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# Use of marble dust as paste replacement for recycling waste and improving durability and dimensional stability of mortar

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## HIGHLIGHTS

- A paste replacement method of adding marble dust to replace equal volume of paste is developed.
- Compared to cement/aggregate replacement methods, this allows cement content to be reduced by up to 33%.
- Adding marble dust as paste replacement reduces carbonation, water absorption and shrinkage.
- This paste replacement method has great potential to be applied to other fillers or waste.

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## ABSTRACT

Lots of marble dust (MD) are generated in stonework factories and just dumped as waste causing environmental problems. Some researchers proposed to use the MD as cement replacement or aggregate replacement in mortar or concrete but the benefits in cement content reduction and performance enhancement are quite limited. Recently, the authors have developed a new method of using inert waste or fillers as paste replacement for greater benefits. By this method, the waste or filler is added to replace an equal volume of cementitious paste without changing its mix proportions. In this study, the authors applied this method to the use of MD in mortar. A series of mortar mixes with varying MD volumes and water/cement ratios were made for mini slump cone test, carbonation test, water absorption test and drying shrinkage test. The test results revealed that adding MD as paste replacement could substantially improve the carbonation and water resistances, reduce the shrinkage strain and rate, and at the same time, reduce the cement content by up to 33%.



## 1. Introduction

Waste recycling is an important part of sustainable development because the reutilization of waste materials can relieve the adverse impact on environment, save resources and energy, add commercial value to the waste and reduce the total cost. In this regard, the construction industry is one of the best targets for solid waste reutilization due to its large consumption capacity. According to statistics, the world's total production in 2015 of cement, steel and glass were about 4.1 billion tons, 1.6 billion tons and 5 6 million tons, respectively [1]. Many solid waste materials, such as fly ash, slag, silica fume, crushed old concrete, rock waste, waste glass, waste rubber and mine tailings, have been added to concrete and found to have certain beneficial effects on various performance attributes of concrete [2–10].

Among the solid waste materials, marble waste generated by the stonework industry cannot be neglected, due to its large quantity and serious impact on the morphology, ecology, hydrology, soil fertility and land occupation [11]. China is the second largest producer of marble in the world and produces about 350 million $m^2$ of marble planks in 2015 [12]. Moreover, the amount of marble waste generated during the production process can be as much as 80% of the volume of marble stone processed [13]. Reutilization of such large quantity of marble waste is not an easy task. Usually, the marble waste, mainly in the form of marble dust (MD), is reutilized as cement replacement or aggregate replacement in concrete production.

When used as cement replacement, the MD is added to replace a portion of the cement or cementitious materials, and such addition of MD as cement replacement has been found to have significant effects on the durability and dimensional stability. In 2009,

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Topcu et al. [14] replaced part of the binder comprising of cement and fly ash by MD to produce self-compacting concrete (SCC), and revealed that a MD content of 200 kg/m$^3$ could improve the capillarity coefficient. In 2013, Bacarji et al. [15] added marble and granite residues to replace a portion of cement and found that the water absorption increased as the cement replacement percentage increased. In 2015, Talah et al. [16] demonstrated that MD could be used to substitute 15% of cement without decrease of compressive strength and with increase of durability. In same year, Rana et al. [11] added marble slurry up to 25% in place of cement and noted that the optimum cement replacement level for durability improvement was 10%. In 2017, Singh et al. [17] used marble slurry to partially replace cement and found that the addition of marble slurry can reduce the shrinkage of mortar.

When used as aggregate replacement, the MD is added to replace a portion of the aggregate. In 2012, Gencel et al. [18] applied MD to replace both fine and coarse aggregates, and found that the addition of MD had positive effect on freeze-thaw resistance of concrete paving blocks. In 2014, André et al. [19] used coarse marble waste to replace normal coarse aggregate and revealed that there was no significant difference in terms of durability between a concrete made with coarse marble waste and one made with normal coarse aggregate. In same year, Gameiro et al. [20] demonstrated that marble sand has beneficial effect on drying shrinkage of concrete. In 2016, Sadek et al. [21] added marble and/or granite powders to replace both fine and coarse aggregates to produce SCC, and found that such addition of marble and/or granite powders could increase the sulphate resistance of SCC. In 2017, Tennich et al. [22] compared the sulphate resistance of SCC containing various wastes, including marble waste, marble tile waste and gravel tile waste, as aggregate replacement, and showed that the SCC containing marble waste had the highest sulphate resistance against seawater and $Na_2SO_4$ solution.

However, the use of MD as cement replacement or aggregate replacement has certain limitations. By using MD as cement replacement, the cement content would be reduced and the effective water/cement ratio would be increased. Therefore, a high cement replacement rate would significantly reduce the strength and durability, thus imposing a certain limit on the cement replacement rate [11,14,15,17]. On the other hand, by using MD 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. There is, therefore, a need to look for a better method of using MD in mortar or concrete production. In this regard, an alternative method that would allow a greater amount of MD to be added to increase the waste recycling rate, lower the cement consumption and carbon footprint, and at the same time improve the performance of the concrete produced, especially the durability and dimensional stability performance, is very much desired.

In recent years, the authors have developed a new method of using fillers or solid waste in mortar and concrete, called the paste replacement method. By this method, the filler or solid waste is added to replace an equal volume of cementitious paste (cementitious materials plus water) without changing the mix composition and water/cementitious materials ratio of the paste. In previous studies [23–27], this method was applied to the use of limestone fines as a filler in concrete and it was found that this method would enable substantial reduction of the cement content in concrete by more than 20%, and, more importantly, also increase the strength, durability and dimensional stability of the concrete produced. In some later studies [28,29], this method was extended to the use of granite dust (GD), which is a solid waste, in mortar and the results demonstrated that the addition of GD as paste replacement has beneficial effects on cement content reduction, waste utilization, strength, microstructure, durability and dimensional stability of mortar.

In the present study, this method was further extended to marble dust (MD). The effects of MD added as paste replacement on the durability and dimensional stability of mortar were investigated by producing a series of mortar mixes with varying MD volumes and water/cement ratios for testing of their workability, carbonation, water absorption and drying shrinkage. It will be seen that the addition of MD as paste replacement can substantially reduce the cement content and at the same time improve the durability and dimensional stability.

## 2. Experimental studies

### 2.1. Selection of materials

Regarding the cementitious materials, an ordinary Portland cement of strength class 42.5 having a relative density of 3.08 and complying with Chinese Standard GB175-2007 [30] was used as the only cementitious material. Regarding 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 employed.

The marble dust (MD) used in this study was a waste generated during cutting, shaping and polishing of marble in a stonework factory located in Yunfu city, a famous hometown of stoneware products in China. Lots of MD are being dumped as waste at high cost by stonework factories in Yunfu and the local government is exerting pressure onto the stonework factories to reduce waste disposal by recycling. Since the MD supplied was wet, a simple treatment of heating the MD at 105 °C for 8 h to remove the water contained therein was carried out before usage. After such treatment, the MD became a dry white powder. Then, it was found that most of the MD (about 95% by mass) had a particle size smaller than 150 μm. So, a 150 μm sieve was used to mechanically sieve away the debris and particles larger than 150 μm. Finally, the MD was measured to have a relative density of 2.70. It should, however, be noted that in actual application, the MD does not need to be perfectly dry and may even be used in the form of a slurry with the water in the MD allowed for in the calculation of the water content during the mix design [11,17]. The energy intensive drying process carried out in this research was to improve the accuracy of the batching process for scientific investigation.

The particle size distributions of the cement, MD and fine aggregate are plotted in Fig. 1. It can be seen that both the cement and MD have continuous graded particle size distributions. Whilst the

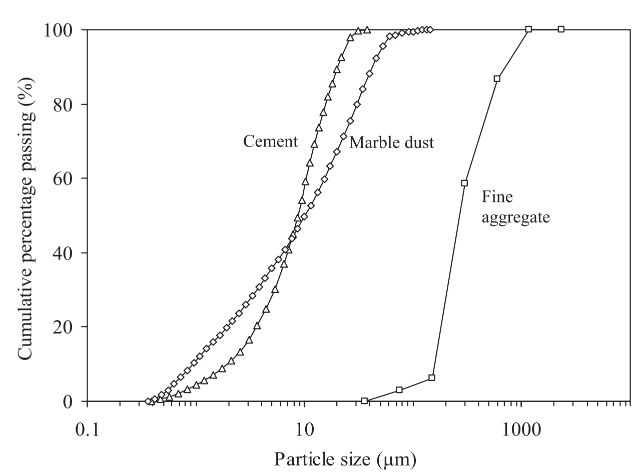


**Fig. 1.** Particle size distributions of cement, marble dust and fine aggregate.