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Feasibility Analysis of Mortar Development with Ornamental Rock Waste for Coating Application by Mechanized Projection

Ana Luiza Paes [1], Jonas Alexandre [2], Gustavo de Castro Xavier [2], Sérgio Neves Monteiro [3] and Afonso Rangel Garcez de Azevedo [2,*]

1 Laboratory of Advanced Materials, State University of the Northern Rio de Janeiro, Campos dos Goytacazes 28013-602, Brazil; alcpaes@gmail.com
2 Civil Engineering Laboratory, State University of the Northern Rio de Janeiro, Campos dos Goytacazes 28013-602, Brazil; jonasuenf@gmail.com (J.A.); gxavier@uenf.br (G.d.C.X.)
3 Department of Materials Science, IME—Military Institute of Engineering, Square General Tibúrcio, 80, Rio de Janeiro 22290-270, Brazil; snevesmonteiro@gmail.com
* Correspondence: afonso@uenf.br

Abstract: The industrial production of lime generates greenhouse gases, which contributes to increase the global warming. Therefore, the present study evaluated the feasibility of replacing lime by ornamental rock waste (ORW) as a by-product of the related stone industry, and developed a cost-effective mortars. These new low-costing mortars are intended as fresh fluid paste coatings to be applied on walls by the mechanized projection technique. The ornamental rock waste was collected from a marble and granite industry as ground stone. It was finely crushed before mixing with cement, sand, water and superplasticizer in amounts of 1.0% (R01), 1.2% (R02) and 1.3% (R03), to prepare the mortars, which had the mixture, cement: ORW: sand, 1:1:4 in wt.%. These novel mortars were characterized in both fresh, for well projection, and hardened state, to evaluate the properties after curing performance. The results showed that mortar R03, achieved the best results and did not present cracks in the hardened state. Its water retention was found above 30%. Both tensile strength of 0.312 MPa and compressive strength 7.88 MPa, which are above the corresponding minimum required by the standard for external coating. Water absorption by immersion of 19.37% and void content of 20.23% were close to the corresponding values for hydrated lime mortar. Dry shrinkage showed that the new R03 mortar reached more than 90% of their total retraction at 7 days of cure without sign of cracking. These findings revealed the R03/ornamental rock waste -based mortar applied by mechanized projection as a promising sustainable substitute for common lime-based mortar.

Keywords: ornamental rock waste; projected mortar; construction

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1. Introduction

The civil construction sector accounts for approximately 10% of Brazil's gross domestic product [1]. In order to boost this growth in times of economic uncertainly, development of novel construction materials might be a solution to improve the process production and reduce costs [2]. Coating mortar, largely applied in all reinforced concrete carried out in Brazil, is a construction material with potential to be improved in a sustainable and cost-effective way [3]. Worldwide coating mortars are used, mainly, to protect the masonry, and represent a substantial cost to the total budget.

A conventional coating mortar is usually composed of cement, water, lime and fine aggregate. To optimize the coating mortar process and to achieve high performance in the building coating execution, a modern procedure is to use the mechanized projection method. Indeed, through this system it is possible to cover a substrate at a rate of $60/m^2$/day per worker, which is practically twice as much as would be achieved by conventional hand application [4]. For this reason, the interest in the use of mortars designed as an application system for these coatings has been increasing [5,6].The mechanized projection method, well established around the world, is an adequate solution to minimize the problems in the execution of internal and external coating of the buildings, by reducing human interference during the execution. So, it can be optimized by increasing productivity, and above all, improving the quality and gives uniformity to the coating [5,6]. There are variations of this method, for supplying the spraying equipment with fresh mortar. One system is known in Brazil as *canequinha* or compressed air spray. In more complex processes, there is a mixer coupled to the pump, so that the mortar is homogenized and sent directly to the pump from where it is projected to the substrate [4,5]. This last method was used in the present work.

According to Ribeiro et al. [5], an industrial company using this method can achieve a production up to 0.75 m^2/h, while the average used to be 0.42 m^2/h. With this in mind, a construction company of Campos dos Goytacazes, Brazil, chose this method and decided to replace the hydrating lime. However, it was observed the occurrence of cracks in the coating after drying and, as a reference regional center of study, the company came with this problem to be solved. The most common method of mortar application in Brazil, and in several countries with less industrialization of civil construction, is manual, which leads to higher costs and great waste. Thus, research involving the validation of mechanized projection is important in order to provide subsidies to the civil construction sector for the application of new technologies, which aim to provide greater rationality to the application of mortars. Currently, numerous companies have been using mechanized projection techniques in Brazil in order to increase their productivity. However there are still gaps related to the post-application condition of these mortars [6].

In order to mitigate such shortcomings, the present work has as its main objective to propose a new mortar mixture to be projected replacing the hydrated lime by ornamental rock waste (ORW), from Cachoeiro do Itapemirim, Brazil. There is a large amount of ornamental rock production worldwide, in the past six years, about 150 million tons were produced yearly, mainly in China, India, Turkey, Iran and Brazil [7,8]. China alone has produced in 2015 around 350,000,000 m^2 of marble, while the estimated export from Egypt is nearly 1,360,500 ton/year of stone, either processed or unprocessed [9,10]. In 2019 Brazil exported 2.16 million/ton [10,11]. The rock beneficiation process is divided into two stages: the blocks extraction and their beneficiation. According to Angelin et al. [12], in this last stage, the waste generation can reach 20 to 30% of the block volume. Furthermore, during the extraction of marble and granite, the loss can reach 60%, and this activity produces a fine dust that can cause health problems and damage the soil [10,11,13]. So, not only to reduce the consumption of hydrated lime, a material with high added value and a polluting production process, but also to decrease the amount of rock waste disposal at the cities, recent researches have incorporated this material into concrete, mortar, tile, pavement, and even used it for soil stabilization [10].

Some authors, such as Arce et al. [14], replaced lime by ornamental rock waste and concluded that, when finely ground, this type of waste gave mortars characteristics similar to those obtained with the lime used in fresh state. For Oliveira et al. [15], its use was interesting, since as a powdery material, there was an improvement in packaging. The choice to incorporate the ornamental rock waste into mortars contribute to mitigate the impact generated by its improper disposal. In this way, giving the ornamental rock waste an appropriate final destination by incorporating into mortars, the civil construction sector becomes more sustainable. In addition, its cost is about 90% cheaper than hydrated lime, being related only to its transport from one city to another [16]. The ornamental rock waste material had already been incorporated into self-compacting mortars and concretes by Corinaldesi et al. [17], who concluded that, owing to the waste high fineness, this material ensured cohesion and workability.

Other authors have studied the ornamental rock waste incorporation into mortar, Singh et al. [18], carried out an economic and environmental study of advantages of replacing cement by marble waste in concrete and produced three types of concrete. One type for reference and the other two with waste, from which they obtained compressive strength 20–25% higher than the reference mixture. The properties of porosity, resistance to abrasion and carbonation, as well as resistance to sulfates and water penetration, were found superior for the modified mixtures, which can be justified by the filler effect due to the use of marble waste. In addition, they also report that the marble waste can be used to replace hydrated lime, since this rock is classified as limestone and the waste has a chemical composition similar to lime. Amaral et al. [19] studied the partial replacement of sand by rock waste. The authors defined the mixture in 1:1:6, and replacement percentages between 9 and 21% in sand weight. They analyzed their properties in the fresh state (density, incorporated air content and consistency) and in the hardened state (density, flexural and compressive strength), and concluded that these mortars showed satisfactory results, being the incorporation of 21% of residue the most recommended one. Leite et al. [20] studied mortars with the substitution of sand for residue generated in the cutting and polishing of rocks, in proportions of 0%, 10%, 20% and 30%. The authors tested their properties in the fresh and hardened state and concluded that based on physical and mechanical properties that there was not significant modification with the different incorporation level of residue. However, the sample composed of 20 wt.% of cutting residue showed the best performance for being the only one with an appropriate consistency index. This amount of residue did not significantly change the other properties, except capillarity.

Based on these preliminary considerations, the objective of this research is to evaluate the potential use of ornamental rock waste to replace hydrated lime, in order to develop a mortar to be applied by mechanized projection. Although many researcher works have already evaluated this incorporation, to our knowledge, no work exists specifically for mortar to be used by this method and on how the mechanized projection modifies the mortar properties. Indeed, modifying one component alters the entire mixture and its properties, such as void index, water absorption by capillarity and immersion, as well as the compressive, flexural and tensile bond strengths. Consequently, affects the durability and applicability of mortars. The investigation on how mortars properties were modified due to the replacing the lime by ornamental rock waste, and the creation of a superplasticizer to be used in mortar with ornamental rock waste, generating a new material to be applied by the mechanized projection method, is for the first time performed. It is also noteworthy that there are limited studies regarding the application of mechanized mortar with the addition of solid waste. Indeed, this collaborates in two ways for sustainability, either in the reduction of waste at the time of application, or in the reuse of other solid waste that would be discarded. This complementary approach will certainly fulfill a gap in the main studies already carried out.

2. Materials and Methods

It is important to highlight that for projection application, some mortars characteristics in the fresh state must be different from those used in the conventional application method. The main one being the workability. This can be defined as the material fluidity, i.e., the ability of the mass to flow or spread over the substrate surface [19]. The fluidity required for the projection will depend on the corresponding equipment used. For this purpose, a sample of mortar used by a construction firm in the region of Campos dos Goytacazes, Brazil, was collected and its workability was defined by the consistency index. This test consists of molding a conical trunk with fresh mortar and, after 30 drops on the consistency table, measure its spread [20].

Once this index was determined, the workability was kept constant using the same consistency index in all mixture. Then, the amount of water and proportion of additive, which, each mortar should have as reference consistency index was defined [21].

In addition to develop a mortar suitable for projection without cracks, a mortar with ornamental rock waste and an additive developed at our laboratory, were tested for the creation of a novel and sustainable product. In order to analyze whether the materials are economically viable substitutes for hydrated lime, a cost-effective study was carried out. For that, Table 1 presents a comparison made in three commercial centers at Campos dos Goytacazes to estimate the hydrated lime CH-III price. The only cost related to the ornamental rock waste is its transportation from the city of Cachoeiro do Itapemirim to Campos dos Goytacazes, both in the southeast of Brazil.

Table 1. Price of hydrated lime and ornamental rock waste.

Material	Building Material	Quantity (ton)	Price (U$)	Average Price
Hydrated lime CH III	1	1	80.00	90.00
	2	1	92.00	
	3	1	98.00	
Ornamental rock waste	-	1 1.5	14.70	14.70

The cement used in this work was the same used as the reference mortar, CPIII-40 RS [22], purchased from the same batch so that there was no variation in the constituents percentage (clinker + calcium sulfate, blast furnace slag and carbonate material).

The small aggregates selected for mortars manufacture came was quartz sand extracted from the bed of the South Paraíba River, with a maximum diameter of 2.4 mm [23].

The ornamental rock waste used (Figure 1a) was collected from Decolores, an ornamental rock processing industry, located at Cachoeiro do Itapemirim. To be applied in this study, the ornamental rock waste was first dried naturally in the sun to remove excess moisture and then placed in a greenhouse (Sterilife brand, Brazil) at 60 °C during 72 h. Completely dry, the waste was crushed and passed through the ASTM 50 sieve (Figure 1b). Corinaldesi et al. [17] characterized Italian marble waste and observed that these were mainly composed of calcite (60% calcium carbonate—$CaCO_3$), while Vardhan et al. [24] studied Indian rocks, and concluded that they were composed of 40.73% CaO and 15.21% MgO. This indicates that the waste chemical composition will depend on the region of origin of the rock from which it was extracted [25].

(**a**) (**b**)

Figure 1. Ornamental Rock Waste (**a**) in the ornamental rock industry with humidity, (**b**) dry and passed at #50.

Figure 2 shows a flowchart that demonstrates the experimental steps of this research.

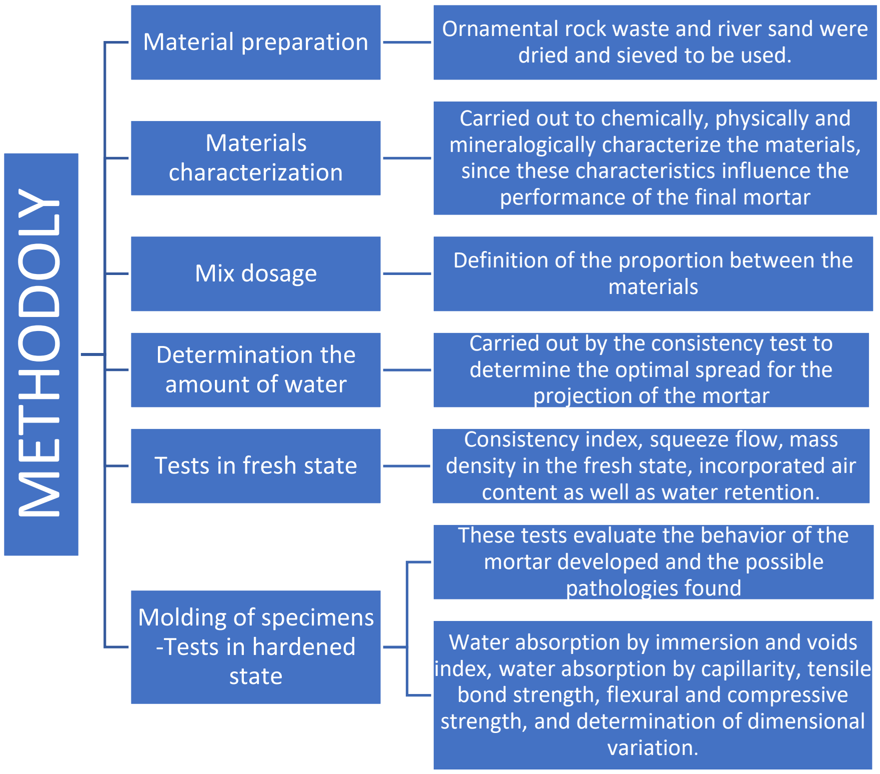

Figure 2. Experimental flowchart of the steps developed.

To increase the mortars workability without adding large proportions of water, and thereby decrease the likelihood of cracking, a superplasticizer additive was developed at our Laboratory of Non-Conventional Materials of the State University of the North Fluminense, in Campos dos Goytacazs), to be added in ornamental rock waste mortars, in order to create an entirely new material. Due to the percentage of fine particle size, which allows the waste to act as a filler and improve packing by reducing the voids left by the other two components, the requirement of water increases as the amount of ornamental rock waste in samples is enhanced [26]. Therefore, superplasticizers are used to achieve the required workability [23], since it is a projected mortar, and workability needs to be superior to the conventional ones.

First of all, the ornamental rock waste characterization was carried out using granulometric analysis [27], dispersive energy X-ray fluorescence (EDX), X-ray diffraction (DRX) and scanning electron microscopy (SEM). The EDX aims to determine the oxides percentages present in the analyzed materials using a Shimadzu EDX-700 equipment. The DRX determines the crystal atomic and molecular structure, in samples using a Rigaki MiniFlex 600. The SEM reveals the particle morphological analysis in a Shimadzu SSX-50 Superscan equipment, Japan. These tests were made concurrently with the consistency test [28], to determine the ideal amount of water for the desired workability.

Once the components have been characterized, their dosage was set for the reference mortar, with design mix of 1:1:4, obtained at the aforementioned construction site, have shrinkage cracks after drying. It contributes to find the consistency index determination to be used to maintain a fixed workability of 310 $\pm$ 5 mm. As mentioned before, this is one of the most important characteristics in a mechanized projected mortar, as it allows the material to flow through the projection pump hose without clogging or disaggregation between the paste and aggregates.

With this in mind, the reference mortar was subjected to the consistency test [28], where it was molded in a conical trunk. After performing 30 drops the spreading was measured. The more fluid the material, the greater this spread and consequently the consistency index. The value found was 310 $\pm$ 5 mm, which is higher than the limit established by NBR

13276 [28]. However, the standard value must be disregarded, considering that it applies only to conventional mortars.

With the known spread, it was possible to determine the amount of water and the percentage of additive that would be used in each mix, as shown in Table 2.

Table 2. Consistency index and water/dry materials ratio.

Sample	Consistency Index	Water/Dry Materials	Additive (%)
Hydrated lime	310	0.189	1.0
R01	314	0.199	1.0
R02	310	0.197	1.2
R03	315	0.192	1.3

As the aim of this work was to develop a mortar with ornamental rock waste to be applied in a mechanized projected way and within the parameters of the Brazilian standard, it was tested in the fresh and hardened state. With the amount of water and superplasticizer known, the mortars were molded following the NBR 13276 [28] procedures and tested by the fresh state for squeeze flow [29], mass density in the fresh state and the incorporated air content [30] as well as water retention [31]. Like the consistency index, the squeeze flow test is used to determine workability. It was carried out in a universal EMIC press, and consists of compressing the sample between an upper plate, which will apply load to the material and has the same diameter as the initial sample, and a lower plate, which has at least twice the sample initial diameter. The sample is placed and spread when the test is started [32,33].

The mass density test in the fresh state is applied to determine the mortar weight at the application moment. This test is important in situations where the mortar is mechanized projected into the substrate and also to determine the incorporated air content. This characteristic affects its workability, and corresponds to the amount of air existing inside the mortar, expressed as a percentage [34]. The water retention property is related to the mortar's ability to retain water in the fresh state, maintaining its workability or consistency when subjected to conditions that cause water loss [35]. Properties such as mechanical strength, adhesion and durability are influenced by this characteristic [36].

For hardened state parameters, the mortars were molded according to NBR 13279 [37] and their parameters analyzed. These were water absorption by immersion and voids index [38] as well as water absorption by capillarity [39], tensile bond strength [40] and determination of dimensional variation [41]. In addition the flexural and compressive strength, were both obtained in the universal EMIC press. The speeds to perform each test, flexural and compressive strength, was respectively, 50 ± 10 N/s and 500 ± 50 N/s. The compressive strength is statistically associated with the ability to resist surface abrasion, traction, impact and shear, being representative of the others. The water absorption tests by immersion and capillarity are related to coating durability. The first simulates exposure to rain, excessive humidity, and action from coating washing and cleaning. While the capillarity absorption is related to the pores present on the coating surface. The tensile bond strength is the mortar's ability to remain fixed to the substrate when normal and tangential stresses are imposed, without breaking. Its test consists of using a continuous load application equipment to pull the mortar paste from the coating. The shrinkage determination in the mechanized projected mortars is important due to the more fluid consistency of this material and its greater propensity to cracks appearance. The drying shrinkage begins on the coating surface and moves towards its interior, generating tensions and, at the moment when the humidity begins to decrease, the drying rate is not uniform [42].

3. Results and Discussion

3.1. Physical Characterization

Granulometric curve, presented in Figure 3, shows that ornamental rock waste grain size curve, in red, had 95% of its fraction smaller than 0.075 mm, similar to the characteristics of hydrated lime, pink curve, (97% fines content), facilitating the substitution by this material. The specific mass was also defined, using NBR NM 52 [43], resulting in a value of 2.48 g/cm^3 for the ornamental rock waste, approximately equal to that found by Vardhan et al. [24], 2.60 g/cm^3, meanwhile the results found for hydrated lime were 2.27 g/cm^3.

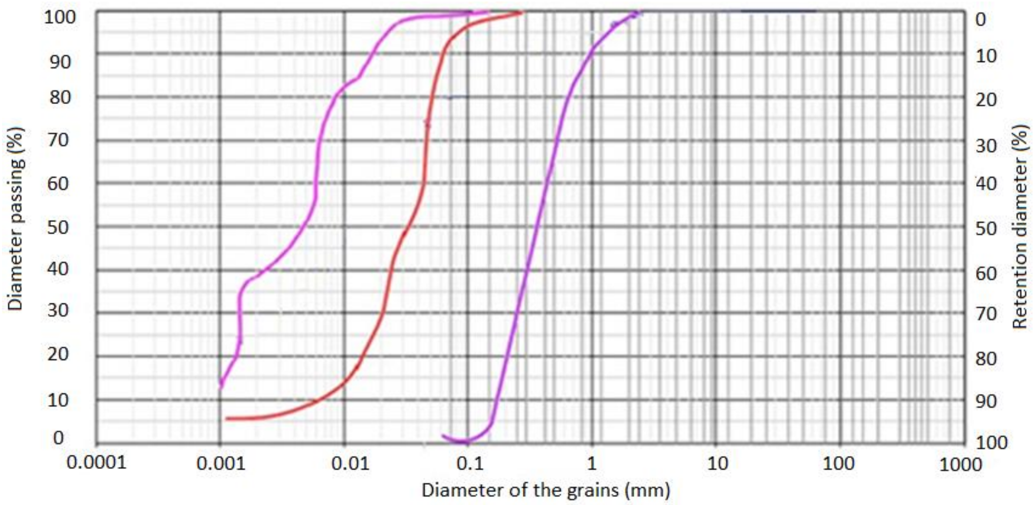

Figure 3. Granulometric curves: hydrated lime in pink, ornamental rock waste in red and sand in purple.

3.2. Chemical and Microstructural Characterization

By the chemical characterization it was observed the presence of 76.34% of SiO_2 and 12.49% of CaO in the ornamental rock waste, close to those found in the literature [16,44–46], while lime is mostly composed of CaO, around 93.43%. In the mineralogical analysis of ornamental rock waste, the predominant minerals were quartz and dolomite, showing good correlation between the chemical analysis performed and studies previously carried out on these materials [8,12,18,20,24,45]. Lime is predominantly composed of portlandite and calcite [46]. Thus, based on chemical and mineralogical characterization, the ornamental rock waste might be an effective substitute hydrated lime.

The microstructural characterization, Figure 4, also reveals similarity between hydrated lime and ornamental rock waste. Both ornamental rock waste and hydrated lime have grains of similar texture in terms of particle size and pore size. Although the shape of its grains is a little different, the lime presents rounder and more homogeneous particles while the waste elongated and irregular grains due to the industrial processing [3,47]. Furthermore, the ornamental rock waste presented a rough surface in many of its particles, as also observed by Lozano-Lunar et al. [48]. The fact that sizes and shapes of hydrated lime and ornamental rock waste are similar, it is believed that the replacement of lime by the ornamental rock waste will not impair at the mortars properties, as could be seen in the following tests.

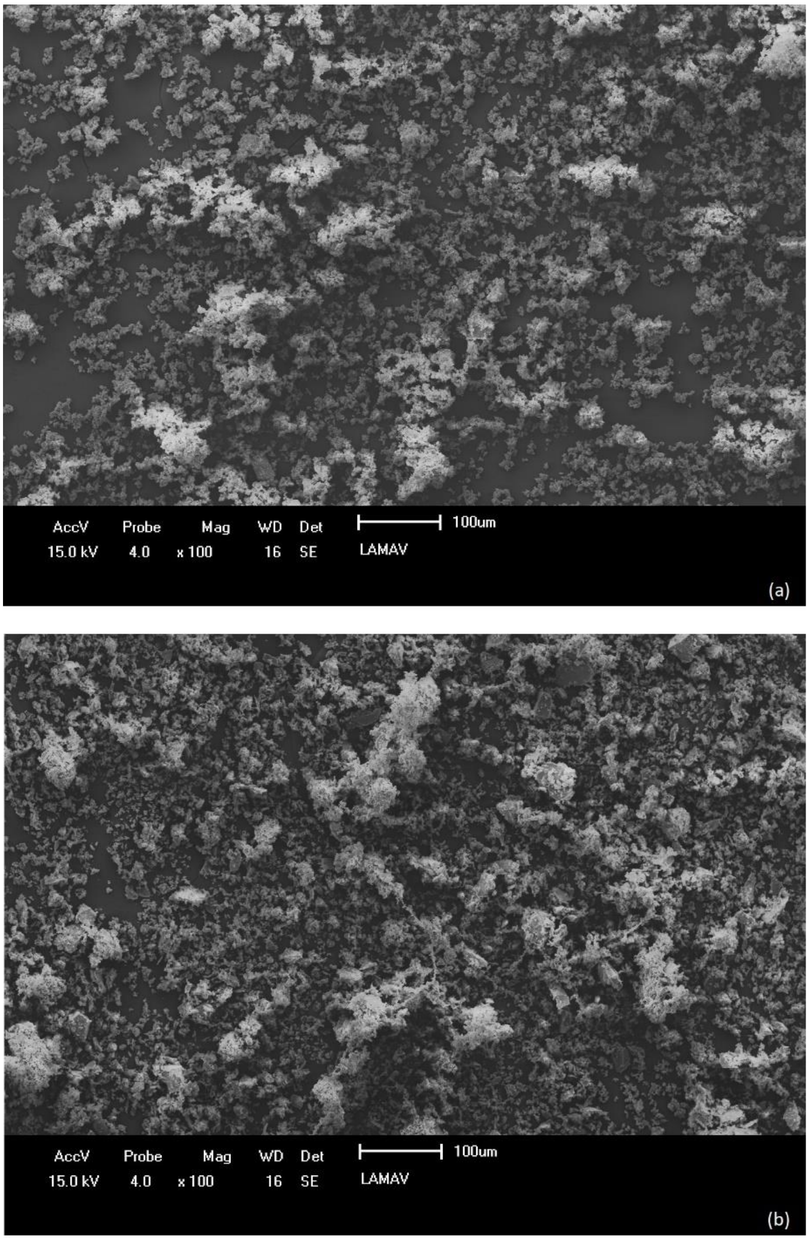

Figure 4. SEM of: (**a**) hydrated lime, (**b**) ornamental rock waste.

3.3. Fresh State Tests

The results obtained in the squeeze flow test [30] are presented in graphs of load x displacement. For this purpose, they are first compared with the reference graph presented in Figure 5. This graph is divided into 3 regions or phases. In region I the material behaves as a solid and has linear elastic deformation. In region II there are intermediate displacements, and the material will flow with plastic or viscous deformation. In phase III there is a significant increase in the load to continue with the material deformation, characterizing the restricted flow of the material, because the frictional forces are predominant, being this stage of great deformations.

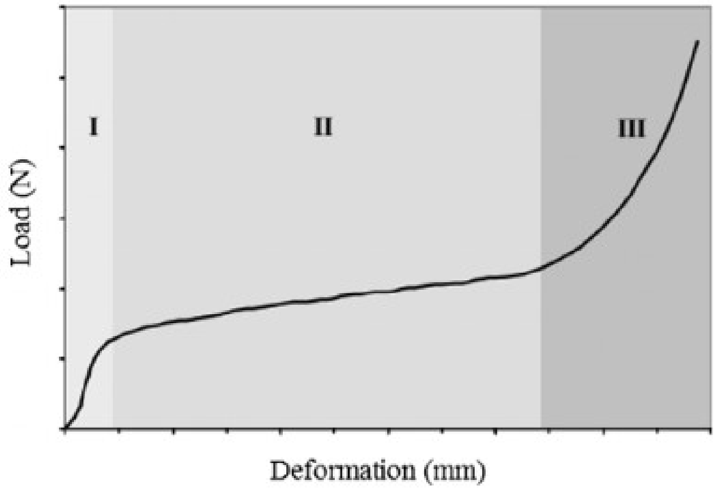

Figure 5. Typical profile load x deformation a squeeze flow test [19].

Each developed mortar in Figure 6 has a specific and unique curve, and comparing them and Figure 5, it is possible to define the most workable ones. The lower the load obtained to reach the same displacement, the less viscous the material is, i.e., the more workable [49]. So, it can be said that these mortars have a predominant stage II. The test was performed at a displacement 3 mm/s speed, with a stop criterion of either 1000 N or 9 mm of displacement, whichever came first. Observing the graphs of Figure 6, for the displacement of 4 mm, the mortar R01 needed a larger load than the others to reach this mark. Therefore, it is considered the least workable among the studied mixtures. All the mortars developed presented curves similar to hydrated lime, concluding that their workability showed also be close. Therefore, it is possible to be replace lime by ornamental rock waste. Of the three regions that are presented in the typical curve of Figure 5, these mortars in Figure 6 have a significant stage II, which means that they will have a higher deformation without a significant increase in strength [50,51].

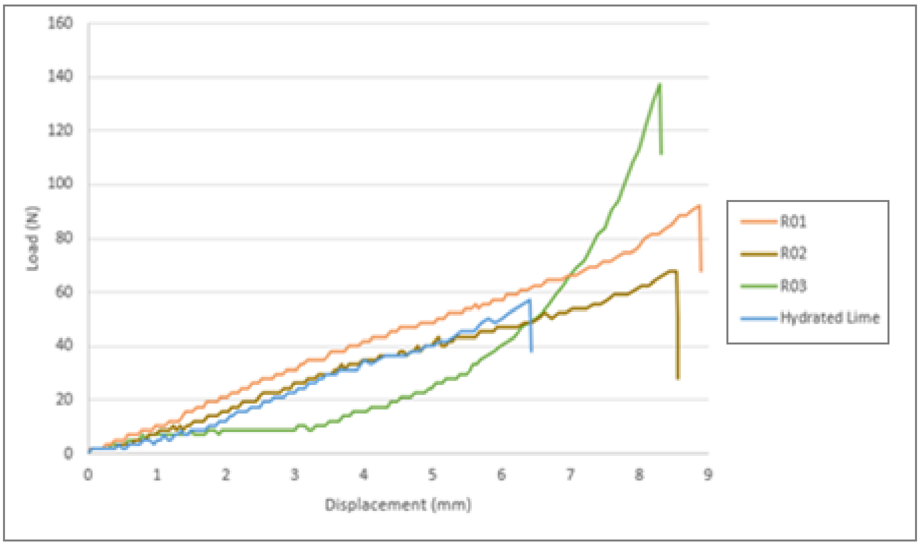

Figure 6. Load x displacement curve of the mixtures developed in this study.

As discussed by Ashish [52] and required by the ASTM standard [53,54], when a material is replaced by another with a larger specific surface, such as cement for ornamental rock waste, the workability of the material decreased, due the specific surface of the waste be higher than that of the cement, generating greater friction between the grains. On the contrary, when a material with a low specific surface is replaced by one with a smaller surface, as sand being replaced by waste, the workability increased, due to fine filler effect of ornamental rock powder. Therefore, the workability was not affected by the incorporation of the ornamental rock waste replacing the hydrated lime, since their grains have similar morphology, and also their specific surface.

Table 3 provides some results of properties of the different mortars in the fresh state. Mortars composed of ornamental rock waste presented a higher mass density when compared to those produced with lime. This result was already expected, considering that the mass density of the residue found was around 2.49 g/cm^3, which is higher than the hydrated lime, 2.27 g/cm^3, according to results mentioned in the literature [7,8,30,36].

Table 3. Fresh state parameters for the developed mortars and hydrated lime.

Parameters	Samples			
	R01	R02	R03	Hydrated lime
Density mass (g/cm^3)	1.954	1.971	1.963	1.366
Incorporated air content (%)	9.35	8.67	8.93	9.50
Water retention (%)	92.259	91.154	91.935	97.000

The incorporated air content is a property with a direct influence on workability. The higher this parameter, the greater the workability and the greater the time the material remains workable, resulting in less effort to handle the mortar, and higher productivity. Therefore, comparing Figure 6 with Table 4, it can be said that the more viscous the mortar the less is the incorporated air content, although the values found are close to each other. Thus it is difficult to say how much this property influenced the others. Knowing that the Brazilian standard does not establish a range of incorporated air content, this result was compared to the literature [53], which indicates that it should be between 2% and 7%, so all the values found are slightly above the recommended by the bibliography. Nonetheless only this result is not enough to validate or discard the mixtures.

Table 4. Results of water absorption by immersion, voids content and capillarity coefficient for the developed mortars and hydrated lime.

Sample	Water Absorption by Immersion (%)	Voids Content (%)	Capillarity Coefficient (g/dm^2·$\sqrt{\text{min}}$)
R01	16.942	17.529	5.452
R02	17.054	17.857	5.846
R03	16.002	16.924	4.767
Hydrated Lime	15.350	16.599	6.800

Regarding water retention, a property that prevents excessive water loss, guaranteeing the workability and complete cement hydration, the Brazilian standard does not stipulate a minimum value. Thus, 90% was adopted according to ASTM C270 [54] and Azevedo et al. [21], reaching the conclusion that the replacement of lime by ornamental rock waste did not influence this characteristic [36].

3.4. Hardened State Tests

A hydrated lime mortar was produced at our laboratory as a reference index's for comparison, and obtained a water absorption by immersion of 15.35%, lower than the three values found in the developed mixtures, although R03 has reached values similar to that of lime [55–57]. From the analysis of this parameter, there was no significant change due to the replacement, a fact explained by the proximity between the granulometries and fine particles found in the rock residue, leading to better packing by the filler effect [17,18,24,58,59].

It is known that the water absorption by immersion and the void index are interconnected. As the absorption tends to increase, the same happens for the void index, evidenced in Table 4. The resulting void indices were compared with that reported by Azevedo et al. [3], and the mixtures developed were below the limit established by these authors. The slight increase in the void ratio was due to the introduction of an inert material replacing one of the mortar's binders. Thus, its contribution is only for the filler effect and not for the development of hydration products [20].

Regarding the water absorption by capillarity, it concerns the capillary pores that are on the coating surface, being its determination important since it is the most effective means of pathological and aggressive agents to penetrate the mortar. Fine particles as ornamental rock waste can be used to reduce void-filling, triggering the reduction of water absorption by capillarity [20]. The capillarity coefficient of R03 mixture in Table 4 displays the best result among the three ornamental rock waste mixtures analyzed. Finally, none of the mortars studied were above the limit established by the literature [1,20,37].

In order to optimize the tests time, the mixtures developed were mechanized projected on the substrate and the cracks appearance was observed, as shown in Figure 7. Despite the appearance or not of cracks being one of the acceptance criteria for the mortars developed, all of them were tested in the hardened state, even those that presented this pathology. Thus, it was possible to analyze whether the mortars with cracks also had other properties affected [55,56].

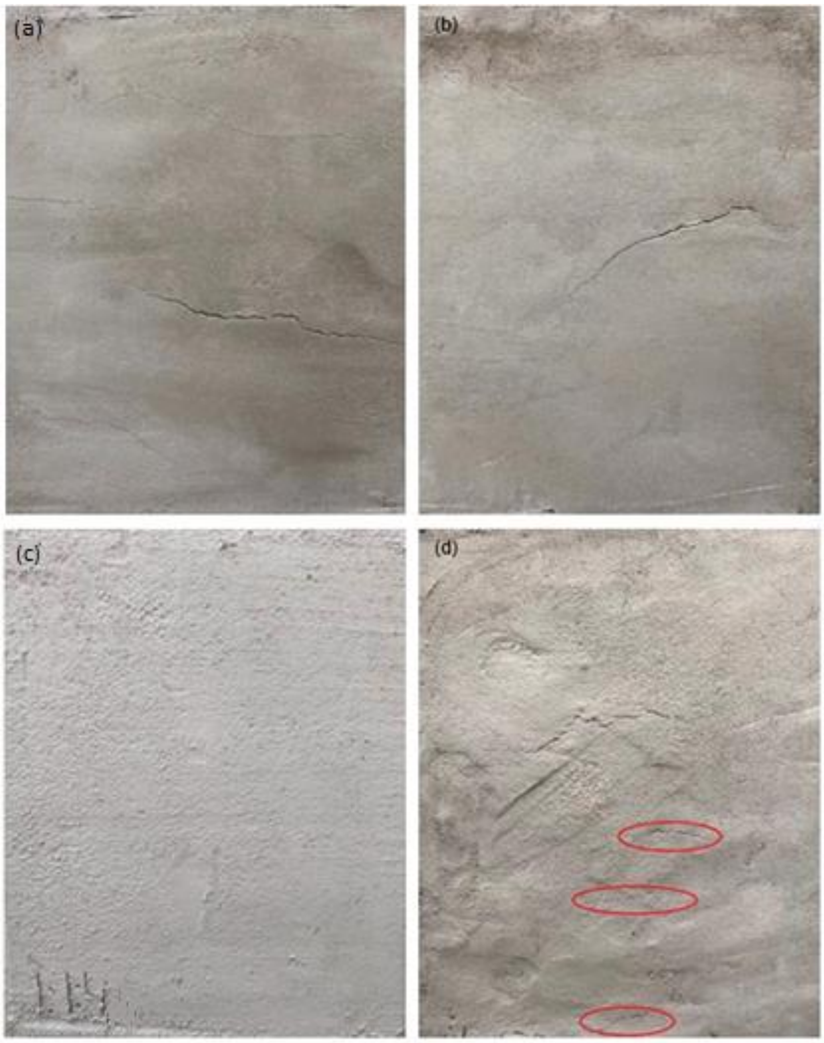

Figure 7. Visualization of cracks presence (red circle). Mixtures: (**a**) R01, (**b**) R02, (**c**) R03, (**d**) Hydrated Lime.

The samples R01 and R02, Figure 7a,b presented a small incidence of cracks, however their amplitude may cause problems. Mortars composed by hydrated lime showed small cracks in greater quantity, while the R03 mixture did not show cracks at all. Although all mortars have the same workability range, sample R03 has a higher percentage of superplasticizer in its composition, thus reducing the amount of water present. The appearance of most cracks was observed when the coating was not fully hardened, configuring the so-called plastic shrinkage, which occurs by the rapid evaporation of the kneading water before the end of the setting and results in a superficial cracking [57,58].

The values found in flexural and compressive strength, Figure 8, were compared with the results of Kamani et al. [36], since the Brazilian standard does not establish minimum limits for these two parameters. Comparing the results obtained with [36], which indicates a minimum of 1 MPa, all the mortars studied showed results above the minimum established, although the R01 and R02 mortars reached the lowest values, the others compositions presented acceptable results. Analyzing the compressive strength, mortars R02 and R01 showed close averages, followed by the hydrated lime and finally, mortar R03. The mixtures containing 1.3% of additive, R03, are above the expected average [7,36,59].

According to NBR 13529 [41], to be used as an external coating, the minimum bond strength that mortar must have is 0.30 MPa and as internal, 0.20 MPa. Therefore, observing Figure 8, only the mixtures R03 and hydrated lime can be used as an internal and external coating, since the other two are below the value of 0.30 MPa, thus they can be used only as internal coating. In the mortars with ornamental rock waste, the flexural strength remained practically constant, as well as the tensile bond strength, while the compressive strength improved in the R03 mix and decreased in the R01 and R02 mortars. The only variation between the developed mortars is the amount of water in the mixture, thus it was responsible for the variation found in the strength.

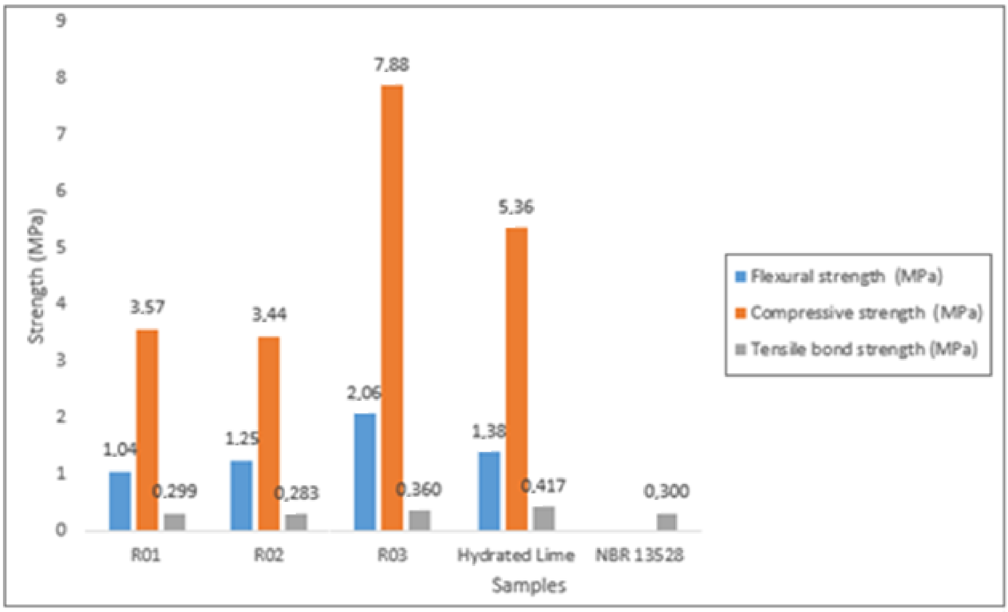

Figure 8. Average flexural strength, compression strength and tensile bond strength.

Due to the existence of cracks, the dimensional variation test [42] was performed, and the curve with its results was plotted in Figure 9. Ornamental rock waste mortars reached 90% of their total retraction at 14 days, while the curve stabilization of hydrated lime occurred around 9 days. The shrinkage found in the dimensional variation test can be correlated to the appearance of cracks in recent aging times observed in the coatings [60].

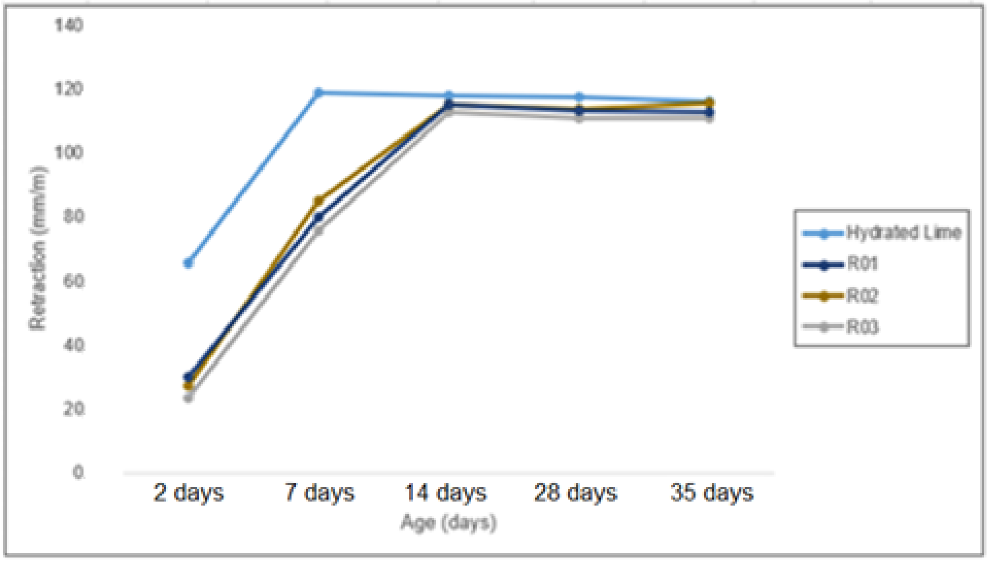

Figure 9. Dry shrinkage (mm/m) x age (days).

4. Conclusions

The material characterization showed that ornamental rock waste () is an advantageous substitute for hydrated lime, since its granulometry is closer to the lime as well as its microstructural composition. Concerning the mechanized projected mortars, workability is a fundamental characteristic for this process to occur correctly, being fixed in this specific case, according to the consistency index, at 310 ± 5 mm. It is influenced by the amount of water and additive in the mixture, incorporated air content and water retention.

The visual cracks analysis showed that among the three mortars developed; only one did not present this pathology, the sample that had the lowest water/dry material ratio. This shows that, although water increases the workability, in excess it affects others properties, such as the coating durability. From the results of dimensional variation, it was observed that all mortars showed a similar process of retraction, although R03 with 1.3% ornamental rock waste had the smallest retraction.

There was an increase in the mass density in the fresh state, of approximately 16%, in all developed mortars with ornamental rock waste in relation to hydrated lime mortars. The incorporated air content was around 9% and the water retention above 90%, following to the adopted values from literature [36].

In relation to the hardened state parameters, the R03 mortar presented a greater performance than the other two mortars, R01 and R02, mainly in the mechanical strength, being approximately 50% above the obtained values. Regarding the capillarity water absorption test, the three mortars, presented good coefficients, close to the values found for the hydrated lime mortar of 6.800 $g/dm^2 \cdot min^{1/2}$. For the void index and water absorption by immersion, the ornamental rock waste incorporated mortar presented values that were approximately the same as lime mortar.

Therefore, it can be said that among the developed mortars, the one that presented the best performances, did not show any cracks, and its workability was in accordance with that required by the projection equipment, was the R03. Thus, with all the arguments presented, the ornamental rock waste studied at this work can replace hydrated lime by mechanized projected mortars in a satisfactory way. These results corroborate other studies on the feasibility of using this waste in mortars for coating. Moreover, they fills an important gap regarding the validation of the condition of mechanized projected application, giving a strong reduction of time, cost and waste in civil construction, contributing to make mortars more sustainable. Thus, this research complements other studies in the literature and advances clearly in this field, aiming at a real and practical application for the industries of the sector.

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