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Durability properties of structural concrete containing very fine aggregates of marble sludge

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HIGHLIGHTS

- Marble industry waste can represent as much as 80–90% of the total extracted material.
- Marble sludge can be used in the production of structural concrete.
- The performance of these modified concrete is highly dependable on the superplasticizer type and content.
- Modified concrete was tested for various durability-related properties.
- The mix with 20% marble sludge and superplasticizer had equivalent performance to the reference mix.

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ABSTRACT

In terms of volume, the ornamental stone extraction industry represents a great waste source. For example, in the marble industry, waste can represent as much as 80–90% of the total extracted soil and stone. In order to use the material resulting from stone cutting, three concrete families were produced to be tested for their durability capacity: the first one contains no superplasticizer, the second one a current plasticizer made with a mixture of organic polymers (SP1) and the third a high-performance superplasticizer, made with a combination of modified polycarboxylates in an aqueous solution (SP2). In each concrete family, four substitution ratios were used representing, by cement volume, 0%, 5%, 10% and 20% of marble sludge.

During the experimental campaign, the aggregates were characterized in terms of water absorption and particle density, size grading, loose bulk density and voids content, Los Angeles wear, and shape index. The tests performed to characterize the marble sludge were sieve analysis, Blaine's specific surface, particles density and mineralogical and chemical compositions. The mixes produced were characterized in terms of workability and bulk density in the fresh state. In the hardened state, compressive strength, water absorption by capillarity and immersion, carbonation, chloride penetration and shrinkage were assessed.

This research showed that the durability characteristics of concrete get worse as cement content increases and marble sludge content increases. However, for the 5% and 10% incorporation ratios, these losses were insignificant. Superplasticizers' incorporation was beneficial to concrete's performance. In particular, the high-performance superplasticizer led to results in the concrete with less 20% cement content similar to those of the reference concrete without admixtures.

1. Introduction

1.1. Preliminary remarks and objectives

In order to meet its needs, Humanity has been exploiting the world's natural resources in an exhaustive and sometimes exaggerated way. This over exploitation of resources is due to many factors, such as population growth, technological innovations, industrialization and the wish to reach a better life quality. As a consequence, the concept of sustainability emerged, defined as a

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balance between the consumption and the guarantee of a good life style for future generations.

According to the European Commission [1], the construction minerals' extraction is the biggest subsector in the non-energetic extraction industry. Therefore, this work tries to evaluate the implications of reducing cement content in concrete by incorporating waste sludge generated by marble stone-cutting. Anticipating some properties' loss, the use of superplasticizers and its benefits together with this type of waste are also evaluated.

The literature suggests that marble waste can be used in concrete. Binici et al. [2], André et al. [3] and Martins et al. [4] all concluded that marble waste used as aggregates may improve concrete's mechanical and durability capacity. Other authors, such as Topçu et al. [5], Bacarji et al. [6], and Corinaldesi et al. [7], studied the effect of marble powder in concrete, concluding that, up to given ratios of addition or replacement, concrete's durability and mechanical capacity can be improved.

1.2. Research significance

The lack of literature regarding this kind of test on concrete containing very fine aggregates led to this study. In Portugal, this subject has not been the object of study and, acknowledging that the marble industry is one of the biggest in the ornamental stones' industry, as referred by the Portuguese General Direction of Energy and Geology, the search for ways of re-using this kind of waste is a priority. Part of the innovation of this research lies in the fact that the marble waste sludge's size analysis showed that they do not provide the intended filler effect, therefore losing part of its compacting potential. This is due to the fact that these aggregates were obtained through wire saw cutting, which leads to aggregates of bigger size than other methods. Also the use of superplasticizers combined with this type of aggregates represents an innovative approach on this matter. This study completes that of Rodrigues et al. [8], focused on the mechanical performance.

2. State of the art

Although the research made on this subject is not very extensive, some works were reviewed and are synthetized in this section.

Concerning the marble waste's aggregates properties, Aruntas et al. [9] studied the addition of marble dust in cement production, obtaining very similar results to the ones observed in our study.

Hebhoub et al. [10] studied the effect of replacing natural aggregates by recycled marble aggregates on concrete's workability. These authors replaced 0%, 25%, 50% and 100% of coarse and fine aggregates with recycled materials, concluding that increasing the replacing ratio lowers concrete's workability. This is because the marble aggregates tend to absorb more water than the natural aggregates, leading to a higher necessity of water to achieve the same workability level. Çelik et al. [11] obtained similar results as Hebhoub et al. [10], but in this case Çelik et al. [11] replaced natural fine aggregates in concrete with limestone dust. Çelik et al.'s [11] explanation was that, since limestone dust has a higher specific surface than the natural fine aggregates, a higher water content is needed to moisten all the aggregates' surface and, therefore, reach the same workability level.

Regarding concrete's bulk density, André et al. [3] and Gameiro et al. [12] studied the replacement of natural coarse and fine aggregates with recycled marble coarse and fine aggregates, respectively, in ratios of 0%, 20%, 50% and 100%. Both concluded that this replacement does not lead to significant changes in concrete's bulk density.

Binici et al. [2] studied the compressive strength of concrete with marble coarse aggregates. Fine river sand was used as fine aggregate, the cement used as binder was an ordinary Portland cement (CEM-II), as in our study, and the water/cement ratio was kept constant at 0.4. Binici et al. [2] concluded that the use of marble waste as coarse aggregate increases concrete's compressive strength, with a greater incidence on low curing ages.

Topçu et al. [5] studied the water absorption by capillary action in self-compacting concrete with marble dust. This incorporation, at contents from 50 kg/m^3 to 500 kg/m^3, proved to be capable of reducing the water absorption by capillary action, mostly due to the fact that the marble dust has a void-filling capacity that reduces the water's capacity to penetrate the concrete's voids. Menadi et al. [13] made a similar study to Topçu et al.'s [5], using limestone dust as an addition, reaching a 5% reduction in water absorption by capillary action for a5% limestone dust addition in terms of concrete's weight.

Vijayalakshmi et al. [14] concluded that replacing concrete's fine aggregates with granite dust increases its capacity to absorb water by immersion. However, up to 15% replacement ratios this increase is practically unseen. Vijayalakshmi et al. [14] explained these results stating that granite dust reduced concrete's workability, lowering its compactness and leading to a higher capacity to absorb water.

Yague et al. [15] reported that the incorporation in concrete of dry sludge, collected from a wastewater treatment plant, can cause an increase in carbonation levels. They used incorporation ratios of 2.5%, 5% and 10% by cement weight, resulting in significant increases for 5% and 10%.

Binici et al. [2] stated that the incorporation of marble coarse aggregates in concrete tends to decrease its chloride penetration, reaching a 70% reduction compared to a reference concrete at 28 days of exposure. Gesoğlu et al. [16] concluded that marble dust incorporation in concrete decreased chloride penetration. In particular, adding 5% of marble dust, by cement weight, led to the greatest decrease in chloride penetration.

Çelik et al. [11], as referred before in this section, replaced natural fine aggregates in concrete with limestone dust, concluding that up to 10% replacement ratios the compressive strength and shrinkage increase when compared to a reference concrete. This is due to the fact that concrete mixes with greater compressive strength tend to have less inner voids but lead to higher shrinkage.

Sumer [17] studied the effect of replacing cement with fillers as well as adding a superplasticizer to concrete, evaluating its compressive strength and bulk density. The compressive strength increased 9% for a 5% substitution ratio and up to 33% when combined with a superplasticizer, compared to a reference concrete. The substitution of cement with filler and the addition of a superplasticizer led to an increase in bulk density, lowering the amount of air inside concrete. This is of extreme importance to our research since the lower air content inside concrete can lead to better results in durability-related properties of concrete.

3. Experimental programme

3.1. Materials used

The materials used to produce the twelve concrete mixes were:

- Limestone gravel, supplied by Cimpor;
- River sand, supplied by Grupo Soarvamil;
- Marble sludge supplied by Solubema;
- CEM II 42,5R A-L cement, supplied by SECIL cement works in Outão, Setúbal;
- Tap water.

3.2. Concrete mixes design

Based on NP EN 206-1 [18] requirements, concrete mixes were designed to be compatible with various structural applications regarding: their compression strength, tested in cubic samples, of approximately 37 MPa (C25/30); and workability, defined by the slump test in the fresh state, within a range of 125 ± 15 mm. Some characteristics were established in order to reach these parameters, such as: