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Using aggregate flowability testing to predict lightweight self-consolidating concrete plastic properties

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ABSTRACT

This paper presents the results of an experimental study on the flow properties of lightweight self-consolidating concrete (LWSCC) which utilizes a new test relating aggregate flow to concrete flow. Three types of LWSCC were tested containing differing proportions of lightweight and normal weight, coarse and fine aggregates, as well as a normal weight self-consolidating concrete (NWSCC) as a control. The flow properties of the aggregate mixes used in the LWSCC and NWSCC specimens were tested using a V-funnel. The concrete flow properties were also tested for comparison, as were the compressive and tensile strengths of the various mixtures. A relationship between the aggregate frictional resistance and the traditional concrete flowability tests—i.e., slump flow, J-ring, and T_{500}—was demonstrated. Compressive strengths were greater in LWSCC mixes that contained smaller sized coarse and normal weight aggregates. Finally, a design procedure is introduced that utilizes the aggregate frictional resistance, paste flow properties, and aggregate void ratio to predict the plastic properties of the concrete.

1. Introduction

Self-consolidating concrete (SCC) was developed in Japan in the late 1980s by the University of Tokyo [1]. In the decades that followed, substantial research has been conducted and SCC has gained worldwide acceptance as an important civil engineering material. SCC has a number of advantages over non-SCC such as: uniform placement without vibration or additional compaction, smaller and more complex shaped structural elements, greater quality of surface finishes, and longer hours for construction in urban areas due to noise reduction [1,2]. The initial cost of the SCC materials is higher due to the increased amount of fines particles and costs for high dosages of chemical admixtures; however, SCC material costs can be offset by the advantages listed above. For this reason SCC is being utilized more frequently as a construction material. The reduced dead load of the structure due to lightweight concrete will reduce the foundation requirements, increased fire resistance due to low thermal conductivity, decreased thermal transfer efficiency due to the reduced density, reduce seismic internal mass, internal curing water maximizes hydration time, and for precast operations the cost to deliver materials is greatly reduced [3–5]. Lightweight SCC (LWSCC) can be utilized in any application where lightweight concrete would be advantageous, and would have the additional advantages of normal weight SCC (NWSCC).

The lower concrete unit weights found in LWSCC mixes are typically achieved through the utilization of low density aggregates [6]. Several lightweight aggregates used in LWSCC mixes are commercially available, including expanded clay, sintered pulverized fuel ash, hydrated volcanic glass, and pelletized slag; however, in order to compensate for the weakness of lightweight aggregates, LWSCC often have lower water/binder ratios [6,7]. Furthermore, due to the relative buoyancy of lightweight aggregate, LWSCC mixes tend to segregate as the concrete flowability increases [8]. The design of a properly engineered LWSCC mix must therefore balance the requirement for high flowability against the possible segregation of the material.

The objectives of this paper is to develop a LWSCC mixes with good flow properties and meet the ACI 211.2 specification for lightweight concrete [9]—i.e., lightweight aggregate air dry density of less than 1842 kg/m^3 and LWSCC compressive strength greater than 17.2 MPa—determine the effects of lightweight aggregate on the plastic and hardened properties of LWSCC, and develop a design procedure for LWSCC based upon aggregate flowability testing .

2. Material properties

Type I Portland cement was used with a water/binder (i.e., cement with fly ash) ratio equal to 0.35. Type F coal fly ash was

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Notation

D_{av}	average aggregate particle diameter	V_c	total concrete volume
d_i	average diameter of the aggregate fraction, $_i$	V_p	paste volume
D_{ss}	average spacing between aggregate particle surfaces	V_v	volume of voids in densely compacted aggregates
m_i	percentage of aggregate mass retained between upper and lower sieve sizes	ϕ	percentage of voids in the aggregate mix

used as a mineral admixture corresponding to 40% by mass of the cement. Expanded clay aggregate conforming to ASTM C330-04 [10] was used for two coarse lightweight aggregates (CLA1 and CLA2), with maximum aggregate sizes of 19 mm and 13 mm, respectively. Crushed limestone was utilized for the coarse normal weight aggregates (CNA1 and CNA2), with maximum aggregate sizes of 13 mm. Expanded clay aggregate was also used for the fine lightweight aggregate (FLA) sand. Siliceous quarry sand was used for fine normal weight aggregate (FNA). The physical properties of the aggregates used can be found in Table 1 and Fig. 1 that details the grading curves for the aggregates. A polycarboxylate-based chemical high range water-reducing admixture (HRWR) was used with a maximum dosage of 1.05 liters per 100 kg of cementitious material. The air-entraining agent (AEA) was an organic acid salt product, meeting ASTM C260-10a specifications [11], with a maximum recommended dosage of 0.195 liters per 100 kg of cementitious material.

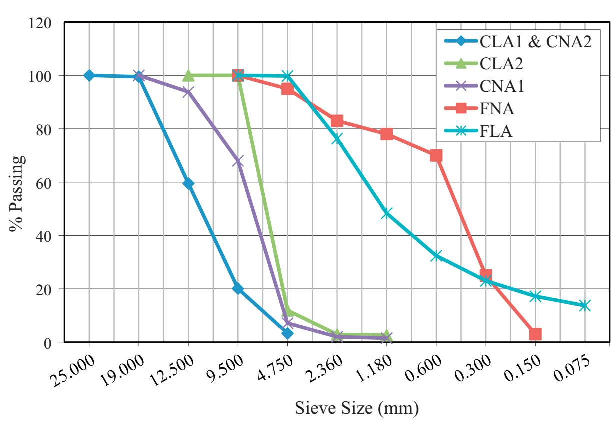

Fig. 1. Aggregate gradation curves.

Table 1
Aggregate physical properties.

Material property	ASTM test method	CLA1	CLA2	CNA1	CNA2	FNA	FLA
Material type		EC	EC	LS	LS	QS	EC
Bulk Specific Gravity (SSD)	C127	1.52	1.25	2.68	2.69	2.62	1.52
Absorption%	C127	14.0	22.1	0.5	0.5	0.1	38.7
Popout	C151	None	None				None
Clay Lumps%	C142	0.0	0.2				0.09
Dry Loose Unit Wt. (kg/m^3)	C29	703	559	1410	1465	1554	679
Fineness modulus	C136					2.46	3.03

CLA = Coarse Light-weight Aggregate; CNA = Course Normal-weight Aggregate.
FNA = Fine Normal Weight Aggregate; FLA = Fine Light-weight Aggregate.
LS = Crushed Limestone; QS = Quarry Sand; EC = Expanded Clay.

3. Experimental procedures

3.1. Mixture design

The ratios of coarse to fine aggregate for the LWSCC were established by constructing a unit weight versus void percentage (ϕ) graph for each aggregate combination, utilizing data produced by performing ASTM C29 [12] tests on the several aggregates used in the SCC mixes. The ratio of the CLA to total aggregate volume of 55% was determined for the first mix because the ratio achieved the smallest ϕ (29.29%) and exhibited a unit weight acceptable for the LWSCC (1426 kg/m^3). Fig. 2 shows the unit weight vs void percentage plot used to determine the first aggregate mix ratio.

In this study, the aggregate unit weight for the LWSCC mixes ranged from 1039 kg/m^3 to 1426 kg/m^3 and NWSCC mixes ranged from 1862 kg/m^3 to 1908 kg/m^3. For LWSCC, the choice of aggregate composition was based upon both the ϕ and the density of the aggregates. Since cement paste is typically a more costly material in comparison to aggregate, the aggregate composition that yields the smallest ϕ allows the addition of the least amount of paste leading to the most economical mix [13]. The density was selected based upon the required density of the concrete.

Three types of LWSCC mixes were tested in this study, utilizing different combinations of CLA, CNA, FNA, and FLA. In addition, NWSCC was also tested for a comparative analysis. Table 2 lists the unit weights, ϕ, and aggregate combinations for all mixes tested in this study.

Whereas the ratios of coarse to fine aggregates were established through aggregate testing, the amount of cement paste to total aggregate volume and HRWR dosage were established by trial and error for each mix. LWSCC mixes with lower paste volumes require higher doses of HRWR to meet the minimum SCC slump flow requirement—550 mm—and as such, the maximum HRWR dosage often controlled the mix design at lower volume ranges of excess paste—which is considered to be the cement paste beyond what is required to fill the aggregate void space [14]. Higher excess paste volumes—requiring lower HRWR dosages—were limited by aggregate segregation. As a result of these requirements—i.e.,

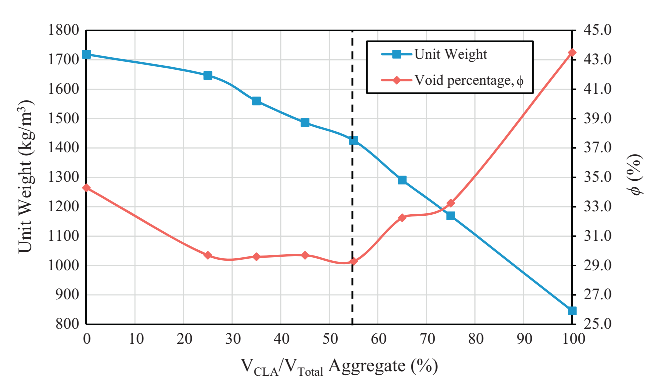

Fig. 2. Unit weight vs void percentage, ϕ.