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Representing a logical grading zone for self-consolidating concrete

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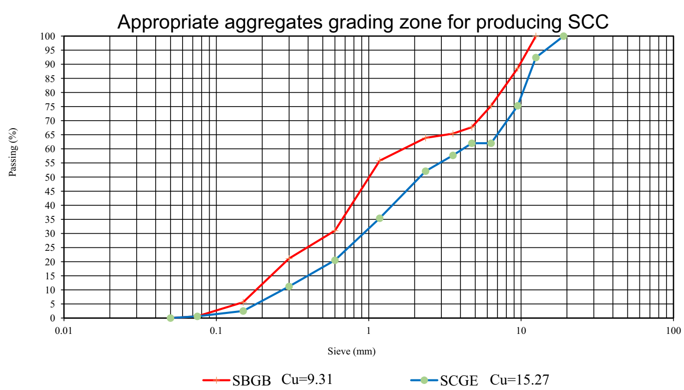
HIGHLIGHTS

- The aggregate proportions were chosen as the main variables to be evaluated.
- The U-box test was used as one of the most challenging controlling factor of SCC workability.
- 25 aggregate grading curves were investigated for SCC qualification.
- The selection of aggregate proportions is based on Cu value in soil mechanics.
- An optimum grading zone was developed in order to adopt aggregate proportions for SCC.

GRAPHICAL ABSTRACT



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ABSTRACT

For an aggregate source with certain geometrical characteristics, grading can highly affect the properties of self-consolidating concrete (SCC). This paper basically focuses on the effect of using different aggregates grading on the properties of SCC. For this purpose twelve aggregate proportions with three different cement contents (450, 500 and 550), three different water-to-cement ratios (0.35, 0.4 and 0.45) and either poly-carboxylate based super-plasticizer as admixture were used. In order to examine fresh concrete properties, slump flow, U-box, L-box and V-funnel tests were carried out; for achieving hardened properties of SCC, tests were limited to compressive strength. The principal objective of this survey is to determine an acceptable aggregates grading zone which can be used in production of SCC with ideal properties. From the experimental consequences, it is observed that aggregate proportions in this zone, will result a SCC with appropriate workability and compressive strength. The optimum curves could be selected with Cu values more than 9.5.

1. Introduction

SCC is a concrete that can spread into place under its own weight and keeps its uniformity; therefore, it can fill the formwork and voids and also covering the congested reinforcement which does not bleed or segregate, without mechanical vibration. This is the exclusive capability of SCC which can be achieved by adjusting a suitable workability characteristics for fresh concrete and sufficient plastic viscosity with a low yield stress. In addition, the application of SCC leads to enhanced concrete quality and a faster casting process [1].

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The four main constitutive elements of SCC is aggregates, cementitious materials, water and additives. The inclusion of supplementary cementitious materials could help improving the fresh properties of SCC as well as enhancing the particle distribution and improving some hardened properties. It also ensures the uniform suspension of particles and reduces the inter-particle collisions that can cause an increase of yield stress and viscosity [2–4]. Application of high powder content and super-plasticizer (SP) is also another outlook of improving SCC mixture proportioning [5].

Filling ability, passing ability and segregation resistance are three fundamental fresh properties of SCC. Decrease of coarse aggregate content is recommended to avoid segregation, which higher cement content is subsequently seen [6]. The fine materials known as an additional component of the SCC, are particles with a large specific surface, which has specific effect on the rheological properties of fresh concrete [7]. In fact, the fine content of SCC is higher than traditional concrete (TC) [8,9] and the absence of vibration lessens the risks of bleeding, segregation and entrapped air [10]. In order to attain a SCC with high workability and to prevent segregation and bleeding during transportation and placing, a high cement content with collaboration of SP and viscosity modifying agents (VMA) need to be employed [11–14] which increases cost of such concretes, remarkably. However, the savings obtained by elimination of expert labors could help decreased SCC cost. Besides, by adjusting the aggregates proportion, the cost of the SCC could be reduced and also fresh and hardened properties of the concrete could be improved [15,16].

The aggregates are the main ingredient of SCC which form more than 60% of the concrete content. This principal component plays a main role in influencing fresh and hardened concrete properties [17]. General recommendation in production of SCC is to decrease the amount of coarse aggregates and to increase the amount of fine ones. Therefore, the concrete becomes more homogeneous and increases the stability of it [18]. For reducing harshness, finer grading is recommended and for decreasing the viscosity, coarser grading is suggested [19].

Although results show that poorly graded aggregate proportions can be used in SCC mixes, this requires providing more paste content to avoid segregation because it contains particles of the same size and more air voids as well [20]. Aggregates content and the maximum size of aggregates play a key role in flowability and blockage resistance of SCC. With this point of view, if the maximum size of aggregates increases, the uniformity of aggregates reduces and causes instability in concrete. In SCC, the maximum size of aggregates are selected 16 mm or 20 mm [18]. In general, with decrease in fineness modulus (FM), the paste demand for covering all aggregates increase; on the other hand, the viscosity and stability of SCC will improve. Beside FM, the passing aggregates through sieve #100 (aggregates with diameter less than 0.125 mm) play an important role in selection of sand. These materials are called filler which enhance the viscosity and stability of concrete [18].

SCC needs to prepare adequate cohesiveness along with high workability which hardens the producing procedure. In a general manner, any increase in SP dosage or decrease of fine aggregates that increases the workability would also decrease the cohesiveness. Insufficient cohesiveness tends to segregate during and after placing. Furthermore, when passing through dense reinforcing bars or any obstacle, blockage is imminent. On the other hand, higher cohesiveness leads to higher viscosity, which decreases the workability. Insufficient workability causes the concrete to have problems in passing through dense reinforcement and fill all spaces [21]. SCC is very responsive to changes in aggregate characteristics such as shape, maximum size, grading and etc. These parameters are collectively reflected in terms of packing density [22]. Packing density of aggregates is an indicator of the voids content. Aggregates with higher packing density result in lesser void content. From the results, it was observed that the mixtures with maximum packing density resulted in minimum porosity, maximum slump and maximum compressive strength [23]. A renowned factor in soil mechanics, is called the coefficient of uniformity (Cu) [24] which expresses the particle size distribution of the aggregates. The Cu value can be derived out through the following formula:

$$\mathrm{Cu} = \frac{D_{60}}{D_{10}} \tag{1}$$

where D_{60} implies the size that 60% of aggregates are finer than this and D_{10} implies the size that 10% of aggregates are finer than this.

There is a good correlation between the packing density and coefficient of uniformity (Fig. 1). As the Cu value increases the packing density of the aggregates increases, therefore, for a constant paste volume, aggregate combinations with lesser voids need lesser paste to fill them up, so the rest of the paste can lubricate the aggregates and increase the flow rate. From the results, it is clear that the Cu is an important parameter and plays an important role in the determination of the combination of aggregates. It is evident that for improving the properties of SCC, the maximum particle size distribution criterion has to be considered along with the selection of appropriate aggregate combinations for the optimization [23]. It should be noted that at the same paste composition, the fresh concrete properties were influenced significantly by the choice of the aggregate proportion [23,25].

Since the first developments in the late 1980s, in Japan [26], adequate research and practice have been done about the cementitious materials, aggregate texture and shape and admixtures. However, there are less available discoveries about the expected aggregate proportions despite their significant influence on the properties of SCC; Hence, the main objective of this research work is to examine the effect of various types of aggregates grading on the workability characteristics and compressive strength of SCC. Another objective is to develop an aggregate grading zone which can be used for aggregate proportions that qualify for SCC.

2. Experimental program

2.1. Materials

For the purposes of the current study, type II Portland cement was used to prepare the concrete. The chemical properties of cement is presented in Table 1. The fine aggregate used was natural sand with the bulk specific gravity of 2640 kg/m^3 ranging from 0.075 mm to 4.75 mm. The coarse aggregate was the natural crushed gravels passed through 19 mm, retained on 4.75 mm with a specific gravity of 2580 kg/m^3. The filler used in this experimental program which is smaller than

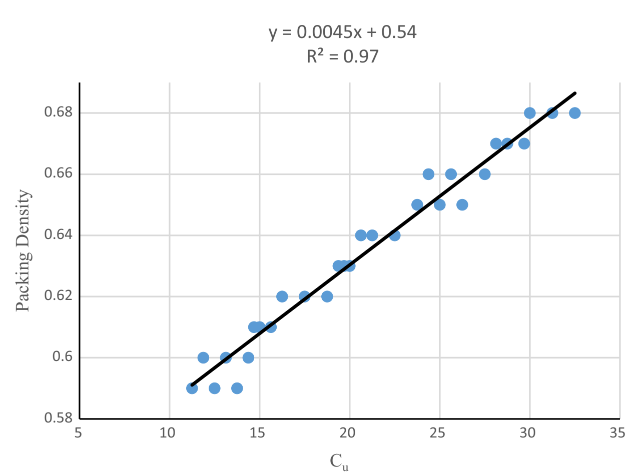

Fig. 1. Relationship between Cu and packing density of aggregates [22].