

Production of granilite concrete plates with recycled aggregates and ornamental rock processing sludge

Produção de placas em concreto granilite com agregados reciclados e lama do beneficiamento de rochas ornamentais

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ABSTRACT

The ornamental rock industry generates millions of tons of waste in different stages of rock processing. These wastes are stored or disposed of inadequately, which causes environmental degradation. The objective of this study was to evaluate the concomitant use of ornamental rock processing sludge as partial replacement of Portland cement in contents of 0%, 5%, 10% and 20% and of recycled stone aggregate as total replacement of coarse natural aggregates in the production and performance of granilite concrete plates. Four concrete formulations were produced with different replacement contents and their characteristics were determined through tests of axial compression strength, flexural tensile strength, water absorption, impact strength and strength to stains. Mechanical results were inversely proportional: the higher the sludge replacement content, the higher the axial compression strength and the lower the flexural tensile strength. Water absorption tests showed a gradual decrease with an increase in sludge replacement, impact tests showed that the plates performed better at resisting shocks best up to a height of 50 cm and, in terms of stain resistance, multi-use products and butoxyethanol-based stain remover were more efficient on waterproofed granilite concretes and natural rock pieces, respectively. It was possible to conclude that it was viable to use up to 20% replacement of the aforementioned wastes in conventional concrete, with additional minimization of environmental impact associated with the extraction and processing of ornamental stones.

Keywords: Ornamental rock processing sludge; Recycled stone aggregates; Granilite concrete; Mechanical properties; Performance.

1. INTRODUCTION

One of the biggest issues in civil construction and its associated supply chain industries is the final destination of solid waste generated in their production processes. Sometimes these wastes are repurposed but mostly are discarded in inappropriate locations or landfills, which contaminates the soil and water resources and impact negatively on human health.

It is estimated that the Brazilian production of ornamental rocks reached approximately 9 million tons in 2020. The Southeast region accounts 58.67% and the state of Espírito Santo stands out with 34.44% of the total [1]. The main stones supplied to the market are marbles (composed of calcite and dolomite) and granites (composed predominantly of quartz).

In ornamental rock production, 20% to 40% of the volume of the block extracted in the quarry becomes waste in the form of sludge as a large amount of water is used to cool the plates in the polishing process [2]. Additionally, further larger amounts of waste from the extraction and cutting phases of commercial parts are generated, around 10% to 20%. According to Karaca et al. [3], the volume of waste generated depended on the

geological, petrographic and textural natures of the stone, cutting and processing machines, dimensions of the blocks and capacity of the plant.

André et al. [4] evaluated the influence of replacing natural aggregates with marble aggregates at 0%, 20%, 50% and 100% content in conventional concrete with a water/cement (w/c) ratio of 0.55. The experimental comparison of the concretes produced with marble aggregates with respect to reference concretes concluded that: workability remained unchanged; there was a small loss of compressive strength at 28 days with increasing replacement content; water absorption by immersion remained similar and capillary water absorption was lower. In terms of durability, the carbonation depth of concretes with marble aggregates was also similar but presented a significant increase in the migration coefficient of chlorides due to the low content of alumina in these aggregates.

In the investigations by Kore and Vyas [5], the replacement content of natural aggregates with marble aggregates were of 0%, 20%, 40%, 60%, 80% and 100% for a conventional concrete with a w/c ratio of 0.55. Results determined that the workability and permeability increased with increasing replacement. Compressive strength showed an upward trend with up to 80% replacement content and the concrete mixtures with marble aggregates showed significant reductions in compressive strength when attacked with sulfuric acid.

In another study, Kore and Vyas [6] maintained the experimental methodology and substitution levels of Kore and Vyas [5] but with conventional concretes with a w/c ratio of 0.60. Results showed that workability, permeability, ideal content and compressive strength with and without chemical attack were the same as in Kore and Vyas [5]. However, it was noted that these concretes could also be used in paving works in view of the acceptable values in the Los Angeles abrasion tests.

Sharma et al. [7] investigated the partial replacement of coarse natural aggregates with granite aggregates at content of 0%, 10%, 20%, 30% and 40% in conventional concretes with w/c ratios of 0.38, 0.40 and 0.42. Results showed that there were no significant variations from different water/cement ratios. However, there was an increase in workability with increasing waste replacement, water absorption and the depth of water penetration decreased with increasing water, and the compressive strength and flexural tensile strength were reduced with increasing replacement waste. Thus, an ideal content of up to 20% was recommended for all applications while 20% to 40% content was indicated for non-structural and paving applications.

Munir et al. [8] evaluated the efficiency of marble sludge as a substitute for Portland cement at contents of 0%, 10%, 20%, 30% and 40% in controlling the alkali-silica reaction in mortars with a w/c ratio of 0.47. Compressive strength results showed an increase in strength with 10% content. The greatest reduction in expansion of the mortar bar was observed at 40% content and the samples with waste replacement showed no signs of cracks characteristic of the alkali-silica reaction. Thus, marble sludge was deemed efficient for the control and expansion of this deleterious effect.

Khodabakhshian et al. [9] studied the mechanical and durability properties of marble powder as a replacement for Portland cement at contents of 0%, 5%, 10% and 20% in concretes with a w/c ratio of 0.45. It was concluded that there was no significant change in bulk density from the incorporation of waste. A replacement content of 5% caused an increase in compressive strength and electrical resistivity was slightly lower than the reference sample. Compressive strength under sulfate attack was reduced and water absorption increased with increasing substitution powder content. In all tests, satisfactory results were obtained with up to 10% replacement.

Singh et al. [10] examined the replacement of cement with marble powder in long-aged concrete at contents of 0%, 10%, 15%, 20% and 25%. Concretes were produced with three w/c ratios: 0.35, 0.40 and 0.45 and tested under various ambient temperatures ranging from 0°C to 47°C. It was determined that, for up to 15% replacement content, greater mechanical strength and durability (resistance to permeability and absorption) of the concrete blocks was obtained from 28 days to 360 days, indicating that the powder densified the cement matrix.

Rashwan et al. [11] analyzed the effects of using marble and granite sludge as a cement substitute on the properties of fresh and hardened concrete mixtures at replacement contents of 0%, 10%, 20%, 30% and 40%. It was observed that, with up to 20% replacement, slump values of the fresh concrete mixtures met design slump limits and mechanical properties were not overly compromised. Water absorption and apparent porosity increased with up to 10% replacement. Depth of water penetration decreased and the strength of concrete under attack with sulfuric acid increased with increasing waste replacement. Generally, sludge replacement of up to 20% was recommended for all concrete applications while 40% replacement was recommended for paving blocks.

In view of these reference studies and, as another alternative for the proper disposal of industrial solid waste, the use of granilite concrete has become a growing trend in contemporary architecture. It has the same composition as other types of concrete but the aggregates used (< 9.5 mm) affect the aesthetic design. Also, the use of white Portland cement allows the incorporation of pigments for a desired color as long as they do not affect its mechanical characteristics. After curing, polishing enhances the presence of the chips and confers

an aesthetically-pleasing effect to the surface. Granilite plaques can be made in situ or pre-molded and can be applied on vertical or horizontal surfaces. Its unevenness allows application in indoor or outdoor areas and are therefore, very adaptable. Granilite concrete imbues a natural beauty and is low maintenance, being cleaned with simple polishing at a relatively low cost. However, the production of granilite concrete is not specified by the Brazilian Association of Technical Standards and there are no standards for the selection and mix ratio of materials, production, installation and care. The execution of all these projects currently relies on individual or company procedures, which are based on experience.

Therefore, this study sought to contribute to the body of knowledge with an evaluation of the concomitant use of ornamental rock processing sludge as a substitute for Portland cement and recycled stone aggregate as replacement for coarse aggregates in the production and performance of granilite concrete plates for application in countertop and floor coverings, which are usually covered with ceramic floor tiles.

2. MATERIALS AND METHODS

For the production of granilite concrete, the following materials were used: white structural Portland cement (CP B-40) as it is the most used due to its color, possibility of pigmentation and high resistance; recycled stone aggregate composed of granites, marbles and basalts; coarse-grained natural quartz sand as fine aggregate; ornamental rock processing sludge (ORPS); TEC-FLOW 8000 superplasticizer additive to improve workability (solids content: 45–49%); V-MAR 3 viscosity modifying additive to improve spread and prevent segregation (solids content: 21–25%); DENSIL 10 air disincorporating additive to improve the finish and water from the public supply (solids content: 10–15%).

The ORPS was dried in an oven to a humidity of 0.37% and subsequently sifted with a #200 sieve for use. In its natural state, without thermal treatment at high temperatures, this waste had characteristics of a filler-type mineral additive. The specific mass of the ORPS was 2.74 g/cm³ as determined from procedures in standard NBR 16605 [12].

Table 1 presents the physicochemical characteristics of the agglomerate and ORPS while Table 2 presents the physical characteristics of the other aggregates. Chemical composition was determined from X-ray fluorescent

Table 1: Physicochemical characterization of white cement and ORPS.

	PROPERTY	CP B – 40	ORPS
CHEMICAL COMPOSITION (%)	Silicon Dioxide (SiO ₂)	17.47	48.38
	Aluminum Oxide (Al ₂ O ₃)	2.06	13.15
	Iron Oxide (Fe ₂ O ₃)	0.19	7.28
	Calcium Oxide (CaO)	64.96	12.74
	Magnesium Oxide (MgO)	0.39	4.00
	Sulfuric Anhydride (SO ₃)	2.95	0.08
	Sodium Oxide (Na ₂ O)	0.04	N/D
	Potassium Oxide(K ₂ O)	0.21	3.54
	Titanium Dioxide (TiO ₂)	ND	1.53
	Phosphorus pentoxide (P ₂ O ₅)	ND	0.87
	Manganese Oxide (MnO)	ND	0.09
	Loss to Fire (LF)	11.73	8.34
PHYSICAL COMPOSITION	Specific Mass (g/cm ³)	2.99	2.70
	Blaine Fineness(m ² /kg)	5.275	NA
	Start of Setting (min)	125	
	End of Setting (min)	175	
	Compressive Strength at 7 days (MPa)	49.30	
	Compressive Strength at 28 days (MPa)	62.20	
	D ₁₀ (µm)	NA	2.93
	D ₅₀ (µm)		8.70
D ₉₀ (µm)	23.19		
D _m (µm)	10.55		

ND = not detected, NA = not applicable.

Table 2: Physical characterization of aggregates.

PROPERTY	COARSE AGGREGATE (STONE WASTE)	FINE AGGREGATE (THICK SAND)	REFERENCE ABNT STANDARD
Specific Mass (g/cm ³)	2.77	2.59	NBR 16917:2021 [14] and NBR 16916:2021 [15]
Unit Mass (g/cm ³)	1.55	1.53	NBR 16972:2021 [16]
Abrasion Los Angeles (%)	15.44	–	NBR 16974:2021 [17]
Water Absorption (%)	2.34	0.33	NBR 16917:2021 [14] and NBR 16916:2021 [15]
Maximum Characteristic Dimension (MCD)	6.30	4.75	NBR 7211:2019 [18]

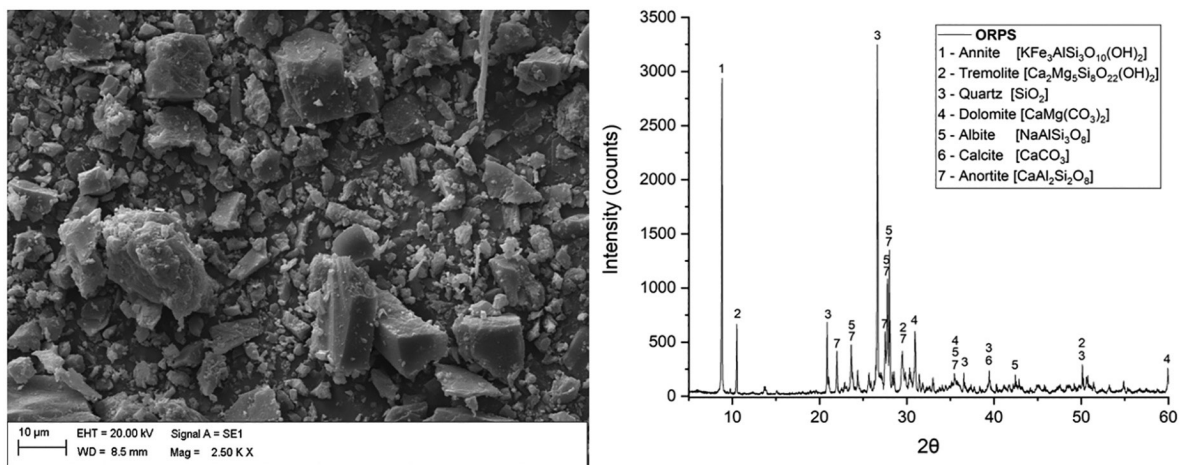


Figure 1: Morphology and mineralogy of ORPS.

spectrometry (XRF) with energy dispersion in a PANalytical apparatus model Epsilon 1. Samples weighed between 1 g and 10 g and were previously dried in an oven at $105 \pm 5^\circ\text{C}$. Figure 1 shows the morphological characterization (rough, irregular and lamellar particles) and the mineralogical characterization (predominantly quartz peaks) of ORPS as verified also by Ribeiro *et al.* [13]. The morphology was determined with a scanning electronic microscope (SEM) model EVO MA 15. Samples were carbon-metallized and analysis was conducted in a high vacuum with secondary electron detection of 20 kV. Mineralogical characterization was obtained from X-ray diffraction (XRD) in a PANalytical apparatus model Empyrean. The apparatus had a copper source with operating tension of 40 kV and current of 40 mA. The angular interval of measurement varied from 5° to 60° with a step of 0.0131° and time of 97.92 s at each interval.

The replacement contents of Portland cement with ORPS were defined as 0% (CG0), 5% (CG5), 10% (CG10) and 20% (CG20) by mass in order to maximize the incorporation of waste without interfering with the properties of the concrete. It was also decided to fully replace the conventional coarse natural aggregate with crushed recycled stone aggregate, ground first in a jaw crusher and later in a knife mill to achieve the desired granulometry.

To determine the initial mix ratio of the concrete, the IPT/EPUSP dosage method was used, where fixed data were defined in order to obtain the lowest possible porosity and ensure moisture level for an easier action of the additives: w/c ratio = 0.40, mortar content (α) = 60% and water/dry material ratio = 8.9%. The resulting mix ratio was 1:1.70:1.80.

To achieve a fluid, oozing and cohesive concrete, the Kantro mini cone test was used on pastes to define the ideal content of chemical additives. Furthermore, in order to standardize the slump of the formulations, half of the values of standard ABNT NBR 15823-2 [19] were used as an adaptation. The established spread was

Table 3: Specific mass of concrete and binder consumption with respect to replacement content.

CEMENT REPLACEMENT CONTENT	SPECIFIC MASS OF CONCRETE (kg/m ³)	CEMENT CONSUMPTION (kg/m ³)	ORPS CONSUMPTION (kg/m ³)	BINDER CONSUMPTION (kg/m ³)
0%	2,283	466	0	466
5%	2,310	452	24	476
10%	2,315	434	48	482
20%	2,354	401	100	501

Table 4: Evaluation methodology for granilite concretes.

TEST	AMOUNT		AGE (DAYS)	TOTAL SAMPLES	DIMENSION OF SAMPLES	REFERENCE ABNT STANDARD
	SAMPLES	TRAITS				
Axial Compressive Strength	3	4	7 and 28	24	4 cm × 4 cm × 16 cm	NBR 13279:2005 [22]
Flexural Tensile Strength	3		7 and 28	24	4 cm × 4 cm × 16 cm	NBR 13279:2005 [22]
Water absorption by immersion and Void Index	3		28	12	5 cm × 10 cm	NBR 9778:2009 [23]
Impact Resistance	2		28	8	60 cm × 30 cm × 2 cm	Adaptated from NBR 15575-3:2021 [24]
Stain Resistance	1		28	4	60 cm × 30 cm × 2 cm	Adaptated from NBR ISO 10545-14:2017 [25]

between 225 mm to 325 mm, classified as SF1 according to the standard ABNT NBR 15823-2 [19]. Gonçalves, Moura and Molin [20] reported that the addition of ORPS increased the cohesion and consistency of the mixture. Consequently, exudation decreased due to the effect of fine particles that acted as a physical barrier to the upward movement of water.

The contents of superplasticizer additive were set at 0.3% for mixture CG0 without cement replacement, 0.4% for CG5, 0.5% for CG10 and 0.7% for CG20. For all formulations, the viscosity-modifying additive content was set at 0.3% due to better spreading stabilization and the air disincorporating additive content was set at 0.8% as it provided less visible voids in the produced test bodies.

Table 3 shows the specific mass of concrete in the fresh state as determined from standard ABNT NBR 9833 [21] and consumption of main materials for production of concrete. It can be observed that, as cement replacement increased, there was a corresponding increase in the density of the concrete due to the filler effect provided by the waste.

The production of concrete was carried out in a vertical-axis planetary concrete mixer and poured into prismatic molds (4 cm × 4 cm × 16 cm and 60 cm × 30 cm × 2 cm) and cylindrical molds (5 cm × 10 cm) to form the necessary test bodies. The molds were covered with glass to prevent water loss, demolded after 1 day and stored in a humidity-controlled chamber until the tests presented in Table 4 were carried out. The prismatic parts were polished with a Diamax brand vertical wet polisher with diamond grinding wheels and sandpaper to the desired shine. The process was water-cooled to avoid dust lift off.

It was acknowledged that, in order to obtain the best flexural tensile strength results, a 4 point-test would be ideal. However, due to difficulties in testing equipment the procedure was conducted with 3 points for ornamental rocks and ceramics.

For the stain resistance test, the plates were polished with exposed grit to a smooth surface. Half of the plate was waterproofed with Repex Oleofugante for comparison with the other half without waterproofing. As no specific parameter was found to verify stain resistance in concrete, the method used in ceramics was adapted with the use of the following staining agents: toothpaste, lemon and olive oil. Four drops of each product were

applied at different points on the surface of each plate and left to act for one day. For comparison purposes, Branco Itaúnas granite slabs and Branco Nacional marble slabs were also evaluated. After staining, the granilite concretes were classified according to the ease of stain removal according to the classes recommended in the ceramic standard.

The cleaning methods applied were:

- a) clean the specimen with hot tap water for 5 min;
- b) clean the specimen manually with a weak cleaning agent (i.e. detergent);
- c) mechanically clean the specimen with a strong cleaning agent (i.e. multi-use soap cleaner);
- d) immerse the specimen in a solvent (i.e. butoxyethanol based stain remover) for 24 h, then rinse with tap water.

3. RESULTS AND DISCUSSION

3.1. Axial compressive strength and flexural tensile strength

The axial compressive strength is considered one of the most important properties of concrete in the hardened state and is the result of the quality of the constituent materials [26]. Figure 2 shows the mechanical strength values at 7 days and 28 days of age.

Figure 2 shows that the compressive strength increased with increasing ORPS content. Formulation CG20 had the highest average compressive strength at both ages when compared to the other concretes with an increase of 15.02% at 28 days with respect to formulation GC0 with no replacement. These results were in agreement with Rashwan *et al.* [11].

The increase in strength could be attributed to the filler effect of the sludge and the presence of silica reacting with calcium hydroxide ($\text{Ca}(\text{OH})_2$), which improved the microstructure of concrete [27, 28] and improved pore structure. The ORPS of this study contained 48.38% of silica, which could have contributed greatly to the gain in strength. Chemically, although ORPS was neither a pozzolanic or inert material, calcite and dolomite in it reacted with the C_3A phase of cement to form calcium carboaluminates, which provided a compact structure and improved concrete matrix bonds [8, 27, 29]. In addition, the porosity of the aggregate determined the stiffness and deformation of the matrix. Consequently, the recycled stone aggregate present also acted as a contributor to the increase in mechanical strength.

On the other hand, CG0 had the highest flexural tensile strength at 7 days and 28 days. As cement was replaced and OPRS content increased, there was a tendency of decreasing flexural tensile strength. The reductions at 7 days were of 5.99% for CG5, 14.03% for CG10 and 18.24% for CG20 with respect to CG0. However, these reductions were not as expressive at 28 days with 7.73% for CG5, 7.84% for CG10 and 10.22% for CG20 with respect to CG0. Divergent results with some studies [28, 30, 31]. This may have occurred due to

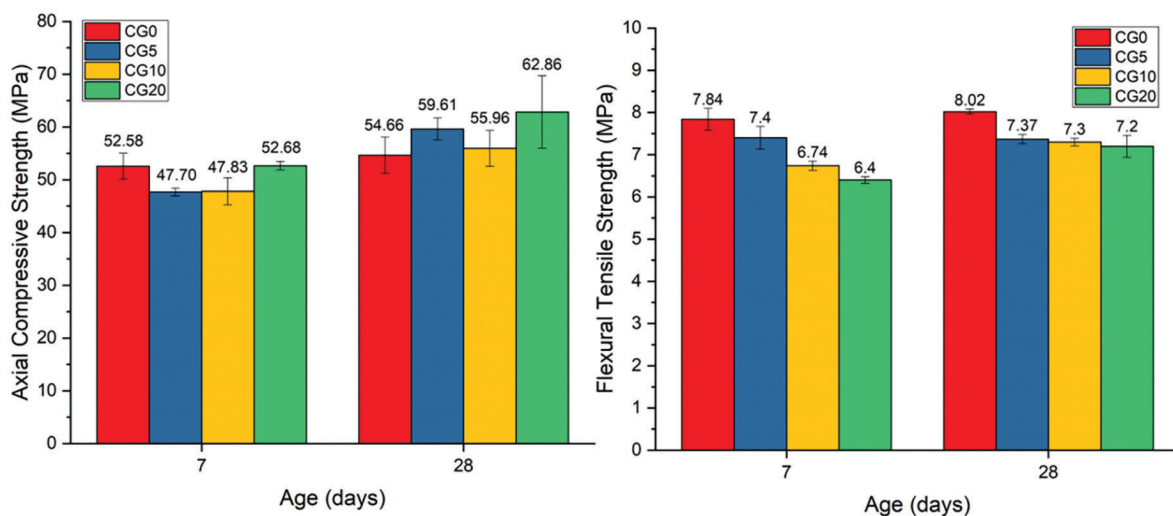


Figure 2: Axial compression and flexural tensile strength of concrete granilite.

Table 5: ANOVA for axial compressive strength e flexural tensile strength tests.

ANOVA: Axial Compressive Strength						
Source of variance	SQ	DF	MQ	F	P-value	Critical F
Between groups	37.3729	3	12.4576	0.3155	0.31548	0.81478
Within groups	157.952	4	39.488			
Total	195.325	7				

Significance: NO

ANOVA: Flexural Tensile Strength						
Source of variance	SQ	DF	MQ	F	P-value	Critical F
Between groups	1.46294	3	0.487646	3.953	3.95295	0.10872
Within groups	0.49345	4	0.123362			
Total	1.95639	7				

Significance: NO

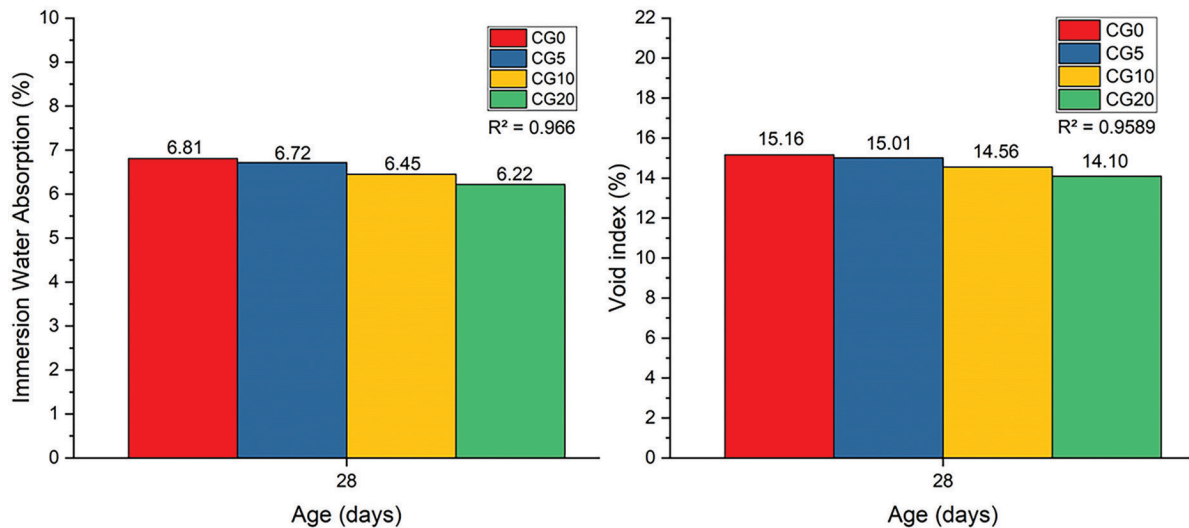


Figure 3: Water absorption and void index of granilite concrete at 28 days.

the adaptation of the method for performing the test. The fragile nature of concrete required an evaluation of this property to determine the crack load [10].



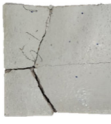


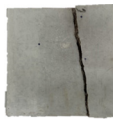


A statistical ANOVA analysis was applied for the different cement replacement levels by ORPS in relation to the aforementioned tests and the results are presented in Table 5. With a significance level of 5%, the analysis indicated that the substitution levels are not significantly different.

3.2. Water absorption by immersion

The mechanical properties of concrete are influenced by the porosity of the matrix, which is linked to the size and distribution of pores. In view of the results presented in Figure 3, it was noted that the absorption of water and the void index gradually decreased with increasing ORPS replacement, despite not observing a significant influence. There were maximum reductions in water absorption and void index of 8.67% and 6.99%, respectively, for CG20 compared to the reference concrete, suggesting a denser concrete matrix.

The reduction in water absorption was related to void filling by the fine aggregates of the sludge, which impacted the capillary pores of the concrete, as well as the low absorption of recycled stone aggregate. Open porosity was caused by excess water not absorbed by the aggregates and not consumed in the cement hydration reactions or by air trapped after the vibration compaction process. The decrease in water absorption values was in line with the results of Ghorbani et al. [32]. Additionally, Figure 3 displays a linear descending trend in which

Table 6: Impact resistance of granite concrete at 28 days.

SLUDGE CONTENT	50 CM				100 CM			
	IMAGE	BREAK ON IMPACT	NUMBER OF IMPACTS	CAVITY	IMAGE	BREAK ON IMPACT	NUMBER OF IMPACTS	CAVITY
0%		No	10	No		Yes	2	No
5%		Yes	7	No		Yes	4	No
10%		No	10	No		Yes	3	No
20%		No	10	No		Yes	4	No

increasing cement substitution with ORPS correlated to a positive effect in water absorption ($R^2 = 0.966$) and decreasing void index ($R^2 = 0.9589$).

3.3. Impact resistance

Impact resistance test results at 28 days are shown in Table 6. According to the results, samples did not show any dents from either 50 cm or 100 cm impact heights, so it was not possible to measure them. The CG5 concrete sample broke at a height of 50 cm (2.5 Joules) but only on the seventh impact, perhaps due to some substantial void caused by improper compaction. The other concretes did not show any damage, even after withstanding 10 impacts as per current regulations. This suggested that the concretes had higher tenacity with the sludge filler effect improving impact resistance behavior.



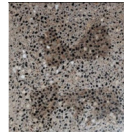


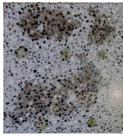

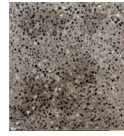


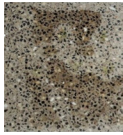
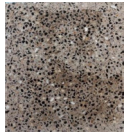
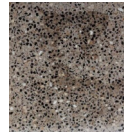

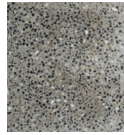





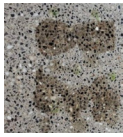


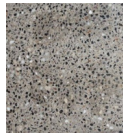
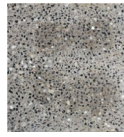
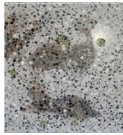









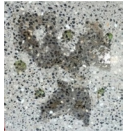

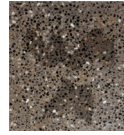







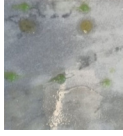

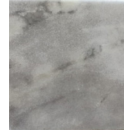
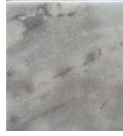

On the other hand, no sample withstood more than four impacts and all broke from an impact height of 100 cm (5 Joules). Thus, it was demonstrated that the plates had a considerable resistance to impacts from heights of 50 cm and, if necessary, reinforcement with metallic meshes or fibers could be incorporated to achieve better performance at 100 cm height.

3.4. Stain resistance

Table 7 shows that after 24 hours of application of staining agents on the polished surface of the plates, all granilite concrete, marble and granite plates suffered stains with and without previous waterproofing. Olive oil caused very dark stains and lemon juice caused light stains with or without waterproofing. On the other hand, toothpaste caused dark stains only on the surface without waterproofing. The stains on the marble and granite plates showed similarities. This might be due to the porosity of the plaques and their ease of absorption after many hours of exposure to staining agents.











Regarding cleaning methods, method “a” was able to remove only the stains caused by toothpaste and method “b” was not able to remove oil or lemon stains but attenuated them. Method “c” was efficient in cleaning waterproofed surfaces of the granilite concrete, leaving the stains barely visible. However, on granilite concrete, marble and granite surfaces without waterproofing, the tone of the stains only decreased slightly. Finally, method “d” did not present significant results in granilite concrete plates but removed most of the stains on marble and granite plates with just one application. Therefore, granilite concretes were classified as class 01, meaning impossible to remove stains with the products used while marble and granite plates were classified as class 02, considering that the solvent used proved to be effective.

Table 7: Spotting caused by staining agents and effect of cleaning methods.

CONTENT	WATER-PROOFING	AFTER STAINING	METHOD "a" _ HOT WATER	METHOD "b" _ NEUTRAL CLEANER	METHOD "c" _ MULTI-USE SOAP CLEANER	METHOD "d" _ BUTOXYETHANOL BASED STAIN REMOVER
0%	Yes					
	No					
5%	Yes					
	No					
10%	Yes					
	No					
20%	Yes					
	No					
M A R B L E	Yes					
	No					

(continued)

Table 7: (Continued)

CONTENT	WATER-PROOFING	AFTER STAINING	METHOD “a”_HOT WATER	METHOD “b”_NEUTRAL CLEANER	METHOD “c”_MULTI-USE SOAP CLEANER	METHOD “d”_BUTOXYETHANOL BASED STAIN REMOVER
GRANILITE	Yes					
	No					

4. CONCLUSIONS

The experimental results allowed the following conclusions:

- Concrete formulations with ORPS content showed greater cohesion and consistency and a decrease in exudation. Increasing the substitution content resulted in increasing cohesion;
- With respect to axial compressive strength, replacing cement with ORPS and using less porous recycled stone aggregate gave concrete a better performance compared to the reference concrete at 28 days. The improvement in strength could be attributed to the filler effect and bonding capacity provided by ORPS;
- Flexural tensile strength decreased with increasing ORPS content when compared to the reference concrete;
- With respect to water absorption by immersion and void index, all concretes with ORPS showed similar values to the reference concrete. This was attributed to the finer pore structure provided by ORPS and low absorption provided by the recycled stone aggregate;
- Granilite concrete plates better resisted impacts best up to a height of 50 cm;
- No cleaning method used in this study was able to clean the polished plates in granilite concrete without waterproofing. However, stains were attenuated on waterproofed plates with the use of a multi-use soap cleaner;
- Butoxyethanol-based stain remover was effective only on natural stone plates.

Therefore, the simultaneous replacement of coarse aggregates with recycled stone aggregate and up to 20% replacement of Portland cement with ORPS (selected as the ideal content) was demonstrated as viable from the mechanical properties point of view. Furthermore, environmental and economic viabilities were also confirmed since incorporating waste in concretes contributed to eco-efficient and sustainable development by conserving non-renewable natural resources, minimizing the inappropriate disposal of these wastes and reducing the cement industry's carbon footprint.

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