Effects of Aggregate on Flow Properties of Mortar

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ABSTRACT

The effects of aggregate characteristics on flow ability of mortar mixtures were investigated. Two types, five single sizes, and three gradations of fine aggregate were considered. Uncompacted voids of the aggregates were measured. Flow properties of 166 mortar batches made with the aggregates, together with different sand-to-cement ratios (s/c) and water-to-cement ratios (w/c), were evaluated using the ASTM C109 flow table test method. The results indicated that w/c, uncompacted voids, size, and volume of aggregate have a great impact on mortar flow ability. Generally, aggregate having higher uncompacted void content provides mortar with a lower flow. When aggregate content was low (s/c=1), the size of aggregate had little effect on flow ability of the mortar; while aggregate content was high (s/c=3), the size of the aggregate significantly influenced the mortar flow ability. A statistical model was developed for predicting flow ability of mortar.

Key words: angularity—content—fine aggregate—flow—size

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INTRODUCTION

Aggregate characteristics (such as size, gradation, shape, and surface textures), as well as its volume fraction, have a significant impact on workability, especially on flow ability, segregation resistance, and compactibility of concrete. Based on the concept of particle packing, well-graded (or well-packed) aggregate has fewer voids between particles than poorly-graded aggregate, and it requires less cement paste to fill the voids. Thus, additional amount of cement paste will coat the aggregate particles and improve the concrete flow. Research results from Smith and Collis (2001) have proved this concept. Differently, Quiroga (2003) recently found that the concrete mixtures optimized for maximum packing density produced poor workability and high susceptibility to segregation, which was possibly due to the reduced spacing and increased friction between aggregates. For the same reason, increase in volume fraction of aggregate in concrete generally results in a reduced flow (Szecsy 1997; Geiker et al. 2002). Crushed sands often require higher water content than natural riversands for given workability owing to their angularity and surface texture (Malhotra 1964; Geiker et al. 2002). However, because of the difficulties in quantitative characterization of aggregate, most existing research focuses on aggregate gradation and volume fraction, and limited work on other aggregate characteristics (such as shape and surface textures) has been done. In the present study, fine aggregate type, size, gradation, shape, and surface textures are all considered, and their effects on mortar flow properties are studied.

RESEARCH SIGNIFICANCE

Aggregate characteristics have significant effects on concrete workability and other properties. However, limited work has been conducted studying the effects systematically and quantitatively. Using the ASTM standard flow table test, this study provides a systematic study of effect of aggregate on mortar flow ability. The research results will provide engineer with an insight on concrete selection and mix design.

EXPERIMENTAL WORK

Materials

Type I Portland cement was used for all mortar samples. Riversand and limestone sand were used as fine aggregates. The specific gravity of the fine aggregates was 2.63 and 2.59 for riversand and 2.53 and 2.42 for limestone under the saturated surface dried (SSD) condition and oven dried (OD) condition, respectively. All aggregates were oven dried before use. Five single-sized aggregates (#8, #16, #30, #50, and #100) and three graded aggregates (G1, G2, and G3), as shown in Figure 1, were employed.

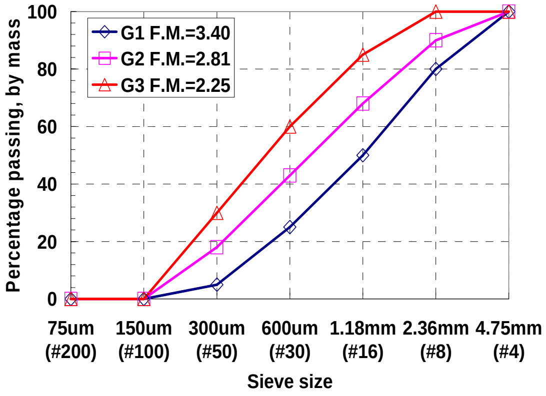


Figure 1. Gradation curve

Mixture Proportions

The mortar mix design is listed in Table 1. The design variables include aggregate types, sizes, gradations, sand-to-cement ratios (s/c), and water-to-cement ratios (w/c). The different w/c was selected to ensure that all mixtures could have a measurable flow. A total of 166 mortar batches were prepared.

Table 1. Mix design for mortar

s/c	Sand	w/c	
		Riversand	**Limestone**
3	#100	0.50, 0.53, 0.56, 0.62	0.37, 0.42, 0.47, 0.57
3	#50	0.44, 0.47, 0.50, 0.53, 0.55	0.32, 0.37, 0.42, 0.47, 0.52
3	#30	0.39, 0.42, 0.45, 0.48	0.35, 0.40, 0.45, 0.50
3	#16	0.33, 0.36, 0.39, 0.42, 0.45	0.24, 0.34, 0.44, 0.49
3	#8	0.27, 0.29, 0.32, 0.35, 0.38, 0.41	0.21, 0.26, 0.31, 0.36, 0.41
3	G1	0.30, 0.35, 0.40, 0.50	0.20, 0.25, 0.35, 0.45
3	G2	0.30, 0.35, 0.40, 0.50	0.20, 0.25, 0.35, 0.45
3	G3	0.33, 0.38, 0.43, 0.53	0.20, 0.25, 0.35, 0.45
2	#100	0.36, 0.41, 0.46	0.31, 0.36, 0.41
2	#50	0.34, 0.36, 0.41, 0.46	0.27, 0.32, 0.37
2	#30	0.30, 0.33, 0.35, 0.40, 0.45	0.28, 0.33, 0.38
2	#16	0.27, 0.30, 0.32, 0.37, 0.42	0.28, 0.33, 0.38
2	#8	0.25, 0.30, 0.35, 0.40	0.20, 0.25, 0.30
2	G1	0.33, 0.38, 0.43	0.29, 0.34, 0.39
2	G2	0.34, 0.39, 0.44	0.28, 0.33, 0.38
2	G3	0.36, 0.41, 0.46	0.28, 0.33, 0.38
1	#100	0.28, 0.32, 0.38, 0.48	0.26, 0.31, 0.41
1	#50	0.28, 0.32, 0.38, 0.48	0.21, 0.31, 0.41
1	#30	0.23, 0.27, 0.37, 0.37, 0.47	0.22, 0.32, 0.42
1	#16	0.21, 0.26, 0.36, 0.46	0.21, 0.31, 0.41
1	#8	0.20, 0.25, 0.35, 0.45	0.20, 0.30, 0.40
1	G1	0.37	0.32
1	G2	0.37	0.32
1	G3	0.38	0.32

Mixing Procedure

All mortar batches were mixed according to ASTM C305 “Standard practice for mechanical mixing of hydraulic cement pastes and mortars of plastic consistency.”

Test Method

Fine aggregate angularity

Particle shape and surface texture of aggregate were characterized with an angularity test based on ASTM C1252 “Standard test methods for uncompacted void content of fine aggregate (as influenced by particle shape, surface texture, and grading).” Fine aggregate angularity was defined as the percent of air voids in a loosely compacted fine aggregate. High void content indicates that the aggregate contains a large amount of fractured and irregular particles.

Flow measurement

Flowablility of mortar was measured using a flow table method modified from ASTM C230, "Standard Specification for Flow Table for Use in Tests of Hydraulic Cement." This ASTM test was originally designed to determine the water content needed for a cement paste sample to obtain a given flow spread of 110±5 mm. The test shall be performed with a standard flow table after the table drops 25 times. In the present research, a mortar sample was placed on the same flow table and subjected to 25 drops, and then the spread diameter of the sample was measured. The flowability of the mortar was expressed as a flow percentage—the percentage of the spread diameter over the original bottom diameter of the sample.

Since the standard flow table had a limited diameter, some mortars having high flow ability flowed out off the flow table when 25 drops were applied. To solve this problem, smaller number of drops was used for the wet samples. The spread diameters of these samples at 25 drops were predicted from a newly developed relationship between the number of the flow table drops and the spread diameter. To develop this relationship, a larger plate was attached on the standard flow table to increase the table surface area. A group of 40 samples were then tested on this modified flow table and their spread diameters were measured under various numbers of flow table drops.

TEST RESULTS AND DISCUSSIONS

Fine Aggregate Angularity

Figure 2 presents the uncompacted voids of all aggregates used. As shown in the figure, limestone sand had a higher percentage of uncompacted voids than riversand because of its irregular shape of the particles. Graded aggregate had lower void content than single-sized aggregate due to proper particle packing.

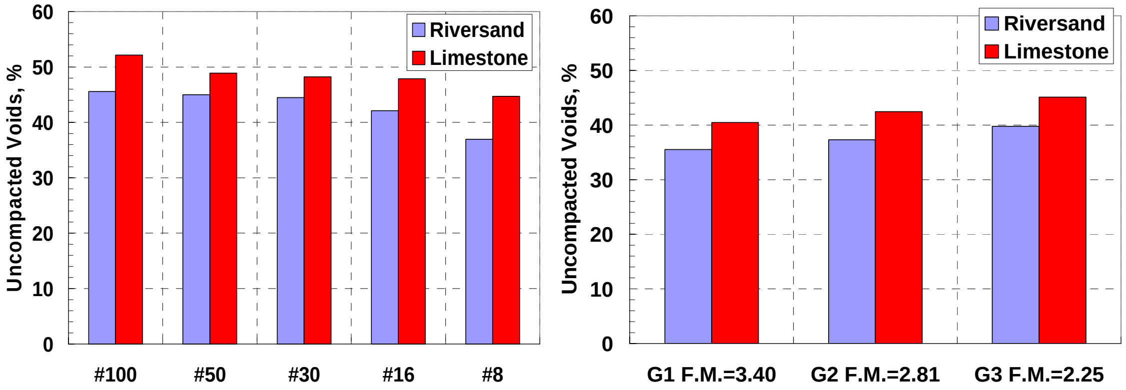


Figure 2. Fine aggregate angularities for different aggregate

Relationship Between Flow Table Drops and Sample Spread Diameter

Figure 3 demonstrates that the flow percentage had linear relationship with the number of flow table drops in logarithm scale. This relationship was used for prediction of the 25-drop flow percentage of the samples actually tested under less than 25 drops. It can be expressed as follows:

$$F_{25} = F_t + 46.779(\ln 25 - \ln t) \tag{1}$$

where t is the drop number of flow table, F_{25} is the flow percentage of mortar at 25 drops, and F_t is the flow percentage of mortar at t drops. The R square value of Equation (1) is 0.98, indicating that the predicted value is very close to the tested value.

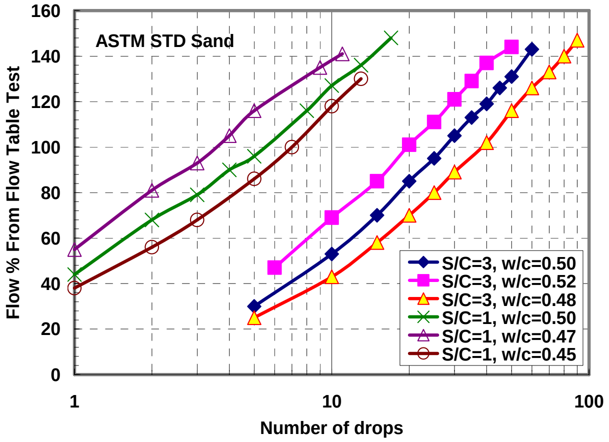


Figure 3. Number of drops versus flow percentage of flow table test

Flow Properties

Figure 5 shows the effects of aggregate size, w/c, and s/c on flow ability of mortar. For a given w/c, the higher s/c (or high aggregate content), the lower the mortar flow. For mixtures with a low s/c (Figure 5 (a)), the difference in mortar flow from different sizes of aggregate was not significant. However, this difference became clear when s/c increased (Figures 5(b) and 5(c)). For a given aggregate content, the mixtures with larger size of sand had a higher flow. Mortar with high w/c provided higher flow ability. Similar results were also found for mortar with limestone as fine aggregate.

Figure 6 shows that limestone provided mortar with lower flow ability comparing to riversand. This result is expected because the high percentage of the uncompacted voids in limestone required more cement paste to fill up the space between aggregate particles. As a result, less amount of cement paste was available to provide mortar with same flow.

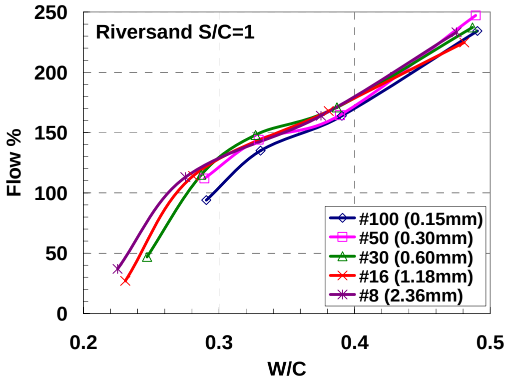
Figure 7 indicated that graded aggregate provided the mortar with a higher flow than single-sized aggregate for similar fineness modulus. It is because graded aggregate had low uncompacted void content and hence required less amount of cement paste to provide the same flow. Statistic analysis presented below confirmed this explanation.

Statistic analysis with linear regression was performed using selected parameters. According to the test results from 166 different mixes, the following equation was obtained:

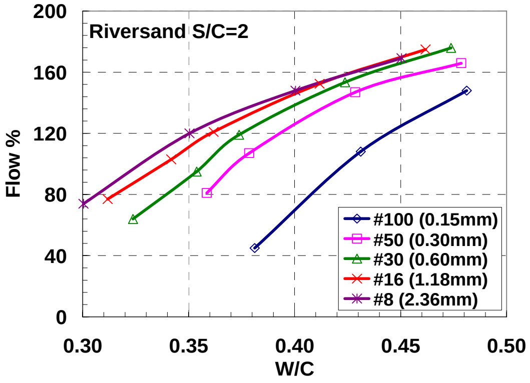
$$Flow\% = 348 - 3.84V_n + 391w/c - 4.59V_s + 12.27r \qquad (2)$$

where V_n is the uncompacted voids (%), r is the average aggregate size (mm), and V_s is the volume of sand (%). The R square value of Equation (2) is 0.79.

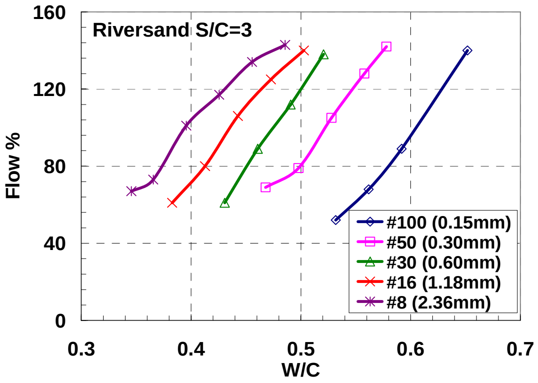
Equation (2) not only demonstrates the major factors that significantly affect mortar flow, but also can be used to predict or quantify mortar flowability based on aggregate characteristics and mix proportions.



(a)



(b)



(c)

Figure 5. Effect of aggregate size and s/c on mortar flow (riversand)

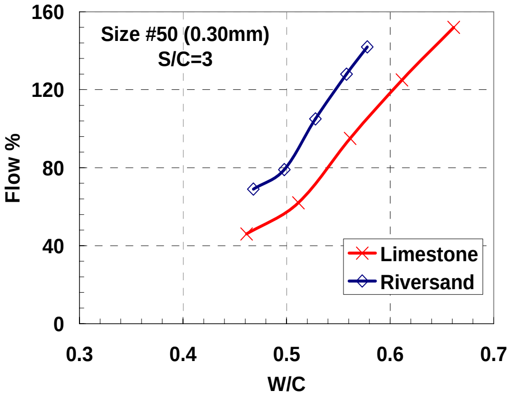


Figure 6. Effect of aggregate type

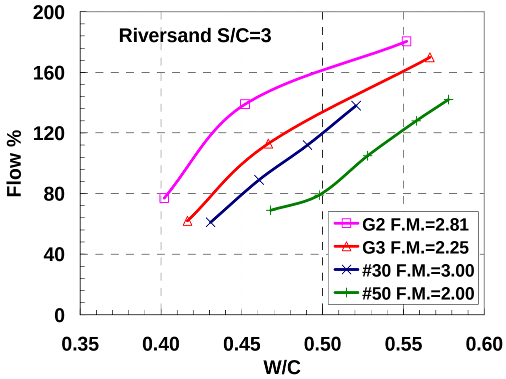


Figure 7. Effect of gradation

CONCLUSIONS

The following conclusions can be drawn from the present research:

1. Aggregate shape, surface texture, and gradation can be all characterized by the uncompacted voids between the aggregate particles. Generally, aggregate with higher uncompacted void content provides mortar with a lower flow.

2. In addition to w/c, uncompacted voids, size, and volume of aggregate are also significantly influence mortar flow ability. (Note that the effect of cement properties was not considered in the present study.) For mortar with a low s/c, the effect of aggregate size on the mortar flowability may not be significant, but the effect will become significant as s/c increases.

ACKNOWLEDGMENTS

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