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Performance evaluation of cement mortars containing marble dust and glass fiber exposed to high temperature by using Taguchi method

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HIGHLIGHTS

- We investigated the performance of the mortar with marble dust and glass fiber exposed to high temperature.
- This article applied the Taguchi method and ANOVA analysis.
- The compressive strength increased with increase of marble dust percentage.
- The most important parameter on the responses was found as temperature degree.

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ABSTRACT

This paper investigated the effects of marble dust and glass fiber on mechanical and physical properties of cement mortars exposed to high temperature as experimentally and statistically. For this purpose, the mixes containing marble dust (0%, 20%, 40% and 50% by volume) and glass fiber (0 kg/m^3, 0.25 kg/m^3, 0.50 kg/m^3, 0.75 kg/m^3) were prepared. The compressive strength and porosity value of the cement mortars were determined after being exposed to high temperatures (400, 600 and 800 °C). In order to reduce the numbers of experiments, an L_{16} (4^3) Taguchi orthogonal array was adopted to the study. Percentage of marble dust, amount of glass fiber and degree of temperature were changed to explore their effects on the compressive strength and porosity values of specimens. Statistically effects of the factors were also determined by using analysis of variance (ANOVA) method. Finally, experimental findings were compared with statistical results and a good agreement between them was achieved.

1. Introduction

Marble has been commonly used as a building material since ancient times. The industry's disposal of the marble powder material, consisting of very fine powders, is one of the environmental problems worldwide today [1]. Marble blocks are cut into smaller blocks in order to give the desired smooth shape. During the cutting process about 25% marble mass is lost in the form of dust. In Turkey marble dust is settled by sedimentation and then dumped away which results in environmental pollution and also causes forming dust in the summer and threatening both agriculture and public health. Therefore, utilization of the marble dust in various sectors that especially the construction, agriculture, glass and paper industries will help to protect the environment [2].

Many researchers recently were interested in studying the possibility of re-use of waste marble dust in useful industries especially with regard to the building and construction materials such as cement, concrete and brick blocks [3].

The technical importance of using waste marble dust in concrete production is expressed by performance improvement of concrete. The economic benefit generally attributes to the reduction of the amount of expensive and or scarce ingredients with cheap materials. Environmentally, when waste marble dusts are recycled, less material is dumped as landfill and more natural resources are saved [4].

The effect of marble dust as sand replacement and cement placement was investigated; many researches indicated 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 way [5]. Corinaldesi et al. [6] investigated mechanical performance of marble dust modified mortar. They showed that 10% substitution of sand by waste marble dust, in the presence of superplasticizing admixtures provided maximum

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compressive strength according to that of the reference mixture after 28 days of curing. Binici et al. [7] showed that the compressive strength of concrete increased with increasing the percentage of marble dust addition. Additionally, they reported that use of marble dust as 15% sand replacement by weight provided the maximum compressive strength up to 360 days of curing. Furthermore, they demonstrated that concrete specimens produced with replacement level of 15% marble dust instead of sand were considerably more resistant to water ingress than those of other concrete specimens and these specimens had the highest sulfate resistance and less reduction in compressive strength after 12 months of exposure. Ergün [8] showed that 5.0% and 7.5% replacement of waste marble dust with cement leads to an increase in the compressive strength of concrete. Demirel [9] showed that the porosity value of concrete decreased and the ultrasonic pulse velocity values increased with the increasing the percentage of marble dust up to 100% as sand replacement. Additionally, Demirel indicated that the filler effect of the marble dust leads to reduction of porosity of concrete.

Generally, in literature waste marble dust has been replaced with either fine aggregate (0–4 mm) or passing 1 mm sieve. But, not a single experimental study on the performance of the cement mortar prepared by replacing very fine sand (passing through 0.25 mm sieve) with waste marble dust. Studies concerning the utilization of marble dust in cement mortar are necessary to fully evaluate the potential using of this waste material.

The main concern with high strength concrete is the increasing brittleness with the increasing strength. To overcome this problem, fiber reinforcement should be used for improving ductility of high strength concrete [10–12]. Short fibers have been known and used for centuries in reinforced brittle materials as cement or masonry bricks. Currently, there are numerous fiber types available for commercial use, the basic types being glass, steel, synthetic materials (polypropylene, carbon, nylon, etc.) and some natural fibers [13].

The main purpose of this study is to investigate the effect of marble dust and glass fiber on the compressive strength and porosity value of the cement mortars exposed to high temperature. The effect of experimental parameters on compressive strength and porosity value was evaluated statistically and the level of significance of the parameters affecting compressive strength and porosity value of the cement mortars was determined by using analysis of variance (ANOVA) method.

2. Experimental study

2.1. Materials

Commercial grade ASTM Type I Portland cement, which is produced in Turkey as CEM I Portland cement, was used in the preparation of all cement mortar specimens used in this study.

The marble sludge consisting of Elazig Cherry and Hazar Beige marble dusts was obtained in wet form as an industrial by-product directly from the deposits of marble factories, which forms during the sawing, shaping and polishing processes of the marbles in the Elazig province of Turkey. The marble sludge was dried before the preparation of the cement mortar specimens. The dried material was passed through 0.25 mm sieve and finally the marble dust was obtained to be used in the cement mortar specimens as very fine sand. The chemical properties of the marble dusts and cement used in the experiments are given in Table 1.

High quality river sand was used as aggregate which is widely employed in cement mortars. Maximum grain size of aggregate was 4 mm. The density of the river sand was 2690 kg/m^3. Various proportions (0%, 20%, 40% and 50% by volume) of the fine sand (passing through 0.25 mm sieve) were replaced with waste marble dust. The grain size distributions of very fine sand and waste marble dust are shown in Fig. 1.

The glass fibers were circular straight fibers obtained from Camelsan. The properties of the glass fiber used in this study are given in Table 2.

In the study, modified polycarboxilate based superplasticizer, obtained from SIKA, was used as 1% of cement weight. Regular tap water was used as the mixing water during the preparation of the cement mortar specimens.

2.2. Casting and testing

Sixteen different cement mortar mixes were prepared to be used in the tests for the purpose of evaluating the compressive strength and porosity value of the specimens containing various amounts of glass fiber and marble dust. The mixture designs of the all cement mortar groups are presented in Table 3. A superplasticizer (SP) was used to improve the workability of the mixes.

Mixtures prepared according to Table 3 were cast into steel cube molds ($50 \times 50 \times 50$ mm) to determine the effect of different temperature degrees on compressive strength and porosity value of the mortar specimens. After casting, these specimens were kept in the molds for 24 h at a room temperature of 20 ± 2 °C. After demolding, these specimens were cured in lime saturated water for 28 days.

The specimens were dried in an oven at about 50 °C until a constant mass was achieved at the end of the 28 days. Then, five specimens for each temperature were heated to 400, 600 and 800 °C using a Protherm HLF 150 electrical furnace. The heating rate was set at 2.5 °C/min based on experience from previous researches [14–17]. The mortar specimens were held at these temperatures for one hour to achieve a thermal steady state. Subsequently, the specimens were cooled down inside the furnace and then tests were conducted one day later to determine the compressive strength and porosity values.

The microscopic analyses of the specimens were performed at the Electron Microscopy Laboratory of Firat University using a Jeol JSM7001F scanning electron microscope.

2.3. Design of experiments

Taguchi's method of experimental design provides a simple, efficient, and systematic approach for the optimization of experimental designs for performance quality and cost [18]. To evaluate the each independent factor or their interaction effects on the process characteristics, Taguchi uses standard orthogonal arrays. A loss function is then defined to calculate the deviations between the experimental value and the desired value. This loss function is further transferred into a signal-to-noise (S/N) ratio, η [19]. Usually, there are three S/N ratios available, depending on the type of characteristic; the lower-the better (LB), the higher-the better (HB), and the nominal-the better (NB). The S/N ratios for each type of characteristic can be calculated as follows:

1. Lower is better, choose when goal is to minimize the response. The S/N can be calculated as given in Eq. (1) for smaller the better

$$S/N = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right) \quad (1)$$

2. Higher is better: choose when goal is to maximize the response. The S/N is calculated as given in Eq. (2) for larger the better

$$S/N = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{Y_i^2}\right) \quad (2)$$

Table 1
Chemical property of the cement and marble dusts.

Oxide compounds (mass%)	CEM I 42.5 N	Marble dust (Elazig Cherry)	Marble dust (Hazar Beige)
SiO_2	21.12	28.35	0.18
Al_2O_3	5.62	0.42	0.03
Fe_2O_3	3.24	9.70	0.12
CaO	62.94	40.45	53.24
MgO	2.73	16.25	0.10
Density (g/cm^3)	3.10	2.80	2.72