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Mechanical, environmental and economic performance of structural concrete containing silica fume and marble industry waste powder

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HIGHLIGHTS

- Studying the effect of the MWP and SF on the mechanical properties of concrete.
- 16 concrete mixes containing MWP and SF as partial replacement of OPC are investigated.
- The mechanical, economic and environmental performances of concrete are evaluated.

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ABSTRACT

Marble waste powder (MWP) is an inert material that is obtained as an industrial by-product during sawing, shaping, and polishing of marble and causes serious environmental problems. This paper describes the procedures and results of a laboratory investigation of mechanical properties carried out on 16 concrete mixes containing MWP and silica fume (SF) as partial replacement of ordinary Portland cement (OPC). OPC was partially replaced at different ratios of SF (0%, 2.5%, 5%, 10%) and MWP (0%, 5%, 10%, 20%). In all concrete mixes, constant water/binder ratio of 0.45 and target initial slump of S2 class (50–90 mm) were used. Workability and bulk density tests were carried out on fresh concrete, while compressive strength, splitting tensile strength and modulus of elasticity tests were performed to evaluate some relevant properties of concrete in the hardened state. Eventually, all of the concrete mixes were evaluated in terms of economic, environmental and mechanical approaches.

It was found that the mechanical properties of concrete containing MWP tend to decline for replacement ratios over 10% but satisfactory results were obtained below that level. Regarding the use of SF, it was observed that it improves the mechanical performance of concrete with MWP by offsetting the decline of its properties relative to conventional concrete. The comparison of the concrete mixes in terms of different approaches has shown that the optimized mix occurs when MWP and SF are used simultaneously. The proper use of MWP as a replacement for cement would have environmental benefits and boost the viability of the marble stone industry.

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1. Introduction

The increase in concrete consumption will escalate cement demand. India'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 [1].

The cement industry is one of the industrial producers of carbon dioxide (CO_2), creating up to 5% of worldwide man-made emissions of this gas, of which 50% are from the chemical process and 40% from burning fuel. Cement manufacture contributes greenhouse gases both directly through the production of CO_2 when calcium carbonate is thermally decomposed, producing lime and CO_2 and also through the use of energy, particularly from the combustion of fossil fuels [2].

In developing countries, the methods used to recycle and re-use waste materials should be investigated in order to benefit from

Abbreviations: AP, acidification potential; ECM, evaluation of concrete mixes; Eco, economic; Env, environmental; FP, fossil fuel depletion potential; GWP, global warming potential; Mec, mechanical; MWP, marble waste powder; OPC, Ordinary Portland cement; RAC, recycled aggregate concrete; SF, silica fume.

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natural resources effectively. Reuse of construction and demolition waste is one of the most important goals of the construction industry. Conversion of raw materials, used or waste materials provides significant energy savings by reducing the number of industrial processes in the production of materials [3].

Marble waste powder (MWP) is a by-product that the marble industry generates in large amounts during sawing and shaping of the marble elements. MWP is mostly not being recycled nor used in the industry. The presence of MWP in the hardened cement paste has a filler effect and reduces the paste's porosity. Today silica fume (SF) is known as a by-product of silicon metal and ferrosilicon alloy industry instead of a waste product and its utilization in concrete technology has increased recently [4].

1.1. Research significance

According to the results of past investigations, the use of MWP as partial replacement of Ordinary Portland cement (OPC) can lead to reduced mechanical performance of concrete at high replacement levels. SF is used for two purposes: to eliminate the disadvantages relative to conventional concrete that come from using MWP and to further reduce cement content while retaining an acceptable concrete performance.

Up to now, few researchers have investigated the compressive strength of concrete with MWP and SF with different incorporation ratios. The lack of detailed investigation to determine the optimal combined content of MWP and SF as partial replacement of OPC in the production of concrete, in terms of mechanical performance but taking into account environmental and economic reasons, led to this study.

In this research, the effects of the use of MWP and SF as partial replacement of cement on the mechanical properties of concrete mixes were examined extensively. Part of the innovation of this research lies in the wider incorporation ratio range analysed to determine the optimal content of MWP and/or SF as partial replacement of cement regarding the mechanical, environmental, economic performance of concrete, simultaneously and separately. This study completes that of Khodabakhshian et al. [5], focused on the durability performance.

2. State of the art

The literature related to the effect of MWP and SF on the mechanical properties of concrete was reviewed to gain a better knowledge of the behaviour of concrete containing MWP and SF. Concerning the effect of MWP with a pozzolanic material, Ergun [6] carried out compressive and flexural tests on concrete with superplasticizer containing MWP and diatomite as a partial replacement of OPC. The author concluded that replacing the OPC with 10% diatomite, 5% MWP and 5% MWP + 10% diatomite in concrete led to the highest compressive and flexural strengths because of the void filling effect of MWP and diatomite, and the pozzolanic activity of diatomite.

Rana et al. [1] studied the effect of using marble slurry as cement replacement in concrete production at substitution ratios of 0%, 5%, 10%, 15%, 20% and 25%. These authors reported that the compressive and flexural strengths of concrete decreased steadily as the marble slurry incorporation ratios increased. This was due to lack of binding ability in marble slurry. The decrease in strength was not significant for 5% and 10% replacement ratios.

Aliabdo et al. [7] substituted cement and sand with marble waste dust at ratios of 0%, 5%, 7.5%, 10% and 15%, separately for each material. These authors concluded that marble waste dust as sand replacement has a more significant effect on compressive strength than as cement replacement. They observed that using up to 10% of marble waste dust as cement or sand replacement improved the compressive strength of concrete. The substitution ratio of 15% in cement replacement led to results similar to those of the control mix. They also reported that replacing cement and sand with marble waste dust improved the splitting tensile strength of concrete.

Mashaly et al. [8] investigated the effect of replacing cement with marble sludge up to 40% in concrete production. They reported that, when increasing marble sludge incorporation up to 20%, the compressive strength of concrete increased but then it decreased gradually for replacement ratios above 20%.

Rodrigues et al. [9] studied the mechanical performance of concrete with various incorporation ratios of marble sludge as cement replacement (0%, 5%, 10% and 20%). These authors concluded that the compressive strength of concrete decreased with increasing substitution ratio. The incorporation of marble sludge decreased the splitting tensile strength and modulus of elasticity of concrete up to 20.6% and 8.1%, respectively. However, 5% replacement of cement with marble sludge led to an increase in splitting tensile strength and modulus of elasticity of about 4.4% and 2.7%, respectively.

Belaidi et al. [10] investigated the effect of substitution of OPC with marble powder and natural pozzolan up to 40% on the mechanical and rheological properties of self-compacting concrete (SCC). They observed that the compressive strength of SCC decreased with the increase of marble dust and natural pozzolan content.

Gesoglu et al. [11] investigated the possibility of replacing OPC with marble powder at ratios of 0%, 5%, 10% and 20% and fly ash at ratios of 0% and 30% in the production of SCCs. The authors found that the compressive strength and splitting tensile strengths of SCC fell when replacing OPC with marble powder. Also, they observed a similar trend for concrete mixes with fly ash and marble powder, which had lower compressive and splitting tensile strengths than the control concrete containing fly ash only.

Vardhan et al. [12] studied the effect of the use of marble powder as replacement of the OPC at ratios of 0%, 10%, 20%, 30%, 40% and 50% on the mechanical properties and microstructure of cement mortar. The authors concluded that the compressive strength and the technical characteristics of the resulting mixes remained unaltered when replacing cement with marble powder up to 10%.

Soliman [13] studied the effect of using marble powder as partial replacement of cement at ratios of 0%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20% on the properties of concrete. The author reported that the compressive strength increased by about 25% by replacing the marble powder up to 7.5%, whereas the compressive strength of concrete decreased by about 26% for replacement ratios above 7.5%, compared to the control mix. The author also reported that using up to 7.5% of marble powder increased the indirect tensile strength and the modulus of elasticity of concrete relative to the control mix and decreased for higher replacement ratios.

Ashish et al. [14] investigated the properties of concrete containing marble waste powder as a partial replacement of cement and sand at proportions of 0%, 10% and 15% separately and in combined form. The authors concluded that the replacement of cement and sand with MWP at a ratio of 15% decreased and increased the compressive strength of concrete respectively. The splitting tensile strength and flexural strength of concrete increased slightly for 10% and 15% cement replacement.

According to the reviewed studies of Arel [15], using marble waste in concrete production reduces environmental pollution and benefits for the economy. The author reported that replacing cement with 5–10% MWP improves the mechanical properties of concrete, whereas reducing the costs of concrete production and the CO_2 emissions of cement production by about 17% and 12% respectively.

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