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Sustainable use of marble slurry in concrete

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ABSTRACT

The Portland cement manufacturing process is a major contributor to greenhouse gas emissions and depletion of natural resources. The partial substitution of cement by industrial waste such as fly ash, silica fume, slag, stone waste etc. not only contributes to sustainable development, but also enhances the durability of concrete. Among the different wastes investigated in the past, the effect of marble slurry on durability of concrete has not been studied. Cutting, grinding and polishing manoeuvres in marble processing plants generate a large amount of slurry, which adversely affects the environment and humans. The present study examines the feasibility of using marble slurry in concrete production, as partial replacement of Portland cement. Six concrete mixes, containing marble slurry (up to 25%) in place of Portland cement were prepared and evaluated for strength, permeability, porosity, morphology, resistance to chloride migration, carbonation and corrosion. Optimal replacement level of Portland cement by marble slurry was found at 10%.

1. Introduction

Concrete is the most commonly used man-made material on Earth (Gautam et al., 2014). The Indian construction industry currently consumes about 400 Mt concrete every year which is estimated to reach 1000 Mt in less than a decade (Pathak, 2009). The increase in concrete consumption will escalate the cement demand. The country's annual cement production is about 370 Mt, manufactured by about 139 major and 365 smaller plants. It is expected to increase up to 550 Mt by 2020 (India Brand Equity Foundation, 2014). The environmental problems linked with greenhouse gases along with the natural resources issue, will govern the sustainable development of cement and concrete industry in this century (Naik, 2008). In order to produce 1 t cement, about 1.5 t limestone is required and nearly 1 t CO_2 is emitted out (Woodson, 2012). India is having limited reserves of limestone and it is expected that these will last only for the next 15–20 y, if consumed at the same rate (Parliament of India, 2011). Thus, the Indian cement industry is striving for the usage of alternative materials for cement production. In the past many studies have been conducted by partially replacing cement with industrial wastes such as fly ash, silica fume, blast furnace slag, stone waste, pond ash etc. Use of waste materials in place of virgin materials results in considerable energy savings by reducing the number of engineering processes required for the manufacturing of the end product (Ismail and Ramli, 2013). The CO_2 emission related to cement production can also be sharply reduced by substituting it with 15–20% such additives (Yang et al., 2014).

Almost half of the marble produced in the world is quarried from four countries, namely Italy, China, India and Spain. India accounts for about 10% of marble produced globally. India is the third largest producer of marble in the world (Ministry of Industry, Energy and Mines, Republic of Tunisia, 2014) with Rajasthan contributing at 85% to this quantity (Department of Mines and Geology, Rajasthan, 2001). After mining, marble is cut into the desired shape. These cutting and sawing operations generate MS as by-product. On average, 20% of the total excavated marble ends up as MS (Pappu et al., 2007). According to a report issued in 2011 by the Department of Mines and Geology, Rajasthan, about 15.7 Mt marble was excavated; due to which 5–6 Mt of MS was generated in Rajasthan (Misra et al., 2010). Large area of land is occupied when this slurry is disposed of and let dry. This deposited waste affects the morphology, hydrology and fertility of soil in the nearby area by reducing its porosity and permeability (Fig. 1). Fine air-suspended dust of this waste can even cause respiratory, visual and skin disorder (Pareek, 2007).

Abbreviations: MS, marble slurry; SEM, scanning electron microscope.

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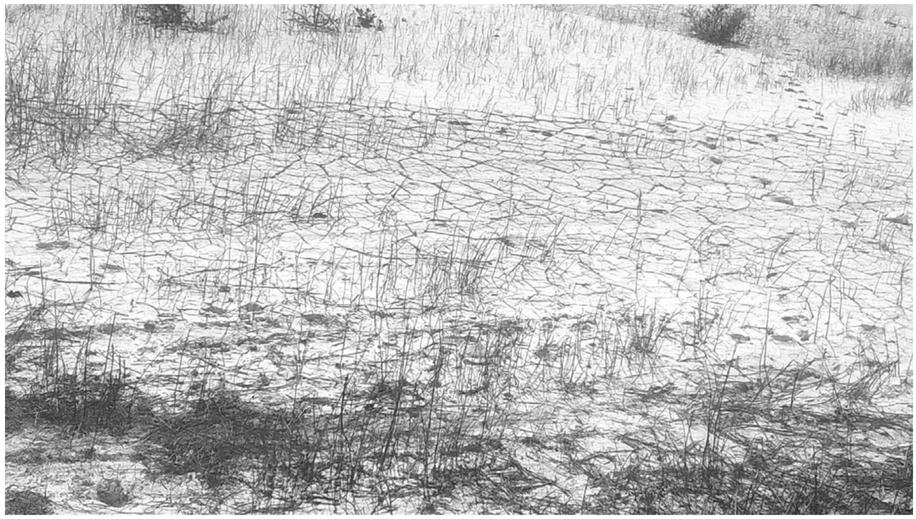

Fig. 1. Fields near to MS deposits.

Researchers have tried to utilize such MS in cement, mortar, tiles, normal as well as self-compacting concrete (SCC), agglomerate marble, pavement, embankment, glues and paints (Elham, 2011). Waste marble dust was interground with Portland cement clinker at varying ratios by Aruntaş et al. (2010). They found that mortar samples prepared with 10% MS possessed high strength in comparison to those prepared with Portland pozzolana cement. Ergün (2011) in his study observed that concrete specimens containing 10% diatomite or 5% waste marble powder or both by weight of cement had better strength than the control. In a recent study, Aliabdo et al. (2014) substituted cement as well as sand of concrete with marble dust and observed improvements in physical and mechanical properties of concrete. They concluded that marble dust as sand replacement has more significant effect on mechanical properties in comparison to cement replacement. Silva et al. (2014) used the waste generated by the marble quarrying industry as secondary fine aggregate in concrete mixes and observed poor mechanical properties. In another study, Corinaldesi et al. (2010) reported that substitution of 10% sand by marble powder provides maximum compressive strength at about the same workability and does not affect cement paste's setting time. Binici et al. (2007) observed that replacing 15% sand with MS led to improved workability, better resistance to sulphate attack, abrasion and lower permeability of concrete mixes. Hameed and Sekar (2009) replaced fine aggregates in concrete with a combination of MS and quarry rock dust. Their mixes exhibited better strength and sulphate resistance at lower permeability, in comparison to mixes containing natural sand. André et al. (2014) replaced natural aggregates with recycled marble aggregates and reported a slight loss in compressive strength. However, durability parameters such as carbonation and water absorption remained unaffected. Gencel et al. (2012) investigated the feasibility of using marble waste in the manufacturing of pavement blocks. They observed that as the marble content is increased, the strength reduces whereas resistance to freeze–thaw cycle and abrasive wear improves. Martínez-Barrera et al. (2013) examined the effect of gamma radiation dose and marble particle sizes on compressive properties of polymer concrete. They reported that the elastic modulus and compressive strain of polymer concrete can be modified by the combination of marble particle sizes and radiation dose.

Looking at the abundant availability of MS and problems associated with its ever increasing production rate, the authors decided to investigate its effect on strength and durability of concrete. The available literature suggests that durability parameters such as resistance to carbonation, chloride migration and corrosion of concrete containing MS as supplementary cementing material have not been studied.

2. Experimental programme

2.1. Materials

For the experimental work, Portland cement of 53 grade complying with IS 12269:2013 and locally procured coarse aggregates were used. Particle size distribution of coarse and fine aggregates is as shown in Fig. 2. Sand of Banas River was used as fine aggregate for concrete mixes. The MS was collected at a dumpsite near a marble processing plant in Kishangargh, Rajasthan. The different samples of MS displayed an in-situ water content of 1–2%. During procurement MS composed of powder and lumps. Before testing, MS was dried at room temperature for 48 h and the dried lumps were completely reduced to powder. Physical and chemical properties of the concrete components were examined before mixing (Tables 1–3). Concrete of 40 MPa target strength at 28 d, was designed considering IS 10262:2009.

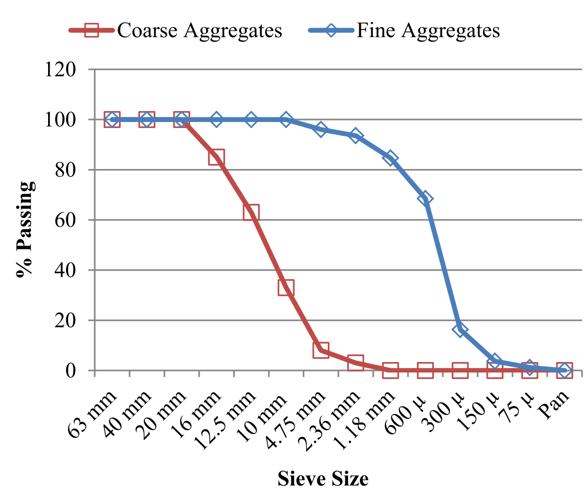

Fig. 2. Particle size distribution of coarse and fine aggregates.