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PRELIMINARY GUIDELINES FOR PROPORTIONING CLASS P CONCRETE CONTAINING MANUFACTURED FINE AGGREGATES

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Preliminary Guidelines for Proportioning Class P Concrete Containing Manufactured Fine Aggregates

Scope

The guidelines described in this document aim at providing guidance on how manufactured fine aggregates (MFAs) can be used in Class P concrete. The goal is achieve the desired properties of concrete (workability, strength, and durability) while using MFAs and minimizing paste content.

Significance and Use

Sources of quality natural sands have begun depleting in metropolitan areas where the need for concrete is high. In such areas the concrete industry has the option to either ship natural sands from outside sources or use local sources of MFAs. Shipping aggregates from outside sources adds to the cost of concrete, this is why it is important to find methods to maximize the use of local materials.
Several problems arise from using MFAs in Class P concrete, these include workability, finish-ability, and skid resistance. These problems exist because of the mineralogy, shape, or grading of MFAs. In general, MFAs are less polish resistant than natural sands, which may cause skid problems in pavements. Workability and finish-ability problems exist as a result of the poor shape and grading of MFAs. To overcome the poor shape and grading of MFAs, additional paste is added to the mixture; the addition of more paste adds to the cost of concrete and affects its durability.

The purpose of this document is to present a method to proportion concrete paving mixtures made with MFAs while achieving the desired performance at the lowest cost and carbon footprint. The method described below is a modified version of the method presented by Fowler and Koehler (2007) and Fowler and McLeroy (2009).

Mix Design Guidelines

The following are the recommended steps for designing a mixture containing MFA:

1. Choose the aggregate system
    a. Evaluate aggregate properties
    b. Determine the maximum allowable MFA content based on polish resistance properties of fine aggregate
    c. Determine optimum grading
2. Choose the paste quantity
    a. Determine minimum paste content based on the chosen combined aggregate gradation
    b. Determine additional paste needed for workability based on shape and angularity of MFA
3. Choose the paste quality
    a. Choose supplementary cementing material (SCM) type
    b. Choose air content
    c. Choose w/cm

I. Choosing the Aggregate System

To improve the performance of concrete, it is important to properly choose aggregates based on the properties obtained from characterization tests. Each of the characterization tests has been developed to evaluate critical aggregate properties that influence concrete performance. This section will discuss aggregate properties and how they effect mixture design and relate to concrete properties.

Coarse Aggregates: The quality of coarse aggregates to be used should meet the TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges Item 421.2.E.1. The properties described in this section insure that the aggregates being used are durable and will not have detrimental effects on concrete properties.
The other properties to consider are maximum size and grading. Larger maximum sizes are beneficial for workability because they extend the range of aggregate sizes which improves grading (Fowler and Koehler 2007). Aggregate grading can also be improved by combining two different grades of aggregates. For instance, a grade 2 and a grade 4 (Table 3 of Item 421) can be combined to result in an improved grading. Improving aggregate grading will help maximize aggregate content, reduce paste content, and thus reduce cost.

Fine Aggregates: The main difference between natural sands and MFAs is mineralogy, grading shape, angularity, and texture. The difference in mineralogy affects the polish resistance of the aggregate as well as the grading. To overcome the low polish resistance of some MFAs, MFAs should be either blended with a polish resistant aggregate (natural sand) or other innovative techniques should be used (examples will be given in the final document). Grading of MFAs differ from natural sands in that MFA have a finer grading. Unless re-graded, calcareous MFAs do not meet ASTM C33 Standards (Table 4 of Item 421) because MFA contain higher percentages of fine aggregates passing the #200 sieve (microfines). To overcome the workability problems associated with sands containing higher fines, the proportioning method described in this document will account for the microfines as part of the paste and not the aggregate when proportioning the mixture. Shape and texture of fine aggregate is affected by the crushing operation and mineralogy of the source. Angular particles with poor shape reduce the workability for a given paste content. This is why it is important to evaluate the shape and angularity of MFAs and estimate the optimal quantity of paste needed to compensate for the effects of poor shape and angularity.

The following aggregate properties should be evaluated as follows:

a. Deleterious Materials such as clays can be tested by using a methylene blue test. Many versions of the methylene blue test exist; the most reliable is the one developed by W.R. Grace. This version of the test utilizes a colorimeter to evaluate the presence of clay in the entire sand samples (not just in the fines) and is more accurate and repeatable. Tex-413-A limits the clay content to 0.5% by weight.
b. Shape and Angularity should be evaluated using an aggregate imaging measurement system (AIMS). AIMS evaluates the shape (2D form) and angularity (angularity index)

of fine aggregates. The data obtained from AIMS will be used to determine the additional paste needed to achieve the required workability.

c. The polish resistance of a concrete pavement is dependent on the fine aggregate used. To achieve adequate surface friction, a certain percentage of the fine aggregates should be polish resistant. In general, this will be the limiting factor on how much MFA can be used in a mixture. To determine the maximum allowable MFA content, the combined aggregate acid insoluble residue should be a minimum 60% by weight (as described in Tex-612-J). (Note that this section might be changed in the final document after the test results for skid are obtained)

d. All other fine aggregate properties should be determined by the methods described in item 421.E.2 of TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges. As noted before, the fine aggregate gradation may not meet item 421 requirements, but that will be accounted for in the mixture proportioning method.

Combined Aggregate Grading: The limit on the quantity of MFA that should be used to achieve skid resistance should have been determined and accounted for before this step is attempted. To achieve the highest packing density of aggregates, more than one grade of aggregate can be used. The combined gradation of coarse and fine aggregate should be evaluated using a modified 0.45 power curve. The modified 0.45 power curve should not take into account the presence of microfines since the microfines will be accounted for as part of the paste rather than the aggregate. The modified 0.45 power curve should go through the #200 sieve (Figure 1).

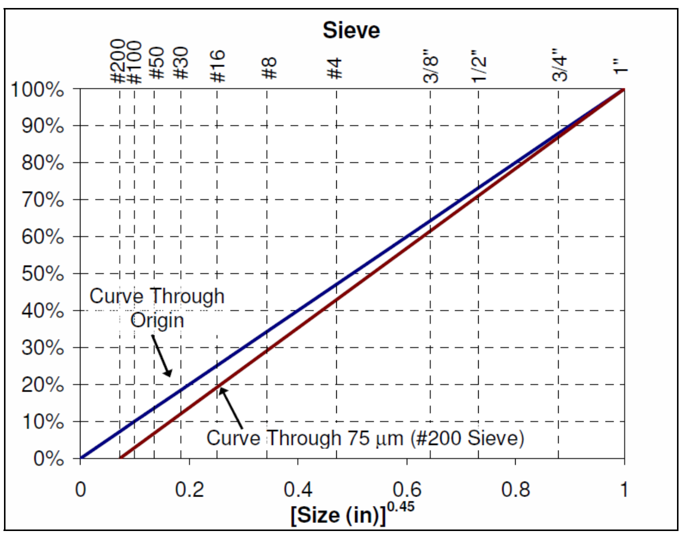

Figure 1: Modified 0.45 Power Curve (Fowler and Koehler 2007)

In addition to using a modified 0.45 power curve, two other methods can be used to ensure that uniform blends of aggregates are being used: the 8-18 grading system and the Shilstone coarseness chart. It should be noted that Fowler and Quiroga (2003) found that the 8-18 grading system was not suitable for evaluating aggregates with high microfine content.

After the optimal grading is determined using the modified 0.45 power curve, the dry-rodded unit weight (DRUW) of the aggregate combination should be evaluated (Tex-404-A rodded method). To ensure that highest aggregate density was obtained, multiple aggregate combinations can be tested using the modified 0.45 power curve and then by obtaining the DRUW; the combination with the highest DRUW correspond to the highest aggregate density.
After obtaining DRUW, the percent compacted voids corresponding to the chosen aggregate gradation should be determined. The percent compacted void content is determined as follows:

$$\%voids_{compacted\_agg} = \left(1 - \frac{DRUW}{\left(62.4\, {}^{lb}/_{ft^3}\right) \sum_{i=1}^{n} \left(p_i \left(SG_{OD} \right)_i \right)} \right) * 100\%$$

where DRUW is the dry-rodded unit weight of the combined aggregate (lb/ft^3), p_i is the volume of aggregate fraction i divided by the total aggregate volume, and $(S_{GOD})_i$ is the oven-dry specific gravity of aggregate fraction i.

II. Choosing the paste Quantity

Figure 2 shows a schematic representation of aggregate in cement paste. The total volume of paste needed for concrete is equal to the volume of paste needed to fill the voids in compacted aggregates + the volume of paste needed to separate aggregate.

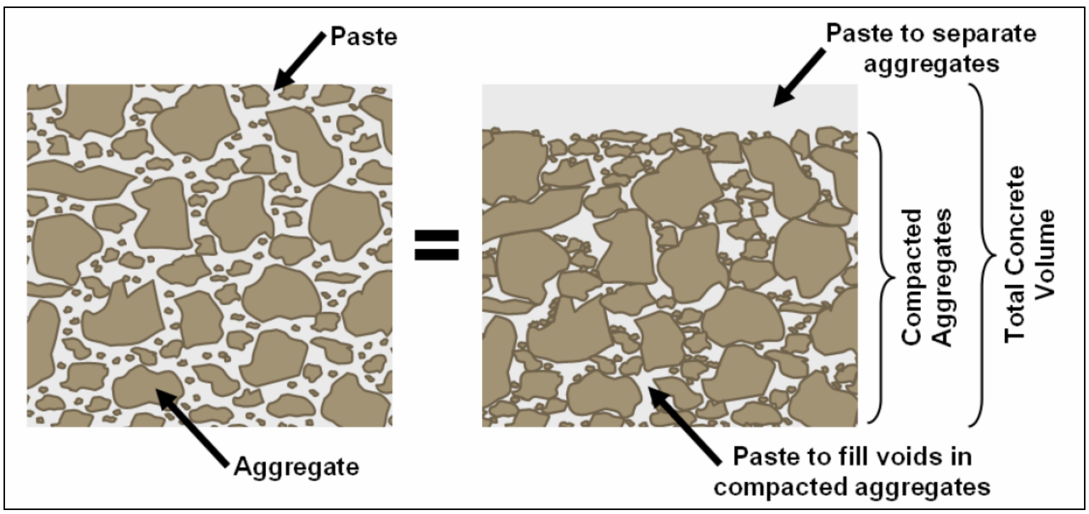

Figure 2: Schematic Representation of Aggregate in Cement Paste (Fowler and Koehler 2007)

$$V_{Total\ paste} = V_{paste-Voids} + V_{paste\_spacing}$$

$V_{paste-Voids}$ corresponds to the $\%Voids_{compacted\_agg}$ calculated using DRUW. $V_{paste\_spacing}$ is related to the shape and angularity of fine aggregate. Fowler and McLeroy (2009) found that $V_{paste\_spacing}$ for a Class P concrete ranges from 3 to 8% paste by volume. Previous work attempted to compute $V_{paste\_spacing}$ through a visual shape and angularity rating system. The problem with using such a method is that it is very subjective. A better method of evaluating shape and angularity can be achieved by using AIMS.

How do AIMS values relate to workability?

AIMS evaluates the shape of fine aggregates by using a 2D form index. The lower the form index the more equi-dimensional a particle is. Four different fine aggregates were evaluated using AIMS (Table 1). Aggregate 1 is a natural sand with a good shape, Aggregate 2 is a manufactured fine aggregate (MFA) with a good shape, Aggregate 3 and 4 are MFA with a relatively poor shape. For each of those aggregates the cumulative percentage of aggregate with a shape ≤ 6 was computed (highlighted in yellow). Aggregate 1 had the highest percentage (indicating a good shape factor), Aggregates 3 and 4 had the worse shape factor (lower cumulative percentages).

Table 1: Cumulative 2D Form Index

	Aggregate 1 (Cum. %)	Aggregate 2 (Cum. %)	Aggregate 3 (Cum. %)	Aggregate 4 (Cum. %)
≤ 6	42.7	29.8	17.8	14.7
≤ 12	96.6	95.1	93.5	93.8
≤ 20	100	100	100	100

AIMS also evaluates the angularity of fine aggregates. The scale used ranges from 0 to 10000; 0 indicates the presence of well round aggregates, and 10000 indicates the presence of highly angular aggregates. Table 2 shows the results of the cumulative angularity index for the four aggregates used in this study. Aggregates 1 and 2 have a higher percentage of particles with an angularity index ≤ 3300, therefore they are less angular than aggregates 3 and 4.

Table 2: Cumulative Angularity Index

	Aggregate 1 (Cum. %)	Aggregate 2 (Cum. %)	Aggregate 3 (Cum. %)	Aggregate 4 (Cum. %)
≤ 3300	79.1	68.2	50.4	55.6
≤ 6600	99.7	99.2	98.5	100
≤ 10000	100	100	100	100

Note that Aggregate 1 has the best shape and angularity index, and aggregate 2 has a shape and angularity index that is better than aggregates 3 and 4. Aggregate 3 has a better shape index than aggregate 4 but seems to be more angular.

To evaluate whether or not those indices of shape and angularity can relate to concrete, the flow of mortars made with these aggregates was evaluated. ASTM C1437 was used to measure the flow of mortar. To evaluate shape and angularity without including the effect of gradation, all fine aggregates were washed, then sieved, and then re-graded to have the same gradation. All mortar mixtures had the same volume (1 liter) and were batched based on SSD values with no additions of admixtures. The results obtained are shown in Figures 3 and 4.

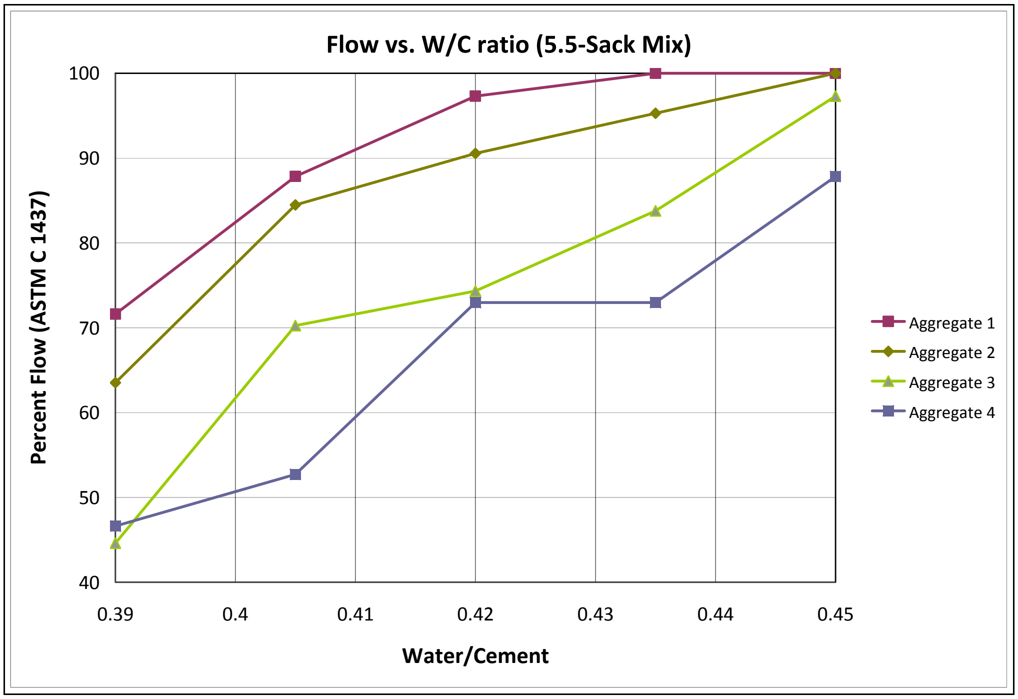

Figure 3: Flow of aggregates with different shape and angularity (5.5 sacks)

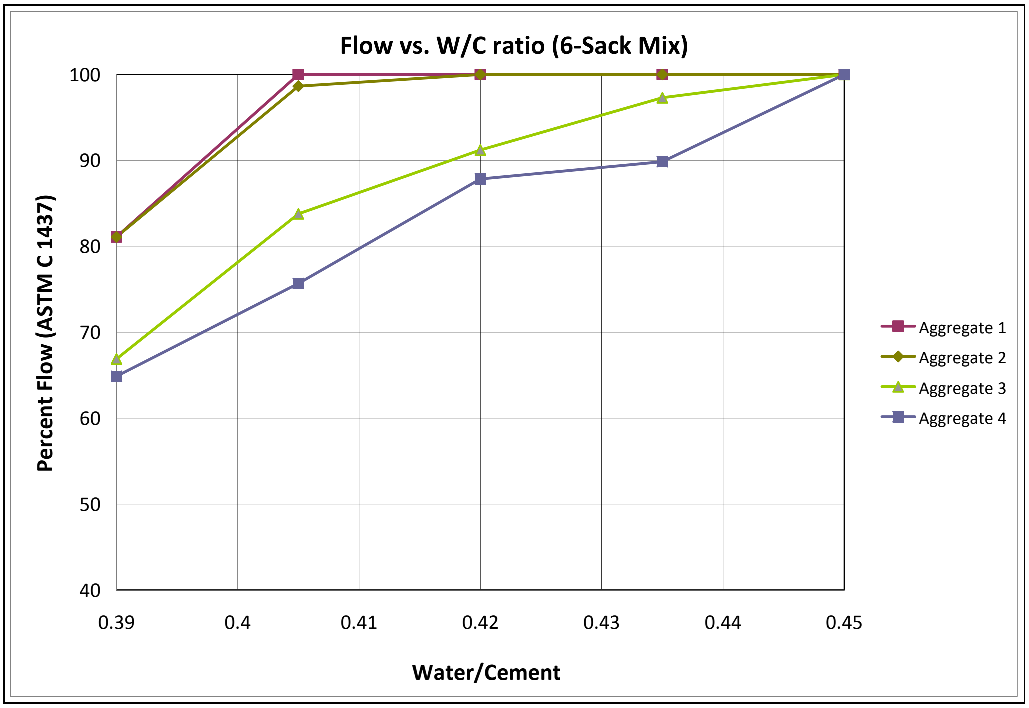

Figure 4: Flow of aggregates with different shape and angularity (6 sacs)

Results in Figure 3 represent a concrete mortar composed of 5.5-sack mix, while Figure 4 represents a concrete mortar using a 6-sack mix. Comparing Figures 3 and 4 to results of Tables 1 and 2, shows that aggregates with higher 2D form and angularity index performed better than aggregates with lower indices. Thus shape and angularity values obtained from AIMS seem to relate to concrete flow as measured by ASTM C 1437.

Note that in this preliminary report, the researchers tried to investigate whether or not AIMS values could be used to replace the visual rating system. In the final report, and after concrete mixtures are evaluated, the researchers will present a method on how to incorporate AIMS values in the mix design (how to determine $V_{paste\_spacing}$ from AIMS values).

III. Choosing the Paste Quality

After the paste quantity is determined, the composition of the paste is selected to achieve the required plastic and hardened concrete properties. The paste is composed of cement, water, SCMS, air, mineral fillers (Microfines present in the fine aggregates are accounted as mineral fillers), and admixtures. Table 3 summarizes the effect and purpose of the different paste constituents. For more information on paste composition requirements and limits refer to Item 421 of the TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges.

Table 3: Selection of Paste Composition (Fowler and Koehler 2007)

	Parameter	Purpose
Water	Water/Cement	Early-age hardened properties
	Water/Cementitious Materials	Long-term hardened properties
	Water/Powder	Workability
Powder	Cement	Strength and durability
	SCMs	Improve workability and durability, reduce heat, reduce cost
	Mineral Fillers	Improve workability, reduce cost, reduce heat
Air	Air Content	Durability

Future Work

As part of project 0-6255, the proportioning method described in this document will be tested and improvements involving the following will be made:

- Identifying better methods to evaluate skid and identify MFA limits.
- The 3-8% paste range that was found to work for Class P concrete will be evaluated.
- A method (formula) to determine $V_{paste\_spacing}$ using AIMS values will be established.
- Evaluate if other factors might be contributing to the workability of concrete (For example mixing time and the presence of a soft MFA).

References

Ahn and Fowler. “An Experimental Study on the Guidelines for Using Higher Contents of Aggregate Microfines in Portland Cement Concrete” Ph.D. Dissertation, University of Texas at Austin, 2000.

Koehler and Fowler. “Aggregates in Self-Consolidating Concrete” Ph.D. Dissertation, University of Texas at Austin, 2007

TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges 2004 Edition.

Quiroga and Fowler. “The Effect of the Aggregates Characteristics on the Performance of Portland Cement Concrete” Ph.D. Dissertation, University of Texas as Austin, 2004.