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Adding granite dust as paste replacement to improve durability and dimensional stability of mortar

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ABSTRACT

In a recent study by the authors, it has been found that the addition of granite dust (GD) as paste replacement (addition of GD to replace an equal volume of cementitious paste with the water/cementitious materials ratio kept constant) to decrease the cementitious paste volume in mortar offers substantial benefits in cement content reduction (and thus carbon footprint reduction), waste utilization, strength improvement and microstructure densification. In this study, the authors extended the research program to evaluate the effects of adding GD as paste replacement on the durability and dimensional stability of mortar. A series of mortar mixes with varying GD volume and water/cement ratio but similar workability achieved by adjusting the superplasticizer dosage were made for mini slump cone test, carbonation test, water absorption test and drying shrinkage test. The test results revealed that adding GD as paste replacement could substantially improve the carbonation and water resistances, reduce the ultimate shrinkage strain and shrinkage rate, and at the same time, reduce the cement content by up to 25%.

1. Introduction

Although very fine filler particles could act as nuclei for precipitation of C-S-H gel and thus increase the rate and degree of cement hydration [1,2], most fillers, such as limestone fines, quartzite fines, rock dust, recycled old concrete, tailings and seashell waste, are not inherently cementitious and therefore should not be treated as supplementary cementitious materials [3,4]. Nevertheless, it has been found that the incorporation of fillers to replace some of the solid ingredients can enhance the various performance attributes of cement-based materials [5–11]. Usually, the fillers are used as cement replacement or aggregate replacement in concrete production.

By using a filler as cement replacement, the filler is added to replace a portion of the cement or cementitious materials, and such addition of a filler as cement replacement has been found to have significant effects on the durability and dimensional stability. For instance, in 2008, Lee et al. used limestone powder to replace cement and noted that the paste and mortar samples incorporating higher replacement levels of limestone powder were more susceptible to sulphate attack [12]. In 2013, Bacarji et al. replaced cement by marble and granite residues and found that the water absorption increased as the cement replacement percentage increased [13]. In 2016, Zhang et al. compared the dimensional stability of high-volume limestone fines concrete (HVLFC) and high-volume fly ash concrete (HVFAC), and presented test results showing that the adiabatic temperature rise and drying shrinkage of HVLFC were smaller than those of HVFAC [14]. In 2017, Han et al. applied both fine and coarse iron tailing powders to replace cement and revealed that the mortar containing fine iron tailing had larger hydration heat, higher non-evaporable water content and finer pore structure than those of the mortar containing coarse iron tailing [15]. In same year, He et al. demonstrated that the addition of lithium slag as cement replacement can effectively reduce the drying shrinkage [16].

By using a filler as aggregate replacement, the filler is added to replace a portion of the aggregate. The effects of adding a filler as aggregate replacement on durability and dimensional stability have also been extensively researched. For instance, in 2010, Yang et al. used crushed oyster shells (COS) to replace a portion of fine aggregate and showed that COS has positive effect on freezing and thawing resistance, but no apparent effect on carbonation and chemical attack resistance [17]. In 2016, Sadek et al. added marble and granite powders to replace both fine and coarse aggregate, and found that after 7 months of sulphate attack, the residual strength of concrete added with marble and granite powders was higher than that of normal concrete [18]. In same year, Seara-Paz et al. investigated the shrinkage and creep of concrete with various amounts of recycled coarse aggregate added as replacement of virgin coarse aggregate and observed that the shrinkage and creep strains increased with the replacement percentage [19]. In

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2017, Wang et al. used reverse flotation tailings (RFT) as aggregate to produce waterproof mortar and proved that the RFT mortars presented good waterproof property with lower water absorption coefficient and higher water contact angle [20].

However, the use of fillers as cement replacement or aggregate replacement has certain drawbacks. By using fillers as cement replacement, the cement content would be reduced and the water/cement ratio would be increased, and therefore a high cement replacement rate would cause deterioration of the durability and dimensional stability [12,16,21]. This has limited the cement replacement rate and rendered the effectiveness in cement content reduction rather low and usually not more than 10%. By using fillers as aggregate replacement, the cement content would not be reduced and thus the water/cement ratio would not be changed. However, this would not help to reduce the cement consumption and carbon footprint of the concrete production, although the use of waste as the filler has certain beneficial effect on the environment [19,22]. There is, therefore, the question of whether we can develop an alternative method of using fillers that would more significantly reduce the cement consumption, reuse a considerable amount of waste, and simultaneously improve the durability and dimensional stability of the concrete produced.

Recently, the authors' research group has proposed a new method of using fillers called the “paste replacement method” [23–27]. By this method, the filler is added to replace an equal volume of cementitious paste without changing the mix proportions of the cementitious paste. This would reduce the cementitious materials content without changing the water/cementitious materials ratio. Furthermore, this would also maintain the powder paste volume needed to fill the voids between the aggregate particles and to provide paste films coating the aggregate particles for lubrication and rendering workability (the powders are the cementitious materials and fillers of powder size, and the powder paste volume is the total volume of water and powders). In this regard, it should be borne in mind that the use of fillers as cement replacement and the concurrent reduction of water content to avoid changing the water/cementitious materials ratio would significantly reduce the paste volume and might cause problem if eventually the paste volume is not sufficient to fill the voids between aggregate particles and provide paste films for workability.

In the previous studies, the authors' research group applied this method to the use of limestone fines and marble dust as a filler in concrete and mortar, and found that this method would allow substantial reduction of the cement content by more than 20%, and, more importantly, also increase the strength, durability and dimensional stability of the concrete produced [23–28]. In a recent study, the authors' research group extended this method to granite dust (GD) and in the study presented herein, the effects of GD added as paste replacement on the durability and dimensional stability of mortar were investigated by producing a series of mortar mixes with varying GD volumes and water/cement ratios for testing of their carbonation depth, water absorption rate, drying shrinkage strain and shrinkage rate.

2. Experimental procedure

2.1. Materials

For the cementitious materials, an ordinary Portland cement of strength class 42.5 complying with Chinese Standard GB175-2007 [29] and having a relative density of 3.08 was used as the only cementitious material. For the fine aggregate, a river sand with a relative density of 2.58, maximum size of 1.18 mm, moisture content of 0.16% and water absorption of 1.10% was used. Besides, for the workability admixture, the superplasticizer (SP) added was a polycarboxylate-based SP with a relative density of 1.03 and a solid mass content of 20%.

The granite dust (GD) employed in this study was supplied by a stonework factory located in Yunfu City, a famous hometown of stoneware products in China. It was a waste produced during cutting, shaping and polishing of stoneware. The GD as supplied was wet and contained some gravel and debris. To dry and reduce the variation in quality of the GD, simple treatment by heating the GD at 105 °C for 8 h to remove water and mechanical sieving to remove particles larger than 1.18 mm was carried out. After such treatment, the GD became a dry powder. Finally, the GD was measured to have a relative density of 2.62.

A laser diffraction particle size analyzer was used to measure the particle size distributions of the cement and GD, while the mechanical sieving method was used to measure the particle size distribution of the fine aggregate, as plotted in Fig. 1. Unlike the cement, the GD has a gap-graded particle size distribution, with 46.2% smaller than 60 μm, 52.9% larger than 150 μm but only 0.9% within 60 to 150 μm. The reason may be that granite is mainly composed of quartz, feldspar and mica, but the hardness of feldspar and mica is relatively low. So during the polishing process, the feldspar and mica were easily ground to smaller size, while the quartz was not easy to be broken and thus tended to remain at larger size.

2.2. Mix proportions

A series of mortar mixes with different amounts of GD added as paste replacement and various water/cement (W/C) ratios were produced for testing. When GD was added, the cement paste volume (volume of water and cement, expressed as a percentage of the volume of mortar) was reduced by the GD volume (volume of GD, expressed as a percentage of the volume of mortar) so that the cement paste volume plus the GD volume remained unchanged. In this series of mortar mixes, the sum of cement paste volume and GD volume was fixed at 60% and the GD volume was varied among 0%, 5%, 10% and 15%. Therefore, at GD volumes of 0%, 5%, 10% and 15%, the respective cement paste volumes were 60%, 55%, 50% and 45%. On the other hand, the fine aggregate volume was fixed at 40% of the volume of mortar. It should be noted that when GD was added, the W/C ratio was not changed. The W/C ratio was varied among 0.40, 0.45, 0.50 and 0.55.

Details of the mortar mixes are presented in Table 1. Each mortar mix was assigned a mix number of X-Y-Z, in which X denotes the mortar type with names of NM (normal mortar with no GD added) or PR (mortar with GD added as paste replacement), Y denotes the W/C ratio and Z denotes the GD volume (as a percentage of the volume of mortar). Unlike the other mix parameters, the SP dosage (in terms of liquid mass of SP by mass of cement plus GD) was not predetermined. Instead, preliminary trial mixing was carried out, during which the SP was added to the mortar mix in small increments until a flow spread of 200 to 300 mm was achieved so as to estimate the SP dosage needed. After the preliminary trial mixing, another mortar mix

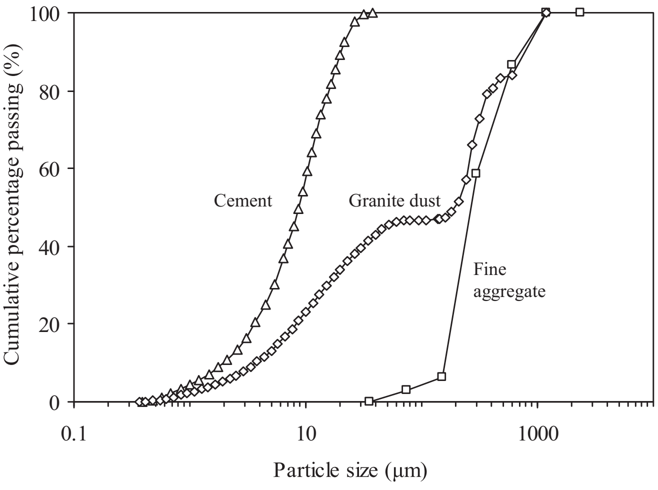

Fig. 1. Particle size distributions of cement, granite dust and fine aggregate.