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Fresh, hardened and thermal properties of coating mortars containing mineral additions and vermiculite

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ABSTRACT: Efforts are made to alleviate thermal problems in buildings. The use of thermal mortars for coating with vermiculite as aggregate is used for this purpose, but the use with mineral additions is still scarce, especially the rheology through squeeze-flow. Thus, it was aimed to evaluate the behavior in fresh, hardened state and in the thermal conductivity of these mortars. Mortars containing Portland cement, lime, vermiculite, sand, and additions of metakaolin or ceramic brick waste, in the proportion of 1:1:6 (Cement: Lime: Sand), were evaluated. The sand was replaced by vermiculite in 40%, and the additions added in the proportion of 20% to the cement mass, and the water content determined with the spread obtained on the consistency table. Mixtures containing 20% mineral addition and 40% vermiculite proved to be feasible, reaching minimum values according to the respective standards.

KEY WORDS: Thermal mortar; Vermiculite; Mineral additions; Rheology; Squeeze-flow.

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RESUMEN: *Propiedades térmicas, frescas y endurecidas de morteros de revestimiento con adiciones minerales y vermiculita.* Se realizan esfuerzos para paliar los problemas térmicos en los edificios. Para ello, se utilizan morteros térmicos para revestimiento con vermiculita como árido, pero su uso con adiciones minerales es aún escaso, especialmente la reología por squeeze-flow. Así, se pretendió evaluar el comportamiento en estado fresco y endurecido, así como la conductividad térmica de estos morteros. Se evaluaron morteros conteniendo cemento Portland, cal, vermiculita, arena y adiciones de metacaolín o residuos de ladrillos cerámicos, en la proporción 1:1:6 (Cemento: Cal: Arena). La arena se sustituyó por vermiculita en un 40%, y las adiciones se añadieron en la proporción del 20% a la masa de cemento: el contenido de agua se determinó para la obtención de una consistencia similar. Las mezclas que contenían un 20% de adición mineral y un 40% de vermiculita demostraron ser viables, alcanzando valores mínimos de acuerdo con las normas respectivas.

PALABRAS CLAVE: Mortero térmico; Vermiculita; Adiciones minerales; Reología; Flujo de compresión.

1. INTRODUCTION

Thermal insulation materials are of great importance today in terms of thermal energy conservation in buildings. One of the important parameters for this type of material is thermal conductivity, which is highly related to the porosity of the materials or composites. Porous materials, such as lightweight aggregates (LWA), are characterized by open pores and high water absorption. The use of LWA in cementitious composites influences the property of thermal conductivity, because the air trapped in the pores reduces the absorption and transfer of heat inside the material (1). Thus, a high porosity is desired to produce a material with low thermal conductivity value.

In order to achieve thermal insulation parameters, LWA such as vermiculite, perlite and expanded polystyrene have been incorporated as partial replacement of sand in cementitious mortars (2). Vermiculite presents a lamellar structure, favoring the formation of voids in its interior, that is, it is a product with internal porosity and low density, high resistance to fire and strong sound absorption (3). Besides this, it results in products that are incombustible, biostable, neutral to the action of acids, and that have stable resistance over time and resistance to deformation. Based on this, several studies (2, 4-9) have investigated the use of vermiculite in mortars in order to contribute to thermal comfort in building environments and concluded that there are significant improvements in thermal properties.

In studies of the thermal properties of mortar with vermiculite, it was observed a reduction of up to 82% in its thermal conductivity with total replacement of aggregate by vermiculite, while this value decreased to 54% when the aggregate replacement was 50% (8). A reduction in thermal conductivity was also obtained with increasing vermiculite/cement ratio, analyzing the ratio of 6 and 8, the attenuation was approximately 28% and 58%, respectively (3).

The use of vermiculite in mortars reduces its density, and consequently, its mechanical strength, thus, the use of mineral additions can contribute positively in this property, since it will be possible to strengthen the existing transition zone. It is possible to notice the refinement of mortar pores through mineral additions, and the reduction of pores of larger volume in mortars with these additions. This reduction becomes more significant when the addition presents pozzolanicity (10). The pozzolanic reaction also improves the quality of the aggregate-matrix transition zone, resulting in gains in the performance of properties related to mechanical strength and durability.

Meanwhile, nano metakaolin was incorporated into white Portland cement and vermiculite mortar in order to improve its mechanical performance. With the replacement of 70% in volume of cement by nano metakaolin it was possible not only to obtain a better mechanical performance, but also to minimize capillary absorption of the composite (7).

Moreover, it was observed that the microstructure of LWA, by presenting more pores and broken particles during mixing, changes the proportion of water needed to achieve an adequate consistency (5). Moreover, the addition of LWA significantly conditions the properties of the paste product, making it necessary to increase the amount of water when increasing the amount of vermiculite in order not to compromise the workability of the mortar (11). At the same time, analyzing mortars with vermiculite/cement ratio, in volume, 4, 6 and 8 required water consumption of 540 Kg/m³, 557 Kg/m³ and 569 Kg/m³, respectively (3).

In general, it is observed in some works that the incorporation of expanded vermiculite in mortars results in greater water retention and viscous behavior, and consequently, less spreading (2, 3, 5, 7, 9, 12). This behavior probably occurs due to the smaller amount of fines present in the granulometry of expanded vermiculite (13).

The use of vermiculite in mortars strongly influences its fresh and hardened properties and depending on the treatment that is made in vermiculite, workability is a characteristic greatly affected, making this property something that hinders the use of this type of mortar in situ. In João Pessoa-PB, the construction companies that make use of vermiculite produced in the region report about the problem in the workability property of mortars with this material.

Most of the works deal with the hardened and thermal properties of these mortars, with little focus on rheological properties; furthermore, researches report on the use of mineral additions in this type of mortar. Therefore, considering that the thermal mortars for coating available in the market, currently, have a high economic value and the use of vermiculite in conventional coating mortars results in a material with excellent thermal properties, this paper proposed to study mortars containing vermiculite and mineral additions with a focus on their rheological properties in the fresh state and their hardened and thermal properties.

2. MATERIALS AND METHODS

2.1. Materials

For the production of the mortars the following materials were used: Portland Cement (CP V), Hydrated lime (CH-I), Fine aggregate (Fine Aggregate – Sand commercial), Expanded vermiculite (Fine particle – Commercial), Ground ceramic brick waste (GCBW – beneficiation in laboratory) and Metakaolin commercial.

The choice of cement type CP V was because it has a minimum value of addition in its composition, allowing a better analysis of the influence of pozzolanic additions used in this study. To obtain the GCBW, the ceramic brick waste was processed through fragmentation and milling of ceramic brick blocks. The fragmentation was done in a jaw crusher, in order to break the blocks into smaller pieces to favor the milling. After the fragmentation, the material was placed in a ball mill. In the grinding, 30,000 rotations were used, because according to a study conducted by Carvalho (2016), the energy expenditure for a higher number of rotations would not bring considerable gains for the fineness of the material.

2.2. Methods

The experimental phase was divided into 4 stages represented below: characterization of materials, analysis of fresh properties, analysis of the hardened properties e thermal analysis.

2.2.1. Material characterization

The materials were characterized in terms of physical, chemical and mineralogical aspects as shown in Table 1.

The physical characteristics of the materials used are presented in Table 2.

The unit mass was determined in the loose state according to (22) and the value obtained was similar to the mass found in other studies (3, 8). For the determination of the specific mass of the materials it was used according to (15).

Figure 1 shows the particle size distribution curves of the fine aggregate and vermiculite. In Figure 2 and 3 the particle size distribution and histogram, respectively, of CP V, CH-I, GCBW and MK. For these last mentioned materials the particle size distribution was obtained by the Laser ray diffraction method, using a laser granulometer, model 1064, to measure the distribution of the material in a size range between 0.5 and 500 µm. The sample was dispersed in the equipment itself in a 400 ml vat of dis-

Table 1. Analyses for material characterization.

Analysis	Test	Reference
Physical Analysis	Unit Mass - aggregate	NBR NM 45 (14)
	Specific Mass - aggregate	NBR NM 52 (15)
	Vermiculite grain size	NBR 11.355 (16)
	Granulometry - aggregate	NBR NM 248 (17)
	Specific Mass - fines	NBR 16.605 (18)
	BET (Specific Surface Area) - fines	–
	Pozzolanic Activity Index (PAI)	NBR 12.653 (19); NBR 5.751 (20) e NBR 5.752 (21)
Chemical Analysis	X-ray fluorescence (XRF)	–
Mineralogical Analysis	X-ray diffractometry (XRD)	–

Table 2. Physical characteristics of the materials.

Materials	Description	Specific Mass (g/cm³)	Unit Mass (g/cm³)	Surface Area - BET (m²/g)
Portland Cement	CP V	3.06	0.92	2.12
Hydrated lime	CH-I	2.47	0.64	5.19
Fine aggregate	Fine Aggregate (Sand) – Commercial	2.65	1.45	–
Expanded vermiculite	Fine Particle – Commercial	0.73	0.15	–
Ground ceramic brick waste (GCBW)	Beneficiation in laboratory	2.58	0.73	13.80
Metakaolin (MK)	Commercial	2.58	0.49	13.10

tilled water under the action of a mechanical agitator for 20 min, this vat had an ultrasound that operates at 55 Hz frequency and 55% amplitude.

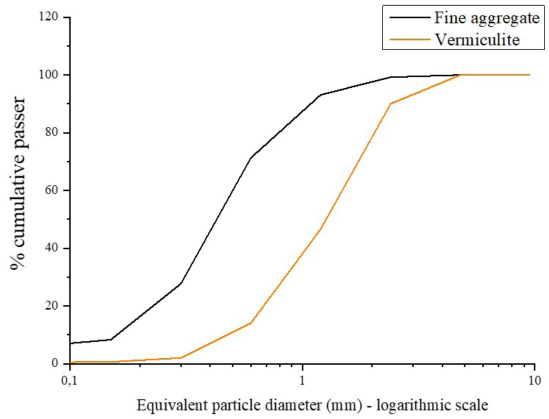

Figure 1. Particle size of fine aggregate and vermiculite.

By analyzing the particle size curves (Figure 1), it is possible to identify that the vermiculite particles, in its majority (86%), have a diameter larger than 0.6 mm. This parameter when compared to sand is approximately three times larger, since only 29% of the sand particles have diameters in this range. However, this difference in particle size distribution between these materials may favor the particle packing effect.

More specifically, based on the analysis of the particle size curve of the fines (Figure 2), 10% of the accumulated solids are smaller than 1 µm; 50% are smaller than 5 µm and 90% are smaller than 45 µm. For GCBW, 10% of the accumulated solids are smaller than 0.7 µm; 50% are smaller 3 µm and 90% are smaller than 30 µm.

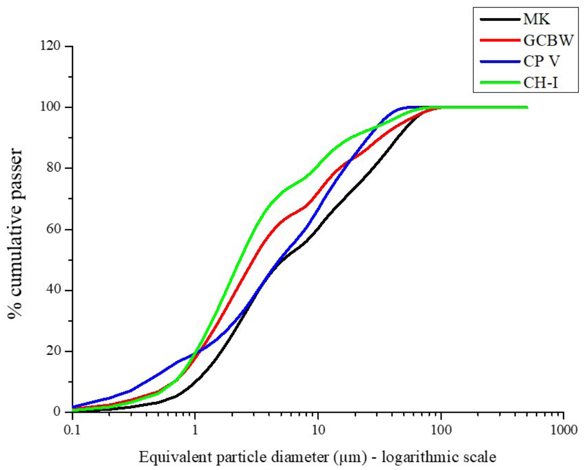

Figure 2. Particle size distribution curve of the fine materials.

Such data are relevant, considering that, the average diameter of GCBW will be responsible for the filler effect and the generation of nucleation points, since fine particles, such as GCBW, although they may not present reactivity, work as nucleating agents, contributing to the acceleration of cement hydration (23).

For MK we see a similar behavior of the curve to the GCBW, but it has a larger volume of particles above 100 µm. While for cement (CP V), 10% of the accumulated solids are smaller than 0.4 µm, 50% are smaller than 5 µm, and 90% are smaller than 27 µm. For lime, 10% of the accumulated solids are smaller than 0.7 µm; 50% are smaller 2.4 µm and 90% are smaller than 20 µm. It is still possible to see that the highest concentration of particles of the fine materials occurs between 1 and 40 µm.

Due to the characteristics of vermiculite, it is not feasible to determine the specific mass based on NBR 11.355 (2015) (16). Thus, its determination was performed through an apparatus, composed of a graduated glass beaker and an infuser, in which initially the mass of the infuser and the volume of water displaced by it in the beaker is determined, subsequently, the mass of the infuser filled with expanded vermiculite and the volume of water displaced by the set is determined.

Based on these data, it is possible to find the relationship between the aggregate mass and the displaced volume, i.e., the specific mass, and this methodology has been used previously (8).

The surface areas (by the BET method) of CP V, GCBW and MK were analyzed in a BELSORP II-MINI model equipment by nitrogen adsorption/desorption at 77 Kelvin. The samples underwent an initial heat treatment at 120 ºC for two hours, in nitrogen flow, to remove possible adsorbed gases in the samples.

To measure the pozzolanic activity index of metakaolin (MK) and ground brick waste (GCBW), the procedures described in NBR 5.751 (20) and 5.752 (21) were used. The MK and GCBW according to NBR 12.653 (19) met the requirements as a pozzolanic material Class N, because they had SO_3 content less than 4%, and the sum of SiO_2, Al_2O_3 and Fe_2O_3 greater than 70% (Table 3). For MK, the compressive strength reached values of 8.37 MPa and 28.18 MPa, with lime and Portland cement, respectively. In the case of GCBW these values were 7.35 MPa and 22.19 MPa.

The chemical composition of the fine materials (Table 3) was determined semi-quantitatively by means of X-ray fluorescence spectrometer in a Shimadzu equipment, model XRF-1800. For this test, the samples of the materials were passed through a n°200 sieve and compressed with a load of 80 kN.

Regarding lime, the sum of CaO and MgO equals 91.5%, enabling the classification as CH-I, based on (24). In parallel, CP V- ARI complies with the criteria of NBR 16.697 (2018) (25), presenting the MgO values below the limit of 6.5% and the SO_3 value less than 4.5%.

For the mineralogical analysis by X-ray diffractometry, the samples were sieved in mesh #200 and

Table 3. Chemical composition of the materials.

Material	CP V	CH-I	GCBW	MK
SiO_2 (%)	25.3	4.24	56.48	53.65
Al_2O_3 (%)	3.88	1.42	24.17	31.79
Fe_2O_3 (%)	4.34	1.95	12.14	9.89
CaO (%)	58.19	84.95	0.20	0.12
MgO (%)	3.01	6.53	2.39	1.17
SO_3 (%)	3.38	0.24	-	0.08
Na_2O (%)	0.33	0.23	1.35	0.20
K_2O (%)	0.45	0.09	0.74	0.65
TiO_2 (%)	0.41	0.19	2.06	1.84
Outros (%)	0.69	0.10	0.42	0.58

then deposited in the sample holder, undergoing a light compression before being deposited in the Siemens Bruker D5000 equipment through CuKα radiation of wavelength λ = 1.5418 with x-rays at 30 kv and 30mA, reading speed of 10/min in a range of 5° to 70° 2θ at an angular step of 0.02° 2θ. X'Pert HighScore Plus 2.0 software was used to identify the peaks. Figure 3 shows the diffractograms of GCBW and MK and Figure 4 shows the diffractogram of lime.

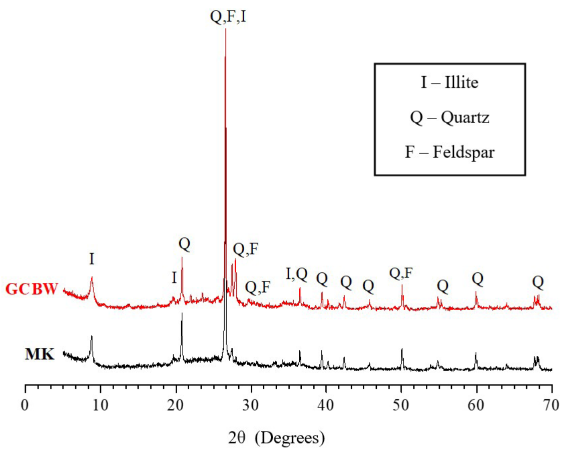

Figure 3. X-ray diffractogram of MK and GCBW.

According to the diffractogram in Figure 3, it can be seen that both materials present peaks mostly of quartz, however, they also present phases such as illite and feldspar. These minerals, when they appear in kaolinitic clay, indicate a contamination of the clay. They can be detrimental to the quality of kaolin, and can affect important properties such as whiteness, viscosity and abrasiveness (26).

In addition, the presence of illite peaks in the XRD of MK and GCBW may indicate that a non-efficient calcination process occurred, which makes the pozzolan not as reactive as Portland cement. Another important factor to be analyzed is the amorphous halo (present between 20° and 30° 2θ), its presence is common in pozzolans and usually indicates the reactive potential of pozzolans. Comparing MK and GCBW, this halo is more evident for MK.

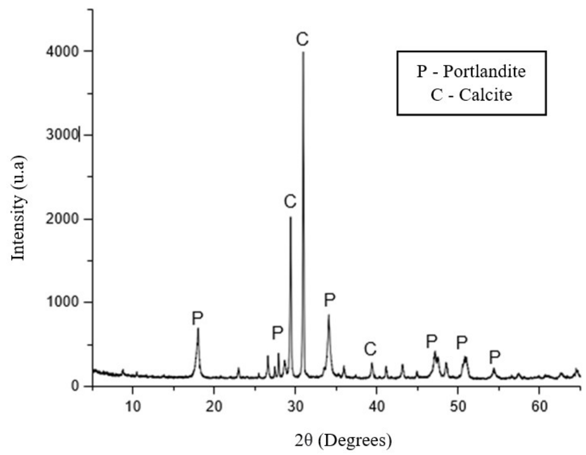

Figure 4. X-ray diffractogram of hydrated lime (CH – I).

The lime diffractogram shows higher intensity peaks of Portlandite (Ca (OH_2)) as well as Calcite ($CaCO_3$), similar to what is seen in the literature.

2.2.2. Mortar mixtures

For the mortar mixtures, a 1:1:6 mixture was used (in volume) and the pozzolans were added in the proportions of 10% and 20% in relation to the mass of cement. The expanded vermiculite content was defined based on the results of initial tests, which used percentages greater than 40% of aggregate replacement by vermiculite. However, higher levels of vermiculite made it impossible to analyze the compositions through the tests defined in the research, since they showed unsatisfactory performance, especially in the tests considered in the article. The amount of water in each mixture was defined

Table 4. Identification of the analyzed mortar mixtures.

Mortar	Cement (g)	Lime (g)	MK (g)	GCBW (g)	Sand (g)	Vermiculite (g)	Water (g)	w/c
REF	138.0	96.6	-	-	1348.4	-	250.79	1.82
V40	138.0	96.6	-	-	809.1	53.1	308.65	2.24
V40–10GC-BW	138.0	96.6	-	13.8	809.1	53.1	300.68	2.18
V40-10MK	138.0	96.6	13.8	-	809.1	53.1	295.72	2.14
V40-20GCBW	138.0	96.6	-	27.6	809.1	53.1	308.43	2.24
V40-20MK	138.0	96.6	27.6	-	809.1	53.1	305.06	2.21

through the predefined standard consistency index of 260 mm proposed by NBR 13.276 (2016) (27), thus forming the group of mixtures present in Table 4. It is important to note that the mass of cement remained equal to 138 g for all mixes, and the same was true for the lime mass with 96.6 g. The sand values were 1348.4 g for the reference mortar and 809.1 for the other mixes.

Still in this context, it is noteworthy that the process of adding water to the dry material diverges from what is prescribed by the NBR 13.276 (2016) standard (27), with a known procedure being adopted (28), because studies conducted by Antunes (2005) show that this process results in a more homogeneous mortar, influencing the rheology of the mixture (29).

The consumption in kilograms per volume of mortar of the materials (water, vermiculite, additions and binders) for each mix is represented in Table 4, and was calculated using the results of mass content and mass density in the fresh state of the mortars. It is worth noting that the MK and GCBW were incorporated into the mortar as additions in relation to the mass of cement.

The consumption in kilograms per volume of mortar materials (water, vermiculite, additions and binders) for each mix is shown in Table 4, and was calculated using the results of mass content and mass density in the fresh state of the mortars. It is worth mentioning that the MK and GCBW were incorporated into the mortar as additions in relation to the mass of cement.

The replacement of aggregate by vermiculite in the proportion of 40%, in relation to the mass of aggregate, caused the mixture to require an increase of water around 23% to the reference mixture. The same behavior was proven in other works (2, 3), being attributed to the porous nature of expanded vermiculite. The adverse effects on the workability of mortars caused by the use of LWA are little discussed, but studies indicate that LWA have a porous structure with high water retention, and when used in mortars it is necessary to increase water consumption to have a good workability condition (30). Despite the application of close levels of vermiculite, the water consumption obtained showed some difference, which can be attributed to the difference in fluidity/flow required in each research, type and content of binder used and difference in the consumption of constituents (3, 6, 8).

The introduction of vermiculite in the percentage of 25% as aggregate does not bring great influence on mortar consistency (6, 8), however, when this percentage is increased, it is necessary to increase water consumption in mortar production. In this research, with the use of 40% vermiculite, the water content was increased from 16% to an average of 27% compared to the reference (31, 32). The high water consumption, as well as its increase as vermiculite is added to the mixture, as found in the cited works, is related to the porous structure of expanded vermiculite.

This may have happened due to the similarities between the physical and chemical characteristics of MK and GCBW, as well as the levels of constituents, especially vermiculite, which, being highly porous, absorbs part of the water in the mixture, directly interfering in the fluidity of the mortar.

2.2.3. Tests in the fresh state

The study in the fresh state of the mortars was evaluated by the consistency table tests of NBR 13.276 (2016) (27), mass density and incorporated air content NBR 13.278 (2005) (33) and the Squeeze-flow method NBR 15.839 (2010) (34).

The bulk density and incorporated air content were obtained immediately after the homogenization of materials in the mortar mixer, and no results were obtained after squeeze-flow test.

For the latter, a mold consisting of a template and plastic ring was made (35) (Figure 5a). The Squeeze-Flow tests were performed in a universal machine using 10 kN load cells, with a constant shear rate of 0.1 mm/s, after 15 min of mixing, repeating the procedure after 65 min of mixture preparation. Images of the test procedure are shown in Figure 5b and 5c.

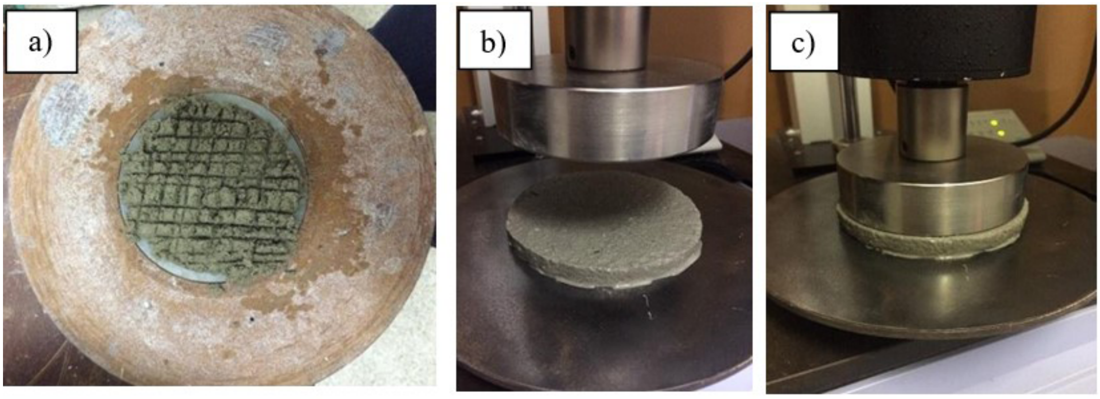

Figure 5. Illustration of the device and the Squeeze-Flow test a) mold used, b) sample ready for testing, c) sample being tested.

2.2.4. Tests in the hardened state

Prismatic specimens were made in molds of 40 x 40 x 160 mm³, according to NBR 13.279 (2005) (36) and later all samples were analyzed at an age of 28 days. Curing took place in air (laboratory environment), with temperature and relative humidity of 23 °C ± 2 °C and 60% ± 2%, respectively.

2.2.4.1. Determination of physical properties

The analysis of the physical properties of mortars was performed by testing the density of apparent mass based on NBR 13.280 (2005) (37) and the determination of water absorption by capillarity, according to the requirements of NBR 15.259 (2005) (38). For both tests the result was the average of 3 samples.

2.2.4.2. Determination of mechanical properties

The mechanical properties of the mortars were evaluated by the flexural tensile strength and compressive strength in a Shimadzu universal machine using a loading speed of 50 ± 10 N/s at 28 days of age, according to the requirements of NBR 13.279 (2005) (36) and the tensile bond strength of the coating mortars according to NBR 13.528 (2010) (39).

The flexural tensile strength test was performed on three samples of each mix, where six specimens of each mix were used for the compressive strength analysis; for the bond strength test, five ceramic block panels were made with 80 cm x 60 cm dimensions, coated with 1:3 roughcast by volume.

The choice of panel size considered the limit distances between the specimen and the edge, as established by NBR 13.528 (2010) (39). At this stage, four of the six mixtures initially studied were selected, based on the results of the rheological tests, to coat the wall panels after roughcast application (Figure 6a), with a minimum curing period of 3 days.

The coating thickness referring to the mortar layer was 2 cm. 12 cuts were made in the panel with the use of a 52 mm cup saw. Then, the panel was cleaned to remove residues that could interfere with adherence, and then a two-component epoxy resin based glue was applied to the sample to fix the metal insert, respecting a minimum time of 24 h for hardening. The pull-out of the specimens (Figure 6b) was performed using a microprocessor-based digital pull-out device at a speed rate of 124 N/s.

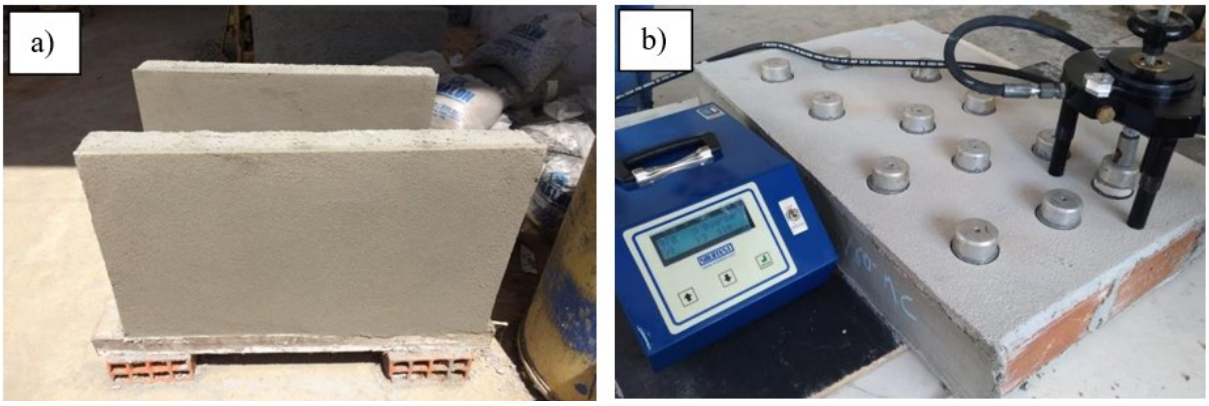

Figure 6. Illustration of the devices, samples, and tensile strength test a) panel made for the scratch test b) test run.

2.2.4.3. Thermal Analysis

The thermal evaluation was performed based on the protected hot plate method using a K30 conductivity meter to determine the thermal conductivity coefficient and the thermal resistivity through the fluxometric method in steady state based on NBR 15.220-5 (2005) (40).

Slabs with dimensions of 30 cm x 30 cm and 3 cm thick were made, 1 slab per sample. The test was performed after curing for 28 days.

3. RESULTS AND DISCUSSION

This section shows the results of the physical and mechanical analyses of the mortars under study.

3.1. Fresh state properties

3.1.1. Density and content of incorporated air

The results of the fresh density and incorporated air content of the mortars can be seen in Figure 7.

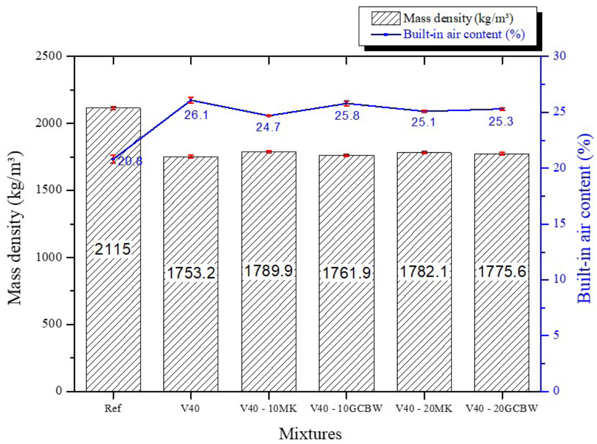

Figure 7. Mass density and air content incorporated in the mortars.

The mass density of mortars also varies with the specific mass of the constituent materials, especially the aggregate (42). That way, the amount of vermiculite in the mortar inversely influenced the value of the bulk density, because it is a LWA that presented a unit mass 72.41% lower than the sand used in this study. When analyzing the mortar with 40% vermiculite (V40), it presented a 17% decrease in its density in relation to the reference mortar.

The introduction of mineral additions in the mortars with vermiculite reduced this difference, since there was an increase of fines in the mixtures thus influencing the packing of the particles in addition to the densification of the cement matrix caused by the pozzolanic reaction. It is possible to notice that there is little difference in the results between the compositions when there is 40% of vermiculite, since the aggregate is the main component that influences this property and also when comparing the type of additive added (GCBW and MK) to the mixture, no significant changes in density values were observed. In the study of the density of mortars with vermiculite, no divergence was obtained between the reference mortar and the mortar with 25% vermiculite, but in relation to the mortar with 50% vermiculite there was a reduction of 13.3%, a value that has already been exceeded in this research with mortar containing introduction of 40% vermiculite (6).

It was found that a mortar containing 10% vermiculite in its composition obtained an increase in the content of incorporated air of 24% compared to the reference (4). In this study the reference mortar, is classified as D5 and those with vermiculite D3, results obtained by the content of incorporated air, in accordance with (41).

As already mentioned, the content of incorporated air influences the workability of the mortar, the lighter the mortar, the lower the effort for its use, on the other hand, the lower its mechanical resistance. Moreover, mortars with fresh state mass density below 1400 Kg/m³ are classified as light and mortars with density between 1400 Kg/m³ and 2300 Kg/m³ are classified as normal (42). Thus, even with LWA in their composition, the mortars studied here are classified as normal.

3.1.2. Squeeze-Flow

With the amount of water defined for each mixture through the consistency table, the rheological analysis was performed through the Squeeze-Flow test. Figures 8 and 9 show the test results after 15 and 65 min of mixing, as recommended by NBR 15.839 (ABNT, 2010) (34).

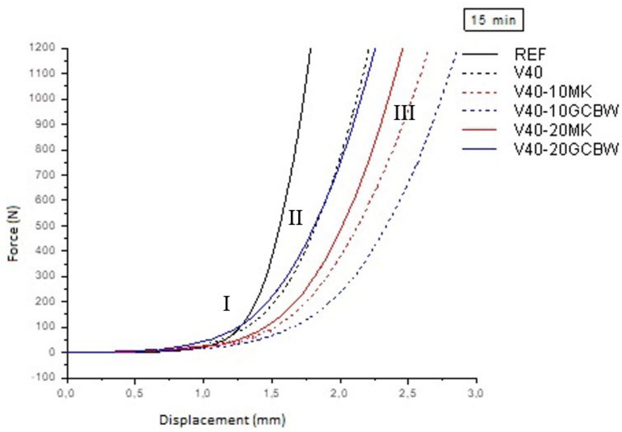

Figure 8. Squeeze-Flow results for the mortars after 15 minutes of mixing.

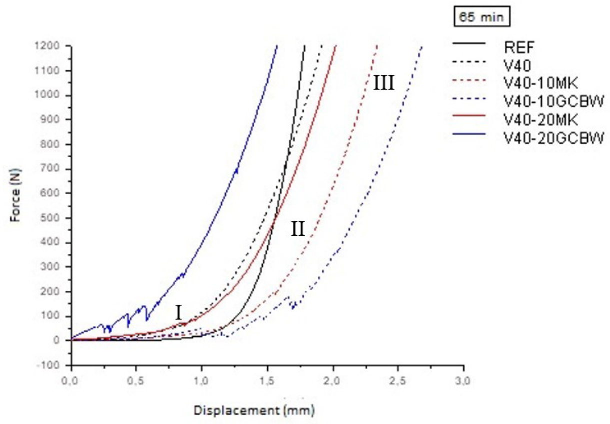

Figure 9. Squeeze-Flow results for the mortars after 65 minutes of mixing.

According to Figure 8, it is possible to notice that all the curves of the mortars containing vermiculite are displaced to the right in relation to the reference curve, due to the properties and physical characteristics of vermiculite in relation to the sand fine aggregate. Analyzing the curves for a single force value, 1000N for example, the reference mortar presented 1.6 mm of displacement, while the other mixtures presented higher values, reaching up to 2.5 mm. Even being different from the displacement of the reference mortar studied here, this value is close to that obtained by (43) for the reference mortar analyzed in their study. Since the reference mortar presents an adequate performance for use already known, it can be considered that the same occurs for the mortars that present a similar behavior to it.

Initially until the displacement of 1 mm, where the particles are still adjusting to start flowing, the mortars show a similar behavior. The rheological differences between the mixtures are accentuated in the displacement between 1 mm and 2 mm, but the difference in the applied force required to perform the displacement is more evident. Thus, it is possible to state that the mixtures with vermiculite had a lower viscosity and greater ease of spreading. One of the influences for this behavior is the water content in these mixtures, since higher values were used than those used in the reference mortar. The higher amount of water improves workability, since it generates a thicker layer of water between the grains.

Another factor that influences the rheological behavior of mortars is the packing and shape of the aggregates. Generally, more spherical grains tend to move more easily, favoring their rolling when involved by the paste, improving the workability of the mortar (44).

Thus, the mortars with vermiculite incorporation, which has a lamellar form, presented a higher yielding. Possibly this fact is due to the greater incorporation of air due to its more lamellar shape, since the mortars with vermiculite present an increase of at least 19% in the content of incorporated air. It is noteworthy that the greater incorporation of air favors the distance between grains, reducing the viscosity of the mortar due to the postponement of the frictional forces, thus presenting a lower surface friction and a lower viscosity of the mortar (29).

It is also possible to make an analogy between the test results and the application of mortar in practice (45, 46). Where the mortar that presents a significant part in stage I needs high loads to deform, being of difficult application, besides having a behavior similar to a solid, presenting elastic deformation and a probable problem of cracking still in the fresh state, because of the elastic recovery after the removal of the force.

The mortar with intermediate loads (stage II) flows by plastic and/or viscous deformation, tend to allow a higher productivity, as the mortar with low loads can be excessively fluid, making it impossible to apply thick layers or immediately after preparation. In the mortars analyzed in this study, one can notice a predominance of stage II and a slight tendency to transition to stage III. The absence of state I is justified by the fluidity presented in all mixtures studied, due to the water and air content incorporated, making the mortars flow from the beginning without the need for a high increase in applied force.

For the time of 65 min after mixing (Figure 9), it is observed that the mortars V40-10GCBW and V40-20GCBW present a behavior of the curve plot where an oscillation of the applied load is observed. This phenomenon is related to the friction between the plates and the mortar, in addition to the internal mechanisms of deformation and flow of the material, especially when the separation of phases acts by increasing the localized concentration of aggregates and friction in the central region (35). This behavior indicates that the material presents high levels of internal shear.

In the V40-20GCBW mortar it is possible to note a unique behavior, because in order to present a displacement of 0.2 mm it was necessary a load around 50 N, under this load the other mortars presented a displacement around 1 mm. That said, V40-20GCBW presents a stiffening by deformation, with stage III predominating. The V40-10GCBW curve is below the REF (reference) curve and shifted to the right, this shows that the amount of water demanded for mixing through the consistency table was higher than necessary, causing the mortar to remain in the plastic stage.

The Squeeze-flow result may present indications of the applicability of the mortars studied, thus, the plastic stage (II) is desirable to have a good applicability, however, it is necessary to have a balance between stages II and III so that there is an adequate stiffness of the mortar and it does not slip during application (47).

The additions influenced significantly for the times of 15 and 65 min. The additions with 10% presented a lower viscosity and greater ease of spreading in relation to the additions of 20% in both times. This behavior can be justified by the increase of addition in the mixture, referring to a lower rate of incorporated air, making it less necessary to spread when compressed in the press (48). This effect is directly related to the volume of particles in suspension, i.e., the greater this volume, the greater the viscosity of the mixture (49, 50).

Thus, the differences proved the sensitivity of Squeeze-flow for rheological analysis of mortars, because those that presented similar consistencies through the consistency table resulted in a distinct behavior, with expressive variation in displacement when the same force was applied.

3.2. Properties of hardened state

3.2.1. Apparent bulk density, compressive and tensile strength of mortars

Figure 10 shows the results of the bulk density test and axial compressive strength of the mortars. The results of the mechanical performance of the mortars regarding flexural strength at 28 days can be seen in Figure 11.

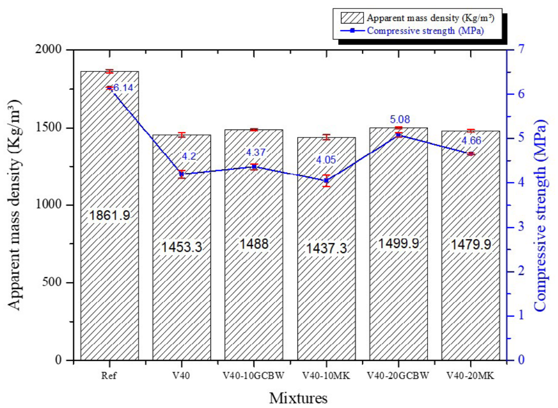

Figure 10. Apparent mass density and compressive strength in mortars.

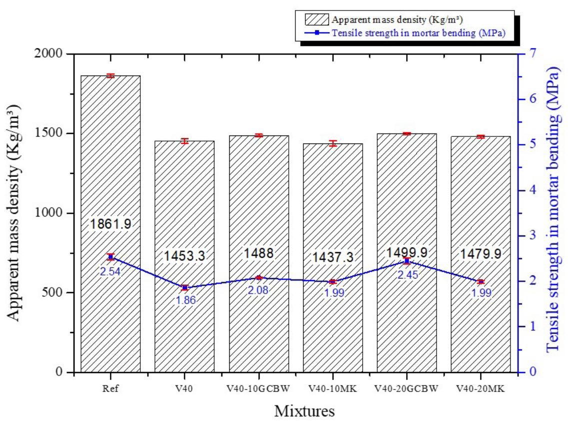

Figure 11. Apparent bulk density and flexural tensile strength in mortars.

The partial replacement of sand by vermiculite brought a decrease in the density of the mortar, reaching 22% when 40% of fine aggregate was replaced by vermiculite, a value very close to that found by Palamar, Barluenga and Puentes (2015) (6) in mortar with 50% vermiculite. This is due to the fact of the low specific mass of vermiculite, in the same way that happened in the fresh mass density. When analyzing the result of the bulk density in the fresh and hardened state, it is possible to note a difference in the results due to the evaporation of part of the mixing water that rises with the increase of vermiculite addition. In sample V40 the reduction was around 17%.

Therefore, at the same time that the amount of water required to obtain the predefined consistency is more significant in mixtures that have a greater amount of vermiculite in their composition, the evaporation of this water during the curing process is also more significant. This factor was also observed in other studies even when other proportions of vermiculite were analyzed (4, 31, 32). Another factor observed is the fact that the mixtures with added MK have a higher density compared to mixtures with GCBW, although the difference in physical, chemical and mineralogical characteristics are not marked.

It is pointed out that the interference of fine materials on the mortar properties depends mainly on the particle size and morphology of the particles (51). By the result of particle size presented in Figures 2 and Table 3 there is much similarity between MK and GCBW. However, the factor that can explain the small difference in the values of density and mechanical strength between the mixtures with additions is the particle volume, since the MK has a lower unitary mass, which may indicate that there is a greater amount of particle to fill in the empty spaces. Therefore, the lowest density and mechanical resistance results in the samples with MK are consistent.

The mortars with vermiculite presented a reduction in compressive strength of 32% in relation to the reference mortar (4, 6, 31). As in compression, the flexural tensile strength was also altered, but this interference in flexural tensile strength was in a smaller proportion in relation to the compressive strength. This result is interesting for coating mortars, since during their use tensile stresses are imposed.

The change in the mechanical strength of mortars is influenced both by the fact that the expanded vermiculite has voids between the lamellae and by the high demand for water that is not necessarily used in its entirety by the mortar hardening reactions, but is lost through evaporation or suction of the base forming pores in the mortar, causing the strength to decrease. This fact can be proven by the high reduction between the density in the fresh and hardened state of the mortars with vermiculite.

Regarding the effect of additions, it is observed that the use of GCBW and MK resulted in an increase in the value of compressive strength. The micro-filler effect caused refinement of the mortar pores. The mixtures with 10% addition, GCBW or MK, did not obtain a significant gain in strength. However, when this value was increased to 20%, it was possible to observe a gain in resistance, mainly for the mixture with the addition of GCBW in relation to the mixture with only 40% of vermiculite. Regarding flexural tensile strength, mixtures with GCBW additions also showed better results, as expected. While the mixtures with MK had a small increase, maintaining the same value of 1.99 MPa, even with a 20% increase in the addition content.

It is worth mentioning that the resistance gain results corroborate the results of gain in apparent mass density. The highest compressive strength obtained, which corresponds to the 20% GCBW mixture, is consistent with the highest value obtained for apparent mass density.

Although mortars with vermiculite present a reduction in compressive strength, it should be taken into account that mortars for coating purposes do not require high values for this parameter. In fact, with a decrease in compressive strength, there is also a decrease in stiffness, favoring the reduction of cracks along the surface, because stiffer mortars have less capacity to deform without rupture, generating a greater risk of cracking (52).

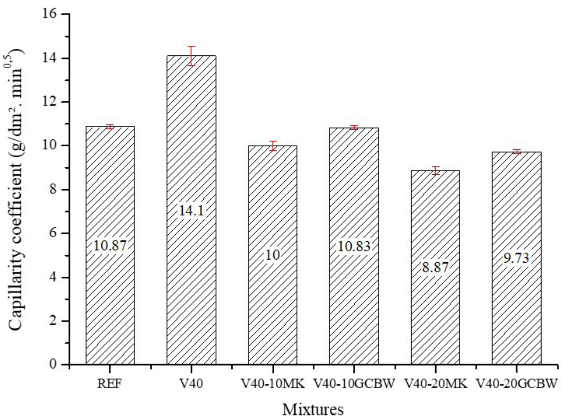

Figure 12. Capillarity coefficient in mortars.

The use of vermiculite brought an increase in the capillarity coefficient (Figure 12), since the vermiculite increased the amount of voids in the mortar. The greater the amount of voids, the more likely there is to be communication between them. This trend is justified by the high absorption rate of the LWA (31). The mixture V40 presents coherence with the result obtained by Barros (2018) (8) in mixtures with 50% vermiculite, since in his study for this mixture an increase of 30% in the value of the capillarity coefficient was obtained, while in the mixture V40, analyzed here, this value was 29%.

When there were additions of GCBW and MK a lower capillarity coefficient was obtained, since the introduction of these fine materials refined the pores of the mortar matrix, hindering the rise of water by capillarity and making these values close to the reference mortar. The existence of interconnected pores interferes with capillarity, since if the pores are discontinuous or ineffective for fluid displacement, capillary permeability will be low even if the mortar presents high porosity (53). Consequently, the addition of fine materials in the mortar may have caused, besides a decrease in the diameter of the pores, a discontinuity between them.

The mortar with only the introduction of 40% of vermiculite obtained the highest capillary coefficient among the mixtures. This can be explained by the possible connectivity between the pores due to the large amount of voids, which facilitates the rise of water by capillarity. However, it must be taken into into account that capillarity is related to the characteristics of the interconnected pores, not to the total porosity of the mortar. Thus, in order to increase capillarity, it is not enough for the mortar matrix to be porous, it is necessary to have communication between the pores and dimensions that favor the effect of the capillary force.

3.2.2. Tensile bond strength

In an attempt to obtain greater reliability in data interpretation it was decided to disregard values that presented an absolute deviation greater than 0.3 MPa, the same parameter adopted by NBR 13.279 (2005) (36) for flexural tensile strength. Thus, the test results are found in Figure 13 and all mortars can be classified as class A3 by NBR 13.281 (2005) (41), where the values presented are greater than 0.3 MPa.

As the mortars with the introduction of vermicu-

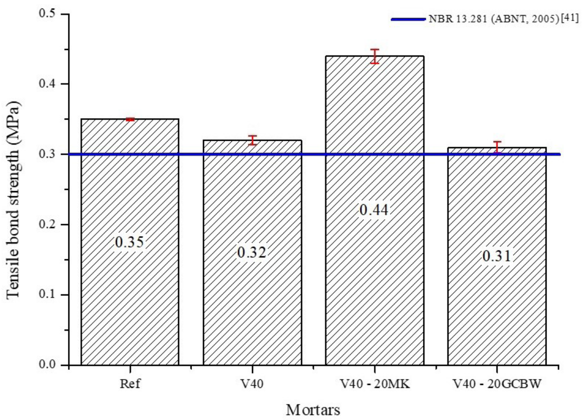

Figure 13. Tensile bond strength (MPa).

lite had a larger amount of voids, as already proven in previous analyses in this work, this fact may cause a decrease in the contact surface between mortar and substrate favoring this reduction in adhesion. In the case of the V40 mortar there was a 7% reduction in strength, still within the parameter acceptable by standard for use in external walls.

The mineral addition increased the adherence strength of the mortars, as well as what happened in the analysis of other mechanical strengths, and also increased the mass density. Because there is a relationship between the mass density and the mechanical strength of mortars, where the decrease in density caused by vermiculite reflects in the mechanical strength of mortars (3).

However, the mixture V40-20MK, even presenting values of hardened density lower than that of the reference mortar, in the bond strength its performance was superior to that of the reference mortar. This may have occurred due to the extent of adhesion, i.e., the ratio between the effective contact area and the total area possible to be joined, since the addition of 20% MK may have changed the effective contact area of the mortar, as an improvement in the cementitious matrix.

3.2.3. Thermal properties

The thermal analysis was performed on the same mixtures that were selected for the bond strength test. Through the hot plate test it was possible to obtain the thermal conductivity and resistivity that are presented in Figure 14.

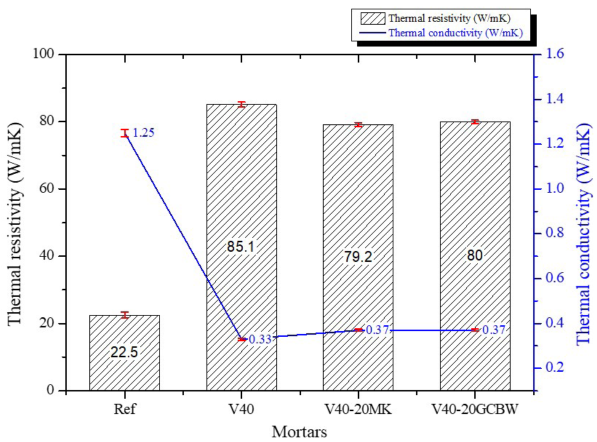

Figure 14. Thermal conductivity and resistivity in mortars.

When analyzing the results, it is noticeable the decrease in thermal conductivity for the mortars with 40% vermiculite, being around 73.6% compared to the reference. This behavior is in accordance with the results in the hardened state discussed in this work. The value obtained for the reference mortar is close to the value specified in NBR 15.220 (2005) (40), which addresses a thermal conductivity of 1.15 W/m.K for a common mortar. The mortars studied here have results close to those of previously developed studies, such as, for example, the mortar with 40% vermiculite was on average 0.35 W/m·K (31).

The mineral additions caused a small increase in thermal conductivity and consequently a decrease in thermal resistivity. This factor is directly related to their fineness as they fill part of the voids formed in the composite and therefore increase thermal conductivity. However, this increase in thermal conductivity value in these samples may be insignificant, since this result was obtained by testing only one sample for each mixture. Thus, it is observed that the conductivity values of these mortars containing MK and GCBW were much lower than the reference, as well as the others, indicating the preponderant role of vermiculite, since it is also present in larger volume in the mixture. The same behavior is observed in another research when increasing silica fume in the mortar with vermiculite obtained an insignificant effect, around 4.7%, of this addition on thermal conductivity (3).

4. CONCLUSIONS

According to the results obtained, one can initially highlight that through the analysis of the materials it is possible to see the similarity between the physical characteristics of the metakaolin (MK) and the ground brick residue (GCBW) used, presenting a specific mass around 2.58 g/cm³.

Further, in the consistency table test, the mixtures with addition of 10% and 20% ground brick waste (GCBW) required a greater amount of water to obtain the consistency of 260mm compared to those with metakaolin (MK), this being 1.38% and 1.65%, respectively. This fact can be attributed to the granulometry of these materials, since GCBW presents a higher proportion of fine particles.

In parallel, the mixtures with vermiculite demanded a higher water content than the reference. The reference mortar presented this parameter around 16%, while the V40 mortars presented a water content of 28%. Moreover, the reduction in density from fresh to hardened state reaches 34% due to the evaporation of part of the water in the curing process.

It is also noteworthy that the addition of 20% of MK and GCBW in mortars in order to improve their mechanical performance was positive, because it resulted in an increase of approximately 18% compared to V40. This behavior is due to the improvement of the cement matrix, either by packing of grains as the pozzolanic reaction. Moreover, it was evidenced in this work that the commercial metakaolin and the brick residue influenced similarly the properties of mortars.

Furthermore, it was found that the use of vermiculite, by making the mortar more porous, favored the thermal performance, reaching a conductivity and resistivity value on the order of 0.37 W/m·K. Therefore, the addition of 20% GCBW or MK improved the mechanical properties without harming the thermal properties.

Finally, it was possible to note that the 40% substitution of vermiculite in the mortar resulted in a significant improvement in relation to the thermal parameters, besides meeting the tensile bond strength recommended for use in external coating and presenting workability characteristics close to the reference mortar.

The technological innovation of this research is related to the test chosen for the rheological analysis of the mixtures with expanded vermiculite and mineral additions, which corresponds to the squeeze-flow, little discussed in the literature, as well as the results of the mechanical and thermal properties in the hardened state of the mixtures. In addition, the chosen mineral additions have different physical characteristics, one of commercial origin and the other originating from a construction waste (laboratory improvement), but which despite this presented satisfactory results.

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REFERENCES

1. Rossignolo, J.A. (2009) Concreto leve estrutural: influência da argila expandida na microestrutura da zona de transição pasta/agregado. *Amb. Constr. Porto Alegre*. 9 [4], 119-127. Retrieved from http://www.seer.ufrgs.br/index.php/ambienteconstruido/article/view/8712/7048.
2. Mo, K.H.; Lee, H.J.; Liu J, M.Y.J.; Ling, T. (2018) Incorporation of expanded vermiculite lightweight aggregate in cement mortar. *Constr. Build. Mater*. 179, 302-306. https://doi.org/10.1016/j.conbuildmat.2018.05.219.
3. Koksal, F.; Gencel, O.; Kaya, M. (2015) Combined effect of silica fume and expanded vermiculite on properties of lightweight mortars at ambient and elevated temperatures. *Constr. Build. Mater.* 88, 175-187. https://doi.org/10.1016/j.conbuildmat.2015.04.021.
4. Silva, L.M.; Ribeiro, R.A.; Labrincha, J.A.; Ferreira, V.M. (2010) Role of lightweight fillers on the properties of a mixed-binder mortar. *Cem. Concr. Compos*. 32 [1], 19-24. https://doi.org/10.1016/j.cemconcomp.2009.07.003.
5. Borges, J.C.S.; Oliveira Neto, M.L. (2012) Análise do desempenho térmico de compósito de poliuretano de manona com carga de vermiculita. VII Congresso nacional de Engenharia Mecânica, CONEM 2012, São Luís, 2012. Retrieved from https://www.abcm.org.br/anais/conem/2012/PDF/CONEM2012-1064.pdf.
6. Palamar, I.; Barluenga, G.; Puentes J. (2015) Lime–cement mortars for coating with improved thermal and acoustic performance. *Constr. Build. Mater.* 75, 306-314. https://doi.org/10.1016/j.conbuildmat.2014.11.012.
7. Shoukry, H.; Kotkata, M.F.; Abo-El-Enein, S.A.; Morsy, M.S.; Shebl, S.S. (2016) Enhanced physical, mechanical and microstructural properties of lightweight vermiculite cement composites modified with nano metakaolin. *Constr. Build. Mater.* 112, 276–283. https://doi.org/10.1016/j.conbuildmat.2016.02.209.
8. Barros, I.M.S. (2018) Análise térmica e mecânica de argamassas de revestimento com adição de vermiculita expandida em substituição ao agregado. Natal, 2018. 86f. Dissertação (Mestrado em Engenharia Civil). Universidade Federal do Rio Grande do Norte, Rio Grande do Norte, Natal, 2018. Retrieved from https://repositorio.ufrn.br/handle/123456789/25165.
9. Benli, A.; Karatas, M.; Anil Toprak, H. (2020) Mechanical characteristics of self-compacting mortars with raw and expanded vermiculite as partial cement replacement at elevated temperatures. *Constr. Build. Mater.* 239, 117895. https://doi.org/10.1016/j.conbuildmat.2019.117895.
10. Senhadji, Y.; Escadeillas, G.; Mouli, M.; Khelafi, H.; Benosman. (2014) Influence of natural pozzolan, silica fume and limestone fine on strength, acid resistance and microstructure of mortar. *Powd. Technol*. 254, 314–323. https://doi.org/10.1016/j.powtec.2014.01.046.
11. Ribeiro, R.A., Silva L.M., Ferreira, V.M., Labrincha, J.A. (2005) Estudo da influência de cargas leves nas propriedades de uma argamassa bastarda. 1º Congresso Nacional de Argamassas de Construção, APFAC, Lisboa, 2005. Retrieved from https://www.apfac.pt/congresso2005/comunicacoes/Paper%2018.pdf.
12. Lubelli, B.; Moerman, J.; Esposito, R.; Mulder, K. (2021) Influence of brick and mortar properties on bioreceptivity of masonry – Results from experimental research. *Constr. Build. Mater.* 266 [Part A], 121036. https://doi.org/10.1016/j.conbuildmat.2020.121036.
13. Guilherme, D; Cabral, K.; De Souza, W. (2020) Estudo do uso de vermiculita nas prorpiedades mecânicas de argamassas leve. *Revista Materia*. 25 [4], 1–10. https://doi.org/10.1590/S1517-707620200004.1194.
14. NBR NM 45 (2006) Agregados – Determinação da massa unitária e volume de vazios. Ass. Bras. Norm. Técn., Rio de Janeiro (2006).
15. NBR NM 52 (2009) Agregado miúdo – Determinação da massa específica e massa específica aparente. Ass. Bras. Norm. Técn., Rio de Janeiro (2009).
16. NBR 11355 (2015) Vermiculita expandida: Análise granulométrica - Método de ensaio. Ass. Bras. Norm. Técn., Rio de Janeiro (2015).
17. NBR NM 248 (2003) Agregados – Determinação da composição granulométrica. Ass. Bras. Norm. Técn., Rio de Janeiro (2003).
18. NBR 16605 (2017) Cimento Portland e outros materiais em pó – Determinação da massa específica. Ass. Bras. Norm. Técn., Rio de Janeiro (2017).
19. NBR 12653 (2014) Materiais pozolânicos - Requisitos. Ass. Bras. Norm. Técn., Rio de Janeiro (2014).
20. NBR 5751 (2015) Materiais pozolânicos – Determinação da atividade pozolânica com cal aos sete dias. Ass. Bras. Norm. Técn., Rio de Janeiro (2015).
21. NBR 5752 (2015) Materiais pozolânicos – Determinação do índice de desempenho com cimento Portland aos 28 dias. Ass. Bras. Norm. Técn., Rio de Janeiro (2015).
22. NBR NM 46 (2006) Agregados – Determinação da massa unitária e do volume de vazios. Ass. Bras. Norm. Técn., Rio de Janeiro (2006).
23. Carvalho, C.M. (2016) Caracterização de resíduos da indústria cerâmica e seu emprego em argamassas de cimento Portland. João Pessoa, 2016. 101 f. Dissertação (Mestrado em Engenharia de Materiais), Universidade Federal da Paraíba – UFPB, João Pessoa, 2016. Retrieved from https://repositorio.ufpb.br/jspui/handle/123456789/14233.

24. NBR 7175 (2003) Cal hidratada para argamassas – Requisitos. Rio de Janeiro (2003).
25. NBR 16697 (2018) Cimento portland - requisitos. Rio de Janeiro (2018).
26. Silveira, L.; Acchar, W.; Gomes, U.; Labrincha, J.A.; Costa, M.C.P.; Silva, B.K.O.; Luna da Silveira, R.V. (2016) Caracterização de caulim e de resíduo de granito para formulação de grês porcelanato. 22° CBECiMat – Congresso Brasileiro de Engenharia e Ciência dos Materiais. 1011-1022. Natal, RN, Brasil, 2016. Retrieved from https://inis.iaea.org/collection/NCLCollectionStore/_Public/48/069/48069727.pdf.
27. NBR 13276 (2016) Argamassa para assentamento e revestimento de paredes e tetos – Determinação do índice de consistência. Rio de Janeiro, 2016.
28. Silva, N.G. (2011) Avaliação da retração e da fissuração em revestimento de argamassa na fase plástica. 2011. Florianópolis, 2011. 322 f. Tese (Doutorado em Engenharia Civil) – Universidade Federal de Santa Catarina, Florianópolis, 2011. Retrieved from http://repositorio.ufsc.br/xmlui/handle/123456789/95497.
29. Antunes, R.P.N. (2005) Influência da reologia e da energia de impacto na resistência de aderência de revestimentos de argamassa. São Paulo, 2005. 187f. Tese (Doutorado em Engenharia) – Departamento de Engenharia de Construção Civil, Escola Politécnica da Universidade de São Paulo, São Paulo, 2005. Retrieved from https://repositorio.usp.br/item/001488734.
30. Lanzón, M.; García-Ruiz, P.A. (2008) Lightweight cement mortars: Advantages and inconveniences of expanded perlite and its influence on fresh and hardened state and durability. *Constr. Build. Mater.* 22 [8], 1798-1806. https://doi.org/10.1016/j.conbuildmat.2007.05.006.
31. Cintra, C.L.D.; Paiva, A.E.M.; Baldo, J.B. (2014) Argamassas de revestimento para alvenaria contendo vermiculita expandida e agregado de borracha reciclada de pneus – Propriedades relevantes. *Cerâmica*. 60 [353], 69-76. https://doi.org/10.1590/S0366-69132014000100010.
32. Xu, J.; Chu, H.; Xu, Y.; Li, C.H. (2015) Prediction of compressive strength and elastic modulus of expanded polystyrene lightweight concrete. *Magazine of Concrete Research*. 67 [17], 954-962. https://doi.org/10.1680/macr.14.00375.
33. NBR 13278 (2005) Argamassa para assentamento de paredes e revestimento de paredes e tetos - Determinação da densidade de massa e do teor de ar incorporado. Rio de Janeiro, (2005).
34. NBR 15839 (2010) Argamassa de assentamento e revestimento de paredes e tetos – Caracterização reológica pelo método Squeeze-Flow. Rio de Janeiro (2010).
35. Cardoso, F.A. (2010) Método de formulação de argamassas de revestimento baseado em distribuição granulométrica e comportamento reológico. Tese para doutorado na EPUSP. São Paulo, São Paulo, 2009. Retrieved from https://www.teses.usp.br/teses/disponiveis/3/3146/tde-21122009 125012/publico/Tese__Fabio.pdf.
36. NBR 13279 (2005) Argamassa para assentamento e revestimento de paredes e tetos - Determinação da resistência à tração na flexão e à compressão. Rio de Janeiro (2005).
37. NBR 13280 (1995) Argamassa para assentamento de paredes e revestimento de paredes e tetos. Determinação da densidade de massa aparente no estado endurecido. Rio de Janeiro (1995).
38. NBR 15259 (2005) Argamassa para assentamento e revestimento de paredes e tetos – Determinação da absorção de água por capilaridade e do coeficiente de capilaridade. Rio de Janeiro (2005).
39. NBR 13528 (2010) Revestimento de paredes e tetos de argamassas inorgânicas - Determinação da resistência de aderência à tração. Rio de Janeiro (2010).
40. NBR 15220 (2003) Desempenho térmico de edificações. Rio de Janeiro (2003).
41. NBR 13281 (2005) Argamassa para assentamento e revestimento de paredes e tetos – Requisitos. Rio de Janeiro (2005).
42. Carasek, H. (2010) Argamassas. Capítulo 26. In: ISAIA, Geraldo (Ed.). Materiais de construção civil e princípios de ciência e engenharia de materiais. 2 ed. 82 IBRACON, 2010. V.1 & v.2.p. 863-891 ISBN 978-85-98576-14-5 e 978-85-98576-15-2.
43. Heineck, S. (2012) Desempenho de argamassas de revestimentos com incorporação de agregados reciclados de concreto. 2012. 132 f. Dissertação (Mestrado em Engenharia Civil) – Centro de Ciências Exatas e Tecnológicas, Universidade do Vale do Rio dos Sinos, São Leopoldo – RS, 2012. Retrieved from http://www.repositorio.jesuita.org.br/handle/UNISINOS/4351.
44. Cincotto, M.A.; Silva, M.A.C.; Cascudo, H.C. (1995) Argamassas de revestimento: caracteristicas, propriedades e metodos de ensaio, Sao Paulo: Instituto de Pesquisas Tecnológicas, 1995. Retrieved from http://www.ime.eb.br/~moniz/matconst2/argamassa_ibracon_cap26_apresentacao.pdf.
45. Freitas, C. (2010) Argamassa de revestimento com agregados miúdos de britagem de região metropolitana de Curitiba: Propriedades no estado fresco e endurecido. Dissertação (Mestrado), Universidade Federal do Pará – UFPA, Belém, 2010. Retrieved from https://hdl.handle.net/1884/24528.
46. Azevedo, V.F.; Barbosa, C.R.F.; Sousa, E.H.V.; Fontes, F.A.O.; Barbosa, C.R.F. (2016) Caracterização de nanofluidos para utilização em compressões de refrigeração: determinação da viscosidade dinâmica, condutividade térmica e estabilidade. *Revista Holos*. 8, 35-46. https://doi.org/10.15628/holos.2016.3802.
47. Stolz, C.M. (2011) Influência da interação entre os parâmetros reológicos de argamassas e a área potencial de contato de substratos na aderência de argamassas de revestimento. Rio Grande do Sul, 2011. 213 f. Dissertação de mestrado – Universidade Federal do Rio Grande do Sul, 2011. Retrieved from http://hdl.handle.net/10183/32021.
48. Rangel, A.; Azevedo, G.; Alexandre, J.; Marvila, M.T. (2017) Influence of incorporation of glass waste on the rheological properties of adhesive mortar. *Constr. Build. Mater.* 148, 359–368. https://doi.org/10.1016/j.conbuildmat.2017.04.208.
49. Trador, T.F. (2010) Rheology of dispersions: Principles and applications., ed. Wiley-VCH, United Kingdon, 2010. ISBN: 978-3-527-32003-5
50. Barnes, H.A.; Hitton, J.F.; Walters, F.R.S. (1989) An introduction to reheology. 1ed., Elsevier, Amsterdan, 1989. ISBN-10: 0444871404.
51. Silva, N.G.; Campiteli, V.C. (2006) Influência dos finos e da cal nas propriedades das argamassas. In: Encontro Nacional de Tecnologia do Ambiente Construído, XI. 2006, Florianópolis. Anais. Florianópolis: ANTAC, 2006. Retrieved from http://paginapessoal.utfpr.edu.br/ngsilva/links-2/noticias/ENTAC2006_Finos.pdf.
52. Bauer, E. (2005) Revestimentos de argamassa – características e peculiaridades. Brasília: LEM-UnB; Sinduscon, 2005, 92. Retrieved from https://doceru.com/doc/nxe5neee.
53. Nakakura, E.H. (2003) Análise e classificação das argamassas industrializadas segundo a NBR 13281 e a MERUC. São Paulo, 2003. 118 f. Dissertação (Mestrado em Engenharia Civil), USP, São Paulo, 2003. Retrieved from https://repositorio.usp.br/item/001319966.