COMPARISON BETWEEN DIFFERENT TEST METHODS USED FOR EVALUATION OF SELF-COMPACTING CONCRETE’S STABILITY

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Abstract

SCC is a highly flowable concrete, which is able to fill every corner of the formwork purely under its own weight. Due to high fluidity, the possibility of non-homogeneity and separation of aggregates and paste (also known as segregation) increases. This high potential for segregation and loss of stability must be considered in the mix design of SCC.

Several methods have been proposed for evaluating the fresh characteristics of self-compacting concretes which are used as indicators of the stability of SCC. Slump Flow, V-Funnel, L-Box, U-Box, J-Ring, GTM Screen and Orimet are the most widely used of these methods. Most of these methods are merely qualitative and not completely reliable. These methods have simply remained as guidelines and recommendations and have not been internationally standardized.

In this paper, different methods for evaluating the stability of self-compacting concrete such as the ones mentioned above are studied and compared. Suggestions are made to improve the current methods in order to obtain new and more detailed results on stability and rheological properties of SCC using the same apparatus.

1. INTRODUCTION

Self-consolidating concrete (SCC), which was originally developed in Japan due to shortage of skilled labor and poor compaction of ordinary concrete, is a mix that flows and fills the formwork under its own weight without mechanical vibration [1]. In order to achieve this property, SCC must have good deformability, high segregation resistance and no blocking around reinforcement [2]. The main challenge when producing SCC is not only to obtain sufficient flowability and stability, but also to obtain sufficient robustness, which is the insensitivity of SCC to small changes in constituent material properties and mix proportions.

Based on the existing literature, slump flow, visual stability, L-box, U-box, V-funnel, J-ring, filling box and column segregation tests are some of the available testing methods used to evaluate fresh properties [3]. Also the fresh mechanical properties of SCC are often determined through the use of rheometers, which measure the viscosity and the yield strength of concrete when it is in plastic state. However, this equipment is lab oriented and not usually
practical for field use [4]. Therefore the above mentioned testing devices are used in quantifying the fresh properties and workability of SCC both in the lab and in the field [5].

Although a large number of test methods are currently available, none of them is incorporated into any American standard. Unfortunately, each of the above test methods determines only a specific kind of instability of SCC. None of the above mentioned test methods are able to assess all fresh properties of SCC at the same time including bleeding, flowability and segregation. Although many researchers have presented correlation equations between these parameters, they have not been able to come up with relationships with adequate precision.

In this paper, different methods for evaluating the stability of self-compacting concrete such as the ones mentioned above are studied and compared. Since most of the current methods are only designed to inspect one or two specific kinds of SCC instability, new ways are suggested to obtain more detailed results on stability and rheological properties of SCC using the same apparatus. The goal is to be able to simultaneously estimate different fresh properties of SCC using a single test method.

Three kinds of instability could be observed in SCC. These instabilities include bleeding, segregation and inhomogeneity. The self-compacting concrete which has none of these instabilities is recognized as a good SCC. Therefore, the concrete which has at least one of these instabilities is not classified as a self-compacting concrete.

2. EXPERIMENTAL PROGRAM

Different test methods are compared in the following sections. 25 SCC mixture designs were prepared and tested in the Construction Materials Institute (CMI) at university of Tehran. V-Funnel, Slump Flow, J-Ring, L-Box, U-Box, GTM Screen and Orimet tests were done on the fresh concrete to inspect stability and rheological properties of SCC. Suggestions are also made to improve each test method. The mixture designs are presented in table 1.

2.1 V-Funnel

This device could be used as a good judgment about segregation and homogeneity of SCC. In addition to the time taken for the concrete to flow through the apparatus, the quality and speed of the discharged concrete is also important. If the concrete is not discharged with an almost constant speed, it could be a probable sign for segregation.

Although this method is not designed for inspecting the passing ability and bleeding of SCC, the bleeding of concrete could be found with visual inspection by considering the additional water on the surface of SCC after five minutes. Figure 1 shows the bleeding of SCC in the V-funnel test.

Figure 1 – Bleeding of SCC in V-Funnel test (mixture design number 2)
| Mixture | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|
| Cement (kg/m³) | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 400 | 400 | 500 | 400 | 450 |
| Powder (kg/m³) | 0 | 0 | 0 | 0 | 0 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 100 | 100 | 100 | 100 | 100 | 0 | 0 | 0 | 0 | 0 |
| Aggregate (kg/m³) | 1740 | 1700 | 1700 | 1700 | 1450 | 1450 | 1450 | 1450 | 1450 | 1450 | 1450 | 1450 | 1450 | 1600 | 1600 | 1600 | 1800 | 1800 | 1800 | 1800 | 1740 | 1700 | 1600 | 1600 | 1600 | 1600 |
| Sand / Aggregate ratio | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 60% | 70% | 70% | 70% | 60% | 70% |
| Super Plasticizer (% by weight) | 1.3% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.0% | 1.5% |
| Max size of aggregate (mm) | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| VMA (%) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Powder or VMA Type | - | VMA (BASF) | VMA (FOSSROC) | CaCO₃ | CaCO₃ | MetaK * | MetaK * | stone powder | stone powder | zeolite | zeolite | silicate fume | silicate fume | stone powder | stone powder | stone powder | stone powder | stone powder | stone powder | VMA (BASF) | VMA (BASF) | VMA (BASF) | VMA (BASF) | VMA (BASF) |

* MetaKaiolion
2.2 Slump-Flow

Using the spreading speed of concrete after raising the cone, viscosity of self-compacting concrete could be estimated. Also, after the flow of SCC is stopped, the bleeding of concrete could be evaluated with inspecting the water which is gathered in the fringe of concrete. Fast spreading of concrete indicates low viscosity and yield stress. This method is incapable of showing the filling and passing ability of self-compacting concrete but it could be used to determine the Visual Stability Index (VSI) of the sample which is introduced by EFNARC.

The homogeneity and segregation of SCC could also be found by grading and obtaining the density of different samples taken from various radiuses of the spread concrete. Figure 2 shows two types of SCC with different stability.

![Figure 2- Slump flow of two samples (a) showing segregation (mixture design number 25) and (b) non-segregating (mixture design number 9)](image)

2.3 J-Ring

This test method is similar to the slump flow test except for a ring of steel bars that is placed around the cone to restrict the flow of concrete. This device excellently shows the passing ability of self-compacting concrete. It is important to note that the distance between steel bars needs to be adjusted according to the maximum size of aggregate. Some recommendations suggest that the bar distance of J-Ring must be three times greater than the maximum size of aggregate. In the self-compacting fiber-reinforced concrete this distance is about 1 to 3 times of fiber length. This test was unable to assess the homogeneity of SCC. Similar to slump flow test, with considering the water which gathered in the fringe of concrete, the bleeding of concrete could be evaluated.

This test also showed when some powders like Metakaolin and Zeolite were used in the concrete, the viscosity of concrete decreased significantly and the concrete spread with a great speed after which the flow of concrete came to a sudden and abrupt end. Thus, after the concrete flow had stopped, a “petal” shape was formed. This type of concrete could not be classified as self-compacting because it will not be able to fill the entire space of the form due to weak filling ability. Figure 3 shows the “normal final shape” and the “petal final shape” of SCC in this test.

2.4 L-Box

The segregation resistance of the sample could be evaluated by noticing whether the coarse aggregates have reached the end of the box or not. If this is not the case and only the fine aggregates are accumulated in the end of the box with coarse aggregates being left behind, the sample could be susceptible to segregation.
From the difference in concrete level at the beginning and the end of the box, the influence of the bars in passing of the concrete (also known as passing ability) could be evaluated. However, it should be noted that in SCC samples with poor segregation resistance, a large mass of concrete is accumulated behind the steel bars. In this case, the difference in concrete level at the beginning and the end of the box isn’t significant. Based only on the difference in concrete level, one might judge that the concrete sample has good stability while the visual observation obviously means otherwise. Therefore, the difference in concrete level before and exactly after the bars should be measured and used as a criterion of passing ability of concrete.

Also by taking samples from the concrete across the L-Box and obtaining the density of these segments, segregation resistance and homogeneity quality of self-compacting concrete could be obtained. It is seen that in concretes with low segregation resistance, the concrete level declines rapidly in the last five centimeter of L-Box and instead, water or mortar fill the remaining space of the box.

In the cases which concrete involved bleeding a layer of water appeared on the surface of concrete. Therefore with visual inspection of the concrete surface the amount of SCC bleeding could be obtained. It should be noted that the results of this test is influenced by opening speed of L-Box gate. Figure 4 shows the L-box device. In a concrete with proper mixture design, concrete completely passes through the bars while in a concrete with improper passing ability, the bars obstacle the passing of concrete.

2.5 U-Box
This is one of the toughest tests that the concrete has to go through before being classified as self-compacting. This test is generally used for assessing the filling and passing ability of
SCC. Unlike all other tests which generally model the free falling or horizontal flowing of the concrete, here the concrete has to be pushed against its own weight. Therefore, in addition to good passing ability, the concrete samples have to acquire a certain range of viscosity and yield stress to pass the test.

With grading and obtaining the density of concrete in two sides of the gate, the amount of segregation and homogeneity could also be estimated. Some critical cases were observed where the samples successfully passed the U-Box test with concrete almost reaching the same level on both sides. But later by grading the concrete on both sides, it was found that segregation had in fact happened which had resulted in coarse aggregates being left behind the bars and the mortar reaching up to the concrete level on the other side.

This test is unable to evaluate the bleeding of SCC unless it is left untouched for some time. Since the concrete usually requires good passing ability and proper viscosity to pass the test, the samples which successfully pass the test could probably be classified as SCC provided that they are being checked for segregation with the method proposed above or by using other segregation-resistance tests like GTM Screen. However, if the concrete fails to satisfy the requirements of this test, final judgment on the quality of concrete should be based on the results from the other test methods.

2.6 GTM

This test is recommended for determining the bleeding and segregation of self-compacting concrete. The range of 5 to 15 percent is generally regarded as acceptable for segregation and bleeding of SCC by different references [6]. In the higher percentages concrete might be segregated and in the lower percentages the final finished surface of concrete is probably not appropriate. However, the results of the tests done in this paper show that GTM test results are unreliable in some cases. Cases are seen (especially in fiber reinforced self-compacting concretes) with low GTM results but showing obvious visual segregation.

2.7 Orimet

If J-Ring is used in combination with the Orimet device, the dynamic segregation of the sample could be evaluated. Most of the concrete samples which were tested had a discharging time in the range of 0 to 5 seconds. EFNARC recommendation accepts this range. But these samples showed extreme and obvious differences in the fresh properties. Therefore the result of the Orimet test could not be used as a stand-alone criterion for stability of concrete but it should rather be used in combination with other test methods to give a right perspective of the quality of concrete. Figure 5 shows the Orimet apparatus in combination with the J-Ring test method.

![Figure 5- Combination of Orimet and J-Ring (mixture design number 18)](image)
3. CONCLUSIONS

- The quality and speed of the discharged concrete is important in the V-Funnel test. If the concrete is not discharged with an almost constant speed, it could be a probable sign for segregation.
- The bleeding of concrete could be found with visual inspection by considering the additional water on the surface of SCC in V-Funnel test after five minutes.
- Using the spreading speed of concrete after raising the cone in the Slump Flow test, viscosity of self-compacting concrete could be estimated.
- It is suggested that the homogeneity and segregation of SCC could be found by grading and obtaining the density of different samples taken from various radiiuses of the spread concrete.
- When powders like Metakaolin and Zeolite were used in the concrete, the viscosity of concrete decreased significantly and the concrete spread with a great speed. The concrete in these cases was unable to satisfy the requirements of self-compacting concrete.
- The segregation resistance of the sample could be evaluated by noticing whether the coarse aggregates have also reached the end of the L-Box apparatus or not.
- Difference in concrete level before and exactly after the bars should also be measured and used as a criterion of passing ability of concrete.
- Segregation resistance and homogeneity quality of self-compacting concrete could be obtained by sampling the concrete along the L-box at different distances from the bars.
- With grading and obtaining the density of concrete in two sides of the gate, the amount of segregation and homogeneity could also be estimated in the U-Box test.
- When interpreting the results of U-Box, attention must be paid to possibility of SCC segregation.
- If the concrete fails to satisfy the requirements of the U-Box test, final judgment on the quality of concrete should be based on the results from the other test methods.
- GTM test results are unreliable in some cases especially when fibers are used in the concrete mixture.
- If J-Ring is used in combination with the Orimet device, the dynamic segregation of the sample could be evaluated.

REFERENCES