Journal of Cleaner Production xxx (2015) 1–11

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Effects of marble sludge incorporation on the properties of cement composites and concrete paving blocks

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ARTICLE INFO

Article history:
Received 12 March 2015
Received in revised form
2 July 2015
Accepted 4 July 2015
Available online xxx

Keywords:
Marble sludge
Cement composites
Paving blocks
Concrete bricks
Physical properties
Mechanical properties

ABSTRACT

The continuous development of the ornamental stone industry in Egypt due to the increasingly great demand of the Egyptian stones, whether on the local or the international scale, led to a continuous and increasing accumulation of huge quantities of marble wastes in different forms which may reach about 55–85 % of the total quarrying and processing stages. The main objective of this study is to demonstrate the possibility of using marble wastes (marble sludge) as a cement substitute in cement and concrete production. The current study presents the characterization of marble sludge and various practical formulations of cement composites and concrete mixtures. With regard to cement composites pastes, the marble sludge was substituted for cement binder up to 40% at certain proportions of 0%, 10%, 20%, 30% and 40%. The mineralogical, physical and mechanical properties of both the fresh and hardened cement composites pastes and hardened concrete mixtures including marble sludge were determined at 3, 7 and 28 d, curing times for cement composites and 28 d for concrete products according to standard test methods (ASTM and BS EN) and the results were compared with the specification requirements of these standards. The results showed that using up to 20% of marble sludge, improved the physical and mechanical properties of concrete products.

1. Introduction

The ornamental stone industry is now considered as one of the most important industrial activities all over the world's economy and is expected to increase annually parallel to the continuous progress in the construction building industry owing to the increasing population.

In Egypt, the ornamental stones are considered as an important source of the mineral resources. This industry is growing progressively due to the increasingly greater demand on the Egyptian stones, whether on the local or the international scale which led to a progressive production rates more than ever before.

There are around 500 big enterprises and at least 3000 workshops working in the ornamental stone industry in Egypt, about 70% of the industry is located in Shaq Al-Thoaban area (South East Cairo, Egypt). Concerning quarry production, Egypt occupy the fourth rank, with a share of 4.3% of the total world market. The total export can be estimated as 1.5 million t/y; 0.9 as raw materials and 0.6 as processed products, which means that Egypt can be considered the seventh exporter in the world, in terms of volume, after China, India, Italy, Spain, Turkey and Brazil (Hamza et al., 2011).

Several references estimated the amount of ornamental stone wastes generating through sawing, polishing and cutting operations. In India about 6 million t of wastes from marble and granite industries are being released through cutting, polishing, processing and grinding (Pappu et al., 2007). The amount of wastes left after mining process and manufacturing of ornamental stone in Brazilian decorative stone industry can reach up to 40% of the total extracted volume, while the amount of wastes from cutting and sawing process can easily reach 20–25 % of the total volume of the block (Saboya et al., 2007). In Turkey about 20–30 % of marble blocks become dust during the cutting process. According to El-Haggar (2007) the total wastes generated from the entire mining process, through the manufacturing process and ending at the finished product is in the range of 50–60 % of the rock.

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http://dx.doi.org/10.1016/j.jclepro.2015.07.023

Please cite this article in press as: Mashaly, A.O., et al., Effects of marble sludge incorporation on the properties of cement composites and concrete paving blocks, Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.07.023

In Egypt, based on the lowest estimates of waste percentages, it can be estimated that Shaq Al-Thoaban industrial area produces around 800, 000 tons of wastes per year (Hamza et al., 2011).

The ornamental stone industry is one of the most environmentally unfriendly industries that producing a huge amount of sludge wastes. Such waste sludge is too huge for stocking. The marble waste are mainly generated in the form of an aqueous sludge. By dumping in open areas, environmental problem can be caused day by day, especially after being dried where it becomes a very fine material able to be dispersed in the air as suspended particles causing air pollution in the industrial areas and the adjacent urban areas and can be easily inhaled by human and animals as well. These air - suspended particles have been blamed as the reason for severe lung diseases among local people (Saboya et al., 2007). The disposal of marble dust in the riverbed reduces the porosity and permeability of the topsoil. Further, the fertility of soil becomes poor due to increase in alkalinity of fine particles of waste (Pappu et al., 2007). The fine powder wastes generate fog that can be easily inhaled causing serious problems of public health (Rego et al., 2001). Fine air-suspended dust of this waste can even cause respiratory, visual and skin disorder (Pareek, 2007).

Many authors have investigated the incorporation of marble sludge wastes in several industrial applications such as cement, concrete mortar, concrete bricks and paving blocks which showed positive results and benefits.

Owing to the fact that the building and construction industry utilizes huge amounts of raw materials, there is an interest in utilizing marble-processing wastes as a low cost alternative raw material. Topçu et al. (2009) found that using up to 200 kg/m^3 of marble dust as a binder replacement achieves the best performance of fresh and hardened properties of self-compact concrete. Aruntaş et al. (2010) found that the composite cement product containing up to 10% of marble dust showed a higher compressive and tensile strength than those of ordinary Portland cements. Corinaldesi et al. (2010) noticed that replacing up to 10% of sand with marble powder in presence of superplastesizers improved the compressive strength of concrete produced at about the same workability level. Ergun (2011) found that using up to 5% of waste marble powder as cement replacement increases the compressive strength of concrete comparable to that of the reference mixture. Aliabdo et al. (2014) found that the concrete mixture containing up to 15% of marble dust as a sand replacement achieved better performance more than as cement replacement. Gencel et al. (2012) investigated the feasibility and effects of using waste marble as aggregate replacement on physical and mechanical properties of concrete paving blocks using different types of cement. They reported that mechanical strength decreases with an increase in marble content while freeze-thaw durability and abrasive wear resistance increase. Rana et al. (2015) have shown that replacing up to 10% of cement with marble slurry achieved the best performance of concrete properties. Rodrigues et al. (2015) found that replacing of cement up to 10% with marble sludge in presence of superplastsizers improved the mechanical performance of concrete relative to conventional concrete.

The main purpose of this research is to characterize the marble sludge wastes generated during the ornamental stones processing operations at Shaq El-Thoaban plants and investigate their effect as cement replacement on the physical and mechanical properties of fresh and hardened cement composites and some concrete products. Testing specimens were prepared by substituting of cement by marble sludge with 0%, 10%, 20%, 30% and 40% by weight. The present study revealed the utilization of marble sludge as cement replacement in fabrication of concrete paving blocks through the characterization of the input materials and investigated the physico-mechanical properties of the products, by conducting the specific tests required to characterize the performance of the products based on the international standard specifications. In addition, the present work proposed the optimum concrete mix ratio between (cement, marble sludge, aggregates and water) used in the production of paving blocks.

2. Materials and methods

2.1. Materials

2.1.1. Cement

The cement used was produced by National Cement Company designated as ordinary Portland cement CEM I 32.5N. The chemical, mineralogical analysis and physical properties of cement are presented in Table 1 and Fig. 1.

2.1.2. Aggregates

Two different types of natural aggregates were used; fine aggregate (sand) and coarse aggregate (dolomite). The physical properties and the gradation of coarse and fine aggregates are shown in Table 2 and Figs. 2 and 3.

2.1.3. Marble sludge

The marble sludge was obtained from marble processing plants at Shaq El-Thoaban area, located in the Southern Cairo region, Egypt. The chemical analysis and physical properties are shown in Table 1, while grain size and mineralogical analyses are shown in Figs. 4 and 5.

2.2. Methods

2.2.1. Characterization of the marble sludge

The chemical analysis of the marble sludge was performed using X - Ray Fluorescence technique (Axios, Sequential WD- XRF, PANalytical 2005).

The mineralogical studies of the marble sludge were performed using X - Ray Diffraction technique (using (Philips 1730 diffractometer with Ni filter, at a scan speed of 0.5 min−1. Cu Kα radiation).

The physical properties of the marble sludge include: specific surface area, was determined using the automated gas sorption method of N_2 adsorption (BET); model NOVA, Version 1.12 from the quantachrome, while the specific gravity was determined using automatic gas pycnometers; model Ultrapyc 1,200e V5.03 from the quantachrome, the particle size distribution of marble sludge was

Table 1
Chemical analysis (Wt %) and physical properties of cement and marble sludge.

Oxides, wt %	Cement	Marble sludge
CaO	66.55	55.32
MgO	2.23	0.11
Na_2O	0.85	0.07
Al_2O_3	3.92	0.10
SiO_2	15.03	0.15
P_2O_5	0.17	0.06
SO_3	3.40	0.13
Fe_2O_3	4.78	0.04
K_2O	0.15	0.01
TiO_2	0.46	–
SrO	0.61	0.05
AIR	–	1.66
LOI	1.6	43.40
Total	99.84	99.35
Specific gravity	3.12	2.67
Surface area, m^2/g	0.32	0.67

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