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Evaluation of strength and durability of lean mortar mixes containing marble waste

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HIGHLIGHTS

- Marble waste was evaluated as a potential substitute of river sand in mortars.
- Marble waste can significantly accelerate hydration process.
- 25% of sand can be substituted by marble waste when mortars are exposed to an aggressive environment.

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ABSTRACT

This study was carried out to test the suitability of marble waste as a fine aggregate in lean mortar mixes. Marble waste was crushed in the form of fine aggregate, then it was substituted in place of river sand from 0% to 100% by volume. It was found that by incorporation of marble waste from 25% to 50%, maximum benefits could be derived in terms of reduced water requirement, improved mechanical performance and enhanced durability. At 50% substitution the water requirement to attain the required workability fell by 6% and compressive strength increased from 2.84 MPa to 7.04 MPa. When exposed to 5% sodium sulphate and sulphuric acid solutions, the mortar mix with 25% marble waste and 75% of river sand performed at par with control mortar. In view of these results it was concluded that marble waste can be safely used in both aggressive and non-aggressive environments by replacing river sand by 25% and 50% respectively in lean mortar mixes.

1. Introduction

Among the stones like granite, limestone and sandstone, marble is one of the most important dimension stone quarried in India. The state of Rajasthan has about 64% of marble resources of India and generated 267 million dollars' worth of marble during the year 2012–13 [1]. On the flip side, this mega industry generates waste of alarming amounts. During mining of marble, about 60% of the rock is lost as waste in the form of blocks of irregular size and shape [2–4].

Apart from the dimension stone industry, the construction industry also consumes a significant quantity of natural resources. Aggregates which form 70% of the concrete/mortar volume, require 5–7.5 billion tonnes to be quarried annually [5]. Hence instead of producing aggregates and minerals from virgin sources, it is more than appropriate to evaluate the utilization of the waste product from one mega industry into another.

Attempts have been made to utilize marble waste in production of concrete and mortars. When marble powder finer than 2 mm was used to replace cement, an incorporation of more than 10% led to fall in mechanical properties [6]. When marble slurry was used as cement in concrete, plasticizer and super-plasticizer had to be used to maintain the desired slump corresponding mixes. The bulk density of concrete reduced with increase in substitution. Modulus of elasticity too followed the same trend. The variations in UPV were insignificant for any change in substitution [7]. In case of mortars, mixes with 10% substitution of cement reached the target strengths [4]. This was because, for higher substitutions, the marble powder did not take part in the hydration process but acted only as a filler agent. This pore filling effect which resulted in increase in compressive strength was significant in a higher water cement ratio of 0.5 when compared to 0.4 [8]. In addition to filling pores, marble increased the viscosity of concrete mixes [9]. On the durability front, due to the pore filling effect fine marble powder, at 10% substitution of cement in concrete, reduced the extent of migration of harmful ions further into the concrete and hence reducing chloride corrosion and carbonation [3]. With regard to

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high performance concrete, the compressive strength was less by 29%, whereas for concrete with marble powder, the reduction was only by 3% when subjected to aggressive environment of 5% calcium chloride ($CaCl_2$). Reduction of air permeability by 85% at the age of one year for concrete with marble waste was also reported [10].

On other hand, it was reported that the positive effect of marble powder was more pronounced when it was used in place of sand than as a cement replacement [8]. Workability of concrete mixtures depends also by the grain size of the aggregates. However on keeping the grading curve as constant, workability of concrete mixtures decreased with increase in percentage incorporation of marble. This was due to the high cohesiveness imparted to the mixes due to increased marble content. This led to higher w/c ratio and reduced compressive strength. Modulus of elasticity is very much related to the compressive strength and the same reasons were concluded for the decline of this parameter too [11]. Reduction in workability was reported by Hebhoub et al. (2011) also, however on evaluation of mechanical properties marble incorporated mixes performed better than control mixes [12]. The increase in strength should be tried to be due to the cementing properties of the marble grains or to chemical reactions [12–15]. Two other studies which were carried out on marble incorporated as fine aggregate in mortars reported that, compressive and flexural strength increased and porosity reduced with increase in marble powder content [16,17]. With regard to durability of the concrete mixes, Gameiro et al. (2014) stated that water absorption by capillary action and immersion was the least for 20% substitution. Resistance to chloride penetration reduced with addition of marble. The aggregates geometry improved the shrinkage behaviour also [18]. Keleştemur et al. (2014) and Keleştemur et al. (2014a) showed resistance to fire improved with increase in marble content and on the contrary, resistance to freeze thaw reduced [16,17]. Marble slurry also has the ability to impart better thixotropic properties to cement pastes. This allows it to flow through narrow sections with less effort [19]. When used as fine aggregate to prepare plastering mortars, marble incorporation resulted in reduction in compressive strength. However adhesive strength increased by 160% when marble substituted sand by 25% [20].

From the above brief literature survey, it can be seen that marble granules have been sufficiently tested as a potential fine aggregate substitute in concrete [8,11,12,15,18,21–33]. Based on particle size and chemical composition most of these studies report a positive performance with the optimum substitution percentages ranging from 15% to 80% [34]. Since only a limited investigation [16,17,19,20] is available in the domain of mortars where marble powder has been evaluated as a substitution of river sand. Hence present study was taken up to evaluate the performance of marble granules as fine aggregate in mortars. Marble powder acquired here consisted of excess of fines. To prevent any further spending of energy on removing these fines, this waste was used as such to replace river sand in variations of 25%, 50%, 75% and 100% in a cement mortar mix of proportion 1:6 by volume. This would also enabled us to judge whether such a gradation can be used in mortar mixes or not. The flow value of all mortars was kept constant and compressive strength with other properties like drying shrinkage, water absorption by immersion and capillary rise, porosity, ultrasonic pulse velocities, resistance to sulphates and acids were evaluated.

2. Materials and methodology

Portland Pozzolana Cement complying with BIS 1489 (Part 1): 1991 [35] was used. The specific gravity was found to be 2.9 with loose bulk density 1100 kg/m^3. Fine aggregate in the form of river sand was procured. Marble waste was sourced from a nearby industrial area. This waste was crushed in the form of fine aggregate. A comparative analysis of particle size distribution of sand and marble powder is presented in Fig. 1. The physical properties like specific gravity, bulk density and water absorption [36] and fineness modulus [37] are presented in Table 1. The chemical composition of river sand and marble powder analysed using and energy dispersive spectrometer and XRF technique is listed in Table 2. The X-ray diffraction patterns are shown in Figs. 2and 3 for river sand and marble powder, respectively. The shape and texture are illustrated through scanning electron micrographs as shown in Fig. 4.

A mortar mix proportion of 1:6 (cement:sand) by volume was chosen. Sand and marble powder were air dried before utilizing them to make the mortar mixes. Sand was replaced by marble powder from 0% to 100%. Water content of mortars was adjusted to attain a flow value of 105% to 115%. Compressive strength, water absorption by immersion, ultrasonic pulse velocity, water absorption by capillarity, drying shrinkage and resistance to sulphate and acidic solutions of the mortar mixes were evaluated. Compressive strength was evaluated after seven and twenty-eight days of water curing. Specimens for evaluating drying shrinkage were moist cured for 72 h after which initial reading was noted. Drying shrinkage was monitored every seventh day from the day of casting for four weeks. Specimens for the remaining tests were water cured for twenty-eight days. Chemical resistance of mortar mixes were quantified in terms of change in weight and compressive strength. Sodium sulphate and sulphuric acid solutions of 5% concentration were used to simulate sulphate and acid attack respectively. Weight and compressive strength were measured at seven and twenty-eight days of exposure. Details regarding the specimen size and numbers with the applicable standards for these tests are listed in Table 3.

3. Results and discussions

3.1. Workability

Workability of the mortar mixes was fixed to attain a flow value of 105% to 115% as per IS 2250 [38]. So water content was adjusted such that the required workability was obtained. This change in water requirement of mortars was quantified in terms of water cement ratio. The variation of water cement ratio to attain the required work ability is plotted in Fig. 5. It can be seen that with incorporation of marble powder into the mortar mixes, water requirement reduced. It reached a minimum value for the 50% substituted mix which was 6% less than that of control mixes. This fall in water requirement of marble incorporated mortar mixes may be due to the thixotropic property of marble powder. This made the mortar flow with application of lesser energy when compared to control mix [19]. Further addition of marble led to the increase

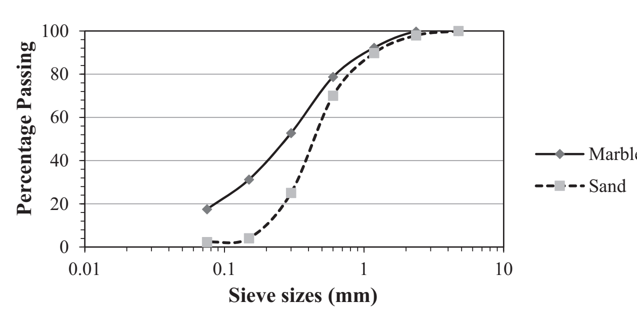

Fig. 1. Particle size distribution of river sand and marble powder.