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Maximum coarse aggregate's volume fraction in self-compacting concrete for different flow restrictions

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HIGHLIGHTS

- Model set by Nepomuceno et al. (2014) for SCC optimized for different flow restrictions.
- Proposed maximum SCC coarse aggregate's volume for different flow restrictions.
- Higher SCC coarse aggregate's volume for lower flow restrictions keeping passing ability.
- Optimization of coarse aggregate volume for different flow restrictions reduces SCC cost.

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ABSTRACT

The volume of coarse aggregates (Vg) in self-compacting concrete (SCC) is usually conditioned to the passing ability (PA) in an L-box test. Some mix design methods use the three bar test results in L-box for proportioning SCC. However, in real structures, gaps can differ from those of L-box. By increasing the gaps, the Vg value can be increased and, consequently, the mortar phase volume can be decreased. In this study, the model proposed by Nepomuceno et al. (2014) to quantify the Vg value was modified to allow the introduction of an additional parameter that takes account for different gaps. Four SCC mixtures with different Vg values and the same mortar phase were produced and the PA value measured in the L-box test for different sizes of gaps: R1 (34 mm), R2 (64 mm), R3 (94 mm) and R4 (no restrictions). The results showed that for less demanding gaps it is possible to increase the Vg value of SCC and comply with the PA value in L-box test ($H2/H1 \geqslant 0.80$).

1. Introduction

The optimization of self-compacting concrete mixtures aims at the reduction of the paste volume and, consequently, the reduction of the production cost. After the general method proposed in the early 90s by Okamura et al. [1], many other research works were carried out, aiming the production of more efficient mixes [2,3]. In general, the optimization process is focused on the constitution of the powders, paste volume, characteristics and proportions of fine and coarse aggregates. In this optimization process, the concrete proportions are determined to meet, among others, the requirements in the fresh state in terms of flow capacity (slump-flow), fluidity (v-funnel) and passing ability (U-box, Box test or L-box) [3].

To evaluate the passing ability (U-box, Box or L-box), the spaces between steel bars (restrictions) are very close to the minimum spacing between reinforcing bars, as specified in structural codes (Eurocode 2, for instance). Therefore, the concrete can theoretically be applied in any situation of reinforcement layout. Another optimization perspective is related to the possibility of adjusting the SCC mixture for specific situations less restrictive. In this perspective some methodologies included different restriction conditions when testing the passing ability of SCC.

General rules and recommendations using different flow restrictions were firstly presented by the Japan Society of Civil Engineers (JSCE) in 1998, as described by Nawa et al. [2] and Domone [3], in where passing ability requirements for the Box test for reinforced concrete structures with different gaps and different reinforcement ratios were proposed. In Europe, one of the first attempts to optimize SCC mixtures for different flow restrictions emerge with the CBI method proposed by Peterson

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et al. [4,5] and Van Bui et al. [6], followed by the proposal of the LCPC developed by Sedran Larrard [7].

The EFNARC specification and guidelines for SCC [8], published in 2002, provided indicative typical ranges of proportions and quantities for initial composition, allowing a coarse aggregate's volume content per cubic meter (Vg) of 0.28–0.35 m^3. Such a volume of 0.35 m^3 for coarse aggregates can probably only be achieved for lower restrictions than the typical 34 mm distance between steel bars used in L-box test, if H2/H1 index is 0.80 or higher [9].

Yahia et al. [10] have used a statistical design approach to evaluate the effect of supplementary cementitious materials (SCM), coarse aggregates volume (Vg) and clear spacing between reinforcement (Cr) on flow properties of SCC. The modelled region includes mixtures with SCM content of 425–525 kg per cubic meter, Vg of 0.27–0.33 m^3 per cubic meter and Cr of 30–52 mm. A crushed limestone coarse aggregate with a nominal size of 14 mm was used. They have found that the flow rate of SCC in the presence of reinforcement is dominated by the content of SCM and by Cr. The established models indicate that flowability performance of SCC in restricted spacing improves with the increase in SCM and Cr.

In a research done in the framework of the European project "Testing SCC"-GRD2-2000-30024, which led to standard EN 12350-10, Sonebi et al. [9] have also used a statistical model to evaluate the influence of three key parameters of mixture composition on flow properties of SCC. Key parameters included the dosages of water, the dosage of a high-range water-reducing admixture (HRWRA) and the volume of coarse aggregates (Vg). Some of the responses of the derived statistical models included the flow capacity (slump-flow), fluidity (v-funnel) and the passing ability (L-box). Water dosage varied from 188 to 208 L, HRWRA varied from 3.8 to 5.8 kg and Vg from 0.22 to 0.36 m^3, per cubic meter. Three rib bars were used in the L-box test with a gap of 34 mm. The derived models showed that the dosages of water and HRWRA, and the volume of coarse aggregates (Vg) significantly influenced the L-box ratio.

In this context, when establishing the additional rules for SCC, the NP EN 206-9:2010 [11] defines two levels of passing ability in the L-box test: PL1 with H2/H1 index equal or higher than 0.80 using two steel bars and PL2 with H2/H1 index equal or higher than 0.80 using three steel bars.

The European Guidelines for SCC [12], published in 2005, have established the mix design principles based in general recommendations, instead of proposing any standard method for SCC mix design, because, as it is mentioned, many academic institutions, admixture, ready mixed, precast and contracting companies have developed their own mix proportioning methods.

More recently, Nepomuceno et al. [13–16] have presented a methodology for the mix design of SCC using different mineral additions in binary blends of powders. This is being used with success in many research works, which attest its validity to different types of materials [17–21]. Such methodology optimizes the mix proportions of SCC by correlating the mix design parameters (mix proportions), flow capacity (slump-flow), fluidity (v-funnel), passing ability (L-box) and concrete compressive strength. In such methodology the passing ability is evaluated for a high restriction level in the L-box, corresponding to a gap of 34 mm between steel bars. Under less restricting conditions (higher gaps) concrete will also be self-compacting. However, in the perspective of the optimization of concrete mixtures, the level of self-compactability should be specifically suitable for the reinforced concrete structure under analysis. In this respect, it is considered that the opportunity for optimization of such methodology proposed by Nepomuceno et al. [14,15] still exists, and designing demands for specific applications where flow restrictions are known can also be set by it.

The optimization of SCC, as defined in this article, aims at increasing the volume of coarse aggregates in the mixture in situations of less restriction to the flow, thereby enabling a reduction in the total volume of the mortar phase, and consequently the reduction of the volumes of powder materials and admixtures and, overall, the reduction of cost production. The model itself can be very useful to optimize SCC mixtures to comply with the requirements of the NP EN 206-9:2010 [11] and has the advantage to be incorporated in the methodology for the mix design of SCC.

2. Materials and methods

2.1. Materials

For the production of self-compacting concrete the following materials were selected: one Portland cement type CEM I 42.5R in accordance with NP EN 197-1 [22] with a density of 3140 kg/m^3 and a fineness value (Blaine) of 3848 cm^2/g; a limestone powder with a density of 2720 kg/m^3 and a fineness value (laser particle analyser Coulter LS200) of 5088 cm^2/g; a polycarboxylate-based superplasticizer with a density of 1050 kg/m^3; a fine aggregate from natural origin (Sand 0/2) with a density of 2640 kg/m^3 and a fineness modulus of 1.96; a fine aggregate from natural origin (Sand 0/4) with a density of 2610 kg/m^3 and a fineness modulus of 2.82; a coarse aggregate from crushed granite (CA 3/6) with a density of 2710 kg/m^3 and a fineness modulus of 5.31 and, finally, a coarse aggregate from crushed granite (CA 6/15) with a density of 2700 kg/m^3, a fineness modulus of 6.39 and maximum dimension of 19.1 mm.

The proportion between the two sands was determined using the reference curve for the fine aggregates proposed by Nepomuceno et al. [14], resulting in 35% for Sand 0/2 and 65% for Sand 0/4, in percentage of the absolute volume of total fine aggregate (Vs). The obtained mixture presented a fineness modulus of 2.52. The proportion between the two coarse aggregates was determined using the reference curve for the coarse aggregates proposed by Nepomuceno et al. [15], resulting in 55% for CA 3/6 and 45% for CA 6/15, in percentage of the absolute volume of total coarse aggregate (Vg). The obtained mixture presents a fineness modulus of 5.79. The grading curves of fine and coarse aggregates and the resulting curves are presented in Fig. 1.

2.2. Mix proportions

The mix proportions of SCC were defined based on the methodology proposed by Nepomuceno et al. [14,15], which assumes the SCC as a two phase material, the mortar phase and the coarse aggregates. The methodology starts by the study of the mortar phase of SCC and, subsequently, the coarse aggregate's volume is estimated to comply with the desirable requirements of flow capacity (slump-flow), fluidity (v-funnel) and passing ability (L-box) for restriction R1 (34 mm).

The designing of the mortar phase includes the definition of the unit volume percentage of each powder material in the total volume of the blend of powder materials (Vp), unit volume percentage of each fine aggregate in the total volume of fine aggregates (Vs), Vp/Vs (ratio in absolute volume between powder materials and fine aggregates), Vw/Vp (ratio in absolute volume between water and powder materials) and Sp/p% (ratio in percentage between the amounts in mass of superplasticizer and powder materials). The volume of voids when calculating mortars and the contribution towards volume of powder materials originating from fine aggregates were both overlooked.

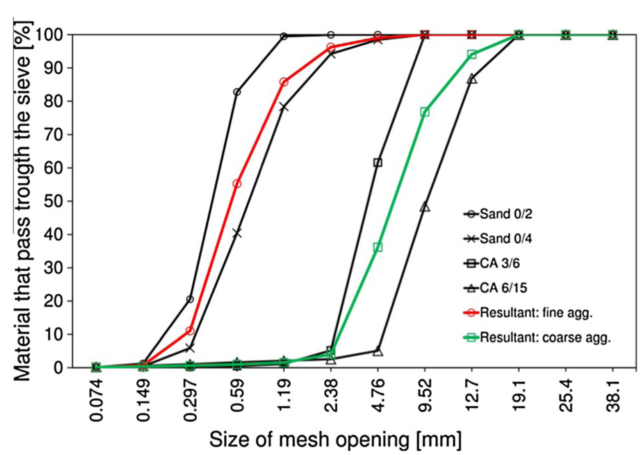

Fig. 1. Grading and resultant curves of fine and coarse aggregates.