

Report of Concrete Investigation  
in  
Research Project C-13

A Study of the Effect of Blended Cements  
on the Durability of Concrete  
Incorporating an Inferior Coarse Aggregate

by  
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## DESCRIPTION

Research Project C-13 was set up for the purpose of studying the effect of blended cement, with air-entraining properties, on the durability of concrete incorporating an inferior grade of limestone as the coarse aggregate. This investigation is not correlated with any Department of Highways field project, being entirely a laboratory study. The tests were begun April 12, 1945, and were completed February 6, 1946.

The cements were blended in the proportions of five to one by volume of normal Portland cement and natural cement with grinding aid.

The limestone was sampled from a central Kentucky quarry and crushed in the laboratory. Its most undesirable property was its excessively high shale content. No tests were made to determine the amount of shale present in the original sample. However, upon inspection of a sample that had been exposed to natural weathering for approximately two years, there was at least four percent of shale that had broken down from weathering. In addition, there was an undetermined amount of larger shale particles not completely broken down by the weathering processes. With the above being in evidence and the likelihood that an appreciable amount of the weathered shale was carried off in the drainage of rain water; an estimate of approximately eight percent of shale may not be in error.

Another undesirable characteristic of this aggregate was its clay content, approximately 17 percent by weight determined by measurement of the insoluble residue. This determination was made by dissolving a sample in hydrochloric acid - the calcium carbonate going into solution and the clay remaining as the residue. The material tested was sampled from larger particles ( $\pm 1$  inch) and is not representative of the original sample. Had this test been performed on a representative quarry sample the percentage of insoluble residue would have been substantially greater due to the presence of shale particles. No attempt was made to analyze the residue for its mineralogical constituents.

## MATERIALS

The cements used in this project consisted of one standard brand each of Portland cement and natural cement - the natural containing a grinding aid.

The fine aggregate, an Ohio River concrete sand, was constant for all mixes. Results of tests made on the sand are listed in Table I.

The coarse aggregate was prepared in the laboratory. The quarry samples were crushed and graded over screens of 1-1/2 inch and No. 4 size (square openings). That between the two screens is designated for reference in this report as Aggregate No. 1. That passing the No. 4 is referred to as dust and was used to make up Aggregate No. 2 in the proportion of 85 percent of Aggregate No. 1 to 15 percent of dust by weight. A list of test data for the coarse aggregate is also given in Table No. 1.

TABLE I. TEST DATA FOR AGGREGATES

Test	Coarse Aggregate		Fine Aggregate		
	Sieve Sizes	Pctg. Passing		Sieve Sizes	Pctg. Passing
		No. 1	No. 2		
Sieve Analysis	1-1/2"	100.0	100.0	3/8"	100.0
	1"	75.0	78.7	No. 4	99.4
	3/4"	43.1	51.6	No. 16	54.6
	1/2"	24.0	35.4	No. 50	5.3
	3/8"	14.2	27.1	No. 100	0.6
	No. 4	0.0	15.0		
Specific Gravity		2.65	2.65		2.65
Pct. Absorption		1.4	1.4		1.3
L.A. Abrasion		37.8			

PROCEDURES

Test specimens were made up in four series; with each series consisting of three 6 x 12 inch cylinders, six 5 x 6 x 20 inch beams, six 3 x 5 x 20 inch beams, and three 12 x 13 x 1-1/2 inch slabs - a total of 72 specimens for the project. Description of the four series with respect to their variables in design are listed as follows:

Series "A" - Normal Portland cement and coarse aggregate

No. 1

Series "B" - A blend 5 to 1 by volume of normal Portland cement and natural cement with grinding aid, and coarse aggregate No. 1.

Series "C" - Normal Portland cement and coarse aggregate No. 2.

Series "D" - Blended cements same as in Series "B" and coarse aggregate No. 2.

All of the four mixes were designed on the same basis of proportioning of the material as follows:

Cement Factor - 6 sacks per cubic yard of concrete

Water-Cement Ratio - 6 gallons per sack of cement

Ratio of Fine to Coarse Aggregate - 40-60 percent by weight.

Slump -  $\pm$  3 inches.

Each mix was designed for an amount sufficient to cast all specimens in one series, and was mixed in three identical batches. Adjustments were made for water underrun by addition of fine and coarse aggregates. The concrete was placed in steel molds and rolded in accordance with standard methods, after determinations had been made for the slump and the weight per unit volume of green concrete. Data for the actual mixes are tabulated in Table II.

The specimens were removed from the forms after twenty hours and were placed in the moist room and cured until 28 days of age. At the end of this period all specimens were removed for testing. Evaluations for the initial sonic modulus of elasticity ( $E_0$ ) were made for all beams. One-half of the beams (3 of each size) in each series were broken in flexure under third-point loadings to determine their moduli of rupture at 28 days, and the other one-half were placed in freezing and thawing (frozen in air at 0° to -5°F. and thawed in water at room temperature). The cylinders were tested for 28-day compressive strength, and the slabs placed in freezing and thawing - frozen under the same conditions as the beams but thawed in ten percent salt-water solution.

The beams were tested at intervals for their sonic moduli of elasticity and were removed from the test when this value had decreased as much as 30 percent of the initial value; or after they had undergone 500 cycles of freezing and thawing. At the end of the test the final sonic moduli of elasticity ( $E_f$ ) were evaluated and the beams were broken in flexure under third-point loadings. The slabs were removed from test when disintegration took place, or after they had undergone 500 cycles of freezing and thawing. All test results are submitted in Table II, and a graphical representation of the relative strengths of the individual specimens is presented in Plate I.

## RESULTS

After summarizing the results the greatest significance can be attached to the increase in the quality of durability of the concrete containing the blended cements with air-entraining properties. With one exception, beams in every set of specimens containing the blended cement resulted in greater average strength after 500 cycles of freezing and thawing than the average of the 28-day companion control beams. The exception was the set of 3 x 5 inch beams in Series D (Columns 25 through 31 of Table II), and Beam No. D-6 in particular in which the resulting low strength can be explained as being a special case of localized failure brought on by the presence of two rather large shale particles. These particles were located near one face in the mid-section of the beam and had been transformed into a soft clay-like material thus weakening and cracking the beam at that point.

This localized condition widely distributed through a large mass of concrete should not produce failures of such serious extent as general disintegration.

With the exception of the set of 5 x 6 inch beams in Series A, all beams made with normal Portland cement failed relatively early (from 256 to 316 cycles) with an average reduction in modulus of rupture of approximately 80\* percent. No definite reason for the comparatively high durability of the larger beams in Series A (Columns 18 through 24, Table II) is apparent, but the fact that each of these beams ruptured at a section near one of the supports indicated that deterioration was far more advanced in the ends than in the mid-section. Furthermore, it was observed

\*Note: The criterion selected for removing specimens from the durability tests when failure occurs is the loss in strength of 50 percent estimated from the evolution of the sonic modulus of elasticity. This is equivalent to a decrease of 30 percent of the initial sonic value. In three instances the above values were exceeded. This was due to the acceleration of deteriorating effects following a previous sonic determination.

that an increasing amount of map checking occurred nearer the ends of the beams, which was also evidence of more progressive deterioration in the end sections. These conditions would lead to the assumption that the moduli of rupture are misleading as a measure of the true values of the concrete affected. It is believed that had the concrete been of uniformly low strength the beams would have ruptured as usual in the mid-section with appreciably lower moduli of rupture resulting.

No conclusive proof can be offered in favor of either size beams, but from overall observations (pertinent to this and other projects) the trend generally favors the smaller specimens for providing more consistent results and uniformity of effect from durability tests.

The use of the blended cement was not particularly detrimental to the strength of the concrete. There are wider differences in the compressive strengths than in the flexural strengths.

The increase of the percentage of fines in the coarse aggregates proved of no especial advantage in this particular project. A resulting decrease in the 28-day strength is evident, and this trend is equally or more pronounced in the moduli of rupture for the durability specimens.

Some consideration should also be given to the variable in the cement factors and the water-cement ratios relative to their influences on strength and durability.

The results from the slabs correspond with those of their companion beam specimens. No scaling occurred.

#### CONCLUSIONS

This investigation proves the value of the blended cements, with air-entraining properties, toward increasing the durability of concrete in which this type of inferior aggregate is incorporated. It is difficult to determine, as yet, where the line should be drawn as to the extent of safe application to low grade aggregates, without a complete knowledge of the characteristics of the aggregates themselves.