Construction and Building Materials 165 (2018) 321–332

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Utilization of marble powder as fine aggregate in mortar mixes

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HIGHLIGHTS

- Dried marble slurry waste was evaluated as a potential substitute of river sand in mortars.
- Marble slurry helps reduce required water content to prepare cement sand mortars.
- Marble slurry hastens the hydration reaction and forms calcium carboaluminates.

ARTICLE INFO

Article history:
Received 26 September 2017
Received in revised form 24 December 2017
Accepted 9 January 2018

Keywords:
Mortar
Marble powder
Masonry
Rendering
Sustainability

ABSTRACT

The construction industry has been responsible for plaguing the environment due to ecological imbalance caused during the extraction and production of building materials. To make this production of construction materials cleaner, the dependency on natural resources has to be reduced. With this aim, marble powder which is a waste product generated during cutting and shaping of marble blocks has been evaluated as a replacement of conventional river sand in cement mortars. For this, four different mix proportions of mortars were evaluated in terms of workability, drying shrinkage, compressive strength, bond and adhesive strengths, density, water absorption and dynamic Young's modulus. Results show that mortar mixes with 20% substitution of river sand by marble powder can be used for masonry and rendering purposes. Such mortars have a distinctively dense microstructure which is a consequence of reduced water requirement and formation of superior quality of hydration products. These were confirmed by scanning electron microscope, thermogravimetric analysis and Fourier transform infrared spectroscopy techniques. Hence, by replacing sand to the tune of 20% by marble powder, would enable the construction industry to reduce their dependency on river sand. Additionally, by utilizing this non-biodegradable marble waste as a building material, would reduce the burden on landfills and therefore help the marble stone industry to be more sustainable.

1. Introduction

For a country like India which has 1931 Mega tonnes of marble resources still left to be exploited [1] has already been plagued with waste disposal problems associated with the marble mining and processing [2]. Based on the mechanism used for sawing, grinding and polishing, the marble slurry generated is about 10%–22% of the stone block [3]. The generated slurry is indiscriminately dumped on vacant lands, river banks or forest areas. These slurry particles are fine enough to fill the pores of the soil, which can prevent water percolation and reduce its fertility. On drying, these particles are lifted by air and can result in respiratory problems in humans [4]. Uncontrolled disposal of marble industrial effluents had also led to increase in pollutants in groundwater, endangered aquatic biodiversity and cause skin, eye and kidney diseases in humans [5]. On understanding the gravity of this problem, researchers all over the globe have tried to provide a possible solution for such waste disposal issues in their respective countries.

Usage of marble fines in production of concrete has been dealt extensively. Alyamac and Aydin (2015) reported that the marble sludge can be used in place of river sand for up to 40% in concrete with a w/c ratio of 0.6. They pointed out that workability reduced with increase in marble incorporation. Compressive strength had a peak at 20% substitution which was 5% more than control mix [6]. For concrete mixes with a w/c of 0.5, Hebhoub et al. (2011) had presented that maximum compressive strength was obtained at 50% substitution of river sand by marble waste (23.65% more than the concrete mix made with conventional fine aggregate) [7]. Demirel in 2010 used marble waste of dolomite origin which was finer than 0.025 mm to replace sand of same size in concrete

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https://doi.org/10.1016/j.conbuildmat.2018.01.061
0950-0618/

with w/c of 0.51. Compressive strength of mixes with marble substitution showed a positive trend with 100% substitution showing the best performance [8]. The pioneer of incorporating marble waste in concrete products, Hanifi Binici in his work Binici et al. (2007) investigated the effect of using marble dust in a concrete of mix ratio 1:1.5:2. On testing, it was seen that compressive strength increased with increase in substitution, with 15% substitution recording the highest value [9].

Studies of inclusion of marble powder as fine aggregate in medium strength concrete have been carried out by Aliabdo et al. (2014) and Silva et al. (2013) [10,11]. Compressive strength for all substitutions decreased, the maximum reduction was for 100% substitution with a difference of 20% when compared to river sand [11]. On the contrary Aliabdo et al. (2014), quoted that compressive strength was more than control (the concrete mix with conventional materials) for the maximum substitution of 15% for sand replacement, peak was obtained at 10% substitution for both w/c ratios of 0.4 and 0.5 [10]. Ural et al. (2013) replaced sand in proportions 5, 10, 15%. Peak values of compressive strength (17% than concrete mix made with river sand) was obtained at 5% substitution which was due to the filler effect of marble dust [12].

With regard to mortars, Khyaliya et al. (2017) had tested the utilization of marble fines (mining waste) as a replacement for fine aggregate in a lean mortar mix of 1:6. Due to thixotropic property of marble, a substitution of 50% of river sand by marble powder required lesser water than the control mix. Eventually the same mix gave best performance in terms of compressive strength. However, drying shrinkage and water absorption of these mixes were same. This was because of increased porosity of marble substituted mix when compared to the control mortar. Consequently this increase in porosity also meant utilisation of marble powder had to be limited to only 25% when there is susceptibility of attack from sulphate and acidic agents [13]. Earlier in 2014, Kelestemur et al.'s study directed at evaluating the utilisation of marble sludge of both dolomite and calcite origin, proved that marble aggregates finer than 0.25 mm help increase compressive strength of mortars [14]. Rai et al. (2011) investigated the effect of marble granules as a replacement of fine aggregate in mortar and concrete. Replacement was done by weight in variations of 5, 10, 15 and 20%. Mix ratio of mortar was 1:3 and concrete mix was designed for a 28th day characteristic strength of 38 MPa. On testing, mortars and concrete mix specimens attained a peak compressive strength for 10% and 15% substitution respectively [15]. Corinaldesi et al. (2010) characterized marble powder generated from marble shaping and cutting industry with a view of using the same in mortars and concrete. Rheological parameters of this slurry were evaluated by preparing cement pastes in which cement was replaced by 10 and 20% levels with and without super-plasticizing admixture with two w/c ratios of 0.4 and 0.5. It was reported that presence of marble powder improved cohesiveness necessary for self-compacting concrete. Marble powder also improved segregation resistance. Thixotropy values of cement pastes with marble powder are high too, indicating better flow through narrow sections was possible when the fresh mixes are set in motion. They also evaluated compressive strength of cement sand mortars of 1:3 proportions. Marble slurry was used in place of cement and sand, 10% by mass. These mixes had the same flow value. There was fall in compressive strength by 20% when cement was replaced, and 10% when sand was replaced. They concluded that marble slurry played the role of filler and showed no sign of taking part in the hydration process [16].

From the above literature survey it can be safely pointed out that marble slurry has been tested as fine aggregate relatively to a lesser extent for utilization in mortars than concrete. Hence there is scope for evaluation of performance of mortar mixes with a wide range of mix proportions (1:3, 1:4, 1:5 and 1:6) with dried marble slurry (in the form of marble powder) at different substitution percentages (0–100%) in place of river sand. By finding an optimum substitution percentage of sand by marble powder in mortars apart from concrete alone would enable the construction industry to further reduce sand mining and hence minimize the environmental problems associated with it [17]. This would also help the marble processing industry to be more sustainable by finding an additional utilization of such non bio-degradable waste. With the above set targets, mortars were prepared with aim of utilizing the same for rendering and masonry purposes. Evaluation was done in terms of workability, compressive strength, bond and adhesive strength, water absorption capacity, fresh and hardened density, stiffness and drying shrinkage. The experimental program of these tests is detailed in the following section.

2. Materials and methods

Portland pozzolana cement complying with IS 1489 (1991) [18] was used. The specific gravity was found to be 2.9 with loose bulk density 1100 kg/m^3 and specific surface area of 0.361 m^2/g. Fine aggregate in the form of river sand was procured from a local dealer in Jaipur, Rajasthan, India. In Fig. 1, an analysis of particle size distribution is presented, where it can be seen that river sand used in this study satisfies the stipulations of fine aggregate required for plaster [19] and masonry mortar [20].

Wet marble sludge was acquired from a firm which processes marble slabs in an industrial area of Jaipur. The slurry was sun dried, hammered to reduce the dried blocks to a powder passing through 1.18 mm sieve. The physical properties like specific gravity, bulk density and water absorption [21] and fineness modulus [22] (as a percentage of oven dried weight) of sand are presented in Table 1. For marble powder in addition to specific gravity and bulk density, specific surface area and plastic limit [23] were identified and listed in the same table. Table 2 lists out the chemical composition of river sand and marble powder used. The X-ray diffraction pattern for marble powder is shown in Fig. 2. SEM micrographs were also be taken to study the particle shape and texture also Fig. 3.

On particle size analysis, 50% of marble powder particles were found to be smaller than 49.68 μm with a surface area of 0.35 m^2/g. This shows that marble powder is as fine as conventional cement. The oxide compositions of sand and marble presented in Table 2 shows that marble has significant amount of magnesium and calcium ions.

On conducting X-ray diffraction analysis marble powder was found to consist of calcium and magnesium carbonate predominantly in the form of dolomite crystals indicated by the peak at a diffraction angle of 31.027°. The Indian Bureau of Mines (2015), classifies marble to be of crystalline nature. From the SEM micro-

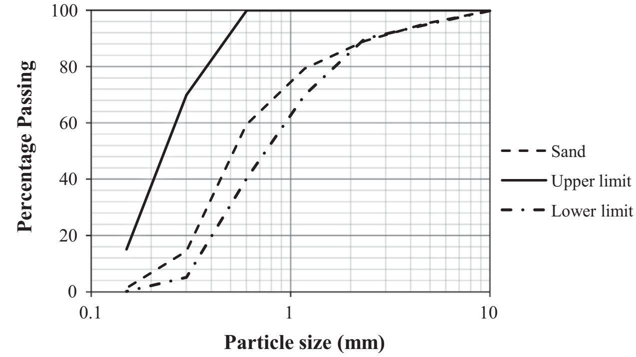

Fig. 1. A comparative statement of particle size distribution of river sand with the required specifications.