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Review

Mechanical properties of structural concrete containing very fine aggregates from marble cutting sludge

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HIGHLIGHTS

- Major environmental impacts caused by the marble extraction industry.
- Untypical size distribution of the marble cutting sludge.
- Mechanical performance of concrete with marble sludge partially replacing cement.
- No significant losses for replacement ratios up to 10%.

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ABSTRACT

The marble extraction industry has a significant impact on Portugal's economy, but it is also responsible for important environmental impacts. Large amounts of waste are produced every year that can be as much as 80–90% of all the materials extracted. Therefore, solutions must be found that will satisfy the increasing production of this waste.

The aim of this research is to evaluate the mechanical performance of concrete with various incorporation ratios of sludge from the marble extraction industry as cement replacement (0%, 5%, 10% and 20% of the total volume of cement), as well as with plasticizers. Workability and bulk density tests were carried out on fresh concrete, while compressive strength, splitting tensile strength, modulus of elasticity, ultrasonic pulse velocity and abrasion resistance tests were performed to evaluate the relevant properties of concrete in the hardened state.

It was found that the mechanical properties of concrete containing sludge from the marble extraction industry tend to decline. However, satisfactory results were obtained for replacement ratios of up to 10%, thereby validating the use of this concrete in the construction sector. Regarding the use of plasticizers, it was observed that they improve the mechanical performance of concrete with marble sludge by offsetting the decline of its properties relative to conventional concrete.

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1. Introduction

1.1. Preliminary remarks

The exploitation of natural resources has been an increasing cause of concern in recent decades and the problems it raises require increasing attention. Every year large quantities of waste are produced in the regions of Estremoz, Borba and Vila Viçosa (some of Portugal's most important marble quarrying areas); it is estimated that such waste amounts to as much as 80–90% of the extracted rock. It is therefore increasingly important to find ways of consuming this waste in order to cope with the increasing extraction and reduce the resulting environmental impacts. The use of the waste derived from marble extraction in the production of structural concrete is therefore justified. However, before its use in the construction sector can be sanctioned we must ensure the quality and safety of the concrete made with sludge from the marble extraction (SME) industry and understand its performance.

Several research works have shown that replacing cement or sand with marble sludge in structural concrete is a viable choice. Topçu et al. [1] found that using up to 200 kg/m^3 of marble powder in self-compacting concrete optimizes the performance of the mixes. Hebhoub et al. [2] showed that the use of waste marble powder to replace sand in ratios up to 75% leads to an increase in the compressive strength of concrete. Experiments carried out by Corinaldesi et al. [3] have shown that replacing up to 10% of sand with marble dust and superplasticizers increases the compressive strength of the concrete produced, for the same level of workability. Aliabdo et al. [4] concluded that the use of marble powder up to 15% by weight as cement replacement leads to results similar to those of the control mix.

1.2. Research significance

Although the literature on this subject is now relatively extensive, the lack of experience in Portugal plus the fact that little is known about the incorporation of waste marble sludge as cement replacement and its interaction with superplasticizers prompted the present study. Part of the innovation of this research lies in the analysis of these aggregates' size, which showed that they do not provide the intended filler effect and therefore lose part of their compacting potential. This is because the aggregates were obtained through wire saw cutting, which leads to larger-sized aggregates than other methods.

2. State of the art

The literature related to this topic was reviewed to gain a better knowledge of the behaviour of concrete containing marble powder.

Binici et al. [5] carried out chemical and physical tests on the marble dusts used in their study to determine their properties. The results showed that their aggregates tended to be very similar to those used in our study.

The initial moisture state of the aggregates also affects the properties of concrete, both in the fresh and hardened states. Poon et al. [6] studied the influence of three moisture states of the coarse aggregates (air-dried, oven-dried and saturated surface-dried) on concrete's slump and compressive strength. The water/cement ratio was kept constant in all mixes and recycled aggregates were incorporated in the mix at substitution ratios of 0%, 20%, 50% and 100%, instead of crushed granite. The results for slump over time showed that oven dried aggregates led to a higher initial slump for all substitution ratios. Oven dried aggregates also led to a quicker slump loss than air dried and saturated surface dried aggregates did. It was also shown that mixes made with air-dried aggregates exhibited the highest compressive strength as the ratio of recycled aggregates increased, while mixes with saturated surface-dry aggregates exhibited the lowest compressive strength. This was due to a high water/cement ratio in the vicinity of the particles, which weakened the bond between the recycled aggregate and the cement matrix.

Concerning workability, Gesoğlu et al. [7], studied the effect when marble powder replaced the concrete binder. Substitutions of 0%, 5%, 10% and 20% were made with the simultaneous use of superplasticizer. The water/cement ratio was kept at 0.35 at all stages. The authors concluded that as the substitution ratio increased the amount of superplasticizer had to be increased to keep the slump flow diameters at similar levels. Tests carried out by Binici et al. [5] and Hebhoub et al. [2] also showed that replacing fine concrete aggregate with marble powder resulted in a slump loss as the replacement ratio increased. This is because natural aggregates have a higher water absorption ratio than marble powder.

Hebhoub et al. [2] and Binici et al. [5] concluded that the bulk density of concrete is not significantly changed with the increasing incorporation of marble powder. Their study notes that the bulk density of concrete is a function of its ingredients' bulk density, the proportion of each material in the mix, the initial and final water content and the hydration level of the concrete.

Regarding the properties of hardened concrete, Corinaldesi [3] concluded that replacing 10% of sand with marble powder and