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ORIGINAL ARTICLE

Effect of filler types on physical, mechanical and microstructure of self compacting concrete and Flow-able concrete

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Abstract The objective of this study is to evaluate the effect of various filler types on the fresh and hardened properties of self-compacting concrete (SCC) and Flow-able concrete. For this purpose, two groups of fillers were selected. The first group was pozzolanic fillers (silica fume and metakaolin) while the second group was non-pozzolanic fillers (limestone powder, granite dust and marble dust). Cement contents of 400 kg/m^3 and 500 kg/m^3 were considered while the used filler material was 7.5%, 10% and 15%. Slump and slump flow, T50, sieve stability and bleeding tests were performed on fresh concrete. The studied hardened properties included unit weight, voids ratio, porosity, and water absorption and cube compressive strength. In addition, thermo-gravimetric analysis, X-ray diffraction analysis and scanning electronic microscope were performed. The test results showed that filler type and content have significant effect on fresh concrete properties where non-pozzolanic fillers improve segregation and bleeding resistance. Generally, filler type and content have significant effect on unit weight, water absorption and voids ratio. In addition, non-pozzolanic fillers have insignificant negative effect on concrete compressive strength. Finally, there was a good correlation between fresh concrete properties and hardened concrete properties for SCC and Flow-able concrete.

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1. Introduction

Self-compaction is often described as the ability of the fresh concrete to flow under its own weight over a long distance without segregation and without the need to use vibrators to achieve proper compaction. This saves time, reduces overall cost, improves working environment and opens the way for the automation of the concrete construction [1–4].

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Self compacting concrete (SCC) mixes always contain a powerful superplasticizer and often use a large quantity of powder materials and/or viscosity-modifying admixtures. The superplasticizer is necessary for producing a highly fluid concrete mix, while the powder materials or viscosity agents are required to maintain sufficient stability/cohesion of the mixture, hence reducing bleeding, segregation and settlement [4]. Benefits of using SCC also include: improving homogeneity of concrete production and the excellent surface quality without blowholes [5].

In Flow-able concrete, introduction of high volumes of mineral admixtures to concrete mixtures is limited due to their negative effects on water demand and strength of the hardened concrete. However, these mineral admixtures can be efficiently utilized as viscosity enhancers particularly in powder-type SCC. Thus, successful utilization of lime powder (LP), basalt powder (BP) and marble powder (MP) in SCC could turn these materials into a precious resource. Moreover, these mineral admixtures can significantly improve the workability of self-compacting [6,7]. When used in SCC, these mineral admixtures can reduce the amount of superplasticizer necessary to achieve a given property [8]. It should be noted that the effect of mineral admixtures on admixture requirements is significantly dependent on their particle size distribution as well as particle shape and surface characteristics. From this viewpoint, a cost effective SCC design can be obtained by incorporating reasonable amounts of LP, BP and MP [9]. The addition of MP is the best mineral admixture among LP, BP and MP, to improve the properties of fresh SCC such as slump-flow, T50 time, L-box ratio, air content and unit weight. All the mineral admixtures have shown significant performance differences and the highest compressive strength has been obtained for the MP mixtures. Incorporation of mineral admixtures reduced the cost per unit compressive strength of these SCC [9].

A lot of researches were performed to study the effects of filler materials on the properties of SCC. These studies showed that the use of filler materials improves workability with reduced cement content. By this way, low heat of hydration and decreased thermal and shrinkage cracking can be achieved [10,11]. Belaidi et al. stated that at a constant water/binder ratio and superplasticizer content, the use of both natural pozzolana and marble powder by substitution to cement has no negative effects on the workability of SCC [12]. Industrial by-products such as fly ash (FA), stone dust, silica fume and blast furnace slag are generally used as filler materials in SCC [6,13]. This helps to provide economical benefits and reduce environmental pollution [14].

Chloride ion permeability decreased considerably when mineral admixtures were used in the production of SCC. Pozzolanic admixtures exhibited better performance than fillers. The SCC mixtures were assessed as "low" chloride permeability concretes as per ASTM C 1202-94 assessment criteria, with less than 2000 coulombs of total charge passing, so the durability of SCC enhances due to the decrease in permeability [7,15].

Ho et al. [3] demonstrated that the granite fines, as supplied, could be used successfully in the production of SCC. Compared to the use of limestone powder, both paste and concrete studies confirmed that the incorporation of granite fines required a higher dosage of superplasticizer for similar yield stresses and other rheological properties. However, it is important to point out that as a waste material, the properties of granite fines are expected to vary over time. Furthermore, the fineness of granite fines could promote durability problems, such as alkali–silica reactions.

The marble has been commonly used as a building material since ancient times. Disposal of the waste materials of the marble industry, consisting of very fine powders, is one of the environmental problems worldwide today. However, these waste materials can be successfully and economically utilized to improve some properties of fresh and hardened self-compacting concrete (SCC) [16].

Valeria Corinaldesi et al. [17] stated that due to its quite high fineness, marble powder proved to be very effective in assuring very good cohesiveness of mortar and concrete. It is used for other ultra-fine mineral additions (such as silica fume) that are able to confer high cohesiveness to the concrete mixture. Moreover, an even more positive effect of marble powder is evident at early ages, due to its filler ability.

The use of fillers is intended to enhance the particle distribution of the powder skeleton, reducing inter-particle friction and ensuring greater packing density. This can promote release of a portion of the mixing water that would otherwise be entrapped in the system [18]. The water–binder ratio controls the amount of free space in the system in terms of void volume and the amount of fine material required to fill the voids. Void filling in packed systems may improve the particle arrangement, ensuring better water distribution and adequate fluidity. However, substantial increases in viscosity and unit weight occur at the concentration at which close packing is reached. The increase in viscosity beyond this limit may be explained by an increase in inter-particle friction due to increased solid–solid contact. In summary, the flow properties of self-compacting concrete depend heavily on powder particle size, shape, surface morphology, and internal porosity in addition to factors such as mixing regimen, sequence of admixture addition, and water/superplasticizer content [19,20].

In general, Dehwah reported that the mechanical properties of SCC incorporating quarry dust powder (QDP) are better than those of SCC incorporating silica fume (SF) plus QDP or only fly ash (FA). The use of quarry dust powder alone results in a significant cost saving in regions where SF and FA are not available locally and have to be imported from other regions [21]. The use of mineral admixtures in various combinations can provide excellent mechanical properties of SCC. As pozzolanic materials FA and granulated blast furnace slag (GBFS) increased the late age compressive strengths of SCC mixtures [22].

2. Experimental programs

The present work aims to study the effect of filler types on fresh and hardened properties of SCC and Flow-able concrete. Fresh and hardened concrete properties such as slump, slump flow, sieve stability, bleeding, porosity, compressive strength and scanning of microstructure for Flow-able concrete (FAW) with slump of 220 ± 20 mm and self compacting concrete (SCC) were considered in this study.

2.1. Materials

Two groups of filler were selected. The first group was pozzolanic fillers); silica fume (SF), metakaolin (MK) while the second one was non-pozzolanic fillers; limestone powder (LP),