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Reusing of marble and granite powders in self-compacting concrete for sustainable development

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ABSTRACT

Huge amounts of solid wastes are generated every day from marble and granite industry. Up to now, most of these wastes are landfilled causing serious environmental problems. With increasing the environmental awareness, it is essential to explore alternative solutions to waste disposal problem. This paper investigates the possibility of using various types of waste powders, generated from marble and granite industry, as mineral additives in self-compacting concrete (SCC). For this purpose, three types of waste powders were used; marble powder, granite powder and mixed powder. The experimental program included two phases. The first phase was the preliminary investigation to optimize the amount of the used mineral additives to cement content at which the highest compressive strength is achieved with acceptable flowability. In the second phase, the fresh and hardened properties of SCC were investigated. Slump flow, V-funnel, and J-ring tests were conducted to assess the self-compactability properties of fresh concrete, while compression, splitting tensile, flexural, water absorption and sulfate attack tests in addition to microscopic investigations were conducted to evaluate its hardened characteristics. The results indicated that high volumes of the investigated waste powders (up to 50% by weight of 400 kg/m^3 cement content) could be used successfully as mineral additives in the production of SCC. In general, SCC incorporating mixed powder showed the superior performance followed by granite powder mixes, while marble powder has a marginal effect on the performance of hardened concrete. However, silica fume could be used for the enhancement of marble powder performance.

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1. Introduction

Self-compacting concrete (SCC) is an innovative concrete characterized by its ability to flow under its own weight without segregation or blocking and to achieve full compaction without vibration (Gesoğlu et al., 2012; Naik and Vyawahare, 2013). Thus, SCC can be cast without honeycombing where it is difficult to mechanically compact fresh concrete, such as underwater concreting, cast in-situ piles, and columns or walls with congested reinforcement. In addition, it can be pumped to great heights in high-rise buildings without segregation (Naik and Vyawahare, 2013; Okrajnov-Bajić and Vasović, 2009). SCC has many advantages compared with normal concrete such as the reduction of construction time, labor, equipment and noise in construction sites because of the elimination of vibrating equipments. In addition, SCC makes the construction of heavily congested structural elements and hard to reach areas easier, and helping to achieve higher concrete quality (Nehdi et al., 2004; Okrajnov-Bajić and Vasović, 2009). For these advantages, SCC is used in the construction of important structural applications such as Burj Khalifa (Dubai), National Museum of 21st Century Arts (Italy), Dragon Bridge (Spain), etc. (Deeb, 2013; Okrajnov-Bajić and Vasović, 2009).

In general, SCC has the same ingredients as normal concrete. However, the key point for producing SCC depends on the mix proportions to obtain a highly fluid concrete while preventing bleeding and segregation during transportation and placing. Some guidelines were set for the proportioning of SCC including the reduction of water/powder ratio, increasing paste volume, controlling the total volume of coarse aggregate and its maximum particle size, and using a powerful superplasticizer along with large quantity of powders and/or viscosity-modifying admixtures (VMA) to fine-tune the balance between deformability and stability (Al-Mishhadani and Al-Rubaie, 2009; Nehdi et al., 2004). Powders

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or VMA are required to maintain the stability of the mix, hence reducing bleeding and segregation (Heirman et al., 2008; Karmegam et al., 2014). High powder content in the range of 500–600 kg/m^3 is often needed in SCC. However, high cement content increases heat of hydration, creep and shrinkage. Thus, mineral additives are needed to satisfy the powder requirement in SCC. The commonly used mineral additives in SCC are industrial by-products such as limestone powder, fly ash and ground granulated blast furnace slag (Poon and Ho, 2004). Similarly, the utilization of other industrial by-products such as marble powder, granite powder, etc as mineral additives in SCC, if they are proven by testing to be appropriate, may be an attractive solution to their disposal.

Egypt produces over 50 different types of marble and granite with a yearly production of about 3.5 million tons. Egypt ranks as the fifth producer and the seventh exporter for marble and granite in the world. As shown in Fig. 1, marble and granite quarries and factories are found in different locations in Egypt (Kandil and Selim, 2006). After mining in the quarries, industrial processes including splitting, sawing and polishing are done for the preparation of slabs and tiles for use in decorative purposes (Vijayalakshmi et al., 2013). Shaq Al-Thoaban area is considered the largest industrial cluster in Egypt for processing marble and granite. It has the highest concentration of marble and granite factories in Egypt reaching around 400 factories, with a total investment of 970 million USD. Shaq Al-Thoaban comes in the third place worldwide in the production of marble and granite (Hamza, 2011). In Shaq Al-Thoaban, a significant quantity of stone slurry is generated from the processing of stones. Generally, it is prohibited to discharge this slurry in the public sanitary system because of its highly alkaline nature. Consequently, slurry is stored in basins and the settled sludge is collected and disposed near the factories. After drying, the accumulated powder heaps become airborne, causing air pollution and water contamination, in addition to increasing soil alkalinity and reducing its fertility and plant productivity. The high pH of the dry slurry makes it harmful to lungs and eyes (Hamza, 2011). The amount of waste powder from the processing stage is 20–25% of the total processed stone (Gesoğlu et al., 2012). The accumulation of this waste is imposing an alarming threat to eco-system, biological components of the environment and public health.

Fig. 1. Location of marble and granite quarries and factories in Egypt (Kandil and Selim, 2006).

In recent years, some attempts have been undertaken to assess the possibilities of reusing marble and granite powders for soil stabilization, desulfurization process, in road embankments, asphalt, ceramics, thermoset resin composites, polymer-based composite materials (Aruntaş et al., 2010; Mendoza et al., 2014; Patel et al., 2013). Moreover, many researches are directed towards the utilization of marble and granite powders in cementitious products to replace cement or sand (Aliabdo et al., 2014; Mashaly et al., 2016; Rana et al., 2015). Using of these powders as sand replacement was found to be more favorable than being used as cement replacement. Corinaldesi et al. (2010) reported that using of 10% marble powder (MP) as sand replacement in mortar is better than being used as cement replacement material. Moreover, the use of superplasticizer is necessary to compensate the high water demand of MP and the consequent evident loss of strength. Allam et al. (2014) found that using granite powder (GP) as sand replacement in concrete causes 8–11% increase in the 28-days compressive strength, while a dramatic decrease in the compressive strength was observed with increasing GP percentage as cement replacement.

Most of the authors confirmed that the optimum percentage of MP as a partial replacement to cement in concrete is 10% (Anwar et al., 2014; Sounthararajan and Sivakumar, 2013; Vardhan et al., 2015). Ali and Hashmi (2014) found that the 28-days compressive and flexural strengths of concrete increased by 16.5 and 12%, respectively for 10% MP, and decreased by 8.6 and 10.4%, respectively at 20% MP. In case of using MP to replace fine aggregate, the behavior of concrete is generally enhanced by increasing MP percentage. Demirel (2010) reported that the compressive strength and dynamic modulus of elasticity of concrete increased by increasing MP percentage substituting very fine sand, while the sorptivity decreased with increasing MP content. On the other hand, most of authors confirmed that the optimum percentage of GP as a partial replacement of cement is about 7.5–10%, which has a slight effect on concrete strength (Soman and Abubaker, 2014; Vaitkevičius et al., 2013). In case of using GP to replace fine aggregate, the results were incongruous. While Vijayalakshmi et al. (2013) reported that the substitution of sand by up to 15% GP does not significantly affect concrete properties; Kala (2013) found that the mechanical properties of HPC are improved by using up to 75% GP as sand replacement.

It is clear that most of researches focused on the utilization of marble and granite powders as cement or sand replacement materials. However, the main problem facing this application is the high fineness of these powders. Mixes containing marble and granite powders require the use of superplasticizer otherwise more quantity of water will be needed for similar workability, which consequently reduces the strength. On the other hand, the high fineness of marble and granite powders may be beneficial for providing good cohesiveness to SCC if they are used as mineral additives. Hence, recent researches have been carried out to study the effect of using waste powders generated from marble and granite processing plants, especially marble powder, in SCC (Tennich et al., 2015; Topçu et al., 2009; Uysal and Yilmaz, 2011). However, extensive researches are needed to evaluate the behavior of SCC containing high volumes of these wastes. The main objective of this research is to investigate the possibility of using marble and granite powders as mineral additives in SCC. The rheological properties of SCC incorporating these wastes in addition to its physical, mechanical and durability-related properties will be investigated and compared with those of the control mixes produced with plain cement.

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