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A new method for determination of dynamic stability of self-consolidating concrete: 3-Compartment sieve test

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HIGHLIGHTS

- 3-Compartment sieve test is a novel test with its functional sieve apparatus.
- The test allows reaching dynamic segregation of self-consolidating concrete (SCC).
- In the test, coarse aggregate distribution of SCC is determined after slump flow test.
- It is recommended as a reliable dynamic segregation test method for SCC.

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ABSTRACT

There are many standard test methods and applications to determine or estimate the workability of fresh concrete mixtures, most of them are focused on highly flowable concrete mixtures. Due to its high flowability, self-consolidating concrete (SCC) is much more vulnerable to segregation compared to conventional concrete mixtures. Thus, researchers have been working on adopting dynamic and static test methods for determination and improvement of segregation stability of those mixtures. In this study, the different segregation test methods presented in the literature were assessed and a novel method, i.e. 3-compartment sieve test, was introduced. The dynamic stability of fresh self-consolidating concrete mixtures was evaluated by the suggested test method after slump-flow and J-Ring tests. In conclusion, the developed new method is recommended for determination of segregation in SCC due to satisfactory concurrency of results with those of visual stability index test ($0.67 \leq R^2 \leq 0.90$) and sieve segregation resistance test ($0.83 \leq R^2 \leq 0.90$), respectively.

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1. Introduction

Self-consolidating concrete (SCC) flows easily and moves around obstructions under its own weight, fill the formwork completely and self-compact without any segregation and blocking [1]. Thus, the fresh concrete must be evaluated considering three main abilities; filling ability, passing ability and segregation resistance, respectively. Although, there is a global consensus on certain standard tests to determine the filling and passing ability of SCC such as slump flow, J-Ring, V-funnel, Orimet, L-box, U-box, etc., there are several researches on measuring dynamic and static stability.

Stability being one of the crucial properties for self-consolidating concrete is comprised of two aspects: static segregation, which is defined as the separation of coarse aggregates and mortar (or cement paste), when concrete is at rest; and dynamic segregation, which mostly occurs during transportation and casting of concrete [2]. Poor stability leading to segregation may cause blocking around reinforcement and increase drying shrinkage strain and cause non-uniform distribution of stresses of within the concrete [3,4]. Thus, it is of great importance to ensure that the suggested tests and procedures correctly detect and quantify the segregation of SCC. Table 1 summarizes the studies performed by researchers and relevant standards for assessment of SCC segregation.

Slump flow test for measuring consistency and relative viscosity of SCC is a commonly accepted global test [12,25,39–41]. Visual stability index (VSI) test developed and applied after the slump flow test is generally used to evaluate the static stability of SCC. Moreover, standard apparatus used in filling and passing ability of SCC such as slump cone, V-funnel or L-box are developed to evaluate its stability. The aforementioned segregation evaluations are depending on coarse aggregate distribution, bleeding, and

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Table 1
Evaluation of segregation stability of fresh SCC mixtures.

Category	Detailed information	Related references
Visual stability	After application of a standard test (e.g. slump cone, V-funnel, L-box, J-ring), segregation is evaluated by naked eye and quantified depending on coarse aggregate distribution, bleeding, separation of the paste from aggregate, blocking etc.	[5–13]
Discharging time	Discharging time of SCC from V-funnel or Orimet with and without a period of rest or a dynamic effect applied on concrete mixture.	[5–7,11,14–16]
Full wet-sieving	In full wet-sieving of SCC after dividing into vertical or horizontal layers inside the molds when the mixture is in fresh state, coarse aggregate distribution is evaluated.	[3,4,14–19]
Partial wet-sieving	Partial wet-sieving of SCC sample is generally used for reaching actual segregation behavior of the concrete with less labor compared to fully wet-sieving. In general, end parts (such as bottom and top compartments in vertical mold or initial and final ends in horizontal mold) of the self-consolidating concrete are taken into account for segregation evaluation.	[1–3,6,17,20–24]
Retaining ability on sieve	Retaining ability of the paste/mortar phase of SCC is used for determination of stability on a certain sieve.	[6,9,10,20,21,25–27]
Electrical conductivity	Variation of electrical conductivity of the fresh SCC in vertical layers	[17,18,28]
Penetration apparatus	Self-penetration of various probes into SCC is used for rapid assessment of static segregation resistance of SCC. The penetration apparatus are applied after just pouring or a certain period of rest.	[2,3,6,9,16,20,22,29,30]
Modeling	Computerized properties of SCC such as conventional segregation, workability and rheology are used for simulating the segregation statements of concrete according to fluid dynamic models.	[1,16,31–38]

separation of paste/mortar from the coarse aggregate phase, blocking or some other similar visual symptoms. In addition, similar visual segregation assessments are applied after J-ring test and modified J-ring test combined with Orimet apparatus. However, these methods may only evaluate the stability of SCC depending on visual observation of the concrete mass, thus the proofs are subjective and their reliabilities are poor.

V-funnel test and Orimet flow time evaluate both filling ability and passing ability of SCC, respectively [42]. After just pouring the SCC into the V-funnel and Orimet tubes, the tests are initiated and discharging time is measured. On the other hand, segregation potential is also evaluated according to the variation in discharging time, continuity and velocity of SCC flow after a certain period of rest in these apparatus. The discharging of SCC may be occasionally incomplete if coarse aggregate settles down excessively resulting in blocking the narrow discharge opening of the tubes. For this reason, the methods cannot always give quantitative results for segregation evaluation.

In full wet-sieving method, coarse aggregate distribution of SCC is generally evaluated as a reference method to measure the actual segregation behavior of SCC and confirm the reliability or validation of suggested alternative methods [2,3,16,18]. The coarse aggregate distribution in vertical or horizontal layers may be quantified and thus, those methods are more reliable for determination of segregation. In these methods, SCC is poured into vertical and horizontal molds with or without period of rest or an applied dynamic movement or with or without rebar obstacles. Then, fresh SCC is divided into layers and each layer is wet-sieved for determination of coarse aggregate distribution.

Partial wet-sieving method firstly classified by Mouret et al. [4] as partial indexes is generally preferred to eliminate the heavy labor. There are several standard and non-standard test setups studied by researchers among the partial evaluation methods to assess the segregation performance in vertical, horizontal and inclined directions of SCC [1–3,6,17,20–24]. Generally, assessment of segregation at the outmost opposite ends is taken into consideration in those methods. The partial evaluation tests also give reliable and quantitative results generally by sampling and wet-sieving from the end parts of the molds.

The methods depending on retaining ability on sieve are used for determination of static and dynamic segregation resistance of SCC [25,27]. After pouring SCC on a sieve or a mold with sieve feature, the retaining ability of concrete on sieve are researched by depending on their passing ratio by weight. Mahoutian et al. [11] pointed out some unreliable results of the sieve stability test compared to visual segregation test results.

Electrical conductivity or its inverse (electrical resistivity) is preferred to assess many properties of fresh and hardened concrete. Variation of this property is generally used for determination of segregation of fresh SCC in vertical layers with multi-electrode conductivity systems. Although indirect results obtained from these methods can be reliable and quantitative [18], an alternative method can be used for the validation of its results with actual segregation parameters.

Probes having certain weights and forms are used to estimate the segregation resistance of fresh SCC depending on the vertical penetration depth under its own weight [2,3,43]. The methods correlate the rate of aggregate settlement with penetration [19]. However, the repeatability and reproducibility of the penetration test can reveal an error proportional to the measured penetration depth indicating a large uncertainty in the judgment of segregation risk [44].

The actual segregation parameters depending on the homogeneity of SCC are significantly important for expressing its workability. Due to SCC's time-dependent properties such as setting time and thixotropic behavior, in-situ applications does not usually allow providing actual segregation results in limited time. Some researchers have attempts to define the segregation of SCC in terms of its rheological properties. However, Anuj et al. mentioned that no correlation had been established between these parameters and segregation resistance behavior of SCC [45]. Moreover, to assess and optimize the all workability properties of SCC in point of filling and passing ability, segregation resistance etc., there are many modeling studies based on the combination of workability, rheology and mixing. These studies are focused on to ease understanding the workability of SCC. However, a whole recognition of SCC workability cannot be sufficient because of its complex nature.

Quality-control of SCC in terms of filling and passing abilities and segregation performance can continuously be performed on site. Development of recent test methods such as visual assessment, coarse aggregate distribution, retaining ability on sieve, electrical conductivity, penetration apparatus, modeling etc. enabled better understanding of static segregation. However, it is important to overcome the shortcomings (overly time-consuming, heavy labor requirement, practical difficulties, inadequate reliability etc.) of the dynamic segregation tests [2,19]. On the other hand, selection of accurate and reliable test methods for determination of either static and dynamic segregation is critical [2,8,33]. Consequently, there is a need for developing reliable dynamic segregation methods for evaluating the actual behavior of SCC on site.

The newly developed 3-compartment sieve apparatus test may assess the dynamic stability of SCC after slump flow and J-ring flow spreading tests depending on coarse aggregate distribution.

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