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Determining the Relative Shear Behavior of Coarse Concrete Aggregate and Associated Matrix

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Abstract. A study of the bond characteristics of carbonate aggregates was made by applying shear stresses to 1/8-inch thick slices of highway concrete. It was found that aggregates can be classified as strong, indeterminate, and weak relative to the matrix of the concrete, when accurate lithological cataloging of the aggregates from the source quarry section is made prior to the shear study. Definite classification can only be made in older concretes (7-15 years in age) since newer concretes tend to fail in the aggregate-matrix bond zone, making it difficult to observe the relative aggregate strength. The method provides a basis for further study of the aggregates as classified, and a basis for correlating important factors revealed by the studies with the observed quality. Such studies might then be extrapolated to evaluate other quarry sections.

INTRODUCTION

An investigation of the bond characteristics of coarse carbonate aggregate in highway concrete was undertaken as part of a larger study on the general behavior of carbonate rock as concrete aggregate[1]. Part of the study of aggregate/concrete behavior required chemical analysis to determine composition changes in relation to age and depth from the highway surface. The samples for analysis were obtained from highway concrete cores of varying ages and containing aggregate from various quarries by cutting a series of 1/8-inch slices from the cores and breaking or shearing the slices to separate the aggregate from the matrix.

During the breaking or shearing phase of the sample preparation it was noticed that the shear behavior maintained specific patterns which varied with: 1) the lithological type of the coarse carbonate aggregate; 2) the age of the concrete; and, 3) the relative extent to which interaction had taken place between the concrete matrix and the carbonate aggregate.

As a result of these initial observations, a more thorough study was undertaken. This was done by preparing slices in the same manner as those for chemical analysis samples, and then breaking the slices solely to determine the shear behavior pattern in order to find the relative importance of the three factors mentioned above.

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This paper presents the details of the procedure and the way in which the data obtained were recorded and correlated for use in evaluation of a coarse carbonate aggregate's contribution to its concrete's resistance to shear failure. The resulting classification of aggregate types provides a basis for further study of strong, indeterminate, and weak aggregates in order to find correlations with aggregate quality which might be extrapolated to evaluate aggregates from other quarries without the need for a service record.

Definition of Terms

In order to clarify the process, it is first necessary to define the terms used in the study.

1. *System studied.* The total number of pieces of aggregate studied in a concrete sample of a particular age with aggregate from a single quarry.

2. *Aggregate type.* Aggregate of a specific lithological texture, color, and hardness; identified by camparison with sawed samples from each unit of the quarry section.

3. *Aggregate studied.* Any piece of aggregate having an exposed surface of 1 cm_2 or larger, on both sides of a 1/8-inch slice of concrete.

4. *Per cent aggregate studied.*

$$\% = \frac{\text{Number of pieces (one type) studied}}{\text{Total aggregate (one system) studied}} \text{ x } 100$$

5. *Tendency to withstand stress.* The observed relative tendency to withstand applied shear stresses of a zone in the aggregate-matrix system. For comparison, it is easiest to assign arbitrary units to this strength. The matrix is the most readily available standard for comparision and is assigned the zero value. The hardest aggregate is assigned a +1 value, and aggregates weaker than the matrix are assigned proportional negative values. For convenience, these are referred to as "K" units.

6. *Unaltered aggregate* (Symbol *A*). The part of a piece of aggregate which appears to have undergone no change since the laying of the concrete. (Figure 1)

7. *Inner rim.* (Symbol R_I). The part inside the outer edge of a piece of aggregate which appears to have undergone change since the laying of the concrete. (Figure 1)

8. *Interface.* (Symbol I). Surface boundary between aggregate and matrix, or aggregate and bond zone. (Figure 1)

9. *Bond zone.* (Symbol BZ). The portion of the aggregate-matrix system outside the interface, which appears to be neither aggregate nor matrix. (Figure 1)

10. *Outer rim.* (Symbol R_o). The area of the matrix outside the bond zone appearing to have undergone change since the laying of the concrete. (Figure 1)

11. *Unaltered matrix.* (Symbol M). The area of the matrix outside the outer rim, appearing to have undergone no change since the laying of the concrete. (Figure 1)

Not all of these features are necessarily present in or around every piece of aggregate.

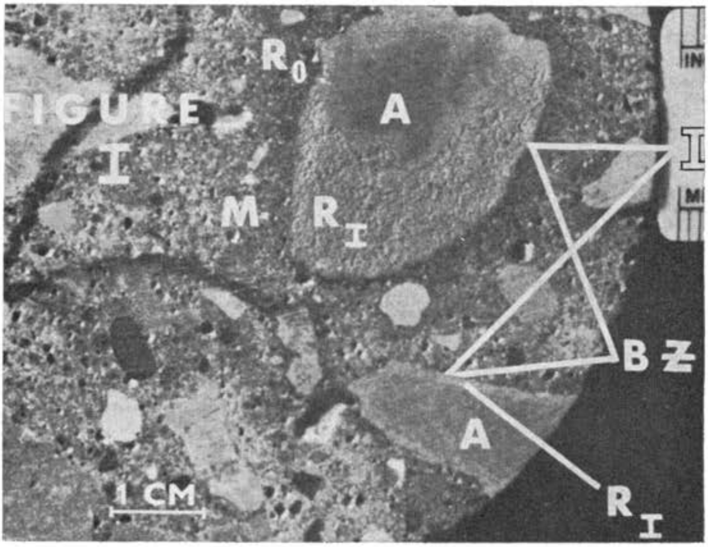

Figure 1. Photograph of a highway concrete core cut surface showing the different zones observed, and the variability of the zones in and around different aggregates.

Procedure

From a set of cores of a specific age taken from highway concrete made with aggregate from a single quarry, 1/8-inch slices are cut at various depths from the top, using an oil cooled diamond saw. The slices are then washed in a stirred benzene bath for not less than 30 minutes, and dried in an evacuated desiccator over anhydrous $Mg(ClO_4)_2$ overnight.

The cut surfaces of the remainders of the cores are studied, and the various types of aggregate are catalogued. A summary sheet of all the aggregate types with their characteristics of appearance is prepared and used for identification of aggregate types in the slices.

The slices are removed from the desiccator to a glove box containing an anhydrous, CO_2 free, atmosphere where the shear study is carried out in order to prevent atmospheric attack of the concrete. Before each slice is broken, all the pieces of aggregate to be studied are identified and marked according to the summary sheet to eliminate as much prejudice as possible. The number of pieces of each type is then recorded.

With a pair of pliers, shear stresses are applied as if an attempt is being made to fold the concrete. This process is begun in the matrix at the edge of a slice, and is moved gradually toward a piece or pieces of aggregate. The stress is applied so that the attempted fold would be parallel to the nearer edge of the aggregate, and the region of first breakage is noted. By careful manipulation it is possible to break areas other than the weakest zone, and therby determine the various relative strengths of other areas.

It is important to note that the shear behavior pattern observed is only valid when the interface of the system is less than 30° from the perpendicular to the slice surface; except in the case of bond zone-interface breakage which may at times parallel the interface as much as 70° to 80° from the perpendicular, especially in concretes only a few years old.

It is possible to make from 3 to 12 or more shear tests on a single piece of aggregate, and it is preferred to make as many as possible. Within the ± 30° limit, a shear behavior pattern is reproducible, provided that aggregate typing is sufficiently specific.

A running tally sheet is kept at the time of the shear study, containing the following information:

I. Aggregate type designation.
II. Aggregate studied tally.
III. Description of aggregate-matrix system, (bond zone size, rim size and color, etc., even if duplicating type summary sheet)
IV. Shear behavior pattern.

Results

From the shear patterns it is possible to classify aggregates in three groups.

I. Strong aggregates: Those which produce first breakage in the outer rim or matrix -i.e.- the aggregate is stronger than the matrix.

II. Indeterminate aggregate: Those which produce first breakage in the bond zone, aggregate and matrix indiscriminately -i.e.- the aggregate is of about the same strength as the matrix.

III. Weak aggregate: Those which produce first breakage in the inner rim or unaltered aggregate -i.e.- the aggregate is weaker than the matrix.

It will be noted that bond zone and interface shearing are commonly found in newer concretes (age less than 7-15 years), while older concretes show pronounced separation into the three quality classes of aggregate. The following three examples illustrate this fact.

Type A Example of strong aggregate. (3-35%; reactive, large inner and outer rims) Although the newer concrete shows bond zone breakage, the older concrete shows that type *A* is making a contribution to the strength of the concrete. (Fig. 2)

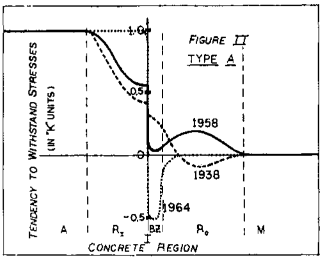

Figure 2. Variation of the shear behavior with age of Type A (strong) aggregate.

Type B Example of indeterminate aggregate. (5-15%; non-reactive, no rims found.) This shows that while not necessarily contributing to the strength, it does not detract from it. (Note the special case where no bond zone is formed, resulting in a very weak area at the interface.) (Fig. 3)

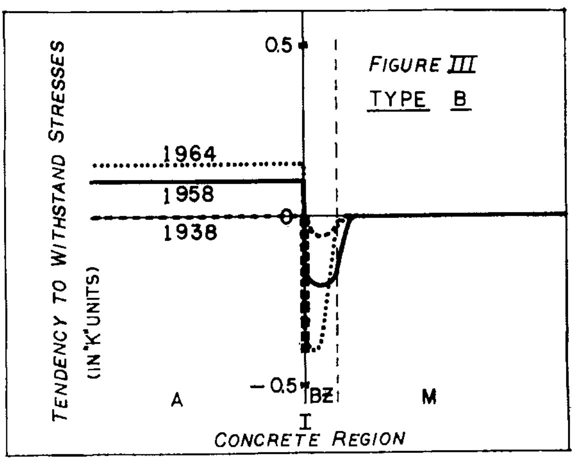

Figure 3. Variation of the shear behavior with age of Type B (indeterminate) aggregate.

Type C Example of weak aggregate. (15-25%; slightly reactive, small to no rims found.) This shows that even in newer concretes it detracts from the strength of the concrete. (Fig. 4)

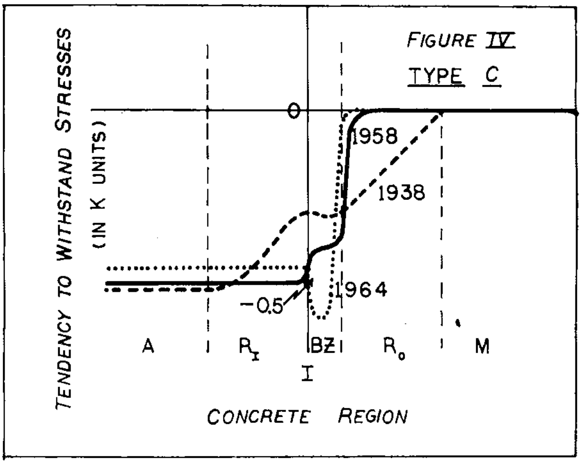

Figure 4. Variation of the shear behavior with age of Type C (weak) aggregate.

Summary

The most significant point revealed by the study is that a particular quarry cannot be considered as a unit, but must be treated according to each individual lithology which produces aggregate of a particular class.

The second point is that inital strength studies of concretes do not test the aggregate contribution to the concrete's strength, but rather test the properties of the aggregate-matrix bond. It is only after a period of from 7 to 15 years that the bond zone sets up to be equal to or stronger than the matrix, revealing the true effect of the aggregate.

Finally this method proves to be of particular value, since by visual correlation with quarry types, microscopic and chemical studies can be made on each type. The studies in turn may show relationships between strong and weak aggregates. The results of such studies might then be extrapolated to aggregates from other quarries for which no service record exists, might indicate the problem sources in quarries having poor service records, or might show how to improve concrete made with aggreate from quarries having a favorable service record.

Literature Cited

1. John Lemish and William J. Moore. Carbonate Aggregate Reactions: Recent Studies and an Approach to the Problem. Highway Research Record, 45:57-71 (1964)