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# Study of Portland Cement Composites Replacing Cement for Waste from the Cutting and Polishing of Ornamental Rocks

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***Abstract***- Due to the concern with the environmental impacts caused by the construction industry and the ornamental rock sector, many studies are being carried out, seeking to take advantage of the waste to develop sustainable materials. The literature review presents the potential of using waste from ornamental rocks in the composition of cement composites, as a partial replacement for Portland Cement. In this way, this work aims to present results that evaluate the durability of cementitious compounds beyond their mechanical performance with the incorporation of waste from the cutting and polishing of ornamental rocks, replacing 20% by mass of the cement. The waste was characterized as its chemical composition, particle size, specific gravity and pozzolanic activity. In the compounds, the consistency and workability, compressive strength and flexural strength, immersion and capillary absorption, modulus of elasticity and electrical resistivity were evaluated. It was observed that the use of the waste did not affect significantly the composites performance, being the filler effect the main one responsible for the maintenance of its properties. The mechanical and durability properties were satisfactory. However, it was observed a small decrease in the compressive and flexural strength and in the elasticity modulus. The capillarity absorption increased.

***Keywords***- *Ornamental Rock Processing Waste, Cementitious Composites, Filler Effect*

## I. INTRODUCTION

The construction industry is one of the main consumers of raw materials, whose productive processes can generate great environmental impact. According to [1], from January 2017 to February 2018, Brazil produced almost 54 million tons of cement, contributing negatively to the emission of $CO_2$ into the atmosphere. The ornamental rocks consumption of also generates concern due to the extraction and processing of those rocks, whose estimated generation of waste is up to 20 to 30% of the raw material [2]. During the processing stages, waste is generated in the form of abrasive sludge, composed mainly of water, lime and stone powder [3]. Ref. [4] presents as main impacts generated by this mud the soil contamination and the water table, alteration of the biological chain of living beings and silting of rivers. In this context, studies are being carried out to search for alternative materials and uses of waste aiming to lower the environmental impact and consumption of natural resources.

The literature review presents the potential of using waste from ornamental rocks in the composition of cementitious composites. Ref. [5] studied the use of the granite polishing waste in concrete making, resulting in better particle packing, porosity reduction and strength gain, with an optimum content of 20%. Ref. [6] verified the maintenance and improvement in the mechanical properties of concretes produced with the incorporation of marble powder. Ref. [7] and [8] studied the mechanical behavior of the concrete as the partial replacement of cement, observing good results for replacement levels of 10% due to the stone powder filer effect. Ref. [9] used the marble waste as a replacement for cement and aggregate in the composition of mortar and concrete, in proportions of 5%, 10%, 15% and 20%, resulting in an increase in compressive strength and tensile strength of mortars with waste as a partial replacement of fine aggregate.

It is observed that the studies mainly evaluate the mechanical performance of the compounds and with incorporation of waste of only one type: granite or marble. In this way, this work aims to present results that evaluate the durability of cementitious compounds, their mechanical performance with the incorporation of heterogeneous ornamental rocks' waste replacing 20% by mass of the cement.

## II. MATERIALS AND METHODS

### A. *Methodology*

For this study, the waste from the cutting and polishing of marble and granite from an ornamental rock processing industry in the northern region of Belo Horizonte, MG - Brazil was collected. The collected sludge was oven-dried at 105 ± 5°C for complete drying. The dry material, with an average humidity of 0.12%, was crushed and passed through a sieve of 75μm aperture, resulting in a fine powder, as shown in Fig. 1. Subsequently, the cementitious compounds were made without waste (ref) and with waste (M20), replacing 20% of the cement by mass, maintaining the water/fines ratio of 0.48 and the 1:3 ratio of cement to fine aggregate (sand). The waste was characterized as its chemical composition, particle size, specific gravity and pozzolanic activity. The composites were evaluated for consistency, compression strength and flexural strength, immersion and capillarity absorption, modulus of elasticity and electrical resistivity. The waste nature was verified through a questionnaire answered by a company's agent. In this questionnaire it was possible to identify the types of ornamental rocks traded and whether there was use of chemicals in the polishing process.

Figure 1. Sample collected & after drying, discharging & sieving process

The chemical composition was made by FRX. The specific gravity determination was done through the Pycnometer method, removing the air existent in the samples with vacuum application by pumps. The granulometric composition was performed by sedimentation, according to [10], technique based on Stokes's Law, measuring the density of the material dispersed in water to determine the diameters and their respective percentages. The pozzolanic activity was evaluated by the Modified Chapelle method, in which the free CaO content of the solution with waste by the titration of solution with HCl and phenolphthalein was measured and compared with a reference solution according to [11]. Normal consistency was obtained for the pastes following [12] and [13] standards and the workability by the flow table method, [14]. Cylindrical test specimens (5x10 cm) were molded to measure the compressive strength at 7, 14 and 28 days, in accordance with the normative requirements of [15], [16], and [17]. In the compression, the Pavitec press, model PCE-20D, with capacity of 20tf was used. For the flexural strength prismatic (4x4x16) cm specimens were molded and ruptured at the ages of 7 and 28 days in the Instron 5582 press, with a capacity of up to 10 tf and a velocity of 0.05 to 500 mm / min. For immersion and capillarity absorption, cylindrical specimens (5x10) cm were used, followed by [18] and [19]. For the modulus of elasticity and electrical resistivity, cylindrical specimens (10x20) cm were used. The modulus of elasticity was obtained by the forced resonant frequency method in the longitudinal mode, using the Erudite MKII Resonant Frequency Test System. The electrical resistivity was evaluated using the Ohm's Law by the reading of the potential difference between two electrodes on the test cup surface at 60 days of age with the Polzerm FG-8102 Digital Function Generator.

## *B. Materials*

The cement composites were made with Portland Cement of high initial strength, CP-V(ARI), for having less additions and also with water, fine aggregate (sand of gneiss) obtained by industrial crushing process and marble waste. The sand used was washed in order to reduce the content of fine materials, and characterized, as shown in Fig. 2 and Tab. 1.

TABLE I. CHARACTERIZATION FINE AGGREGATE

| | |
|---|---|
| Maximum characteristic size (mm) – [20] | 6,3 |
| Fineness modulus – [20] | 3.00 |
| Real density (kg / dm³) – [21] | 2.62 |
| Specific unit mass (kg / dm³) – [22] | 1.62 |
| Clay content – [23] | Free |
| Powder material content (%) – [24] | 1.12 |
| Organic impurities – [25] | Free |
| Shape of the grains | Angular |

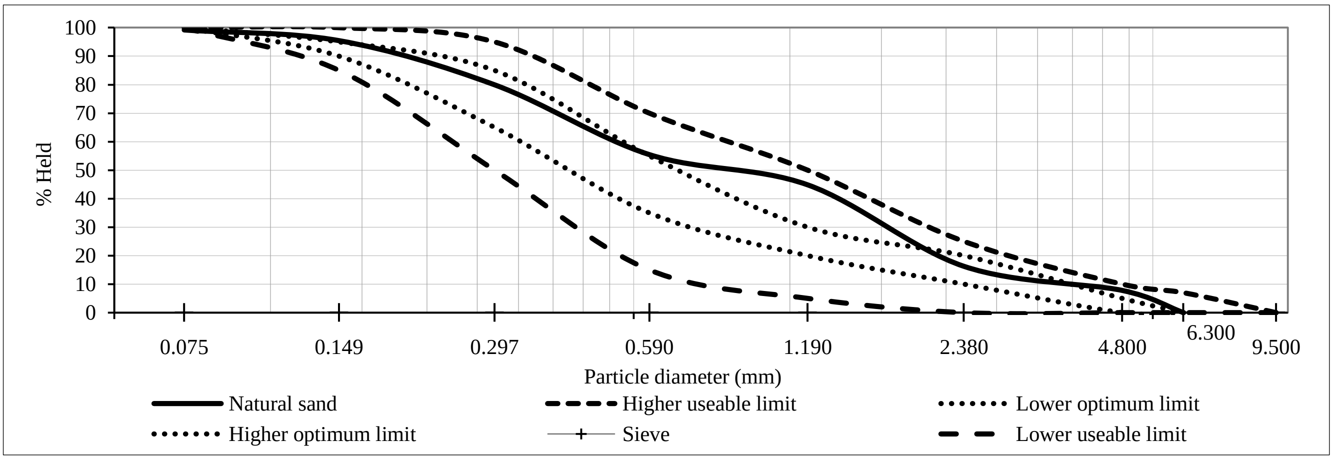


Figure 2. Granulometric curve of the fine aggregate

## III. RESULTS AND ANALYSIS

### A. Characterization of the waste

According to the questionnaire response, the abrasive sludge collected contained only marble and granite waste, in variable volumes, with no chemicals. The granulometric characterization and specific mass of the waste are presented in Tab. 2 and Fig. 3. During the initial sample preparation process, it was observed that more than 75% of the material had dimensions smaller than 75 µm, which adds potential of use of the granulometry close to that of the cement. It was observed that the granulometry of the waste can vary according to the process of beneficiation of each marble. Although the waste has lower density than the cement, which has 3.10 g / cm³, this small difference still allows the cement to be replaced for the waste by mass.

TABLE II. REAL DENSITY (ΥR) AND EQUIVALENT DIAMETER - D10, D50 E D90

| $\gamma_r$ (g/cm³) | $D_{10}$ (µm) | $D_{50}$ (µm) | $D_{90}$(µm) |
|---|---|---|---|
| 2.78 | 41.4 | 10.3 | 1.6 |

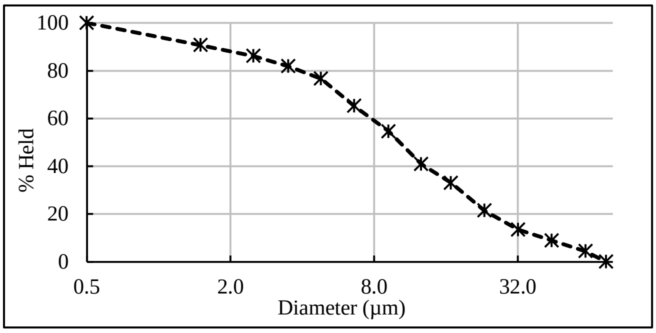


Figure 3. Waste Granulometry by sedimentation

The chemical composition analysis revealed that the main components were silica (42.80%), calcium oxide (19.00%) and aluminum trioxide (8.07%) and also small amounts of other oxides, according to Tab. 3.

Although it presents in its chemical composition $SiO_2$, $Al_2O_3$, and $Fe_2O_3$, it is concluded that these components are in the crystalline structure, therefore being non-reactive. According to [26], the pozzolanicity of the material is checked by fixing at least 330 mg of calcium hydroxide per gram of material analyzed in the Chapelle test. As the test resulted in the fixation of only 170.2 mg, the waste was characterized as non-pozzolanic, corroborating with the results found by [5] for granitic rock waste and by [27] for marble and granite. As the test resulted in the fixation of only 170.2 mg, the waste was characterized as non-pozzolanic, corroborating with the results found by [5] for granitic rock waste and by [27] for marble and granite. It is also observed that in these studies, although the material did not react, its filler effect was verified.

### B. Study of the waste replacing the cement

#### 1) Normal consistency and Consistency index

The amount of water in the composition of cement pastes can influence the properties of mortars and concretes, both in the fresh and hardened state. In this study, it was verified that there is no influence in the water demand to reach a standard consistency with the replacement of 20% of cement by the waste. Both the reference paste, without waste, and that composed of cement and waste required 32% of water in relation to the dry mass.

The workability, evaluated by the flow table method in mortars, was not significantly affected by the incorporation of the waste, as can be seen in Fig. 4, obtaining a difference of only 5.1%, less, in relation to the reference mortar. Ref. [3] and [28] obtained similar results for granite slab. The authors observed an increase of cohesion with consequent reduction of exudation, which resulted in a lower reduction of the concrete.

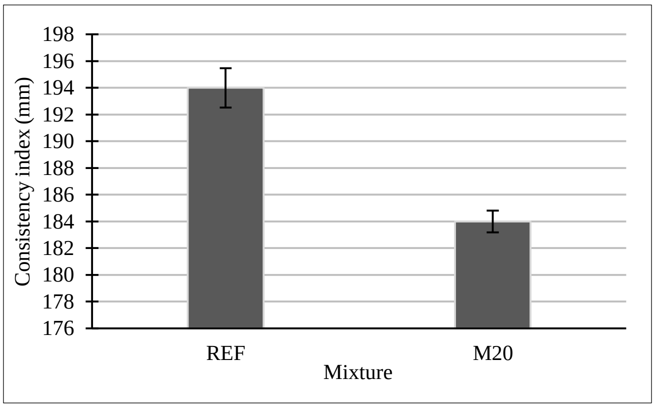


Figure 4. Result of the consistency index by the flow table method

TABLE III. TABLE 1 CHEMICAL COMPOSITION OF THE ANALYSED MATERIALS (%) AND LOSS ON IGNITION (LOI)

| Specimens | FeO | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $TiO_2$ | $P_2O_5$ | $Na_2O$ | $K_2O$ | MnO | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ciment | 0.16 | 20.00 | 4.62 | 2.76 | 60.10 | 1.69 | 0.23 | 0.23 | 0.22 | 0.95 | 0.16 | 5.24 |
| Waste | 1.67 | 42.80 | 8.07 | 2.63 | 19.00 | 3.89 | 0.69 | 0.33 | 1.85 | 2.59 | 0.04 | 17.40 |

*2) Compressive strength*

The results of the compressive strength are shown in Fig. 5. It was observed a decrease tendency of the compressive strength in the mortars replaced with waste in relation to the obtained in the reference mortar (7.44% at 28 days), however, this is considered not significant for this replacement level. This result is due to the presence of the inert material replacing the cement, increasing the water/cement factor. According to [5], the higher the water/cement ratio, the greater the need for the presence of fines acting as filer in concretes. Maintaining the w/c ratio of 0.45, the author observed a maintenance of the compressive strength of concrete with 20% addition of granite and marble waste. Ref. [29] and [30] obtained an increase in concrete strength, however, in smaller amounts of cement replacement by marble waste, 10 and 15% respectively. Ref. [6] obtained a small strength gain in concrete with 10% of marble waste replacing the cement and with 15% of waste replacing the fine aggregate, with w/c ratio of 0.40.

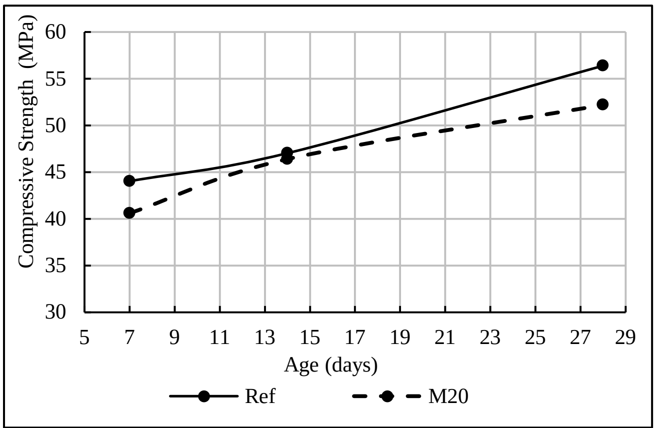


Figure 5. Compressive strength results

*3) Dynamic elastic modulus and flexural strength*

Fig. 6 shows the results of dynamic modulus of elasticity and flexural modulus. The dynamic elastic modulus showed a decrease of 9.4%, which is probably due to the lower density of the waste in relation to the cement and the excess water in the mixture. This result was also observed in the study by [31], with a clear reduction of the modulus of elasticity with increasing mineral content of basalt, limestone and granite in the concrete. Given the replacement content of cement by ornamental rock waste in this research, it was considered that this reduction was not significant, and the filler effect is responsible for the satisfactory performance in this property.

The results of the flexural strength testing showed that, for the age of 7 days, the reference trace reached an average value of 8.82 MPa and for 28 days, 10.02 MPa. Similar to compression, the mortar with waste incorporation showed close results of flexural strength, with variation of 8.5% and 4.7% for 7 and 28 days, respectively. Therefore, the low influence of the wastes on this property is observed.

*4) Immersion absorption and porosity*

Permeability and porosity can be measured through the immersion test. From the results presented in Fig. 7, it can be observed that the absorption by immersion in the sample with waste presents a slightly higher value than the reference trait, with an increase of 13.7%. According to [32] and [33], a rate of water absorption is a great indicator of the potential durability of concrete. According to [34], a good quality concrete has an absorption rate of less than 10%. Although the result obtained is higher than the reference composite, the water absorption is still satisfactory.

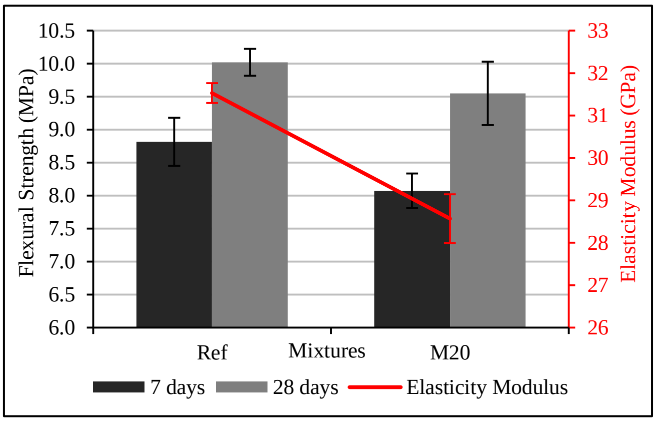


Figure 6. Flexural Strengh and dynamic elastic modulus results

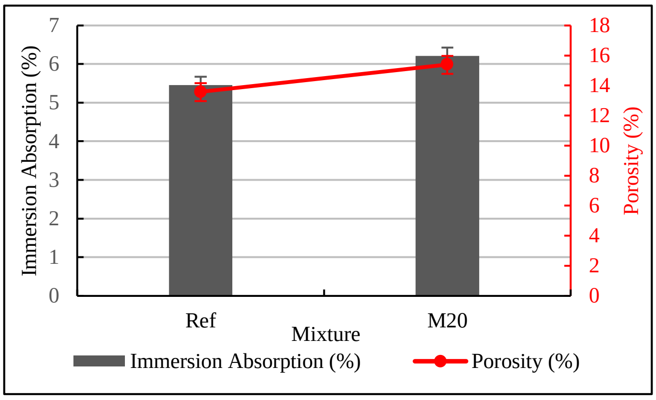


Figure 7. Immersion absorption and porosity results

The porosity for the mortar with waste incorporated was also higher (13.3%) to the reference mortar due to the exit of the unreacted water with the cement, leaving empty spaces [35]. This result was similar to [27], which obtained porosities close to 13% for concrete with addition of granite powder waste in the proportions of 10% and 15%. These results justify the values obtained for compressive strength modulus of elasticity. According to [36], the smaller volume of permeable voids makes the concrete more durable and compact, providing greater results of compressive strength.

### 5) *Capillarity absorption*

By observing the values obtained in the capillarity water absorption test (Fig. 8), it was verified an evolution of the absorption over time, with a higher absorption rate in the initial phase of the test and a tendency in the continuity of growth of the curves. This fact induces a possible interconnection of the conduits and a greater suction force due to pore refinement [37] and [38], thus creating preferential paths for water to rise. In addition, ref. [36] states that samples with lower w/c ratio have lower water penetration values.

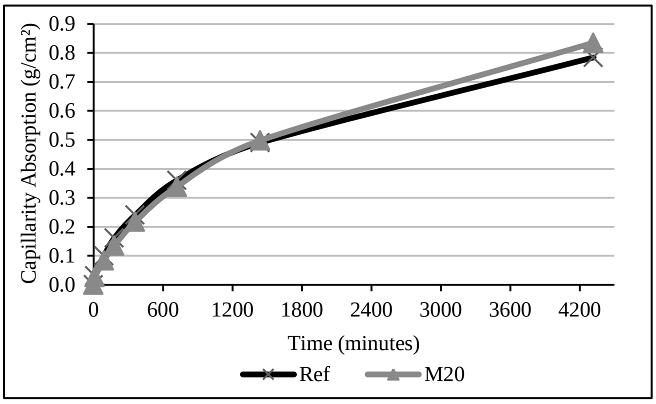


Figure 8. Capillarity absorption results

### 6) *Electrical resistivity*

The results of the electrical resistivity (Fig. 9) show very close values and therefore the variation in relation to the reference trace is not significant. Since the electrical resistivity is an important parameter in the evaluation of the corrosion of reinforced concrete structure [33] and, according to [39], the high corrosion range from 50 to 100 Ω.m and low corrosion range is above 200 Ω.m. The values found demonstrate a micro-concrete with a high propensity to corrosion of the steel reinforcements. As the order of magnitude and the corrosion range were not changed, the introduction of wastes into the mixtures did not significantly affect this property.

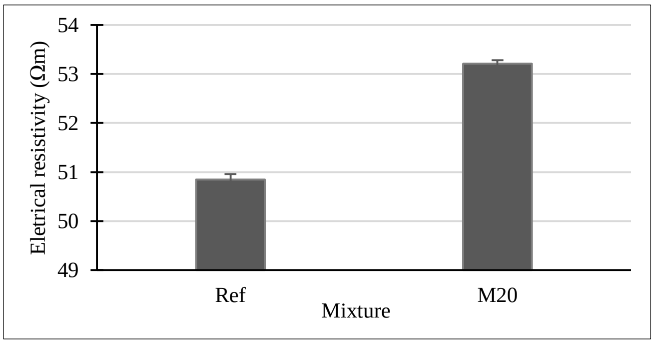


Figure 9. Electrical resistivity results

## IV. CONCLUSION

After the tests were carried out, it was observed that the use of the waste did not affect significantly the majority of the analyzed properties. The research shows the feasibility of using the wastes from the processing of ornamental rocks as a partial replacement of cement in the proportion of 20% by mass. The filer effect of the waste was observed, improving the particle packing, increasing the cohesion of the composites and reducing the exudation. The mechanical properties were satisfactory, however with reduction of the compressive strength, flexural strength and modulus of elasticity. There was no stabilization but rather an increase of capillarity absorption, which shows the need to study the properties of durability in compounds of other traits and varying the w/c ratio, which was the main influencer in the negative results. However, the durability performance of the compounds with 20% waste was satisfactory. It is worth mentioning that the use of the wastes in cementitious compounds is a solution to the aforementioned environmental problem, adding value to a product in the market and avoiding the impacts caused by the inadequate disposition of the wastes in the environment.

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