9. The tests indicate a probable definite relation between the ultimate compressive strength of the mortar content and the ultimate compressive strength of the concrete when the test specimens of the former are produced from mortar of the same mix and consistency as that used in the concrete.

Historical

The use of mortars dates from a time so remote that its beginning cannot be ascertained. However, its modern use in the form of an intimate mixture of lime or cement, sand and water doubtless dates back to the "constructive" Roman period. Both Romans and Normans well understood its use; both had a thorough knowledge of mortar.

Doubtless the method of proportioning the cementing material and aggregates by volume originated among these early artisans. However, the earliest authentic record of its use is credited to General Pasley (1827). This method as commonly specified and used is not only illogical and unscientific, but also unfair to the development of the true value of the materials entering into the composition of both mortar and concrete.

Cement is the binder holding together the aggregates. The fundamental theory of the combination is that the two materials, the one active, the other inert, act as a single unit.

With regard to the item of strength, the ideal mortar contains a proportion of cement sufficient to develop the full strength of the particles of sand aggregate; while the ideal concrete contains a mortar component, in itself ideal, which will develop the full strength of the particles of stone aggregate. The actual proportioning and combining of the cement and aggregates fall somewhat short of reaching this theoretical perfection; practical considerations render it impossible to distribute the cement perfectly, and thus to secure that absolute adhesion between the particles of aggregate which is necessary to the perfect transmission of the stresses from one particle of aggregate to another. Perfection in this regard is therefore unattainable, at least in so far as commonly used field methods and operations are concerned.

Those having experience in practical tests of mortar and concrete know that with given volumetric proportions of materials, comparatively slight variations in the granulometric composition of the sand aggregate produce marked differences in the strength, toughness, and other physical properties of the product.

There should be no place in engineering for guesswork and empiricism whenever scientific determination is possible. With this idea in mind and with a due allowance for the practical considerations mentioned above, it remained to set about the task of finding a structural reason for the wide variations of strength obtained in mortar tests. In November, 1917, a most natural solution presented itself, namely:

1. The strength of mortar is primarily dependent upon the character of the bond existing between the individual particles of the sand aggregate. Upon the total surface area of these particles depends the quantity of cementing material. Furthermore:

2. The amount of water required to produce a "normal," uniform consistency of mortar is a function of the cement and of the surface area of the particles of the sand aggregate to be wetted.

This idea of proportioning the cement in relation to the surface area of the aggregate was new to the writer and appealed to him as a reasonable, although rather radical, departure from the time-honored practice of proportioning by volume measurement. However, he discovered in February, 1918, that it is in reality at least twenty-five years old. Prof. A. H. Heath describes it very clearly in his book "A manual of Lime and Cement," 1893, as here quoted:

> "Sufficient cement should be used to furnish a coating to the surface of each particle of the matrix, and the extent of surface of particles as compared with their bulk is much greater with fine sand than with coarse sand. For instance, a 3-in. sphere has one-eighth the bulk of a 6-in. sphere, but its surface area is one-fourth that of the 6-in.
>
> "To ensure the perfect coating of each particle, a larger proportion of cement must be taken with fine than with coarse sand. If the proportion of cement taken for fine sand be that sufficient only for coarse sand, the cement films enveloping the particles will probably be imperfect, and the concrete will be deficient in strength."

No attempt was made by Professor Heath to develop the surface-area method of proportioning, of which he was a pioneer or possibly the originator.

This paper presents the results of tests made by the city of Toronto Department of Works, under the direct supervision of the writer.

Object and Scope of Tests

The tests were made with the object of developing the surface-area method of proportioning and securing information relative to (1) the surface area of aggregates of varying granulometric composition; (2) the quantity of water necessary to produce a "normal," uniform consistency of mortar for varying sands and cement content; and (3) the strength of mortar attained by varying the proportion of cement in the mix.

The range or scope of the tests was sub-divided as follows:

1. The determination of the average surface area of sand and stone particles of varying sizes based upon an actual count of the number of particles in given weights.

2. The determination, by trial, of the quantity of water necessary to produce, for any given sand and proportion of cement, a mortar of "normal," uniform consistency.

3. The determination of the reliability of the surface-area method of proportioning mortars in so far as strength alone is concerned.

4. The determination of the relative strengths resulting from variations in the cement content of mortars within practical limits.

5. The securing of miscellaneous general information pertaining to the foregoing phases of the tests.

The investigations herein described involve compression and tension tests upon 240 mortar cylinders, 2 ins. in diameter by 4 ins. long; 45 concrete cylinders 6 ins. in diameter by 12 ins long; and 324 standard briquettes.

Surface Area of Aggregates

Possibly the fact that the relation of the surface areas to the volumes of particles of matter depends upon their size and shape needs no demonstration; however, the following example will serve to bring this fact more clearly to mind:

Assume three masses of material, each made up of the following particles:

1. Spheres 2 ins. and 7/8 in. in diameter.

2. Spheres 2 ins., 1 7/16 ins. and 9/16 in. in diameter.