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The effect of clays on the properties of masonry cement

William Joseph Smothers

THE EFFECT OF CLAYS ON THE PROPERTIES OF MASONRY CEMENT

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INTRODUCTION

Portland cement is not a material of great antiquity. It was discovered only a little over a century ago and quite by accident. It has been the custom in the manufacture of hydraulic limes to heat argillaceous limestones to temperatures not greatly above that at which the carbon dioxide would be liberated, but this process was carried out in a stack furnace under conditions such that some parts of the material were heated to temperatures which produced sintering. These hard lumps of sintered material were discarded because they were so much more difficult to grind than the unsintered material. However, in 1824, Aspdin ground some of these hard lumps and, in confirmation of a report of Vicat, found that they produced a cementing material far superior to any of those formerly produced by the old process. To this the name "portland cement" was given because of a similarity in sppearance, when made into concrete, to a natural rock quarried on the Isle of Portland in England.

Cement manufacturers are naturally interested in new developments and one of these is the use of clay as a plasticizer in cements to be used by masons. The object of this investigation is to study the effects of clay admixtures to masonry cement.

THEORY

Masonry cement usually consists of a mixture of Portland cement and hydrated lime. At present, the manufacturers of cement have gone into the production of prepared masonry cements by adding such materials as finely ground limestone, finely ground shale, or clay refuse from common clay ware manufacturing plants. In the last few years, efforts have been made to correlate properties of the admixed material with the properties of the cement. However Grant, in 1891, reported the results of tests on a sample of well washed sand compared with one containing 18 per cent of clay in a mortar composed of one part of cement and two parts of sand.[1]

The most important function of a brick masonry mortar is to bind the masonry units into a strong durable structure. Insofar as strength is concerned, Portland cement mortar is more than adequate, but a number of other properties are concerned in establishing their utility.

[1]Grant, W. H., Notes on Cement, Mortars, and Concrete; Trans. Amer. Soc. Civil Eng.; 25, 498, September, 1891.

The lime technology literature is replete with information on mortars. Some differences of opinion exist in regard to matters of detail, but there is a general agreement that the following properties are determining factors in the quality of brick masonry mortars:[2]

1. The mortar should have excellent adhesion to the brick. This is especially important for the vertical joints which are not under pressure and hence may be subjected to tensile stresses.
2. It must produce maximum waterproofness of the wall by reason of its durability of adhesion under conditions of service.
3. The mortar should have such body characteristics that it will not fall away when the joints are formed, thereby saving mortar.
4. It must have good plasticity and workability, thereby making it possible to lay more wall per day and permitting better trowelling which is conducive to good workmanship.
5. It should, by its attraction for moisture and the sealing of the pores in the mortar, retain water long enough and in sufficient

[2] Schurecht, H. G., Corbman, M.; Use of New York State Clays in Masonry Mortars, New York State College of Ceramics, Alfred, N. Y.

amount for the cement to set properly.

6. It should not dry out rapidly on the mason's boards.

7. The mortar must not burn or bleach mortar colors, nor should it be injurious to the mason's hands.

8. It must be of superior quality in its resistance to deterioration by heat.

9. It should be made of ingredients which do not have to be added in the form of a putty, and of such a character that tender's labor is reduced to a minimum in making the mortar.

10. It must not cause efflorescence on the brick work.

11. It should remain fairly constant in volume under conditions of service.

12. The mortars should be resistant to freezing to insure a durable bond in freezing climates.

Mortar ingredients known as plasticizers perform the functions listed above, but those that have been and are being used vary a great deal in their effectiveness. Some plasticizers function effectively in one or more respects but are deficient in others. The most satisfactory plasticizer is the one that performs all these functions in maximum degree at minimum cost.

It was not until quite recently that the superior quality of clay as a masonry mortar plasticizer was demonstrated. Probably the first use of clay as a plasticizer in mortar was about 1884 when a cement mortar containing clay was used in constructing some kilns at Brazil, Indiana. It was claimed that these mortars proved to be more resistant to weathering than those in which other plasticizers were used.[3] In 1888 a building was erected by Ayer, McCorel, Regan Co. near Brazil with mortar containing fire clay substituted for one-half of the cement. Thirty-five years later, an inspection of this building showed the mortar to be in an exceptionally good condition.

According to Anderegg,[4] a fire clay stratum in western Pennsylvania at Kittanning yields, on hard burning, an extremely vitreous brick of very low absorption, almost pure white in color. For many years the brick makers themselves have been using a mortar made of portland cement with about 25 per cent of this clay admixture. The writer has examined such mortar after it had been

[3]Straight, H. R., Clay Manufacturers Find a New Market Using Waste Clay for Mortar Mix, Brick and Clay Record, 85, 2, 51-52, August 1934.

[4]Anderegg, F. O., Mortar Properties Improved by Adding Mortar Mix, Brick and Clay Record, 90, 5, 280, May 1937.

exposed for ten years and could detect no evidence of weather.[4] He then made some similar mortar and placed in a very exposed position and has been able in five years to observe no evidence of weathering action. Sharp points purposely left have remained apparently as sharp as ever.

In pioneer days clay was often the only material for mortar, and had to be renewed every year or two. Then lime became available and has been used for a great many years, but its durability in chimneys and other exposed positions was unsatisfactory, so that when portland cement came into use many went too far to secure strength and durability.

By proper proportioning of portland cement and lime, with special regard to the absorption rate of the masonry unit, joint thickness and season of the year, satisfactory workability and durability are secured. Valuable and well balanced results have been obtained by replacing part of the lime with properly ground limestone, the end product of the lime. Others have used various clays and shales, and when their choice has been fortunate, often very excellent results have been obtained.

As a result of the manufacturers' experiences, and the many engineering tests which Iowa State College at Ames has made, it is now believed that any clay plant having a clay not too high in alumina and organic matter can prepare a mortar mix which will pass specifications.[5]

In general, the presence of clays in sands for concrete and mortar has been rightly regarded with suspicion, because most clays in sands are contaminated with organic matter which interferes with the setting and hardening of the portland cement.[6] In addition, many clays contain appreciable quantities of alkali metal compounds which are set free in the mortar or concrete by base exchange with lime. These alkalis then are apt to appear as unsightly efflorescence on the surface of the wall. The sodium hydroxide test used on sands for concrete will give a satisfactory estimate of deleterious organic matter, while an efflorescence experiment provides information concerning alkali compounds. Moisture is drawn up through the specimens and on evaporating from the sides leaves an encrustation of alkali salts if present. If practically none appear within two weeks the clay may be regarded as satisfactory.

About 1924, Johnston Bros. Company of Fort Dodge, Iowa, developed a market among silo builders for mortars containing fire clay which they called "Mortar Mix."

[5]Brick and Clay Record, 51, August 1934.

[6]Anderegg, F. O., Mortar Properties Improved by Adding Mortar Mis, Brick and Clay Record, 90, 5, 280, May 1937.

In 1930 and 1933, Spangler[7] reported the results of tests on mortars containing clay and found that when ground clay was used up to 35-50% (by volume) in place of the cement, mortars were produced which were at least as strong and durable as those with an equal percentage of hydrated lime. In 1935, Withey and Wendt[8] reported the results of some tests on mortars containing clay and concluded that a 1 cement and 3 sand mortar with 17 to 25% of cement replaced by clay may be used where high strength and weather resistance are required.

In 1936, Collin[9] reported the results of some tests on mortars containing clay and found that they were of high quality. Among other things, he also found that with the exception of the straight cement mortar, the mortars containing rock dust, which may be comparable with the ground limestone in the masonry cement used in the investigation, ranked first in weather resistance, tensile and compressive strengths, and absorption. However, the plasticity and bond strengths are not satisfactory.

[7] Spangler, M. G., Ground Clay as a Plasticizing Agent, Jour. Amer. Cer. Soc. 13, (12), 927-28, 1930; Spangler, M. G., Strength and Durability Tests on Mortar Mix, Jour. Smer. Cer. Soc., 16, 246-49, 1933.

[8] Withey, M. O., and Wendt, K. F., Tests on Mortars for Reinforced Brick Masonry, Amer. Soc. Test. Mat., 35, Part II, 426-45, 1935.

[9] Collin, I. P., Clay as a Plasticizer in Masonry Mortars, Jour. Can. Cer. Soc, 5, 35-41, 1936.

A more recent investigation on the subject was carried on at the New York State College of Ceramics, Alfred, N. Y. These tests were conducted to demonstrate the utility of fine ground New York state clays as plasticizers in masonry mortars. It was found that the substitution of finely ground New York state clays for lime in mortars raised the average bond or adhesive strength about 55%. The average compressive strength was increased 36%, and the average tensile strength was raised 40% by the substitution of clay. Greater resistance to freezing and thawing was obtained with the clay mortars and the shrinkage was less than corresponding mortars containing lime. Water retentivity was higher. In general, the mortars made with the New York state clays compared favorably with those made in Iowa.[10]

The requirements of the clay admixtures which are to serve as plasticizers and pozzolanic materials are of high plasticity and 14 to 20 per cent solution of silica. This latter property is accomplished by carefully heating a suitable plastic clay at 500 to 600°C until the desired silica is liberated in the amorphous state by the expulsion of part of the chemically held water.[11]

[10] Brick and Clay Record, 94, 38, May 1939.
[11] Berendt, E., Preparation of Highly Plastic Clays for Use as Reactive Admixture to Concrete and Mortar, Ziegelwelt, 69, 160-61, 1938.

RAW MATERIALS

Clays:

Kentucky Ball Clay (No. 4)--was obtained from the Kentucky-Tennessee Clay Co., Mayfield, Ky.

Wyoming Bentonite- - Black Hills, Wyoming.

Mississippi Bentonite--Panther Creek Bentonite, Aberdeen, Miss. It appears to be a sandy clay with moderate to high plasticity--does not seem to be a true bentonite.

Plastic Flint--occurs near Fulton, Mo.; a hard or flint like clay occurring as an unstratified massive rock with low natural plasticity and breaking with a conchoidal fracture.

Iowa Kaolinitic--occurs near Clinton and is reported to outcrop naturally in great quantities. It appears to be a good quality sedimentary kaolin as shown by the following analysis:[12]

SiO_2	45.94
Fe_2O_3	.72
Al_2O_3	36.15
CaO	.40
MgO	.14
Loss	13.15
Alkalis ...	.95
TiO_2	1.78

Gray Shale--occurs at Prospect Hill, St. Louis, Mo.

[12]Missouri Portland Cement Co., St. Louis, Mo.

The following analysis is given:[12]

SiO_2	64.28
Fe_2O_3	4.90
Al_2O_3	19.64
CaO	.70
MgO	2.62
Loss	5.17
Alkalis	----
TiO_2	----

Zadoc--

a stoneware clay located two miles north-east of Dexter, Mo. in Stoddard County.

Cement:

Red Diamond Masonry Cement of the Missouri Portland Cement Co. of St. Louis, Mo. This cement is prepared by grinding Portland Cement clinker and limestone in the proportion of approximately 50-50.

Sand:

Standard Ottawa Sand conforming to the requirements of Sections 36 to 38 of the Standard Methods of Sampling and Testing Portland Cement (A.S.T.M. Designation: C 77) of the American Society of Testing Materials.[13]

PROCEDURE

From the review of the literature, it is seen that clay, as an admixture to masonry cement, gives desirable properties. In order to limit the problem, a fixed amount

[13]Supplement of Book of A.S.T.M. Standards, p. 23, 1932.

of each clay was added to the cement as a replacement. In most cases, it was found by other investigators that a 25% substitution for regular Portland cement gave the most desirable properties. Since the cement used was not all Portland cement, a 10% substitution of clay for the masonry cement was used in all cases.

According to the Federal specifications for masonry cement, the residue on a Standard 200 sieve shall not exceed 12 per cent by weight.[14] Therefore the clays were ground and passed through a 200 mesh sieve before being added to the cement mix.

The following proportions were held constant:

360 grams cement (masonry)
40 grams clay
1200 grams standard Ottawa sand

as against the standard mix

400 grams cement (masonry)
1200 grams standard Ottawa sand

The procedure for mixing was approximately the same as given by the Federal Standard Stock Catalog[14] and was as follows:

> The mortars were mixed in a nonabsorbent bowl of about 1-gallon capacity. The cement and clay were placed in the bowl which has previously been wiped with a damp cloth and then mixed with an estimated amount of water to give 100 flow as called for.

[14]Federal Standard Stock Catalog, Section IV, (Part 5), No. SS-C-181b, January 12, 1938.

Approximately 800 grams of sand were then added and the stirring continued for 30 seconds. The remainder of 1500 grams of sand were then added and the mortar mixed for 75 seconds by vigorous and continued stirring, squeezing and kneading with one hand. The mortar was then allowed to stand for 60 seconds and then mixed for another 60 seconds. During the operation of mixing the hands were protected by rubber gloves.

The top of the flow table was carefully wiped dry and the flow mold placed at the center and filled with the mortar. In filling the mold the mortar was not rammed, but gently puddled to insure uniform filling. The mortar was then smoothed off level with the top of the mold by aid of a trowel and the mold then removed. Immediately the table was dropped through a height of $\frac{1}{2}$ in., 25 times in 15 seconds. The flow was the resulting increase in diameter of the mortar mass, expressed as a percentage of the original diameter. Standard consistency was judged to be between 100-115 flow.

If the flow was not that for standard consistency, more water was added to bring the flow within the given limits. Immediately after the flow test was made, the mortar on the flow table was remixed with that remaining in the mixing bowl for 30 seconds.

A comparative test was used to determine the water retentivity--the apparatus consisting of a brass ring two inches in diameter and ½ in. high, a red face brick (maximum absorption 14%), and a Gilmore initial set needle. After the mortar was remixed from the flow test, the brass ring was placed on the face of the brick and filled with the mortar. The surface was smoothes with a trowel and the brick tapped 25 times with one end slightly elevated. The timing was started just after smoothing the surface of the mortar in the ring. The time of apparent initial set as recorded by the Gilmore needle was used as an indication of the water retentivity of the mortar mix.

During this "setting time" test cubes were prepared for compressive strengths. The surfaces of the molds and plates in contact with the cubes were oiled with a medium viscosity oil. The molds were half filled with mortar, the mortar puddled into place with the finger tips of the gloved hand, the mold then filled to overflowing and the mortar again puddled with the finger tips. The mortar was then trowelled off flush with the top of the molds.

All test pieces, immediately after molding were kept in the molds on plane plates in a damp closet, maintained at a relative humidity of 90 per cent or more for from 48 to 52 hours in such a manner that the upper surfaces were exposed to the moist air. The cubes were then removed from the molds and placed in the damp closet for 5 days in such a manner as to allow free circulation of air around at least five faces of the specimens. At the age of 7 days the cubes for the 28-day tests were immersed in clean running water in storage tanks of noncorrodible materials.

The compressive tests were made on a mechanically operated testing machine of a suitable type as called for in the specifications. The load was applied uniformly and without shock, the rate of moving of the head being approximately 0.05 in. per minute when the machine was running idle. The specimens were tested immediately upon removal from the damp closet.

The total load indicated by the testing machine at failure of the test cube was recorded and the unit compressive strength calculated in pounds per square inch of the cross-sectional area of the cube.

DATA

Admixture	% H_2O	Brick test (minutes)	Compressive strength 7 day	Compressive strength 28 day
None	12.9	14	688	963
Wyoming Bentonite	20.0	17	420	
Iowa Kaolinitic	17.0	17	555	758
Miss. Bentonite	16.5	15	725	1065
Kentucky Ball	15.3	19	525	718
Plastic Flint	15.2	16	583	678
Zadoc	15.0	20	565	723
Gray Shale	13.7	15	700	968

MISSOURI PORTLAND PROCEDURE

Similar tests for determining the water retention were made by the Missouri Portland laboratory on all of the clays with the exception of the Wyoming Bentonite clay.

A different method of mixing was employed by this laboratory and was as follows:

The clay and cement were placed in the pan of the stirring resistance machine--the final mix being of the following proportions:

405 grams cement (masonry)
45 grams clay
1350 grams standard Ottawa sand

A portion of the sand was added and a known amount of water then added to the pan. After the pan had rotated a few turns, the remainder of the sand was placed in the pan and water added until the stirring resistance of the mix was 150 grams.

We have a description of this device in the A.S.T.M. Bulletin which is as follows:[15]

> "A device for measuring the workability of fatness of mortars called the mixing bowl plasticimeter has been devised by Mr. L. A. Wagner while employed by the cement reference laboratory of the National Bureau of Standards. This device is used for measuring the fatness of masonry cements. It consists essentially of an electrically driven pan mounted on a vertical axis; a paddle also mounted on a vertical axis tends to rotate with the mortar but is prevented from doing so through a system of levers arranged so that the resistance required to prevent rotation may be measured by means of weights on a scale pan. Mr. Wagner has said, 'The conceptions on which the test is based may be stated as follows: It is assumed that the plasticimeter measures stirring resistance. Next, it is assumed that stirring resistance is inversely proportional to additive factors, namely, (1) wetness of the mortar and (2) fatness of the cement. Finally, it is assumed that wetness is indicated by the flow table. Hence, if stirring resistance is made constant, then fatness becomes inversely proportional to flow'."

After bringing the mortar to this stirring resistance of 150 grams the flow was determined as described in the other procedure. The brick test was also made

[15] A.S.T.M. Bulletin, P. 43, October 1938.

in the same way as before.

DATA

Admixture	% H_2O	Flow (%)	Brick test (minutes)
None	11.6	105	19
Gray Shale	13.5	105	16
Miss. Bentonite	16.1	103	13
Plastic Flint	14.0	103	15
Kentucky Ball	15.6	101	22
Zadoc	14.5	102	18
Iowa Kaolinitic	16.3	100	18

DISCUSSION OF DATA

In the experiments conducted, the flow was brought to a constant value to give the same plasticity to all mixes before determining the water retentivity. In the diagram (Fig. 1), it is seen that the yield value, which is a measure of the plasticity, is constant, and the water necessary to bring the mix to this yield value is a measure of the plasticity.

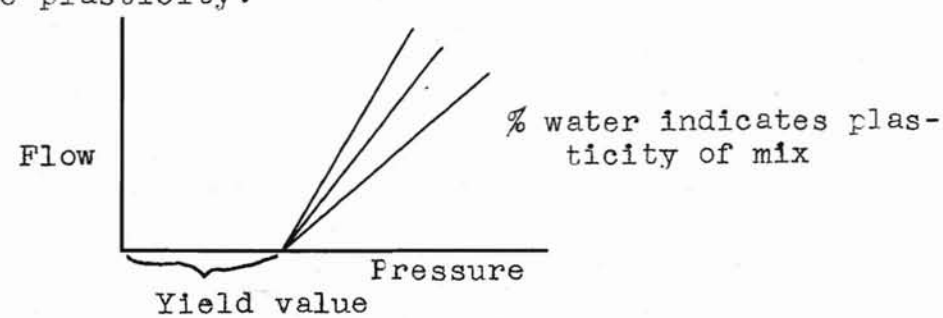


Figure 1.

By the methods at the laboratory of the Missouri Portland Cement Co., the mixes were brought to an equivalent viscosity; therefore the flow obtained is a measure of the yield value, i.e. the plasticity.

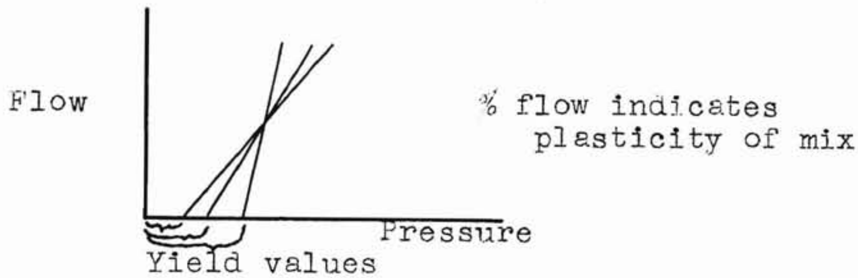


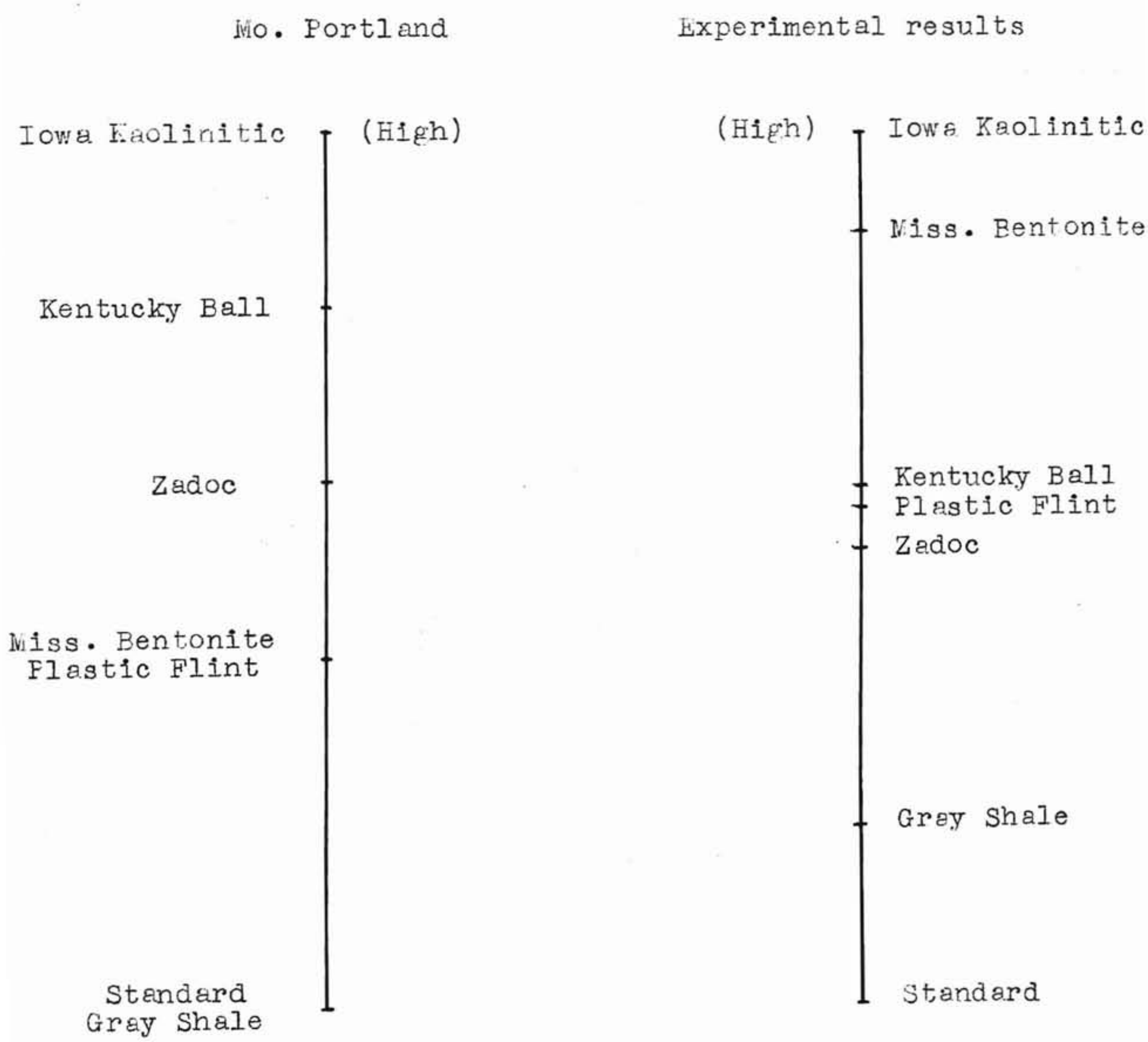
Figure 2.

The above statement is brought out bya comparison of plasticity obtained by both methods. This appears in Figure 3.

The strengths do not seem to show any definite relationship to any property of the clays. Since the 7-day test for Wyoming Bentonite fell below the specified 500 #/in.^{2}, a 28-day test was not made. On an experimental freeze and thaw test, the cube containing Wyoming Bentonite completely fell apart on the first cycle. It is strange that the Mississippi Bentonite should increase the strength in contrast to the reduction of the strength by addition of other clays.

To clarify the following discussion of the water retentivity, the data concerning the brick tests is repeated:

PLASTICITY COMPARISON



Missouri Portland points were placed on the basis of the % flow and the experimental results on the basis of % water added.

Figure 3.

	Mo. Portland	Experimental results
Kentucky Ball	22	19
Zadoc	18	20
Iowa Kaolinitic	18	17
Plastic Flint	15	16
Gray Shale	16	15
Miss. Bentonite	13	15
Cement	19	14

It is noted that for the cement with the brick test of 14 minutes, all of the admixtures increased this time. However, for the cement with a test of 19 minutes, the admixtures decreased this time--with exception of the Kentucky Ball clay. This leads to an interesting supposition that clay might act as a stabilizing influence upon the water retention of cements with variable brick tests, as indicated above. However, the above data is entirely insufficient to qualify the statement.

CONCLUSIONS

From the tests made, it was found that of all the clays used, Kentucky Ball clay and Zadoc stoneware clay gave the best results, considering the water retention as one of the main criteria. According to the Missouri Portland research laboratory, "The mortar made with Kentucky Ball clay was the best mortar of this series of tests. It was better than the straight Red Diamond mortar in all respects. The mortar containing Zadoc was not quite as good as the Kentucky Ball clay, but was better than all the other materials".

It is suggested that further work be done on the theory concerning the possible stabilizing influence of the clay--in the oil industry, clay is used as a stabilizer, but this is in a different sense of the word.

ACKNOWLEDGMENTS

The writer wishes to express his indebtedness to Dr. P. G. Herold, Head of the Ceramic Department of the School of Mines and Metallurgy of the University of Missouri for his supervision, helpful suggestions and criticisms during the course of the investigation as well as in the compilation of the thesis; to the research laboratory of the Missouri Portland Cement Co. for their helpful work; and to Mr. I. A. Wagner, Director of Research for the Missouri Portland Cement Co. for his suggestions and information pertaining to the problem.

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