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Testing dynamic segregation of self-consolidating concrete

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HIGHLIGHTS

- Dynamic segregation may be distinguished from static segregation.
- A flow trough was developed to measure dynamic segregation.
- Static and dynamic segregation were not always found to occur simultaneously.

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ABSTRACT

Segregation is a common problem in self-consolidating concrete, which often uses a high dosage of high-range water-reducing admixture to achieve high flow and passing ability. Dynamic segregation, when the aggregate lags behind in flowing concrete, may be distinguished from static segregation, when the aggregate sinks in concrete at rest. In this study, a flow trough was developed to measure dynamic segregation. The trough was found to provide a promising method for measuring this behavior. Static and dynamic segregation were not always found to occur simultaneously, and the slump flow test was not always sufficient to detect dynamic segregation, especially over a long travel distance. A simple procedure was proposed to set the maximum flowing distance based on mix proportions and the flow trough results.

1. Introduction

The main functional requirements for self-consolidating concrete (SCC) during the fresh state are flowing ability, passing ability, and segregation resistance. Segregation refers to movement of coarse aggregate relative to the mortar. It is useful to distinguish between two types of segregation, dynamic and static. Dynamic segregation occurs when the concrete is flowing and the coarse aggregate lags behind the mortar. Static segregation occurs when the concrete is at rest and the coarse aggregate sinks in the mortar. Segregation may cause lower flowability, aggregate blocking, higher drying shrinkage, and non-uniform compressive strength. The present paper provides a new test for measuring dynamic segregation based on earlier work of the authors [14].

Segregation resistance in SCC is normally achieved by reducing free water content and adding a finely powdered material such as silica fume, fly ash, or limestone filler [9]. A viscosity-modifying admixture (VMA) is sometimes used to control segregation by increasing the capacity to retain free water and increasing the viscosity of the suspended liquid phase [10]. In spite of these strategies, segregation problems are commonly observed in SCC mixtures. Fig. 1 shows a serious example of dynamic segregation observed in an L-shaped wall, 15 m in length and 9 m in height (50 ft and 30 ft), made using SCC. The drilled cores were cut longitudinally and examined to estimate aggregate content using image analysis. In the cores taken 16 m and 17 m from the discharge point (53 feet and 56 feet), all coarse aggregates particles were lost during the flowing process and only mortar was observed.

Accurate and reliable test methods are essential in order to study segregation of SCC. Several methods are available for static segregation, including Column Segregation [3], Penetration Test [5], V-Funnel test [7], Electrical Conductivity [8], Sieve Segregation Resistance Test [6], Hardened Visual Stability Index ([1]), Image Analysis of Hardened Cylinder [11], among others. The V-funnel, L-Box, U-Box and J-Ring tests [10,2] do not predict segregation directly, but are related to both static and dynamic segregation by considering the rheological properties measured by these tests [18]. Currently, the only standard method for testing dynamic segregation of SCC is the Visual Stability Index (VSI) determined by observation of the periphery of concrete during the slump flow test

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[4]. A VSI value from 0 to 3 can be given according to criteria in the standard. The VSI value provides only a rough estimation of dynamic segregation and is limited to a very small flow length. Some researchers question whether it identifies static or dynamic segregation [17]. To better quantify dynamic segregation and to understand the mechanisms responsible, a more reliable dynamic segregation test is urgently needed. In this research, a test method was developed that is rapid and reliable. The test may be performed in the laboratory or in the field. Segregation measured using this test was shown to correlate well with segregation observed in the field.

2. Test procedure

A laboratory test for dynamic segregation needs to satisfy several requirements. First, the test must be sensitive enough to detect meaningful differences in dynamic segregation. To that end, the flowing distance should be long enough to give useful information about dynamic segregation in typical field conditions. Typical flow distance of SCC in the field ranges from 2 to 10 m (6–33-ft). Obviously it is not practical to make a 10-m (33-ft) long apparatus for testing dynamic segregation. At the same time, a testing method with a short traveling distance may not sensitive enough to reveal dynamic segregation in a long traveling distance. As discussed in later sections, SCC with a good visual stability rating from the slump flow test, in which the traveling distance is quite short, can exhibit severe dynamic segregation over a longer traveling distance. The second requirement is that the amount of sample concrete should be small enough to be easily handled in the laboratory. The testing apparatus should be portable and easy to construct. Finally, the test results must be sufficiently precise and accurate that results can be used with confidence.

To meet these requirements, the flow trough shown in Fig. 2 was developed. It was made by assembling 25-mm (1-in.) thick wood boards to form a 0.15-m by 0.15-m by 1.80-m (6-in by 6-in by 6-ft) trough. The 0.23-m (9-in.) height difference between two ends gives a 7° angle of inclination, which was the smallest slope that allowed the SCC to flow to the lower end based on previous experience of the authors. The surface of the trough was painted to make it water-resistant and easy to wash.

Using this trough, the test was performed according to the following procedure:

1. Before the test, the surface of trough was slightly wetted with water and superficial water was wiped off.
2. Fresh concrete was measured using a single lift into one 100-mm by 200-mm (4-in by 8-in.) cylinder mold, one 150-mm by 300-mm (6-in. by 12-in.) cylinder mold, and a water-tight container having a volume of around 13.5 l (~3.5 gal).
3. The concrete in the 150-mm by 300-mm mold was poured onto the trough from the higher end as a priming step.
4. After the concrete stopped flowing, the trough was straightened up vertically for 30 s to let the priming concrete flow off and leave a mortar layer on the trough surface.
5. The trough was then put back into initial inclined position and the concrete in 13.5-l container was poured gradually and continuously on the trough from the higher end.
6. Another empty 100-mm by 200-mm (4-in. by 8-in.) mold was filled with the leading portion of concrete flowing through the trough.
7. Coarse aggregates were collected from the concrete samples in the two 100-mm by 200-mm molds, one collected at the beginning of the flow test (step 2) and the other collected at the end of the test (step 6), by washing the concrete samples over a 4.8-mm (0.19-in., #4) sieve.
8. Each coarse aggregate sample was weighed.
9. The Dynamic Segregation Index (DSI) was then calculated as

$$DSI = (CA1 - CA2)/CA1 \quad (1)$$

where CA1 is the weight of coarse aggregate in the first mold, collected at the beginning of the test, and CA2 is the weight of coarse aggregate in the second mold, collected at the end of the test.

The priming step has two main advantages. First, it eliminates any variation in surface friction when different materials are used to construct the flow trough. Second, it more closely simulates the situation in formwork, where SCC is flowing over previously poured concrete except at the very beginning of the pour.

3. Experimental program

Three experiments were performed to assess various properties of the flow trough. In the first, flow trough was verified with dynamic segregation measured directly from the field. In the second, flow trough values were compared to VSI values measured using the slump flow test [4], currently the only standard test for dynamic segregation. In the third, static and dynamic segregation of SCC mixtures with different flowability were tested.

3.1. Verification with field results

The flow trough was used several times in a field application to compare the results with dynamic segregation measured directly in the formwork. The purpose was to observe dynamic segregation over a long flow distance and to ascertain whether the flow trough reproduces dynamic segregation in the formwork. Two samples of concrete were tested, using the mix proportions FC1 (Field Concrete1) and FC2 (Field Concrete2) in Table 1. These concretes were prepared in a ready-mix plant and transported to the job site in a concrete truck. Two samples were tested, FC1 and FC2. They had slump flow values of 710 mm (28 in.) and 610 mm (24 in.), respectively. About 1 h after raw materials were first mixed, each concrete was pumped from the truck into formwork with dimensions of about 1.3 m (50 in.) in thickness, 9 m (30 ft) in length, and 6 m (20 ft) in height. When the top surface of the concrete was near the top of the formwork, samples were taken using 100 by

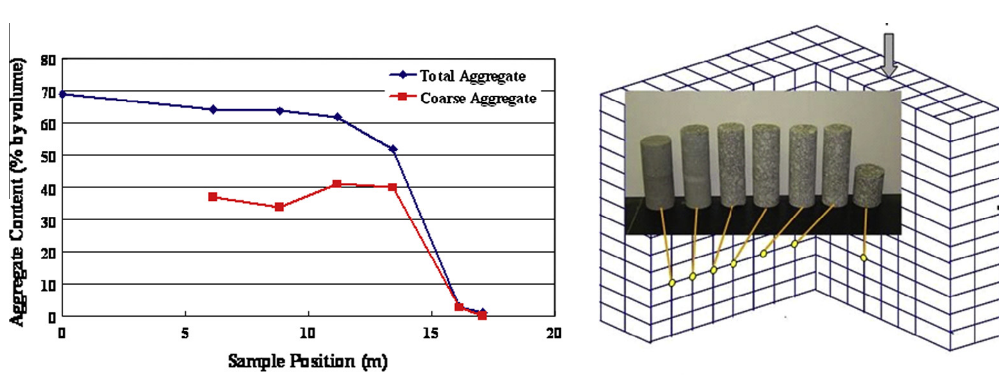

Fig. 1. Dynamic segregation in concrete wall. The sample positions ranged up to 17.1 m (56 ft) from the pump discharge.