Construction and Building Materials 96 (2015) 615–621

Contents lists available at ScienceDirect

Construction and Building Materials

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

Mechanical properties and microstructural analysis of cement mortar incorporating marble powder as partial replacement of cement

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HIGHLIGHTS

- Utilization of marble powder as replacement of cement is main objective of the study.
- Use of 10% marble powder improves workability, without adversely affecting strength.
- Marble powder has no effect on expansion and setting characteristics.
- Large levels of cement replacement leads to delayed hydration of the mix.

ARTICLE INFO

Article history:
Received 7 May 2015
Received in revised form 26 July 2015
Accepted 9 August 2015

Keywords:
Marble–cement paste
Cement paste
Microstructure
Flowability
Compressive strength
Setting behavior

ABSTRACT

Waste marble powder is an inert material obtained from the sawing and procession operations of marble stone. The main objective of the research work is to investigate the possibility of utilizing marble powder as partial replacement of cement. The setting behavior, soundness and flowability characteristics of cement pastes made by partially replacing cement with marble powder are studied. Along with this, strength development and micro-structural properties of cement modified with marble powder are investigated. XRD analysis is also performed on the mixes. The results of the study indicate that up to 10% of marble powder can be used as replacement of cement with no compromise on the technical characteristics of the mix. However, large levels of replacement leads to delayed hydration of the mix and porous microstructure. Results indicate that difference in chemical composition between marble dust and cement have not adversely affected the expansion and setting characteristics of the resultant mix.

1. Introduction

India is recognized as a nation well-endowed in natural mineral resources. The country produces about 87 minerals, which include metallic, non-metallic, atomic minerals and minerals used in construction industry. Among minerals used as building materials, India has large deposits of high quality marble, with its various varieties available in different parts of the country. It is a metamorphic rock that results from the transformation of pure limestone. Chemically, it consists predominantly of calcite, dolomite or serpentine minerals [1,2].

Along with the contribution of marble industry in providing building materials, it has led to the development of major environmental problem due to large amount of waste generated during sawing and processing operations of marble stone [3]. The waste sludge generated depends upon the processing and quarrying methods adopted. On an average, 20–25% waste sludge is generated from the processing operations, depending upon the kind of processing operations [3–5] and the waste generation can be as high as 60% during quarrying of marble blocks [6]. It is reported that around 3 million tons of waste marble powder is produced per year in India [7]. The powder produced is extremely fine grained [8] and if it is dumped as landfill, it reduces porosity of the soil along with reducing its fertility by increasing its alkalinity. The fine marble dust, if left in the environment, gets suspended in air and cause health related hazards.

Marble powder is an inert material [9] and has been attempted to be used as mineral addition in the production of concrete. It is used either as replacement of cement [3,4,10,11] or as aggregates [11–14]. It is also successfully used for production of self-compacting concrete [5,9,15].

Ergün [10] used marble powder along with diatomite as partial replacement of cement. Strength tests on concrete specimens concluded that either 5% marble powder separately or 5% marble powder along with 10% diatomite can be utilized to improve

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http://dx.doi.org/10.1016/j.conbuildmat.2015.08.071
0950-0618/

mechanical properties of concrete [10]. Aliabdo et al. [4] studied the effect of use of marble powder as replacement of either cement or sand at replacement ratios of 5%, 7.5%, 10% and 15% by weight. The investigation concluded that marble powder improves properties of concrete when used either as replacement of cement or sand, mainly due to filler effect [4]. Corinaldesi et al. [11] evaluated various mixtures based upon cement or sand substitution and stated that 10% substitution of sand by marble powder provides maximum compressive strength at about same workability [11]. Hebhoub et al. [12] investigated effect of addition of marble aggregates either as substitution of gravel or sand and confirmed use of waste marble aggregates up to 75% as an alternative to natural aggregates [12]. Similar results were obtained by Gameiro et al. [13]. Aruntas et al. [3] studied the usability of waste marble powder as an additive material in blended cement clinker by intergrinding marble powder with cement clinker at different blend ratios of 2.5%, 5%, 7.5% and 10%. The studies carried out on mortar prisms concluded that 10% marble powder can be used as an additive in cement production [3].

Gesoglu et al. [5] studied the effect of addition of marble powder as replacement of concrete binder in self-compacting concrete at substitution ratios of 5%, 10% and 20%. The authors concluded that high replacement ratios adversely affect the fresh properties of self-compacting concrete. Belaidi et al. [9] concluded that the addition of marble powder resulted in improvement of workability of self-compacting concrete, although compressive strength of the mixes with marble powder decreased.

The main purpose of this research is to investigate the use of marble powder as replacement of cement, concentrating this investigation on cement paste.

2. Experimental program

2.1. Materials

Ordinary Portland Cement (OPC) 43 grade confirming to BIS: 8112-2013 [16] was used in this investigation. Waste marble powder was obtained from the marble processing industry in northern region of India. The chemical composition and physical properties of both OPC and marble powder are presented in Tables 1 and 2, respectively. The mineralogical composition of marble powder was determined by the XRD technique and expert-pro software was used to identify the phases present in marble stone powder. As shown in Fig. 1, XRD spectrum indicates that dolomite ($MgCO_3 \cdot CaCO_3$) is the main crystalline mineral with small amounts of quartz (SiO_2) present in marble stone powder. Standard sand conforming to BIS: 650-1991 [17] was used in all mortar mixtures. The standard sand was of quartz and is whitish in color. The standard sand of three different sizes i.e. passing through 2 mm sieve and retained on 1 mm sieve; passing through 1 mm sieve and retained on 500 μm sieve; passing through 500 μm sieve and retained on 90 μm sieve in equal proportion was used in manufacturing of all mortar mixtures. Regular tap water was used for performing all experiments.

2.2. Mix proportions

The study is conducted on pure cement pastes, made with and without marble powder used as partial replacement of cement. Control cement paste (without marble powder) was designated as M0.

Table 1
Chemical composition of cement and marble powder.

Chemical composition (%)	Cement	Marble powder
Calcium oxide (CaO)	65.10	40.73
Silicon dioxide (SiO_2)	22.30	6.01
Aluminum oxide (Al_2O_3)	5.93	0.6
Iron oxide (Fe_2O_3)	2.80	0.8
Sulfur trioxide (SO_3)	1.30	0.09
Magnesium oxide (MgO)	0.80	15.21
Potassium oxide (K_2O)	0.40	0.05
Sodium oxide (Na_2O)	0.80	0.06

Table 2
Physical properties of cement and marble powder.

Property	Cement	Marble powder
Fineness (m^2/kg)	307	329
Specific gravity	3.13	2.6
Loss on ignition (%)	2	37.87

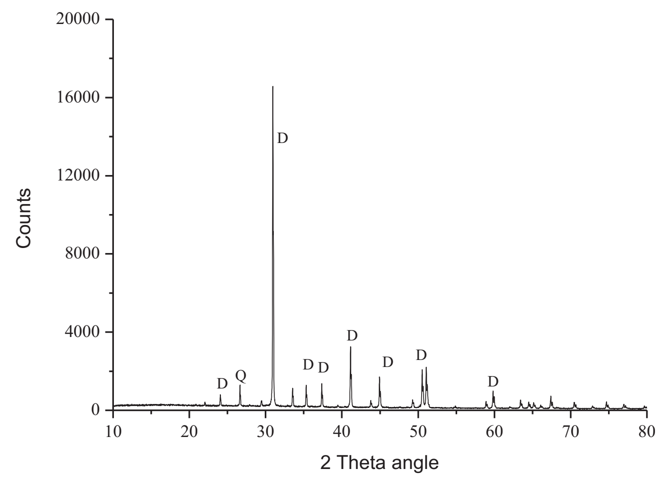

Fig. 1. X-ray diffraction spectrum of waste marble powder (Q = quartz; D = dolomite).

The replacement levels of cement by marble powder were kept at 10%, 20%, 30%, 40% and 50% and the corresponding binder pastes were designated as M1, M2, M3, M4 and M5, respectively. The test matrix for cement pastes is illustrated in Table 3.

Along with cement pastes, cement mortar mixtures were also prepared to study compressive strength of the resultant mix. The replacement levels of cement by marble powder were kept same as were fixed for paste mixes. Standard sand was used for preparation of cubes and the binder/sand ratio was kept at 1:3, by weight. Water in mortar mixtures was decided based on the guidelines given in BIS 4031-Part 6-1988 [18] and was calculated as per equation given below:

$$\text{Water} = (P/4 + 3.0) \text{ percent of combined mass of binder and sand},$$

where P = the percentage of water required to produce a paste of standard consistency.

2.3. Test procedures

2.3.1. Consistency, soundness and setting times

The standard consistency, i.e. water required to produce standard cement paste was measured as per BIS: 4031-1988 Part 4 [19]. The setting and expansion behavior of the binder paste made with or without marble powder were evaluated by measuring initial setting time (IST) and final setting time (FST) as per BIS: 4031-1988 Part 5 [20] and by conducting soundness tests as per BIS: 4031-1988 Part 3 [21], respectively. Three samples were tested to evaluate standard consistency, soundness and setting times of binder paste mixtures.

2.3.2. Workability

Workability measurements of control cement paste and binder paste mixtures incorporating marble powder were made over a range of w/b ratios, i.e. 0.48, 0.50 and 0.52. The workability of the cement/binder paste mixtures was evaluated through marsh cone test as per ASTM C 939-10 [22]. The procedure for mixing the cement paste and for performing the test is as follows:

(i) For mixing the cement paste sample, cement and marble powder was dry mixed in the standard mortar mixer for one minute with the mixer operating at slow speed of 140 ± 5 rpm. Two-third of mixing water was then added during the next one minute. Then, the remaining water was added and was mixed for one-and-a-half minutes at slow speed. The mixer was then stopped and the paste was scrapped from the sides of the mixer and hand mixed. Further, mixing was continued for two minutes at high speed of 285 ± 10 rpm.

(ii) The prepared mix is ready to be filled in the marsh cone that is attached to the stand. A graduated cylinder is placed underneath the orifice of the marsh cone.