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Assessment of fresh properties and compressive strength of self-compacting concrete made with different sand types by mixture design modelling approach

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HIGHLIGHTS

- Sand is the main component in SCC, for that, it has a larger effect on their fresh and hardened properties.
- A mixture design modelling approach is used to highlight the effect of RS, CS and DS on the properties of SCC.
- Statistical models are established to predict fresh and hardened properties of SCC as function of different sand types.
- Ternary contour plots are used to provide flexibility in optimizing RS, CS and DS blends.

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ABSTRACT

The present paper provides a statistical approach to evaluate the effect of different sand types on the properties of self-compacting concrete (SCC). A mixture design modelling approach was used to highlight the effects of river sand (RS), crushed sand (CS) and dune sand (DS) as proportions in binary and ternary systems, on flowability, passing ability, segregation and mechanical strength of SCC. The responses of the derived statistical models are slump flow, v-funnel time, L-box, stability and compressive strength at 2, 7 and 28 days. The derived mathematical models make it possible to illustrate the variation of different responses in ternary contour plots with respect to the proportions of RS, CS and DS. This provides flexibility to optimize RS, CS and DS blends with tailor-made of a given property that suit particular recommendations. Results indicate that when flowability requirements are combined, proportions of DS and CS in binary or ternary systems with RS must be below 0.24 and 0.6 respectively. Moreover, it is shown that passing ability can be satisfied by using a CS proportion above 0.3 in RS–CS binary system and above 0.65 in CS–DS binary system. On other hand, proportions above 0.5 of CS in RS–CS binary system and above 0.2 of DS in RS–DS binary system are recommended to meet stability limits. Results also indicate that compressive strength at 2, 7 and 28 days increased with the increase of CS proportion and decreased with the increase of DS proportion in binary and ternary systems.

1. Introduction

Self-compacting concrete (SCC) is a new type of concrete which main characteristic is to fill the forms and consolidate without the need of vibration [1]. Along with these advantages, SCC results in considerable reduction of the acoustic noise levels and the use of secondary raw materials. Recently, there is a growing interest on SCC technology in southern countries. The principal reasons for this interest are not only for the technical advantages of SCC, but concern also the severe shortage of coarse aggregates in these countries even though sands of different types and grading (such as dune sand and crushed sand) are available in large quantities [2,3]. In this regard, the development of new concretes that require less coarse aggregates to be used, such as SCC responds to some of the urgent needs of the construction sector. The limitation of coarse aggregates volume in SCC is also one of the most factors affecting their passing and filling abilities while preventing segregation [4,5].

On the other hand, several research works have investigated the use of sand as total or partial substitute of coarse aggregates to develop new concretes, which have mechanical properties comparable with conventional concretes [5,6]. In fact, sand is the main component in SCC, besides coarse aggregates, cement, mineral additions and superplasticizers. For that, the sand type and gradation have a larger effect on fresh and hardened properties of SCC. Due to the fineness of sand, SCC requires a high water demand and a large cement content to achieve high fluidity. Therefore,

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the use of superplasticizers and fine powders are thus two of the central aspects of self-compacting concrete mixture proportioning [7–9]. Sand from natural deposits or crushed rocks is a suitable material used as a fine aggregate in concrete production [2]. Bédérina et al. [6], reported that dune sand is a useful component in optimizing particle size distribution of river sand and thereby improving workability and compressive strength of sand-concrete mixtures. Kay et al. [10] also investigated the potential of using dune sand as fine aggregates in concrete. Results indicated that dune sand may provide a readily available alternative material for use as fine aggregate in concrete. Crushed sand, produced from crushing rocks units, can has a large potential of applications in various fields of civil engineering [3]. The employment of crushed sand may be a second alternative source of filler and thereby can improve the cost effectiveness of SCC, by reducing the demand for external filler addition [11].

Nowadays, some research results about the effect of sand type on the properties of flowable mixtures have been established, however, the related researches are focused on flowing sand-concretes and self-compacting mortars [12,13]. Therefore, the effects of sand type and content on fresh and mechanical properties of SCC needs more investigate.

In this study, the properties of SCC made with different sand types have been evaluated in term of flowability, passing ability and stability. Mechanical strengths of SCC were also investigated. A mixture design modelling, based on statistical approach was used to highlight the effect of three types of sands proportions, river sand (RS), crushed sand (CS) and dune sand (DS) on these properties.

2. Mixture design approach

Statistical modelling approaches are commonly used to identify the relative significance of primary mixture parameters and their coupled effects on relevant properties of SCC [14–19]. For the present work, experiments were designed according to a mixture design approach. In contrast to classical non-mixture designs (factorial and response surface designs), all factors are constituent proportions of a mixture. Since these proportions must always sum to 1, the last component proportion is dictated by the sum of all the others. In this mixture situation, the factors are not independent, which has consequences on the design process [20].

A simplex-lattice mixture design was carried out, with three factors and five levels, to evaluate the effect of three types of sands (RS, CS and DS) on the properties of SCC. All other SCC components (coarse aggregate, cement, addition, superplasticizer and water) were kept constant. The simplex-lattice design is a space filling design that creates a triangular grid of combinations, as shown in Fig. 1, where the number of combinations (C) is expressed by the flowing relation:

$$C = \frac{(q+m-1)!}{m!(q-1)!} \quad (1)$$

where, q is the number of factors and m the number of levels.

With three factors and five levels, the number of combinations to be treated is 21.

Using this approach, a mathematical model describing the effect of three types of sands proportions and their blends on given property can be established. In this study, a second-degree model was used with three non-independent variables (proportions of RS, CS and DS) and five levels. The model is expressed as follows:

$$Y = b_1 \times \mathrm{RS} + b_2 \times \mathrm{CS} + b_3 \times \mathrm{DS} + b_4 \times (\mathrm{RS}\cdot\mathrm{CS}) + b_5 \times (\mathrm{RS}\cdot\mathrm{DS}) + b_6 \times (\mathrm{CS}\cdot\mathrm{DS}) \quad (2)$$

The model's coefficients (b_i) represent the contribution of the associate variables on the response Y. These coefficients are determined by a standard least-square fitting. Analyses of variance are used to evaluate the significance of each term in the model. The residuals are used to calculate the variance of the coefficients, which is used to find the standard for testing whether a coefficient is significant or not [20].

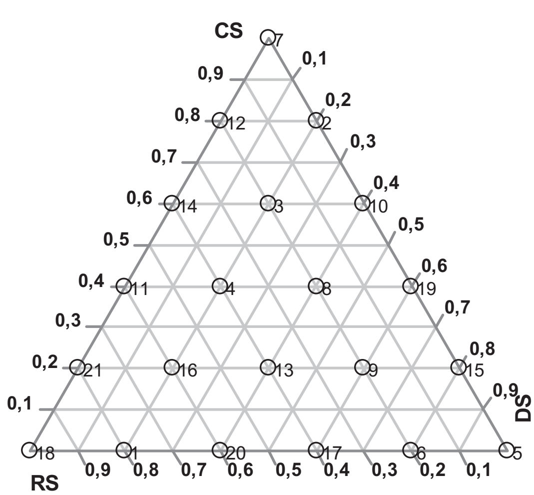

Fig. 1. Illustration of the simplex-lattice design with three factors (RS, CS and DS) and five levels.

3. Experimental program

3.1. Materials

Ordinary Portland Cement CEM I 42.5 and marble powder lime-stone type were used in this study. The chemical and physical properties of cement and marble powder are presented in Table 1. Three types of sand (RS, CS and DS) and crushed limestone-type gravel were used. The particle size gradations obtained thorough sieve analyses method of selected sands and gravel are presented in Fig. 2. The maximum sizes of aggregates are 10 mm for gravel, 5 mm for RS, 4 mm for CS and 1.63 mm for DS. Moreover, Scanning Electron Microscope (SEM) views of RS, CS and DS grains are given in Fig. 3. SEM investigations reveal the rounded shape of RS and DS grains and the angular shape of CS grains. They show also the finesse of DS grains and the high filler content of CS. Physical properties of used aggregates are presented in Table 2. A polycarboxylate-type high range water reducing superplasticizer was used. The solid content, pH and specific gravity of the superplasticizer are 30%, 6 and 1.07 respectively.

3.2. Mixture proportions

A total of 21 SCC mixtures were prepared for this investigation. In all the mixtures, the amounts of gravel, cement, marble powder, superplasticizer and water were kept constant. The mix proportioning has been designed according to AFGC recommendations [21]. In other words, the gravel/sand ratio was kept equal to 1 and the volume of paste was chosen 360 l/m^3 (in the range 330–400 l/m^3). Total sands content was 848 kg/m^3, in which 21 combinations from different proportions

Table 1
Chemical composition and physical properties of cement and marble powder.

Analysis (%)	Portland cement	Marble powder
CaO	65.9	55.6
SiO_2	21.9	0.6
Al_2O_3	4.8	0.4
Fe_2O_3	3.5	0.2
MgO	1.6	0.1
K_2O	0.5	–
SO_3	0.48	–
$CaCO_3$	–	90
Na_2O	–	–
Cl	0.1	0.1
LOI	1.2	43
Specific density	3.1	2.7
Blaine Surface (cm^2/g)	2792	2126