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OPERABLE AGGREGATES PROPERTY TO MINIMIZE CEMENT QUANTITY IN PORTLAND CEMENT CONCRETE

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ABSTRACT

Aggregate shape, texture, and grading have a significant effect on the performance of fresh concrete. Aggregate blends with well-shaped, rounded, and smooth particles require less paste for a given slump than blends with flat, elongated, angular, and rough particles. At the same time, uniform grading with proper amounts of each size result in aggregate blends with high packing and in concrete with low water demand. Optimized Aggregate blends have high packing, requiring low amounts of paste. As a result, they are less expensive and will have less durability problems caused by the paste such as heat generation, porosity, and drying shrinkage. Current C 33 standard limits the amount of material passing the N 200 sieve (micro fines) to 7 percent. However, manufactured fine aggregate (MFA) usually has between 10 and 20 percent micro fines.

These limits, intended for natural sands, force MFA producers to wash aggregate incrementing costs and generating environmental issues. Research at The University of Texas and experience in other countries show that good quality concrete can be made with MFA with high-micro fines content.

Keywords: Aggregate, Concrete, Cement.

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1. INTRODUCTION

Aggregate, the main constituent of concrete, constitutes of sixty to eighty percent of the total volume of concrete. Proper selection of the type and particle size distribution of the aggregates affects the workability and the hardened properties of the concrete. There are two main reasons for increasing the amount of aggregates in concrete. The first is that cement is more expensive than aggregate, so using more aggregate reduces the cost of producing concrete. The second is that most of the durability problems, e.g. shrinkage and freezing and thawing, of hardened concrete are caused by cement. Generally, concrete shrinkage increases with increase in cement content; aggregates, on the other hand, reduce shrinkage and provide more volume stability. Furthermore, cement production is a key source of carbon dioxide (CO_2) emissions, and reducing its usage should be a goal for concrete production Various projects have explored methods of minimizing cement in concrete; amongst the most common of those is replacing cement with cementations and pozzolanic materials such as fly ash.

Aggregate shape, texture, and grading significantly affect concrete workability. To achieve the same workability, poorly shaped and poorly graded aggregates usually require more paste (cement and water). The additional paste is needed to compensate for the low packing density of those aggregates and for the higher inter-particle friction between them. Selecting the proper gradations for different blends of aggregates can minimize the paste volume and thus minimize the amount of cement.

2. OBJECTIVES

1. Cement content can be reduced for a given strength level in several ways. This research had the objective of decreasing paste volume by varying aggregate grading and replacing cement with mineral fillers (micro fines).
2. To Study the effects of packing density and inter-particle friction were also tested by varying the types and gradations of the aggregates used.

3. LITERATURE REVIEW

Quiroga and Fowler 1994 Galloway

- The sphericity measures how nearly equal are the three principal axis of the aggregate (length *L*, width *W*, and height *H*). The sphericity increases as the three dimensions approach equal values.
- The form or the shape factor, describes the relative proportions of the three axes of a particle. It helps distinguish between particles that have the same sphericity

Quiroga and Fowler 2004 Graves

- The angularity describes the proportions of the average radius of curvature of corners and edges to the radius of maximum inscribed circle

- The roundness describes the sharpness of the edges and corners Particle shape can be classified by the following description.

Lamond and Pielert 2006

- Natural gravel subject to transport mechanisms tends to be smoother than manufactured aggregates. instance, gravel would have a surface smoother than crushed limestone.
- Nevertheless, there is no reliable method to determine the surface texture of manufactured aggregate

4. TEST METHOD & MATERIALS

The test method described in C 136 "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates" was used to determine the gradation of the fine and coarse aggregates.

These procedures are described here:

1. The fine aggregate and water were placed in a mixing bowl and mixed at a low speed for 30 seconds.
2. The mixer was then turned off and the material was allowed to rest undisturbed for 4 minutes.
3. On low speed, the cement was added to the mixture over a period of 30 seconds.
4. The mixer was then turned to medium speed for an additional 30 seconds and then turned off.
5. The mortar was allowed to rest for 1 minute and during this time the sides of the bowl were scraped and a dose of HRWRA was added.
6. The mortar was then mixed for an additional 1 minute at medium speed.
7. The mortar flow test was then performed (as described in C 1437).

To identify differences in the performance relating to material properties of mortar and concrete mixtures, materials used in this research are discussed in this Chapter. Two coarse aggregates were used, a limestone and a natural river gravel. Three fine aggregates were tested, one river sand and two manufactured limestone sands; one well shaped, and another poorly shaped. Three micro fines that included a limestone obtained as pond fines, a limestone obtained by sieving from screenings, and granite obtained by sieving from screenings. A Type I/II cement was used along with one high-range water-reducing admixture.

4.1. Cement

The Portland cement used in this project was a TXI Type I/II cement. This cement satisfies the C 150 "Standard Specification for Portland Cement" specifications for a hydraulic Portland cement. Type I/II satisfy the composition of a Type I (normal cement) and a Type II (moderate sulfate resistant cement).

4.2. Chemical admixture

Since the study had the goal of achieving concrete mixtures with slumps of 6-in. ± 1-in., a HRWRA, Glenium 3030 NS was chosen. Glenium 3030 NS (manufactured by BASF), is a polycarboxylate-based HRWRA that meets C 494 "Standard Specification for Chemical Admixtures for Concrete" requirements for Type A (water-reducing) and Type F (high-range water-reducing admixture). Glenium 3030 NS can be added to concrete mixtures with the initial mixing water or delayed until the final water is added.

4.3. Coarse aggregates

Two coarse aggregates were tested and used. The coarse aggregates (3/4-in. Maximum size) included a cubical, well-rounded natural coarse aggregate (NAT-CA) and a cubical angular crushed limestone coarse aggregate (LS-A-CA). The aggregate properties refer to the standardized tests performed on the materials (Table 4.1). These tests were described in Chapter 3 and include bulk density and voids in aggregates, specific gravity, and absorption.

Table 4.1 Summary of Coarse Aggregate Properties

ID	Source	Mineralogy	SG_{SSD}	Absorption (%)	Dry-rodded Pkg. Density (%)
NAT-CA	Austin, TX	River Gravel	2.56	1.30	62.4
LS-A-CA	Garden Ridge, TX	Limestone	2.55	1.43	58.6

The specific gravity and absorption of both materials are nearly the same. The main difference was in the dry-ridded packing density. The natural gravel has a higher packing density; therefore, mixtures containing natural gravel usually need less mortar to fill the voids as compared to angular, crushed aggregate.

Using C 136 as described in Chapter 3, the gradation of the two coarse aggregates was measured. Figure 4.1 shows the particle size distribution obtained in terms of percent passing. The particle size distribution of the coarse aggregates is somewhat similar; the limestone aggregate is slightly coarser.

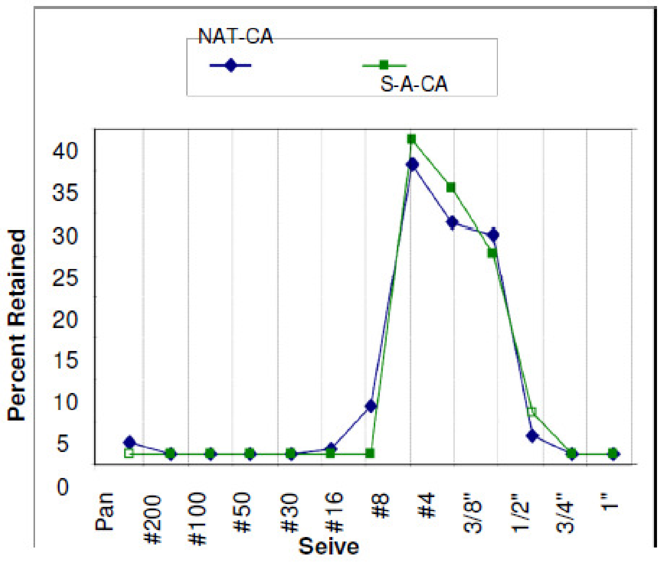

Figure 4.1 Percent Retained for Course Aggregate

4.4. Fine aggregates

Three fine aggregates were tested and used in the project: a natural sand (NAT-FA), a well-shaped limestone manufactured sand (LS-A-FA), and a poorly shaped limestone manufactured sand (LS-B-FA). Table 4.2 shows the fine aggregate properties as obtained using the tests described in

Chapter 3. The specific gravities of the three fine aggregates were about the same. The well-shaped manufactured

Limestone (LS-A-FA) has a higher absorption capacity, while the river sand (NAT-FA) has the highest packing density.

Table 4.2 Summary of Fine Aggregate Properties

ID	Source	Mineralogy	SG_{SSD}	Absorption (%)	Dry-rodded Pkg. Density (%)
NAT-FA	Austin, TX	River Sand	2.60	0.56	67.6
LS-A-FA	Garden Ridge, TX	Limestone	2.61	1.62	66.6
LS-B-FA	Perch Hill, TX	Limestone	2.67	0.58	64.2

Figure 4.2 contains the particle size distribution of the fine aggregates. The river sand (NAT-FA) is finer than the other two sands, while the poorly shaped manufactured sand (LS-B- FA) is the coarsest.

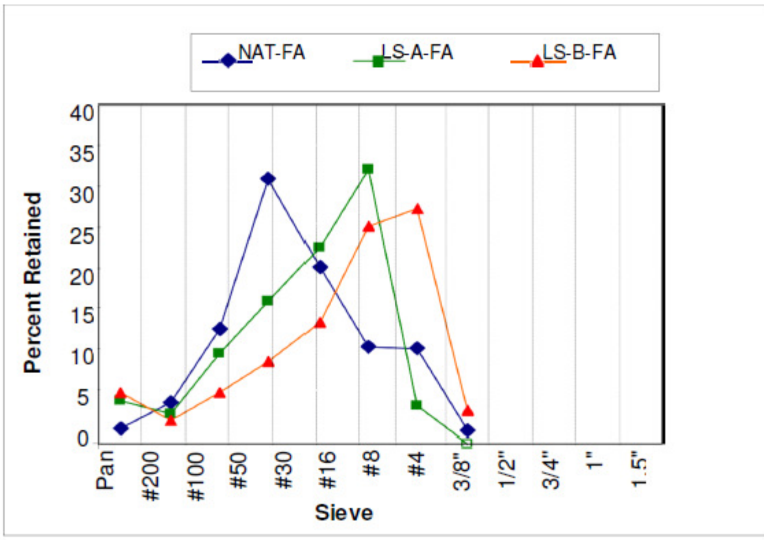

Figure 4.2 Percent Retained for Fine Aggregate

4.5. Micro fines

The properties of the three micro fines used in Phase II of the project are shown in Table These properties include the methylene blue, single drop, and laser diffraction test described in Chapter 3.

Table 4.3 Micro fines Properties.

Source Location	Mineralogy	ID	MBV	Single Drop Test		Laser Diffraction	
			mg/g	w/f	Packing Density	Span	SSA
Garden Ridge, Tx	Limestone	LS-A	1.63	0.401	0.714	6.673	1.394
Calica, Mx	Limestone	LS-C	2.25	0.415	0.707	4.688	1.806
Liberty, Sc	Granite	GR-A	0.63	0.559	0.642	2.192	0.467

4.6. Combined aggregate properties

To estimate the minimum paste content needed for the concrete mixtures, the dry-rodded unit weight was obtained for the different blends of aggregates. The same method used to determine the dry-rodded unit weights for individual aggregates was used (described in Chapter

3). Four combinations of fine and coarse aggregates were blended to achieve four different gradings: three gradings with sand-to-aggregate (S/A) ratios of 0.30, 0.40, and 0.50 and a fourth gap grading where all coarse aggregate finer than the 3/8-in. Sieve were removed and the remaining material used with an *S/A* of 0.40. The aggregate combinations included NAT-CA with NAT-FA, NAT-CA with LS-A-FA, NAT-CA with LS-B-FA, and LS-A-CA with NAT-FA.

Table 4.3 contains the values of the combined dry-rodded unit weight of different combinations of aggregate. For each *S/A* ratio the percent solids and percent voids were computed. Those values were later used to estimate the minimum percent paste for the concrete.

Table 4.4 Percentage Voids in Compacted Aggregate Blends

Coarse Aggregate ID	Fine Aggregate ID	S/A	Dry-rodded Unit Weight (lb/ft^3)	% Solids	% Voids
NAT-CA	NAT-FA	0.3	118.8	74.11	25.89
NAT-CA	NAT-FA	0.4	120.4	75.02	24.98
NAT-CA	NAT-FA	0.5	122.0	75.93	24.07
NAT-CA (GAP)	NAT-FA	0.4	120.4	75.02	24.98
NAT-CA	LS-A-FA	0.3	112.4	70.28	29.72
NAT-CA	LS-A-FA	0.4	116.8	73.00	27.00
NAT-CA	LS-A-FA	0.5	119.2	74.47	25.53
NAT-CA (GAP)	LS-A-FA	0.4	118.0	73.75	26.25
NAT-CA	LS-B-FA	0.3	110.4	68.39	31.61
NAT-CA	LS-B-FA	0.4	114.0	70.37	29.63
NAT-CA	LS-B-FA	0.5	116.4	71.61	28.39
NAT-CA (GAP)	LS-B-FA	0.4	115.2	71.12	28.88
LS-A-CA	NAT-FA	0.3	115.6	72.31	27.69
LS-A-CA	NAT-FA	0.4	119.6	74.69	25.31
LS-A-CA	NAT-FA	0.5	123.6	77.07	22.93

4.7. COMBINED AGGREGATE GRADATIONS

The following section shows the gradations and the 0.45 power curve corresponding to different combinations of coarse and fine aggregates. The workability factor is also plotted as a function of the coarseness factor; this plot helps identify expected performance relating to the combined gradations.

The 0.45 power curve for combinations of NAT-CA and NAT-FA is shown in Figure 4.4. The best combined gradation for those two aggregates is S/A=0.4; since it is the closest to the

0.45 power line. S/A=0.3 is too coarse (the curve is below the 0.45 power line) while S/A=0.5 is too fine (the curve is above the 0.45 power line). The gap graded gradation is the coarsest among the four blends.

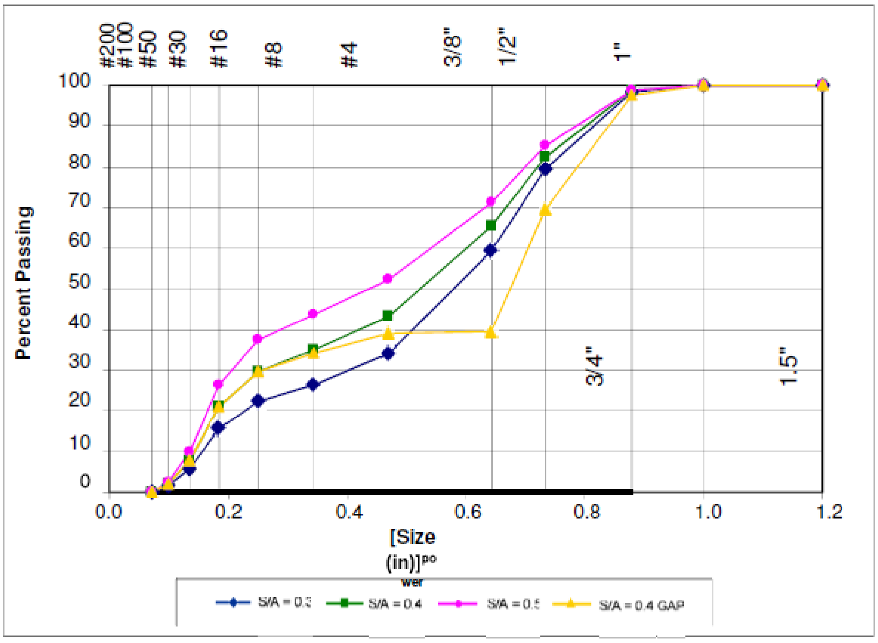

Figure 4.4 0.45 Power Chart for NAT-CA and NAT-FA Blends

The workability factor is plotted as a function of the coarseness factor for the blends of NAT-CA and NAT-FA (Figure 4.5). The results obtained from Figure 4.5 confirm what was previously deduced from Figure 4.4. The gradation corresponding to *S/A*=0.4 is expected to yield a good result. *S/A*=0.5 is too sandy and concrete mixtures containing this gradation are likely to segregate and yield a low strength. *S/A*=0.3 is too coarse, while the gap graded gradation.

5. CONCLUSION

The results obtained in this research confirm that aggregate type and gradation can play an important role in optimizing the cement content of concrete mixtures. Improving the aggregate shape and grading allowed a reduction in paste volume while maintaining workability and hardened properties. Both shape and grading affected workability. Aggregates with angular shape resulted in increased paste volume and HRWRA demand. Aggregates with coarser grading generally required lower HRWRA demand but required higher paste volume to ensure adequate cohesiveness. Higher packing densities were associated with lower minimum paste volume to ensure adequate cohesiveness; however, it was not clear the extent to which the lower minimum paste volume was due to a finer grading or a higher packing density.

In Phase I, the compressive strength was only affected by paste reductions in sandy concrete mixtures, and no other major changes in compressive strength were observed for the different aggregate combinations. Both shrinkage and permeability improved when paste content was reduced; however, compared to mixtures containing siliceous aggregates, mixtures containing limestone shrunk less because of differences in stiffness.

The use of aggregate microfines allowed the reduction of cement content while maintaining or improving the performance of the baseline mixture. Since microfines are typically similar in size as cement, they should be considered as part of the paste not as part of the aggregates when evaluating the workability of a mixture. If the microfines are considered as part of the aggregate, the mixture would have too many fine particles (cement and microfines) which would decrease the workability or increases the HRWRA demand.

Microfine additions improved the hardened properties of the concrete. The compressive strength of the mixtures containing microfines was higher than for the baseline mixture. The performance of the concrete in shrinkage and permeability improved also. As for abrasion resistance, the mixtures containing more microfines were more resistant than the baseline mixture.

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