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Re-use of waste marble dust in the production of cement and concrete

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HIGHLIGHTS

- This paper presents a study about the utilization of waste marble dust in producing cement and concrete.
- Marble dust was added by 0.0%, 5.0%, 7.5%, 10.0% and 15.0% replacement ratios by weight of cement and sand.
- TGA, XRD and SEM analysis were applied for further investigation.
- Both cement mortar and concrete modified with marble dust are enhanced due to the use of marble dust.
- Concrete made of marble dust as sand replacement showed better performance compared to cement replacement.

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ABSTRACT

The main objective of this research is to investigate the possibility of utilizing waste marble dust (MD) in cement and concrete production. The research work was divided into two sections. The first section deals with the properties of cement modified with marble dust (marble dust blended cement), whereas the second section discusses the properties of concrete contained marble dust as a cement replacement and as a sand replacement (cement addition). The replacement ratios which have been studied were 0.0%, 5.0%, 7.5%, 10.0% and 15% by weight. Water to powder ratio (w/p) or water to cement ratio (w/c) were 0.50 and 0.40 in case of cement replacement and in case of sand replacement respectively. Physical, mechanical and chemical properties of cement and concrete modified with marble dust were investigated. In addition, TGA, XRD and SEM analysis were performed. Test results of cement paste and cement mortar indicate that the marble dust blended cement remains within the acceptable ranges of the Egyptian standards. Also, generally, the use of marble dust in concrete production as cement replacement or as sand replacement (cement addition) gradually enhances both of the mechanical and physical properties of concrete especially with lower w/c ratio. Marble dust showed a filler effect in concrete and had no noticeable role in the hydration process. Yet, concrete made with marble dust as sand replacement achieved better performance compared to concrete made with marble dust as cement replacement.

1. Introduction

Nature has gifted Egypt with large deposits of high quality marble and granite. Egypt produces over 25 different types of marble and ranks as the ninth among the world's leading producers of marble varieties. During the nineteenth and most of the twentieth century, marble and granite were used on a limited scale in Egypt for luxurious buildings such as palaces and museums, and were mainly imported [1].

For now Egypt's rank is the fifth country in the world in marble industry, as it comes after Italy, Spain, turkey and Iran. The marble industry in Egypt is to be divided into marble quarrying and marble processing. Marble quarries are found in different locations all over the country, along the coast of the Red Sea (Zafarana), Sinai, Menia, Assiut, Aswan and the Eastern Desert. The area of "Shaq El Thu'ban" in Katameyya has become a conglomeration of factories working in the marble and granite industry. It has the highest concentration of marble and granite factories in Egypt reaching around 400 factories, constituting 60%–70% of marble factories in the whole country [1].

In general, the industry of dimensional stone marble has contributed to the development of major environmental problems due to waste generation at different stages of mining and processing operations. Waste generation continues from mining process to finished product and is about 50% of mineral mined; the dried slurry product is quiet fine. 90% of the particles are below 200 m [2]. Depending on the kind of process involved, the sludge generated is equal to between 20% and 30% of the weight of the stone worked [3].

Leaving the waste materials to the environment directly can cause environmental problems. Hence, many countries have been working on how to reuse the waste material so that they reduced

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Fig. 1. Wastes of marble in solid and slurry form resulted from marble factories in Egypt.

hazards to the environment [4]. Among these waste materials, waste marble dust, where it is a byproduct of marble processing factories. Fig. 1 shows the quantities of wastes resulted by a marble factory in Egypt. Actual figures about the quantity of waste produced in Egypt from the marble and granite industry are inaccessible since it is not calculated or monitored by the government or any other party [5]. Some references estimate that 20–25% of the marble/granite produced results in powder in the form of slurry, as for each marble or granite slab of 20 mm produced; 5 mm is crushed into powder during the cutting process [6,7]. This powder flows along with the water forming marble slurry. Based on the lowest estimates of waste percentage, it can be estimated that Shaq Al-Thu'ban industrial cluster produces around 500,000 tons of waste per year [5].

Many researchers recently were interested in studying the possibility of re-use of such wastes in useful industries especially with regard to the building and construction materials such as cement, concrete and brick blocks.

The technical importance of using wastes and by-products in concrete production is expressed by performance improvement of concrete. The economical benefit usually attributes to the reduction of the amount of expensive and or scarce ingredients with cheap materials. Environmentally, when industrial wastes are recycled, so that not only the CO_2 emissions are reduced but residual products from other industries are reused and therefore less material is dumped as landfill and more natural resources are saved [8]. For the cement industry produces large amounts of CO_2 because of clinker calcinations and so the use of alternative materials added after the clinker grinding process contributes to reducing the emission of CO_2.

The effect of marble dust as cement placement and as sand replacement was investigated, most of the researches showed positive results and benefits. Waste marble dust can be used as an additive material in production of cement and cost of cement production can be reduced by this application [2]. In terms of mechanical performance of marble dust modified mortar Valeria et al. [9] concluded that 10.0% substitution of sand by waste marble powder, in the presence of superplasticizing admixtures provided maximum compressive strength comparable to that of the reference mixture after 28 days of curing.

Shirule et al. [10] investigation showed that the compressive strength of cubes and splitting tensile strength are increased with the addition of waste marble powder up to 10% replace by weight of cement. Binici, Kaplan and Yilmaz [4] reported that the compressive strength of concrete had a significant increase with increasing the percentage of marble dust addition where the use of marble dust as 15% sand replacement by weight (an additive) provided the maximum compressive strength up to 360 days of curing. Ergün [11] reported that the 5.0% and 7.5% replacement of waste marble powder with cement leads to an increase in the compressive strength.

For porosity, pulse velocity (UPV), water penetration and sulphate resistance; Demirel [12] reported that the porosity of concrete decreased and the UPV values increased with the increasing percentage of marble dust up to 100% as sand replacement. Demirel pointed that the filler effect of marble dust on cement hydration was associated with the reduction of porosity. Binici et al. [4] found that, concrete specimens with replacement level of 15% marble dust instead of sand were considerably more resistant to water ingress than those of other specimens and they had the highest sulphate resistance and less reduction in compressive strength after 12 months of exposure.

2. Research significance

The main purpose of this research is to investigate the possibility of utilizing waste marble dust generated during cutting and polishing process in marble factories in order to reuse it in cement and concrete production. Physical and mechanical properties of paste, hardened mortar and hardened concrete made of marble dust modified cement were investigated. The effect of marble dust addition on the internal microstructure and hydration products of paste samples were also investigated. Testing specimens were prepared by blending marble dust with cement and sand in 0.0%, 5.0%, 7.5%, 10.0% and 15.0% replacement ratios by weight.

3. Experimental program

3.1. Materials

In this study, ordinary Portland cement CEM I 42.5 N was used which complies with the ASTM C150. Natural siliceous sand with fineness modulus of 2.35 and crushed pink lime stone with nominal maximum size of 19.0 mm was used. The grading of both fine and coarse aggregate satisfies the ASTM C33-03 grading limits as presented in Fig. 2. Marble dust used was obtained in wet form as slurry; from marble factories as a by-product resulted from marble cutting and shaping process; therefore it was dried in an oven in the laboratory then manually sieved through sieve No. 200. Deformed high tensile steel bars of 16 mm diameter were used. High range water reducing admixture which complies with ASTM C494 Type F was added in different ratios by weight of cement to obtain a required average slump within range of 100 ± 200 mm. Potable water was used for mixing and curing processes throughout the research.

Chemical, physical and mechanical properties of cement and marble dust are given in Table 1.

3.2. Test parameters and mixture proportions

The present study is divided into two sections. Section one includes the properties of cement blended with marble dust. Marble dust was added to cement in 0.0%, 7.5%, 10.0% and 15% replacement ratios. Section two discusses the effect of using marble dust in concrete production. Marble dust was used as a substitutional material for cement and sand. For concrete mixtures; marble dust was added in 0.0%, 5.0%, 7.5%, 10.0% and 15.0% as cement replacement by weight with 0.50 and 0.40 w/p ratios. Same manner was followed as sand replacement by weight with 0.50 and 0.40 w/c ratios. For control mixtures, cement content was taken as 400 kg/m^3, for marble dust modified concrete, cement content varied according to replacement ratios of marble dust.

To consider the effect of marble dust on concrete; a total of 18 concrete mixtures divided into four groups were prepared. Mixtures were designed according to the absolute volume method. Materials' proportions of each mix are given in Table 2. Mixing was carried out using a laboratory rotary mixer having capacity of 125 L in the materials testing laboratory in Faculty of Engineering, Alexandria