AN EXPERIMENTAL STUDY OF THE EFFECT OF SAND PARTICLE SHAPE ON THE STRENGTH OF MORTAR

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An Experimental Study of the Effect of Sand Particle Shape on the Strength of Mortar

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by

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Sands have long been classified in general terms as being either sharp or dull sand. These classifications of course are relative and very vague. Sharp sand in general is sand that has sharp corners, ridges, and projections; dull sand being sand that has had the sharpness worn off by the action of water, wind, ice, etc.

In many varied phases of sand use, the importance of the shape of the grains has been recognized. The author's first experience with differentiating between sharp and dull sand came when caring for clay tennis courts. It was soon found that when a dull sand was rolled into the damp clay, the mixture would not hold up well. The courts would break up easily and had a tendency to be slippery due to the loose grains acting as rollers. In trying to operate heavy equipment through sand there is a vast difference in the footing present, depending upon if the sand is sharp or dull.

The shape of the sand particles in present day concrete specifications and tests is in general ignored. It is the purpose of this paper to find an indication as to the advisability of this situation.

It has been firmly established in the concrete world that the strength of Portland Cement Concrete is directly dependent upon the water cement ratio, providing that the aggregate factors do not enter into the picture. This thesis does not intend to suggest that this law is not true, but only intends to investigate one possible factor as to the part that aggregate plays in the strength of concrete.

I believe that it is easily imagined that sharp sand might produce stronger concrete than dull sand, other conditions being constant. In sharp sand the ridges and projections will interlock and also will give a better chance for the cement paste to make good contact with the sand. Also it is possible that dull sand could produce a stronger concrete due to the sand particle actually being less likely to fail by shear when it is in a rounded shape. If any of these actions, or others, have a substantial effect upon the strength of concrete, then some notice should be taken of sand particle shape in specifications and testing of fine aggregate.

To experimentally investigate this subject, the author tested sands with different characteristic shapes, as to strength developed in a standard mortar. The following material outlines the procedure followed.

Four sample sands were selected, two sharp sands and two dull sands. For convenience they will be designated as numbers 1, 2, 3, and 4.

Sand No. 1 is a sharp sand used as a general laboratory sand at the Michigan State College Cement Laboratory. It is from a local source.

Sand No. 2 is a sharp sand which was obtained at the Delhi Gravel Company at Holt, Michigan.

Sand No. 3 is a dull sand obtained from the northern-most point of Lake Michigan's shore line.

Sand No. 4 is standard Ottawa sand and is a dull sand.

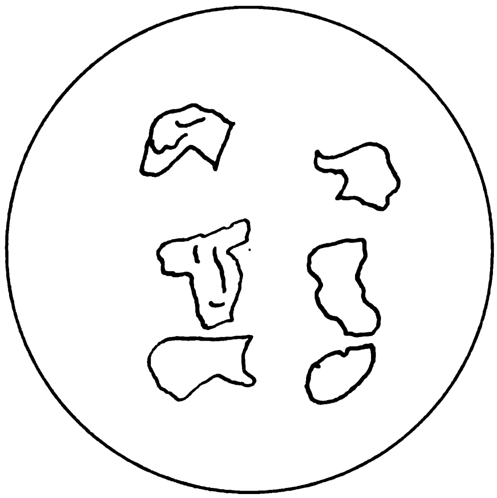
These sands were viewed under a microscope using a magnification of 50 diameters. Sketches of the characteristic shapes were made and are shown in figure one.

The sands were washed and shaken. All tests were run using sand passing a U. S. No. 30 sieve and retained on a U. S. No. 40 sieve or that sand passing a U. S. No. 40 and retained on a U. S. No. 50.

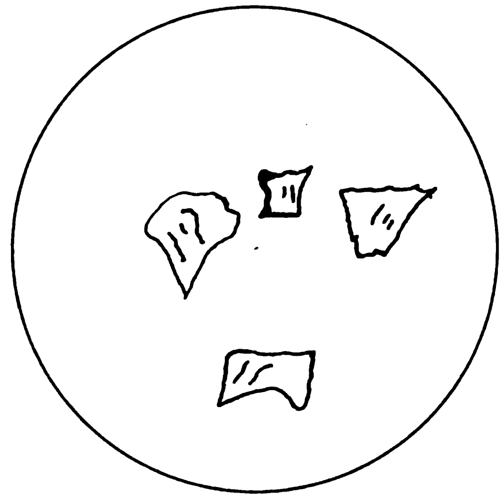
The standard methods of test for compressive and tensile strength of hydraulic-cement mortars, A.S.T.M. designation C-109-44 and C-190-44, were used. The proportions of dry materials used in the standard mortars were one part of cement to 2.75 parts of sand. The amount of water used was 53.4 percent of the weight of the cement. Six compression specimens and six tension specimens were made for each of the four sands using that gradation passing a U. S. No. 30 sieve and retained on a U. S. No. 40. Half of the specimens were broken after seven days of curing and half were broken at twenty-eight days. The same testing was repeated using the gradation passing a U. S. No. 40 sieve and retained on a U. S. No. 50 sieve as a check.

In this manner the author was able to secure two sets of results with sand particle shape being the only variable. Tables 1, 2, 3, and 4 show these results and table 5 summarizes them.

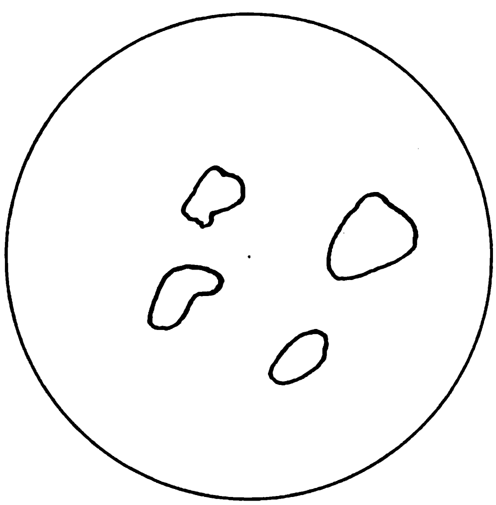
Figure I



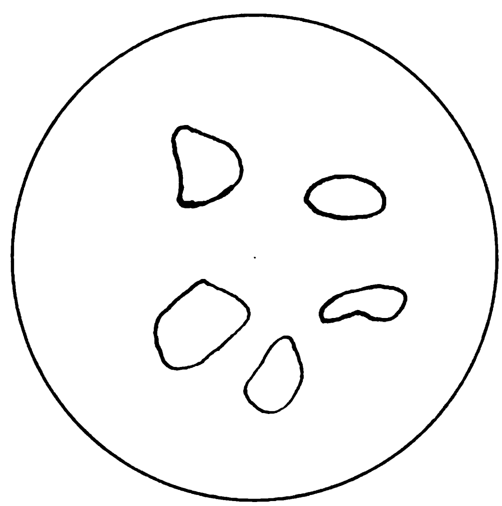
No. 1
Laboratory Sand



No. 2
Delhi Sand



No. 3
Lake Michigan Sand



No. 4
Standard Ottawa

Table IV

28 Day Compression Tests
Sand Passing 30 Retained 40
Strength in Pounds Resisted by 2'' Cubes

Trial	Sand No. I	Sand No. II	Sand No. III	Sand No. IV
1	10178	10450	10415	12026
2	9982	9945	10916	11910
3	10058	11310	11121	12051

28 Day Compression Tests
Sand Passing 40 Retained 50
Strength in Pounds Resisted by 2'' Cubes

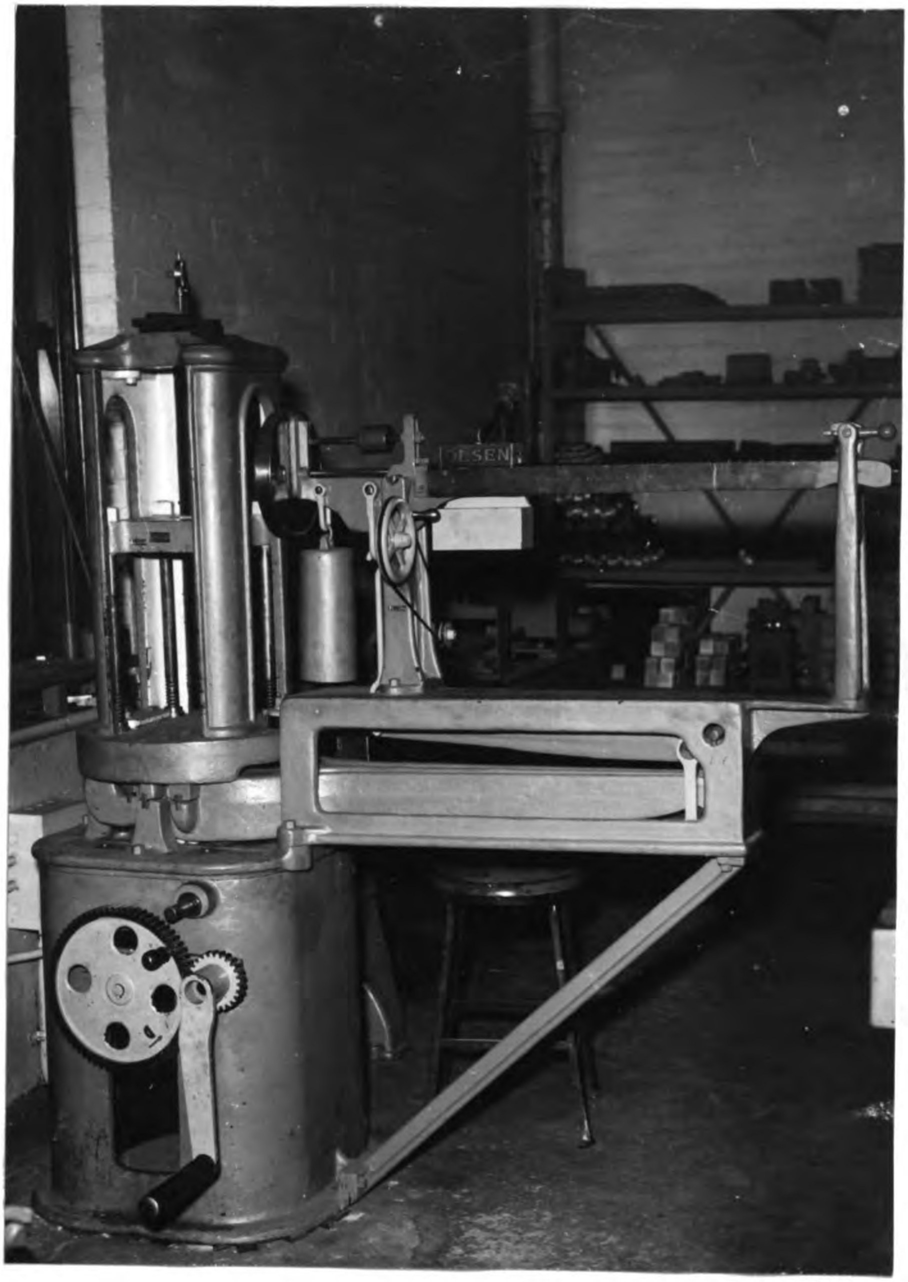
Trial	Sand No. I	Sand No. II	Sand No. III	Sand No. IV
1	9827	10411	11132	11899
2	10002	10265	10764	12117
3	10115	9898	10519	12010

Table V

Summary of Mean Values
Pounds per Square Inch

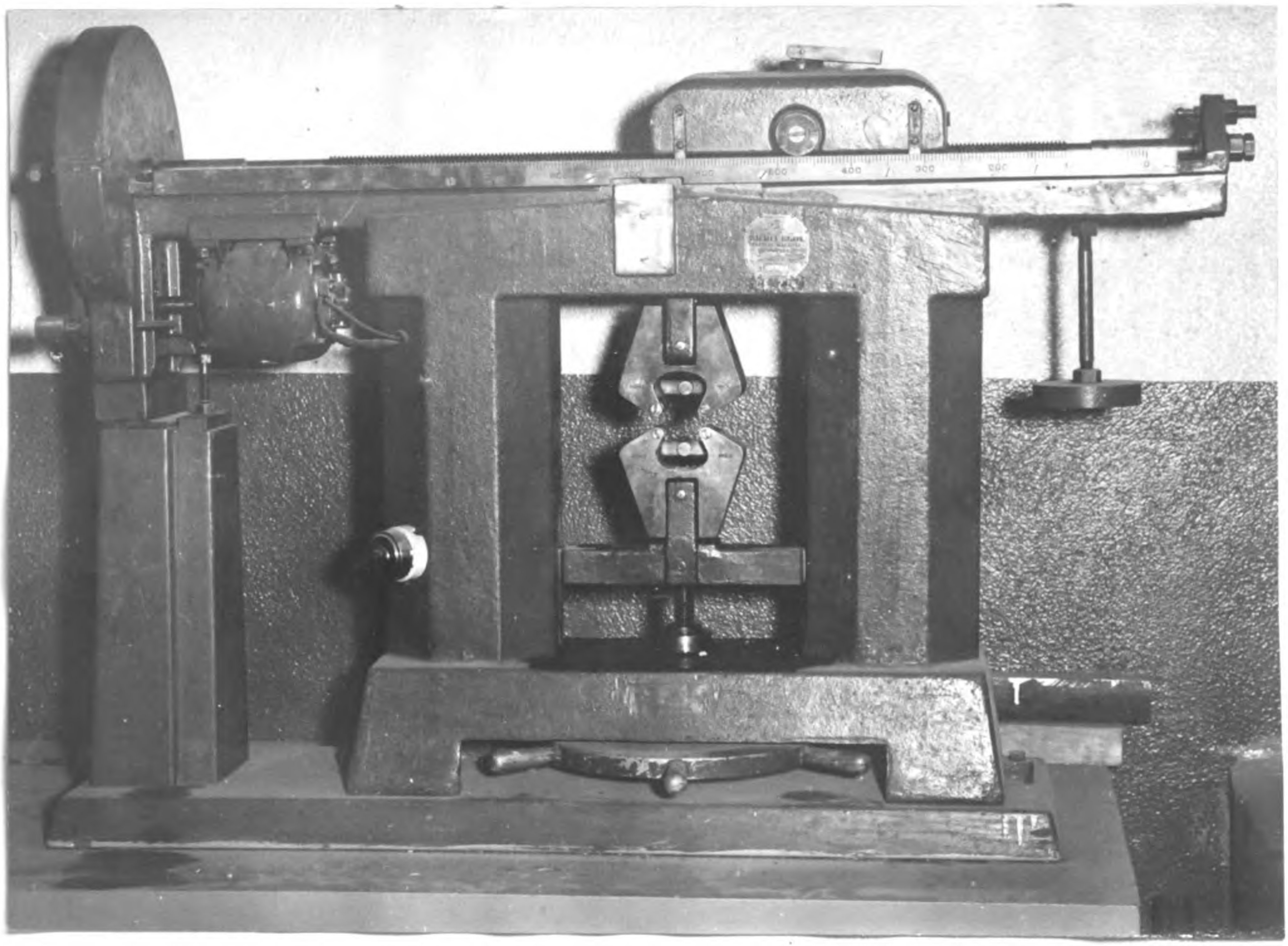
	Sand No. I (Lab.)	Sand No. II (Delhi)	Sand No. III (Lake)	Sand No. IV (Ottawa)
Compression 7 Days	1690	1706	1495	1427
Compression 28 Days	2520	2595	3000	2700
Tension 7 Days	224	216	189	197
Tension 28 Days	257	262	358	296

Figure II



Machine used to break compression specimens. Hand powered - Screw Type.

Figure III



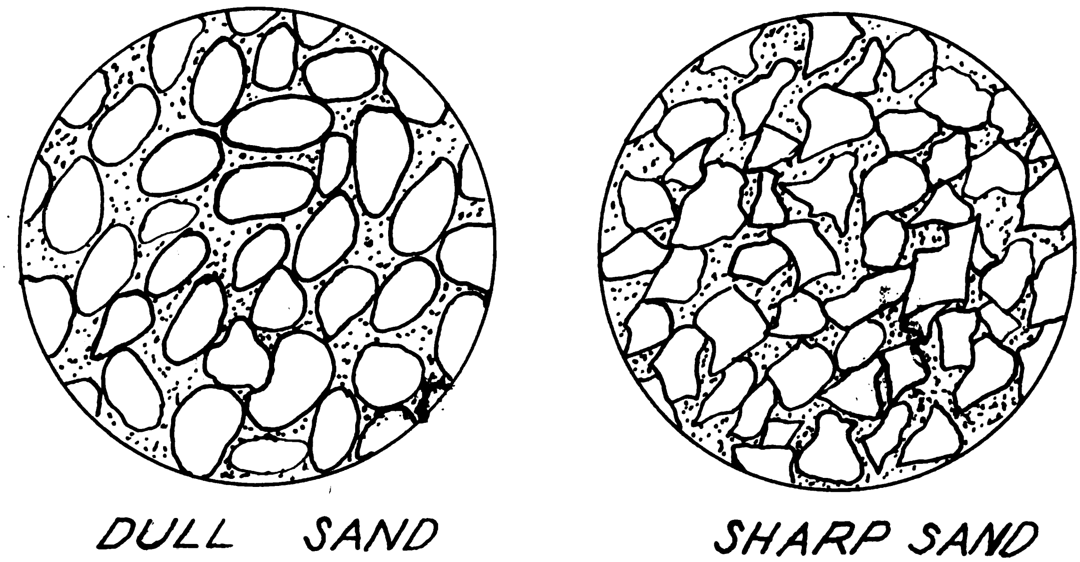
**Machine used to break tensile specimens.
Electric Driven - Screw Type.**

The results summarized in Table V show that sharp sand tends to produce a stronger mortar than dull sand at 7 days of curing. This is probably due to the interlocking qualities of the sharp sand.

The results obtained at 28 days in this investigation were quite surprising to the author. From the results in Table V it is apparent that the Lake Michigan beach sand gave the strongest mortar at twenty-eight days. This sand was a dull sand, but not quite so smooth as the Ottawa sand which was the second strongest of the four sands. The two sharp sands produced mortar of definitely less strength. Judging from these results it seems that the most ideal shape might be somewhere between the sharpest and the dullest sands. Perhaps it would be a rough round grain shape or it might have a cubical shape. The limited scope of this thesis prevents the author from drawing any definite conclusions concerning grain shape.

The results obtained could be due to many possibilities. One of these is, the actual bond between the neat cement paste and the face of the grain of sand is very small. This means that the mortar is actually like a honey comb or uniformly bubbled neat cement, the voids being filled perfectly with sand grain. The shape of the sand particles would determine the structure of the neat cement. The nature of this structure would affect the strength, since it is the neat cement that fails and not the aggregate. The sketches in figure IV illustrate the possible neat cement structure and their possible failure sections. It is quite likely that the sharp sand would form a weaker structure of neat cement.

FIGURE IV



If there is one best grain shape for sand, I believe it would be worthwhile to determine it. In all probability other factors, along with the strength produced, should be considered such as resistance to freezing and thawing. If the best shape or shapes for sand particles were determined it would be very valuable in selecting sands. It could also be valuable in selecting types of crushers, when crushed rock is used for fine aggregate. It is likely that the different types of rock crushers will give different grain shapes.

At first glance, the results obtained showing the lake sand to give a stronger mortar seem to be at variance with the generally accepted conclusion that lake and ocean beach sands are inferior for concrete purposes. Their inferiority is probably not due to their dullness, but more likely to the organic matter and salt present in them. Another factor that could reduce their concrete making properties is their poor gradation.

It has been shown through the results given in Table V that the affect of sand particle shape is at least a mildly important factor in the strength of mortar. The experimental results obtained by this thesis are of little practical value in themselves, but point the way toward future work which should follow. The author believes that a thorough investigation of sand particle shape is in order. It should establish the best grain shape for mortar strength as well as for freezing and thawing resistance and other possible properties affected.