to the longitudinal axis of the beam and passing through the center of gravity of the longitudinal reinforcing area at the point of maximum moment.

Notation

The notation and equations used in computations for reinforced gypsum beams are the same as those recommended by the Joint Committee on Concrete and Reinforced Concrete to apply to corresponding terms and operations.[254] Modifications, additions, and omissions have been made where the two reports do not cover the same ground, but an attempt has been made to avoid conflict in the use of terms.

Definitions of all symbols used in the equations referred to and sketches illustrating their application are here given.

(*a*) *Dimensions and Angles.*

- d = depth of beam to center of steel;
- b = width of beam; for T-beams, width of flange;
- b' = width of stem of T-beam;
- jd = arm of resisting couple;
- kd = distance from compression surface to neutral axis;
- x = distance from section of zero shear to any section of the beam;
- i = distance from section of zero shear to center of reaction of beam;
- s = maximum allowable distance between points of bending up bars;

254Loc. cit.

a = diameter of reinforcing bar;
h = width of U-hook;
o = perimeter of reinforcing bar;
Σo = sum of perimeters of all reinforcing bars in beam;
θ = the angle which the bent-up straight portion of the reinforcing bar makes with the longitudinal axis of the beam.

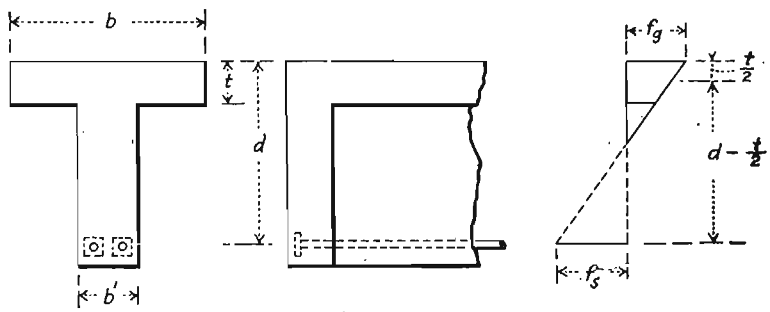

FIG. 108.

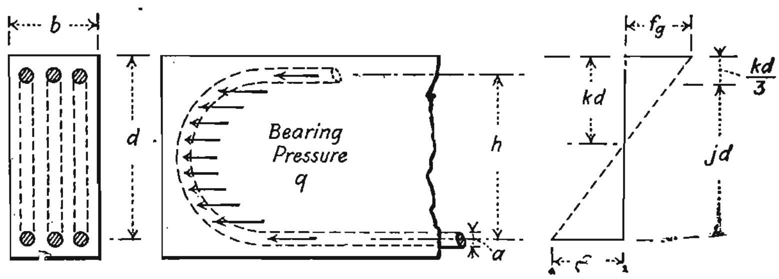

FIG. 109.

(*b*) *Areas.*

A_s = cross-sectional area of longitudinal reinforcement at point of maximum moment;
A_b = sum of cross-sectional area of bent-up bars between section of zero shear and any section at a distance x from the section of zero shear;
B = effective bearing area of anchor.

(*c*) *Moments, Stresses and Properties.*

M = bending moment or resisting moment;
f_s = tensile unit stress in steel;
f_g = compressive unit stress in gypsum;

f'_g = ultimate compressive unit strength of gypsum determined from 3 by 6-in. cylinders, or any other cylindrical test specimen whose height is twice its diameter;

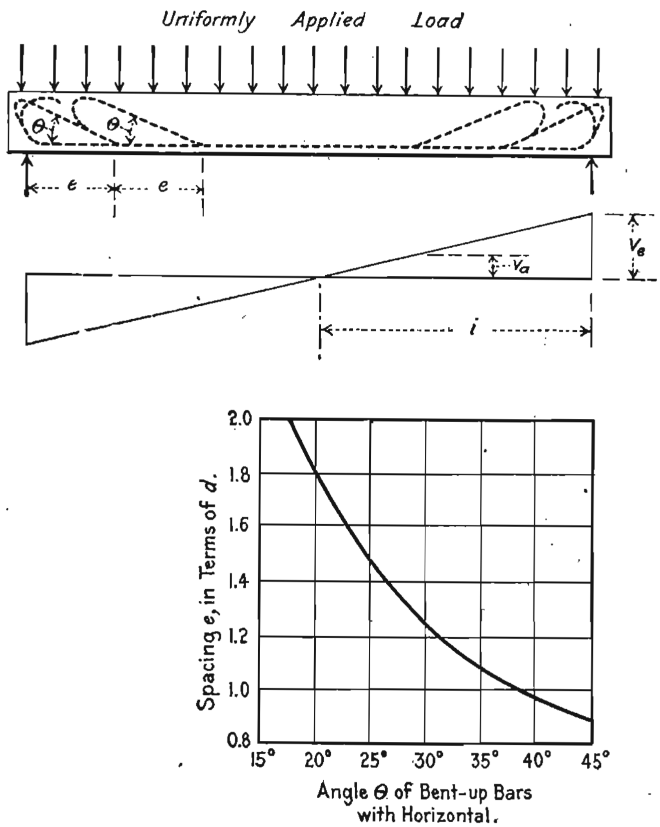

FIG. 110.—Curve showing spacing of bent-up reinforcement for various angles of bend, $e = \frac{0.62\ d}{\sin\ \theta}$ (See footnote to Eq. 12.)

v = shearing unit stress in gypsum;

v_a = allowable maximum shearing unit stress at reaction for beams without web reinforcement, or at first bend for beams with bent-up bars;

v_e = shearing unit stress at reaction of beam having bent-up bars;

u = bond unit stress between gypsum and steel;

q = bearing unit stress between gypsum and anchor;

E_s = modulus of elasticity of steel;
E_g = modulus of elasticity of gypsum.

(*d*) *Ratios.*

k = ratio of depth of neutral axis to depth d of beam;
j = ratio of arm of resisting couple of depth d of beam;
$n = \frac{E_s}{E_g}$, ratio of modulus of elasticity of steel to that of gypsum;
p = steel ratio $= \frac{A_s}{bd}$.

Summary of Equations for Computations for Reinforced Gypsum Uniformly Loaded, Simple Beams.

Rectangular Beams.

$$f_s = \frac{M}{A_s jd} = \frac{M}{pjbd^2} \qquad (1)$$

$$f_g = \frac{2pf_s}{k} = \frac{2M}{kjbd^2} \qquad (2)$$

$$v = \frac{V}{bjd} \qquad (3)$$

$$k = \sqrt{2pn + (pn)^2} - pn \qquad (4)$$

T-Beams.[255]

$$f_s = \frac{M}{A_s\left(d - \frac{t}{2}\right)} \qquad (5)$$

$$f_g = \frac{M}{bt\left(d - \frac{t}{2}\right)} \quad \frac{kd}{kd - \frac{t}{2}} \qquad (6)$$

$$v = \frac{V}{b'\left(d - \frac{t}{2}\right)} \qquad (7)$$

$$kd = \frac{2ndA_s + bt^2}{2nA_s + 2bt} \qquad (8)$$

Either Rectangular Beams or T-Beams

$u = \frac{V}{jd\Sigma o}$ (to be used when no anchorage is used) ..... (9)

$u' = \frac{1}{2}\frac{V}{jd\Sigma o}$ (to be used when anchorage conforming with requirements is furnished) ..... (9*a*)

$q = \frac{\pi a^2 f_s}{8B}$ (used when anchorage is furnished by means of plates rigidly attached at their center to the reinforcing bar) ..... (10)

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[255] For all T-beams in which the neutral axis falls within the flange the equations will be the same as for rectangular beams except Eq. 7 for shear, in which for all T-beams the width b' of the stem should be used instead of the width b of the flange. Because of the low position of the neutral axis found with so high a value of n as 30 it will seldom be found that the neutral axis lies within the flange. For cases in which the value of p is less than 0.002 or in which t/d is 0.3 or more, the position of the neutral axis should be determined by means of the formula for rectangular beams. The substitution of $(d-t/2)$ for jd is an approximation giving errors of not more than about 2 per cent for the majority of cases. For more exact formulas for T-beams, reference is made to the Report of the Joint Committee on Concrete and Reinforced Concrete. *Proceedings*, Am. Soc. Test. Mats., Vol. XVII, Part I, p. 260 (1917).

$$q = \frac{\pi f_s}{8}\frac{a}{h}$$ (used when anchorage is furnished by means of U-hooks on the ends of the reinforcing bars) ....(11)

$$e = \left\{\frac{2}{3\tan\theta} + \frac{1}{2}\tan\theta - \frac{1}{6}\right\} d$$ ....(12)[256]

$$\frac{A_b}{A_s} \begin{matrix} = \\ < \end{matrix} \left\{\frac{x}{i}\right\}^2$$ ....(13)

$$\frac{A_b}{A_s} \begin{matrix} = \\ > \end{matrix} 0.7\left\{\left\{\frac{x}{i}\right\}^2 - \left\{\frac{v_a}{v_e}\right\}\right\}^2$$ ....(14)

Summary of Permissible Working Stresses and Constants.

The working stresses are expressed in terms of the ultimate strength wet and of the ultimate strength dry. In all cases the lower of the two values should be used. Stresses and moduli are given in pounds per square inch.

f_s	16,000
f_g	0.22 f'_g (dry specimen) 0.44 f'_g (wet specimen)
v_a	0.015 f'_g (dry specimen) 0.030 f'_g (wet specimen)
v_e	0.040 f'_g (dry specimen) 0.080 f'_g (wet specimen)
u (for beams without anchorage)	0.01 f'_g (dry specimen) 0.02 f'_g (wet specimen)
u' (for beams with anchorage)	0.05 f'_g (dry specimen) 0.10 f'_g (wet specimen)
q	0.40 f'_g (dry specimen) 0.80 f'_g (wet specimen)
E_s	30,000,000
E_g (for dry hydrated gypsum from mixture of normal consistency)	1,000,000
n (for dry hydrated gypsum)	30

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[256] It has been found, upon further study, that Eq. 12 may be stated more simply as:

$$e = \frac{0.62\ d}{\sin\theta}$$ (See Fig. 110.)

The values of s as given by the two equations are approximately the same. However, the equation here proposed gives a slightly smaller maximum spacing than the first equation. The main advantage in the change is that of simplicity, and this advantage is considerable. With the second equation the distance between bent-up bars measured at right angles to their direction is held constant at 0.62d.

EXPLANATON OF FIGURE 111.

The upper curve of Figure 111 (the graph of Eq. 13) is a parabola with its vertex at the lower left-hand corner of the diagram. Taking the bottom of the beam as drawn, as the zero line, the parabola may be used to represent a moment curve for the beam under uniform load. Therefore, the vertical distance from the bottom of the beam to the curve at any

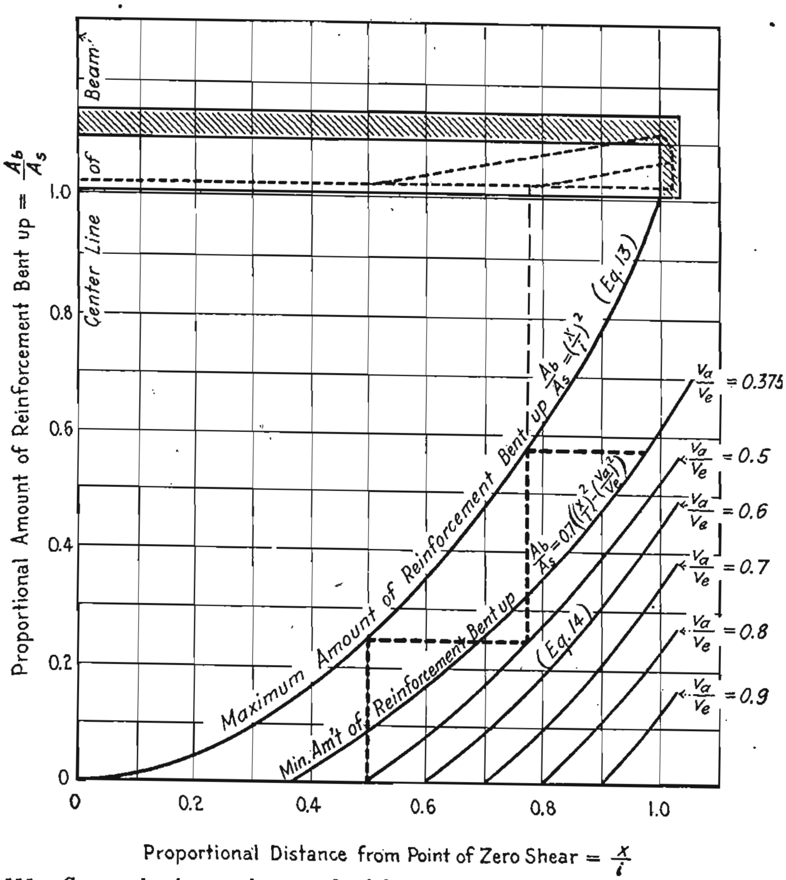

FIG. 111.—Curves showing maximum and minimum amounts of bent-up reinforcement. These curves are graphs of Eqs. 13 and 14, as indicated.

point will be proportional to the area of longitudinal reinforcement required at that point, and the vertical distance to the curve from the horizontal line tangent to it at its vertex will be proportional to the total amount of reinforcement which may be bent up for web reinforcement between the center of the span (or the point of zero shear) and the point considered. Therefore this parabola represents the maximum amount of reinforcement which may be bent up.

The other curves on the sheet represent the minimum amount of reinforcement which must be bent up for different designs in which the end shear varies from the maximum allowable amount ($0.04f'_g$) to the lowest for which web reinforcement is required ($0.015f'_g$).

In any beam the first point at which web reinforcement will be required is the point at which the shearing unit stress is $0.015f'_g$.

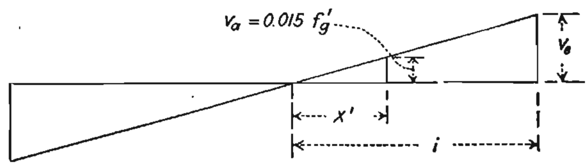

FIG. 112.

Letting x' be the distance from the point of zero shear to the first point of bending, it is apparent from figure 112 that

$$x' = \frac{v_a}{v_e} i = \frac{0.015\ f'_g}{v_e} i.$$

Using various values of the end shear v_e, ranging from $0.04f'_g$ down to $0.015\ f'_g$, corresponding values of x' are found and through these points curves are drawn which represent the minimum amount of bent-up reinforcement required for these cases. These latter curves are graphs of Eq. 14 with different values of $\frac{v_a}{v_e}$ substituted.

Solution.—To illustrate the practical use of the diagram let it be required to design the web reinforcement of a beam 8 ft. long to carry a load of 228 lb. per lin. ft. (dead and live load), using gypsum whose ultimate strength is 1600 lb. per sq. in. The allowable end shear is $0.04 \times 1600 = 64$ lb. per sq. in.; but if it be assumed that the minimum section for this span is as shown in figure 113, the end shear will be:

$$v_e = \frac{W/2}{b'(d - t/2)} = \frac{912}{262 \times 7.25} = 48 \text{ lb. per sq. in.}$$

$$v_a = 0.015 \times 1600 = 24 \text{ lb. per sq. in., and}$$

$$x' = \frac{v_a}{v_e} i = \frac{24}{48} i = 0.5\ i.$$

Therefore the first bar will be bent up midway between the center of the span and the support as shown by the stepped line in the diagram, and the intersection of the "riser" of the first step with the parabola shows that one-fourth of the longitudinal reinforcement may be bent up here. The intersection

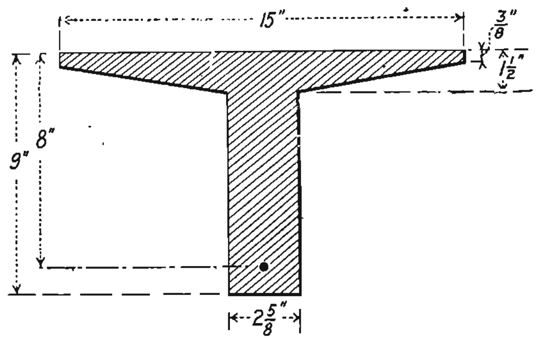

FIG. 113

of the "tread" of the first step with the minimum curve shows that the next bend may be at a distance not greater than 0.76 i from the center of the beam. The riser of the second step shows that at this point the total amount of bent up reinforcement must be not greater than about $0.59A_s$. The horizontal line through this point passes above the minimum of the bent-up reinforcement required at the end of the beam and below the maximum allowed at this place, hence the amount of reinforcement bent up is satisfactory. This gives two bends, but if the "treads" of the steps shown were greater than the maximum spacing allowed by Eq. 12 it would be necessary to design the beam with a larger number of bars of smaller area so that bends might be made at closer intervals. Any arrangement of bends which falls between the limiting curves and provides not less than three-eighths of the total area as "through" bars is allowable.

The combination which employs one 1/4-in. round, one 1/4-in. square and one 5/16-in. round nearly meets the conditions required as shown.

ADDENDUM

Mr. Slater wished to have certain changes made in the report on Design of Reinforced Gypsum Beams which is published above but since this is a committee report (though prepared by Mr. Slater) it has seemed best to print these suggested changes separately rather than to incorporate them in the main body of the report. The changes which are suggested are as follows:

Page 457. Omit portion beginning with "In order that the working stresses" in the fourth paragraph, and ending with "should not be greater than the distance *s*", at the end of the ninth paragraph. For the omitted portion above outlined substitute the following:

"The allowable shearing stress at any section within the distance *s*, however, should not exceed

$$(1)\quad v = .015\, f'_g + \frac{A_v}{bs}(\sin\Theta + \cos\Theta)\, f_s \text{ when } \Theta \text{ is less than } 45^\circ$$

or

$$(2)\quad v = .015\, f'_g + \frac{A_v}{bs\sin\Theta} f_s \text{ when } \Theta \text{ is } 45^\circ \text{ or greater.}$$

The distance *s* measured in the direction of the axis of the beam between two successive stirrups or between two successive points of bending up of bars or from the point of bending up of a bar to the edge of the support should not be greater than that given by the equation

$$(3)\quad s = \frac{40}{\Theta} d \text{ where the angle } \Theta \text{ is given in degrees.}$$

Page 457. Omit from the last two lines the words "nor be less than the maximum value given by equation (14)."

Page 459. Add under "(b) Areas":

A_v = right sectional area of bars bent up (or of stirrups) within the distance *s*.

Page 459. Change definition of f_s to the following:
f_s = tensile unit stress in longitudinal or in web reinforcement.

Page 460. Omit symbols v_a and v_c and their definitions.

Page 462. Substitute new equations 12 and 14 for the old ones and add new equation 15, as follows:

$$(12)\quad s = \frac{40}{\Theta} d$$

$$(14)\quad v = .015\, f'_g + \frac{A_v}{bs}(\sin\Theta + \cos\Theta) f_s \text{ when } \Theta \text{ is less than } 45^\circ.$$

or

$$(15)\quad v = .015\, f'_g + \frac{A_v}{bs \sin\Theta} f_s \text{ when } \Theta \text{ is } 45^\circ \text{ or greater.}$$

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APPENDIX IX

GYPSUM COMPANIES OPERATING IN THE UNITED STATES, CANADA AND MEXICO IN 1921

Acme Cement Plaster Co.
703 Frisco Bldg., St. Louis, Mo., Works—Acme, Tex.; Acme, N. M.; Cement and Acme; Okla.; Laramie, Wyo.; Grand Rapids, Mich.; Gypsum, Ore.; Los Angeles & Palmdale, Cal.; Marlow, Okla.

Albert Manufacturing Co.
Hillsborough, N. B., Can.; Sales Offices—30 Church St., New York City, N. Y.

American Cement Plaster Co.
Lawrence, Kansas; General Sales Office—Chicago, Ill.; Sales Offices—Chicago, Ill.; St. Louis, Mo.; Minneapolis, Minn. Fort Dodge, Iowa; Kansas City, Mo.; Milwaukee, Wis. Works Agatite, Tex.; Blue Rapids, Kans.; Grand Rapids, Mich.; Fort Dodge, Iowa; Gypsum, O.; Milwaukee, Wis.; and Akron, N. Y.

American Gypsum Co.
Livingston Bldg., Rochester, N. Y.; Works—Akron, N. Y.

American Gypsum Co.
Port Clinton, O.; Cleveland, O.; and Detroit, Mich. Works—Port Clinton and Cleveland, O.; and Detroit, Mich.

American Keene Cement Co.
Sigurd, Utah; Sales Offices—Salt Lake City, Philadelphia, Chicago and San Francisco.

Arden Plaster Co.
411 Merchants Nat. Bk. Bldg., Los Angeles, Cal.

Arizona Gypsum Plaster Co.
Douglas, Ariz.

Best Bros. Keene's Cement Co.
Medicine Lodge, Kan.; Sales Offices—New York and Chicago; Works—Medicine Lodge, Kan.

Bestwall Mfg. Co.
McCormick Bldg., Chicago, Ill.; Sales Offices, Chicago; Cleve-

land, O.; New York, N. Y.; St. Louis, Mo.; Works—Grand Rapid, Mich., and Akron, N. Y.

Black Hills Rock Products Co.
(Successor to Rapid City Gypsum, Lime & Portland Cement Co.)
Rapid City, S. D.

Cardiff Gypsum Plaster Co.
Fort Dodge, Iowa; Works—Gypsum, Iowa (no P. O.).

Cayuga Gypsum Co.
Ithaca, N. Y.; Quarries—Union Springs, N. Y.

Centerville Gypsum Co.
Centerville, Iowa.

Chazy Marble Lime Co.
Chazy, N. Y.

Colorado Portland Cement Co. (Gypsum)
Denver, Colo.; Works—Portland, Colo.; (Plaster, Red Buttes, Wyo.)

Conneaut Lake Marl Co.
Meadville, Pa.; Works—Harmonsburg, Pa.

Construction Materials Co.
133 W. Washington St., Chicago, Ill.; Works—20th Ave and Georgia St., Gary, Ind.

Dakota Plaster Co.
Rapid City, S. D., Works—Black Hawk, S. D.

Empire Gypsum Co.
Cutler Bldg., Rochester, N. Y.; Mills—Garbutt, N. Y.

Globe Plaster & Mining Co.
Commerce Bldg., Kansas City, Mo.; Works—Globe (P. O. Carlsbad), N. M.

Grand Rapids Plaster Co.
1204 Grand Rapids Savings Bank Bldg., Grand Rapids, Mich.; Works—Grand Rapids (Eagle Mills) and Grandville, Mich.

Higginson Mfg. Co.
Office and Works—Newburgh, N. Y.

International Gypsum Corp., Ltd.
Annapolis Royal, Nova Scotia; Sales Offices, Montreal, Que., Can.; Works—Eastern Harbour, Nova Scotia.

Iona Gypsum Co.

Iona, Nova Scotia.
*Iowana Plaster Co.
Fort Dodge, Iowa.
Jumbo Plaster & Cement Co.
Sigurd, Utah.
Kelly Plaster Co.
Butler, Pa.; Sales Office—Sandusky, O.; Works—Castalia, O.
J. B. King & Co.
17 State St., New York City; Sales Offices—Boston, Mass.; Buffalo, N. Y.; Philadelphia, Pa.; and Norfolk, Va.; Works—New Brighton, N. Y. and Roslyn, N. Y.
La Tolteca Cia De Cemento Portland, S. A.
Avenida Independencia No. 8, Mexico City, Mexico.
Lycoming Calcining Co.
120 W. Fourth St., Williamsport, Pa.; Works—Garbutt, N. Y.
Manitoba Gypsum Co., Ltd.
504 Loan & Trust Bldg., Winnipeg, Man., Can.; Works—Gypsumville and Winnipeg.
Michigan Gypsum Co.
Grand Rapids, Mich.
Clifford L. Miller Co.
110 E. 23rd St., New York City, N. Y.; Works—Brooklyn, N. Y.
National Wall Plaster Co. of America.
830 New Bank Bldg., Syracuse, N. Y.; Works—Dewitt, N. Y.
Nephi Plaster & Mfg. Co.
322 Ness Bldg., Salt Lake City, Utah; Works—Gypsum, Utah.
Newark Plaster Co.
Newark, N. J.; Sales Office—30 Church St., New York, N. Y.
Niagara Gypsum Co.
Oakfield, N. Y., Sales Offices—597 Michigan Ave., Buffalo, N. Y.; Works—Oakfield, N. Y.
Oklahoma Portland Cement Co.
Denver, Colo.; Sales Offices—Oklahoma City, Okla.; Works—Ada and Homestead, Okla.
Overland Cement Plaster Co.
Laramie, Wyo.
Pacific Coast Gypsum Co.
403 Perkins Bldg., Tacoma, Wash.; Mine—Gypsum, Alaska.
Pacific Portland Cement Co., Consolidated.

* Taken over by the Universal Gypsum Co. in 1922.

827 Pacific Bldg., San Francisco, Calif.; Works—Mound House, Nev.

Phoenix Gypsum Co., Inc.

Livingston Bldg., Rochester, N. Y.; Mines—Wheatville (no P. O.), N. Y.

*Plymouth Gypsum Co.

Fort Dodge, Iowa; Branch Offices—211 Lumber Exchange, Minneapolis, Minn.; 1313 Chamber of Commerce Bldg., Chicago, Ill.; Builders Exchange, Milwaukee, Wis.

Puget Sound Cement and Lime Co.

424 New York Blk., Seattle, Wash.

Red Buttes Cement & Plaster Co.

606 Ideal Bldg., Denver, Colo.; Works—Red Buttes, Wyo.

Rock Plaster Corporation.

(Successor to Rock Plaster Mfg. Co.)

381 Fourth Ave., New York; Works—150th St. and East River, N. Y.

Southern Gypsum Co., Inc.

North Holston, Va., and Chicago, Ill.; Works—North Holston, Va.

John E. Stewart

Plaster Rock, N. B., Can.

Superior Plaster Co.

925-931 Dime Bank Bldg., Detroit, Mich.; Works—foot of Lycaste Ave., Detroit, Mich.

Texas Cement Plaster Co.

Hamlin, Tex., Sales Offices—Oklahoma City, Okla.; Works—Plasterco, Tex.

Three Forks Portland Cement Co.

Denver, Colo.: Sales Offices—Butte, Mont.; Works—Hanover and Trident, Mont.

Turkey Creek Stone, Clay & Gypsum Co.

304 Central Block, Pueblo, Colo.; Works—Stone City, Col.

United States Gypsum Company

205 Monroe St., Chicago, Ill.; Sales Offices—Boston, Mass.; Buffalo, N. Y.: Chicago, Ill.; Cincinnati and Cleveland, O.; Denver, Colo.; Detroit, Mich.; Kansas City, Mo.; Los Angeles, Calif.; Milwaukee, Wis.; Minneapolis, Minn.; New York, N.

* Taken over by the Universal Gypsum Co. in 1922.

Y.; Omaha, Neb.; Philadelphia and Pittsburgh, Pa., St. Louis, Mo.; and Washington, D. C. Works—Alabaster, Mich.; Piedmont, S. D.; Blue Rapids, Kan.; Cleveland, O.; Eldorado, Okla.; Fort Dodge, Iowa; Gypsum, Ohio; Southard, Okla; Genoa, O.; Grand Rapids, Mich.; Oakfield, N. Y.; Plasterco, Va.; Detroit, Mich.; Milwaukee, Wis.; Denver and Loveland, Colo.; Amboy, Calif.; Arden, Nev.

Utah Natural Products Co., Inc.
Sigurd, Utah; Sales Offices—Salt Lake City, Utah.

Wassem Plaster Co.
720-721-722 Snell Bldg., Fort Dodge, Iowa; Works—3 miles southeast of Fort Dodge, Iowa.

Windsor Plaster Co., Ltd.
Windsor, Nova Scotia.