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Self-leveling Mortars with Marble and Granite Waste: Reduced Shrinkage and Improved Performance

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Abstract: The development of self-leveling mortar dosages by using a powder from marble and granite cut waste (MGCW) is a sustainable alternative. The presence of waste in dosages improved the workability of self-leveling mortars. Comparative tests were conducted with polypropylene synthetic fibers to minimize shrinkage phenomenon. The mixture optimized with 50% MGCW, water/cement ratio of 0.55, cement/sand ratio of 1:1.5 (in mass using CPV-ARI-RS cement) had 28 days compressive strength of 38.89 MPa. The incorporation of polypropylene fibers reduced the shrinkage in 68.92% in 7 days, 42.51% in 14 days, 46.48% in 21 days and 47.63% in 28 days. MGCW and fiber did not influence thermal conductivity.

Key words: Self-leveling mortar, marbles and granites waste, limestone filler, polypropylene fibers, mechanical properties.

1. Introduction

Subfloor mortars are construction materials used to change and correct surface defects in floors. Self-leveling mortars are intended to avoid several problems found in the conventional system having characteristics as self-leveling, minimized risks of cracks, the material can be pumpable, heals fast, can be applied quickly, reduces the load on the structure because it can be applied with low thickness [1]. On the other hand, the production of self-leveling mortars requires a better and more accurate manufacture inspection.

Self-leveling mortars has the property of densification by action of gravity in a cohesive and homogeneous way, i.e., it can consolidate over their own weight without any compaction energy. This is caused by the material has a rheology that makes it very fluid without exudation and segregation occur [2]. The use of superplasticizer additive is key for the material to reach the fluidity desired for self-leveling, as well as a modifying agent of viscosity to combat sedimentation and exudation [3]. Due to high consumption of cement in self-leveling mortar dosages, polypropylene fibers and shrinkage reducing additives have been incorporated in studies of dosages. The polypropylene is a good thermal and electric isolation material, highly chemically resistant, non-porous and, in principle, has hydrophobic surface. Is chemically inert, highly resistant to conditions of aggressive action of acid and salts as well. In addition, the alkaline environment typical of mortars has a minor effect in the change of quality or durability of polypropylene fibers [4]. Polypropylene-steel fiber can improve both the mechanical properties and impact resistance [5].

To meet the characteristics desired in self-leveling mortars, several studies have been developed with diversified mineral additions, but not promising greater damages to the environment, i.e., materials providing fluidity without segregation of components, such as fly-ash [6, 7], silica fume [8], phosphogypsum [2, 9], grounded slate from quarrying waste [10], calcined waste foundry sand [11], limestone powder [12, 13, 14], Porcelain and Red Ceramic Wastes [15]. Therefore, using such residues in the application of self-leveling mortars can be seen as an alternative

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material in civil construction, contributing for the sustainable development and reducing the environmental impacts.

The laminitic residue obtained in the process of cutting ornamental rocks is abundant and causes serious environmental concerns, as well as to public health [16]. The use of this material can become a valuable source of raw material if properly applied as a partial replacement of cement in the production of concrete and mortar [17].

In this study, mixtures of self-leveling mortars with the addition of a Marble and Granite Cutting Waste (MGCW), an inert and extremely fine material, were analyzed and optimized. Self-leveling subfloor mortars were prepared under the parameters described in ASTM C1708 [18]. The present work aims at promoting an appropriate and sustainable purpose for the MGCW, applying the material in some mixes of self-leveling mortar. Polypropylene fibers were incorporated in dosages determined to evaluate the effect on the linear shrinkage. The use of the MGCW incorporated in the mixture of self-leveling mortars may reduce the environmental impacts of beneficiation activities of ornamental rocks and improved the properties of the mortars combined with fiber and limestone filler.

2. Method and Materials

2.1 Materials

2.1.1 Cement and additives

Portland CPII Z-32 cement was used for self-leveling mortar dosages. It is a cement made by pozzolana and its properties serve from concrete structures to mortars for lining and laying. This type of cement has a particle size of less than 41 μm and has a composition of 6% to 15% pozzolan [19]. It was chosen because it is widely used and for having several possibilities of application in mortar and concrete.

Tests were performed with Initial High Strength Cement (CPV-ARI-RS) for comparison. The use of this type of cement in the dosages of self-leveling mortars for subfloor meets the need of using/working on the pavement, hours after its execution [19]. Characteristic of works with high execution speed. This type of cement has no pozzolan in its composition.

The liquid superplasticizer (SP) chemical additive used to disperse grains is based on the brown and synthetic polycarboxylate polymer chain. According to the technical report, the sample had a density of 1.10 g/ml, a solids content of 45.6% and a PH of 4.6.

The SP additive prevents the agglomeration between the suspended particles and increases fluidity by acting as dispersants, adhering to the surface of the particles and exerting repulsion forces between them. Comb-shaped polycarboxylic ether SPs are characterized by a hydrophilic backbone adsorption unit and a polyethylene oxide side chain [20]. However, the superplasticizer additive, when excessive, affects the mixture stability and reduces segregation resistance [21].

To eliminate segregation problems of the aggregates, a liquid viscosity modifying chemical additive has a transparent color. According to the technical report, the sample had a density of 1.00 g/ml, a solids content of 0.680% and a PH of 6.9.

2.1.2 Aggregate and fibers

The fine aggregate (natural pit sand) used in the production of mortars has a fineness module of 1.24, maximum grain size of 1.18 mm and specific mass of 2.57 g/cm³, as shown in Fig. 1a - granulometric distribution. This particle size supports the study performed by Cambaz Topçu and Atesin [1], which use of natural river sands with a particle size of 0 to 1 mm, when compared with natural and artificial sands of 0 to 3 mm, shows better results in self-leveling mortars, in relation to densification, resistance to compression, pulse propagation and water absorption and capillarity.

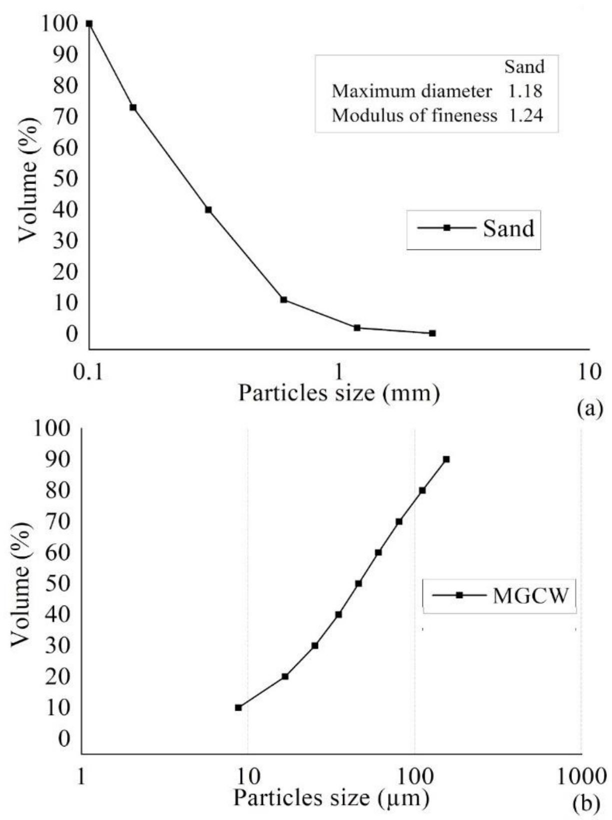

Fig. 1 Granulometric distribution of fine aggregate (a); and MGCW (b).

For the tests of shrinkage and flexural tensile strength, specimens were made with synthetic polypropylene fibers in the proportion of 4g of fibers to 1Kg of cement.

The fibers are 6 mm long and 12 μm in size. Its surface area is 366 m²/Kg. The material has a relative density of 0.91 g/cm³, deforms 25% of its length at break by traction, has a melting point of 160° C and a flash point of 365 °C.

Through scanning electron microscopy, it is possible to see the presence of fibers in self-leveling mortar dosage (Fig. 2a-b) close to the aggregate. Fig. 2c-d show the fibers aspect without magnification and with 50x magnification.

Table 1 Chemical analysis of MGCW (%).

Chemical composition	(%)
SiO_2	40.46
Fe_2O_3	10.83
Al_2O_3	15.52
CaO	13.18
K_2O	4.57
TiO_2	2.39
Other	2.23
Loss on fire	10.82

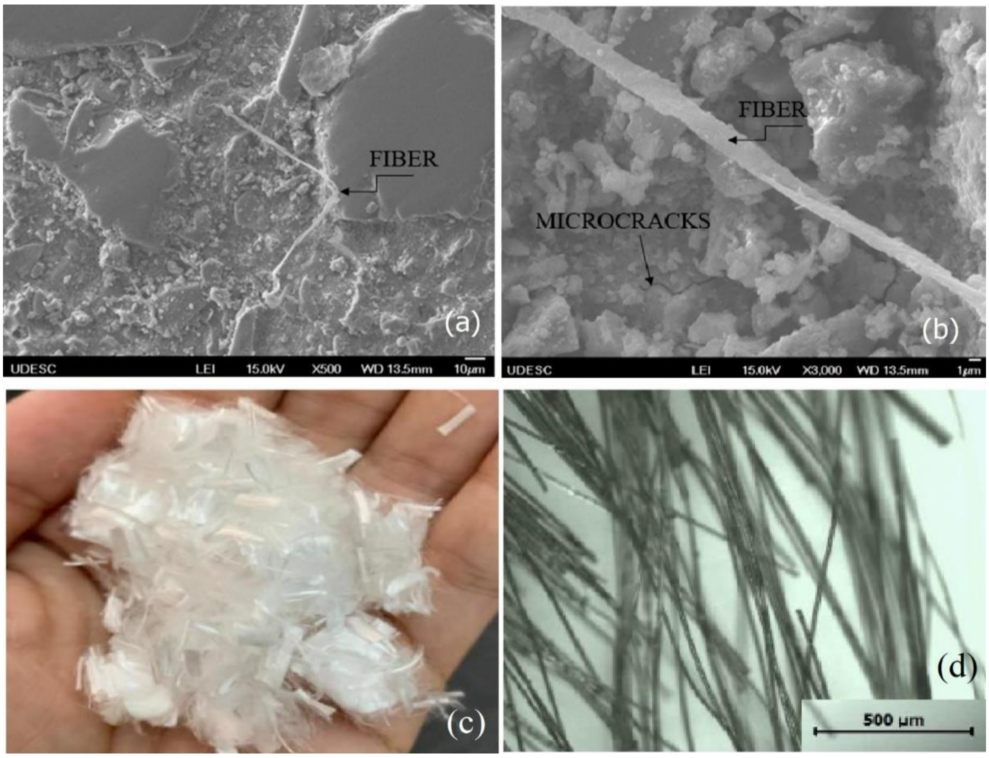

Fig. 2 T01 FIBER dosage with increase of 500x (a); Increase of 3000X in mortar (b); Fiber aspect without magnification (c); and fiber aspect with 50X magnification.

2.1.3 MGCW and Limestone Filler

The MGCW used was obtained through the ornamental rocks processing. The material was collected in the settling ditches near the cutting area. The residue mixed with water was in a muddy state. After collection the residue was dried in an oven for 48 hours at a temperature of approximately 100 ± 2 °C.

The specific mass of the Marble and Granite Cut Waste was 2.81g/cm³, obtained by pycnometry with Helium gas. As for granulometry (Fig. 1b), it has an average grain size of 45.98 μm (D50%), a maximum grain diameter of 153.81 μm (D90%), and 67.17% passing through the 74 m sieve, characterized as a powdery material. A chemical analysis test was performed by FRX, and the results found for the MGCW are described in Table 1.

Residues rich in fluxing oxides ($Fe_2O_3 + CaO + K_2O$) are usually originated through the processes of levigation, polishing or grit. Calcium oxide (CaO) and iron oxide (Fe_2O_3) come from the lime used as a lubricant and from the shot as an abrasive agent in the beneficiation process [22].

Through electron microscopy with secondary electrons, it can be concluded that the morphology of the MGCW particles as powder are irregular with an angular shape - Fig.3 (a).

The limestone filler, as for granulometry, has an average grain size of 37.38 μm (D50%), a maximum grain diameter of 146.07 μm (D90%), and 63.54% passing through the 74 m sieve, characterized as a powdery material. The average grain diameter is 18.70% smaller than MGCW. The limestone filler as powder has a heterogeneous morphology of angular shape, with larger particles distributed among the smaller ones, as shown in Fig.3 (b).

2.2 Method and Tests

Five dosages of self-leveling mortars were validated in laboratory, based on the criteria established in the standard ASTM C1708 [18] for minimum initial flow of 125 mm, absence of segregation and exudation. Improperly formulated self-leveling mortars are subject to the appearance of segregation and exudation, consequently the mechanical and durability properties can be seriously compromised [15].

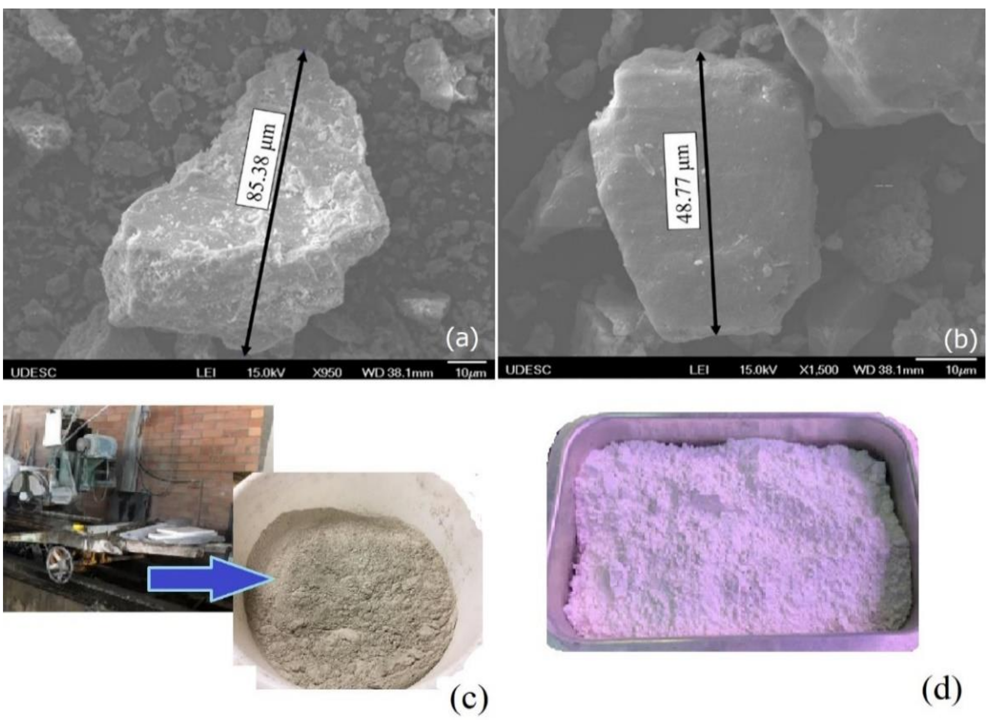

Fig. 3 Morphology of MGCW grains with 950x magnification (a); and limestone filler with 1500x magnification (b); MGCW aspect without magnification (c); and limestone filler without magnification.

Table 2 Dosages of self-leveling mortars studied.

Dosage	Mass proportion of materials							
	C	A	R	F	W/C	SP	V	Fi
T01 (50%)	1	1.5	0.5	-	0.55	0.50%	1.00%	-
T01 ARI	1	1.5	0.5	-	0.55	0.50%	1.00%	-
T01 FIBER	1	1.5	0.5	-	0.55	0.50%	1.00%	0.004
T01 FILLER	1	1.5	-	0.5	0.55	0.50%	1.00%	-
T02 (40%)	1	1.5	0.4	-	0.50	0.50%	1.00%	-
TCOMMERCIAL	Formulated in proportion 1: 0.2 (dry materials: water); 3400g of mortar to 690g of water							

Key: C – Cement; S – Sand; R – Residue (MGCW); F – Filler; W – Water; SP – Superplastifyng (% of cement mass); V – Viscosity modifier (% of cement mass); and Fi – Fibers.

Mortars were formulated based on the following materials: Portland cement, sand, marble and granite cutting residue (MGCW) or limestone filler, polypropylene fibers, in addition to chemical additives such as: superplasticizer and viscosity modifier.

The T01 dosage (50%) was prepared in the proportion (in mass) of 1: 1.5: 0.5: 0.005: 0,01 (cement: sand: MGCW: superplasticizer additive: viscosity modifying additive). From this dosage, other formulations were made with the addition of synthetic polypropylene fibers in the proportion of 4g of fiber for each Kg of cement (T01 FIBER), addition of limestone filler replacing the MGCW (T01 FILLER) and replacing the cement CP II – Z32 by the high-strength cement CPV-ARI-RS (T01 ARI). In the T02 dosage (40%) the amount of MGCW was reduced in relation to the T01 dosage (50%); however, due to the higher cement consumption, variations were not developed from the T02 formulation (40%). To compare the performance in fresh and hardened states, a commercial dosage was tested (TCOMMERCIAL). The proportion of materials is listed in Table 2.

The initial flow tests were performed with a cylinder 30 mm size and 50 mm high (volume of 35.34 cm²), called the flow ring on a square base of glass with the dimensions 400 x 400 x 6mm. To perform the procedure, the mortar is inserted into the cylinder just after mixing in a period of 2 seconds; the ring is raised to 50-100 mm height above the base and the timer is started. The mortar must spread for 240 ± 10s, so the flow diameter in two directions is then measured. The average diameter corresponds to the initial flow. For the mortar to be called self-leveling the minimum flow diameter (Dmin) must be 125 mm and the maximum diameter must be 150 mm [18].

To determine the flow retention, the initial flow test – spreading is repeated at 20 and 30 minutes after the water is added to the dry mortar mixture – the so-called "starting time" moment. Then the diameters obtained are compared for flow retention assessment. Before each spreading test, the mortar must be mixed over a period of 5 to 10 seconds.

The procedure for determining the regeneration time consists of making cuts in the mortar until it does not return to its original state, without marks, recesses and unevenness in the surface. To perform the test the mortar, immediately after mixing, is deposited in a rectangular mold with minimum dimensions of 210 x 210 mm and minimum depth of 9 mm in metal or glass. The cuts start after 10 minutes of mixing the dry mortar components with the water - starting time; the other cuts are carried out every 5 minutes. The time elapsed between the starting time and the first cut in the mortar that does not correct itself naturally determines the regeneration time of self-leveling mortars.

For the compressive strength tests, 9 cylindrical specimens with 50 mm size and 100 mm height were molded, tested at 1, 7 and 28 days of age, 3 specimens on each date, respectively, for each type of mortar [23, 18]. For tensile strength, six 40 x 40 x 160 mm prismatic specimens were prepared for each dosage, being three specimens with 3 days and three specimens with 28 days of age tested [24, 18].

The start and end setting times of self-leveling mortars were determined using the Vicat Apparatus. Periodic penetration tests were performed with the 1.0 mm Vicat needle, recording the time elapsed between the initial contact of the mortar with water and the time when the needle penetration in the sample matches 25 mm. The measurements started 30 minutes after the mortar mixture. The final setting time was determined when the needle did not visibly penetrate the paste [25].

The linear shrinkage monitoring test uses prismatic specimens sized 2.5 x 2.5 x 28.5 cm, which have a metal pin at each end axially centered [26]. The test checks the change in length in the prisms in a preset period, detecting the presence of shrinkage or expansion in the tested mortars.

The mortar's adhesion resistance test was carried out with traction equipment, coupled to a digital handheld dynamometer that allows continuous load application [27]. Tablets sized 50 mm and glue based on high-adhesion epoxy resin with a approximately 2 mm thickness were used. The pullout points were spaced apart, in addition to the corners, by 50 mm (minimum spacing).

To determine the thermal conductivity was used the conductivimeter model K10N, equipment based on ASTM C-518 [28] (Fig. 4).

3. Results and Discussions

3.1 Flow Retention, Healing Time and Setting Time

Mortars T01 (50%), T02 (40%), T01 ARI, T01 FIBER and T01 FILLER did not show flow retention, and the initial spreading diameter and after thirty minutes remained the same, as shown in Table 3. The commercial mortar reduced 20 mm after 20 minutes of the initial mixture and 40 mm after 30 minutes, the mortar loss of fluidity can be attributed to the wider surface area [8]. The regeneration time for all mortar dosages was between 15 and 20 minutes.

The Setting Time test was performed for T01 (50%), T01 ARI, T02 (40%), T01 FILLER and TCOMMERCIAL dosages - Table 3.

Fig. 5 shows the spreading diameter test, the aspect of T02 (40%) mortar without the presence of exudation and the healing time test.

The setting time of formulated mortars was at least 3x longer than the tested TCOMMERCIAL mortar. The CP II-Z32 cement replacement used in the T01 dosage (50%) by the CP V-ARI-RS cement used in the T01 ARI mortar did not decrease the setting time. The T02 mortar (40%) had a initial setting time 47.86% shorter compared to the T01 mortar (50%) and the end setting time 48.46% shorter. Such difference is related to the water/cement factor of the T02 dosage (40%), which is lower in relation to other mortars. The incorporation of limestone filler (T01 FILLER) to replace the MGCW (T01 50%) decreased the initial setting time by 44.12% and the end setting time by 35.81%.

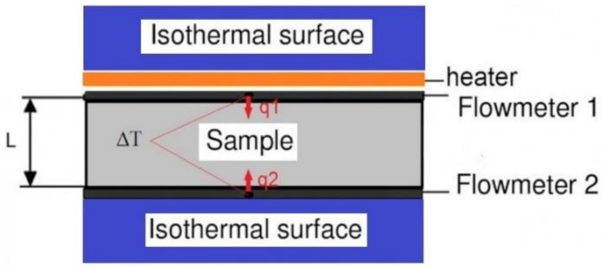

Fig. 4 Conductivimeter scheme for measuring the thermal conductivity.

Table 3 Results of flow retention tests, regeneration time and setting time.

Mortar	TCOMMERCIAL	T02 (40%)	T01 (50%)	T01 ARI	T01 FIBER	T01 FILLER
Initial Spreading (mm)	135	140	133	135	135	136
Spreading in 20 min (mm)	115	140	133	135	135	136
Spreading in 30 min (mm)	95	140	133	135	135	136
Regeneration Time (min)	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 – 20
Initial Setting Time (h:min)	1:40	5:54	11:20	11:33	-	6:20
End Setting Time (h:min)	2:06	6:26	12:20	12:23	-	7:55
Difference between initial and end setting time (h:min)	00:26	00:32	1:00	00:50	-	1:35

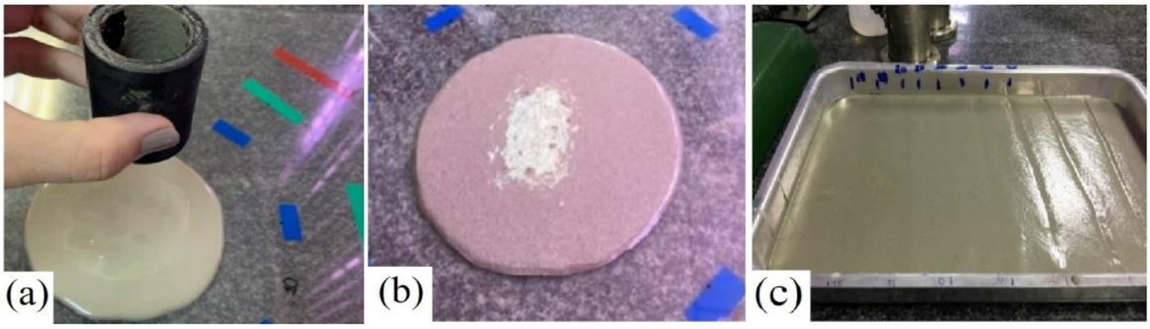

Fig. 5 Spreading diameter test (a); aspect of T02 (40%) mortar without the presence of exudation (b); and Healing time test (c).

3.2 Compressive and Flexural Tensile Strength

For the results of compressive strength obtained with the 5 dosages, the T01 ARI mixture (50% MGCW and CP V-ARI-RS) showed values higher than 1, 7 and 28 days when compared with the other prepared mortars - Fig 6 (a).

The T02 dosage (40%) showed better results of compressive strength at 1, 7 and 28 days compared to the T01 mortar (50%). The increase in the amount of MGCW and the water/cement factor decreases resistance by 31.86% at 1 day, 12.14% at 7 days and 10.65% at 28 days. MGCW is characterized as inert, without pozzolanic activity, reducing the compressive strength values when added from 40%-50% of the cement mass in the mortar dosages.

TCOMMERCIAL mortar had the lowest compressive strength values at 7 and 28 days in relation to the other mortars studied. However, with 1 day the resistance gain was 22.9% higher than the T01 dosage (50%) and 18.22% higher than the T01 FILLER.

The addition of limestone filler (T01 FILLER) increased the compressive strength in all analyzed ages in comparison with the T01 dosage (50%), which has MGCW addition in the same proportions, in 1 day it increased by 3.96%, in 7 days 17.20% and in 28 days 8.04%.

To analyze the results of flexural tensile strength - Fig. 6 (b) the samples were considered small, independent, and non-parametric (seen after Shapiro-Wilk test). The samples were compared to each other using the Kruskal-Wallis test and analyzed two-by-two by the Dunn test to conclude whether the modified parameters between the dosages changed the resistance values.

It is verified through the Kruskal-Wallis test that the tensile strengths at 3 days are considered different (p-value = 0.0124), as well as at 28 days (p-value = 0.0109) comparing all mortar dosages with a 95% significance level.

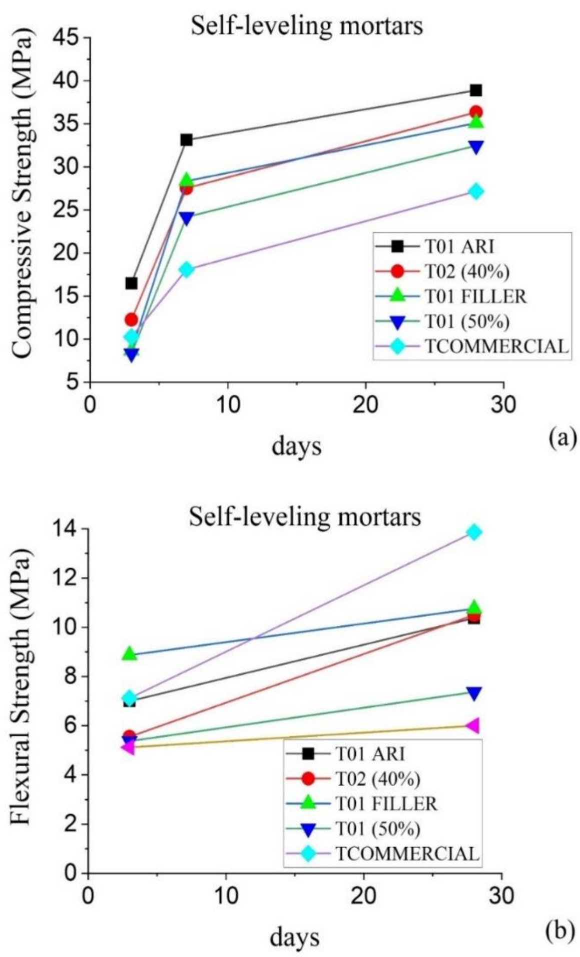

Fig. 6 Compressive strength (a); Flexural tensile strength (b).

When analyzing the influence of fiber on the T01 dosage (50%), no difference is statistically observed in the values of flexural tensile strength at 3 days (p-value = 0.7593) and at 28 days (p-value = 0.4906). The presence of fiber, in the proportions of 4 grams of fiber for each kg of cement (T01 FIBER dosage) does not increase the mortar resistance in this parameter. However, it is found that the mortar, despite presenting a rupture, remains united by the incorporated fibers, without loosening.

The T02 dosage (40%) did not show advantages regarding the tensile strength at 3 days, showed an average resistance considered statistically equal to the resistance of the T01 mixture (50%), (p-value = 0.8482). However, for the tests performed at 28 days, the T02 dosage (40%) showed a resistance 42.47% higher than the T01 mixture (50%).

Comparing the mortars T01, ARI and T01 (50%), we can see that the replacement of CP II-Z32 cement with CP V-ARI-RS cement increased the tensile strength by 30.35% at 3 days and 40.71% at 28 days, being efficient in the analyzed parameter.

The replacement of MGCW with limestone filler resulting in the mixture (T01 FILLER) increased the tensile strength by 65.17% at 3 days and 45.86% at 28 days compared to the T01 dosage (50%). Therefore, we conclude that the addition of limestone filler improves the tested property in both ages tested.

The TCOMMERCIAL mixture at 3 days of age statistically obtained a resistance equal to the T01 ARI mixture (p-value = 0.877); however, at 28 days it was 33.75% higher.

3.3 Linear Shrinkage

The linear shrinkage test was performed for all dosages formulated in laboratory and for commercial mortar according to Fig. 7. To better see the results, a line at the -1.0 mm/m mark was established.

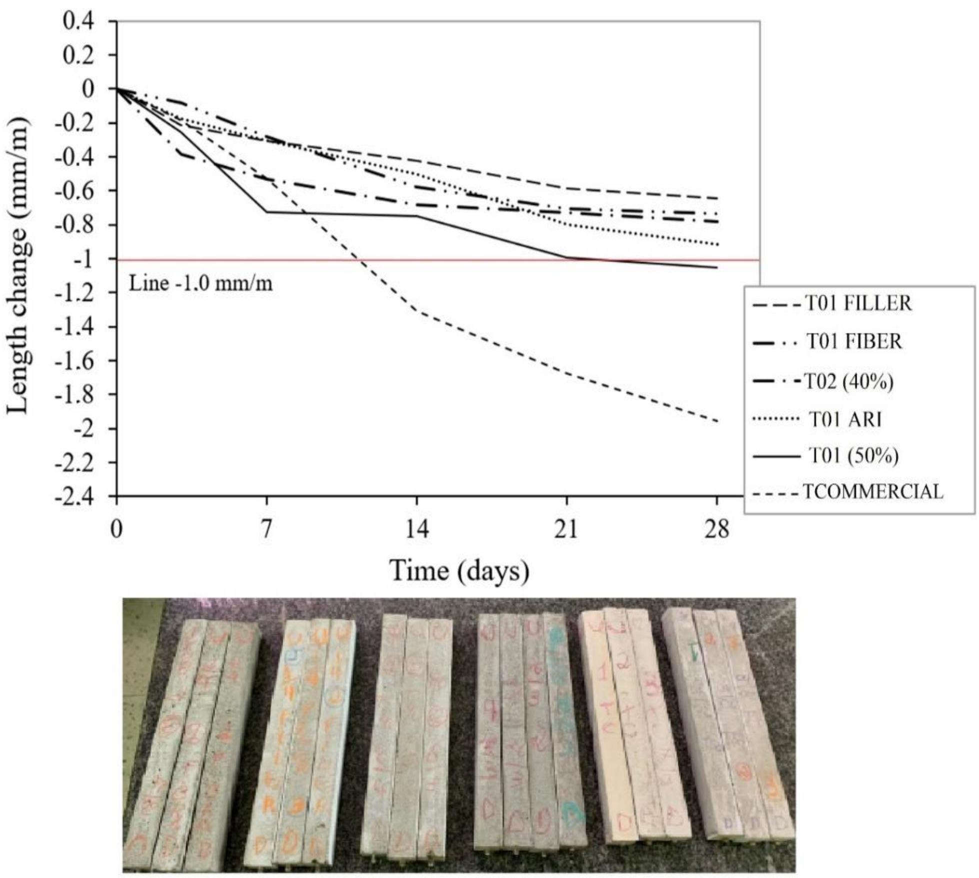

Fig. 7 Comparative graph of linear shrinkage of mortars.

The CP V-ARI-RS cement used in the T01 ARI dosage did not increase the linear shrinkage of mortars over time, compared to the T01 mixture (50%) in which CP II-Z32 cement was used.

The use of limestone filler in the dosage (T01 FILLER) reduced linear shrinkage in all ages compared to the T01 mixture (50%), providing a reduction of 38.99% at 28 days. T02 mortar (40%) had the greatest shrinkage at three days of age with a 50.59% shrinkage more than dosage T01 (50%) at this age.

Comparing all the mortars made at 7 days of age the T01 dosage (50%) showed greater linear shrinkage (-0.724 mm / m). However, at 14, 21 and 28 days the TCOMMERCIAL mortar was the one with the greatest shrinkage, -1.956 mm / m at 28 days, 85.56% higher than the T01 mortar (50%).

The incorporation of polypropylene fibers in the T01 dosage (50%), resulting in the T01 FIBRA dosage, decreased the linear shrinkage by 68.92% at 7 days, 42.51% at 14 days, 46.48% at 21 days and 47.63% at 28 days. The fiber action effectiveness in reducing the linear shrinkage of mortars was proven at all ages tested.

Self-leveling mortars show greater shrinkage by drying and less autogenous shrinkage than ordinary mortars due to late hydration and pore structure change caused by the addition of organic additive [12].

Fig. 8 shows a shrinkage crack that could be avoided by adding polypropylene fibers to the mortar.

3.4 Specific Mass, Voids Index and Water Absorption

TCOMMERCIAL, T02 (40%), T01 (50%), T01 FIBER and T01 FILLER mortar samples were tested to determine water absorption, voids index and specific mass, and the results are shown in Table 4.

The TCOMMERCIAL mortar sample was the dosage that showed the highest water absorption and voids index among all the mortars tested, absorbed 23.22% more water compared to the T01 FILLER mixture, consequently presenting 18.51% more number of voids.

The incorporation of polypropylene fibers in T01 dosage (50%) resulting in the T01 FIBER mixture, increased the water absorption by 21.18% and the amount of voids by 18.96%. In general, there is a large number of pores in the hardened cement structure, especially in mortars with high fluidity. This is one of the significant factors to affect the mortar and concrete performance [8]. The microstructure of a T01 (50%) mortar sample (Fig. 9) at 28 days of hydration shows the sand particles surrounded by a dense matrix of C-S-H, in addition to sand holes corresponding to the holes left by the removal of sand particles and air voids [11].

The microstructure of mortars formulated with finer components and containing discontinuous pores favors increased strength and durability. The water absorption of mortars does not vary simply depending on the size of the pores, but also depends on the type of porosity and its connectivity with the sample surface. Secondary

Fig. 8 Photograph of a linear shrinkage of subfloor mortars.

Table 4 Water absorption values, voids index and specific mass for the tested mortars.

Mortar	Water absorption (%)	Voids index (%)	Specific mass (g/cm³)
TCOMMERCIAL	12.31 ± 0.11	26.31 ± 0.27	2.54 ± 0.01
T02 (40%)	9.70 ± 0.23	21.65 ± 0.52	2.57 ± 0.01
T01 (50%)	9.87 ± 0.27	22.05 ± 0.39	2.58 ± 0.02
T01 FIBER	11.96 ± 0.00	26.23 ± 0.00	2.62 ± 0.00
T01 FILLER	9.99 ± 0.41	22.20 ± 1.02	2.67 ± 0.03

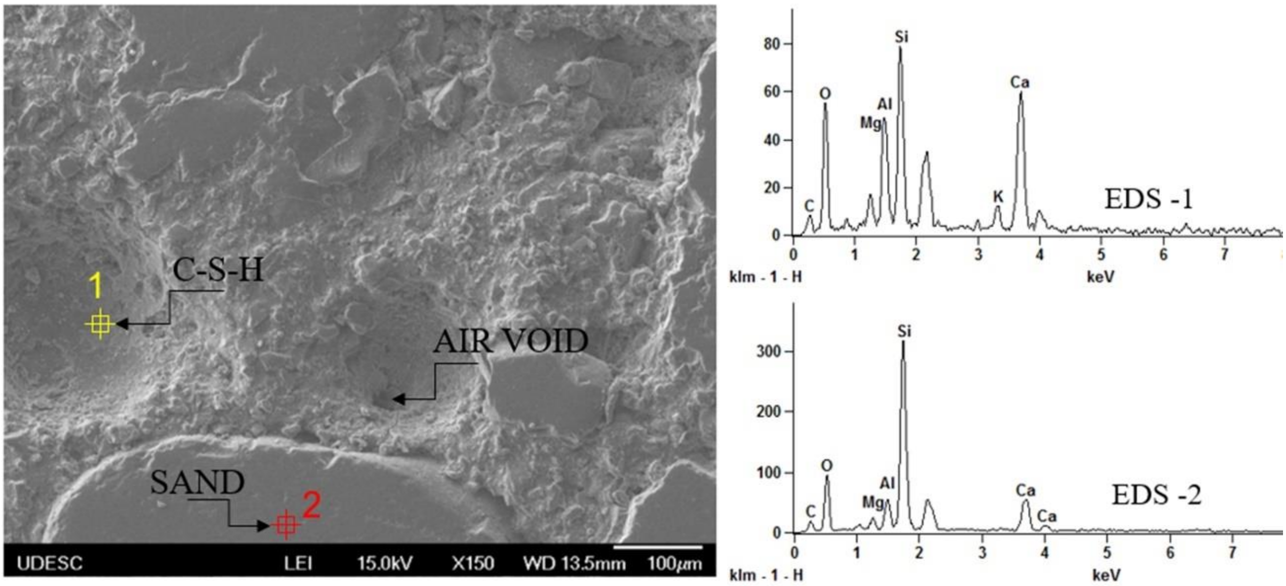

Fig. 9 Microstructure of T01 mortar (50%) with 150x magnification.

raw materials with internal porosity when used in self-leveling mortar systems can result in greater relative water absorption, but not necessarily in lower resistances. Such systems may have some type of connectivity on the sample surface but shows discontinuity inside [6].

The specific mass varied 0.13 g/cm³ among all formulated dosages, thus showing great similarity between the results obtained.

3.5 Tensile Adhesion Strength

The mortar tensile adhesion strength test was carried out in the T01 (50%) and TCOMMERCIAL dosages.

T01 (50%) mortar showed an average tensile adhesion strength of 0.51 ± 0.25 MPa at 30 days. TCOMMERCIAL dosage mortar showed an average tensile adhesion strength of 0.37 ± 0.14 MPa at 30 days. The resistance was 27.45% lower than the value obtained for the T01 (50%) mixture.

In observation of the box graph, Fig. 10, 100% of the samples obtained for the TCOMMERCIAL mortar are below the T01 (50%) median dosage.

Through the analysis of mortars by Shapiro-Wilk test, it was concluded that the T01 (50%) mixture has normal data (p-value = 0.988), with a 95% confidence interval. The TCOMMERCIAL dosage, however, for a 90% confidence interval, does not show normality in the data presented (p-value = 0.063).

For comparison, the samples were considered independent and as the data obtained for the TCOMMERCIAL dosage showed little indication of normality, two hypothesis tests were used to compare the tested mortars: Student's T and Wilcoxcon-Mann-Whitney, and the p-values obtained, respectively, were 0.1869 and 0.1763. With 95% confidence, the samples are considered equal.

The tensile adhesion strength of self-leveling mortars is directly related to the layer thickness, the type of application and the substrate. Mortar applied on a surface will tend to dry from the edges to the center, presenting a non-uniform shrinkage, causing buckling and resulting in tensile and compression tensions in the interface with the adhered layers. The greater the shrinkage of the material, the more tensions are induced for the subsequent layers, causing a decrease in the adhesion force [29].

3.6 Thermal Conductivity

Table 5 shows the results of the thermal conductivity test. The conductivity test showed very close results between the mixtures, showing that there is no significant effect of the MGCW residue and of the

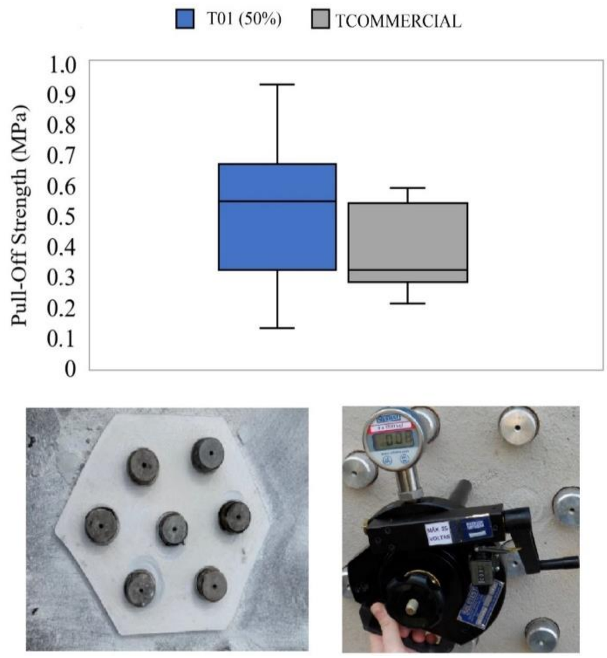

Fig. 10 Boxplot chart for tensile adhesion strength testing and test sample.

Table 5 Thermal conductivity for the mortars.

Mortar	Thermal conductivity (W/mK)	Sample size (mm)	Sample thickness (mm)
TCOMMERCIAL	0.90 ± 0.11	100x100	18.0
T01 (50%)	1.00 ± 0.08	100x100	17.8
T01 FIBER	1.25 ± 0.15	100x100	18.5

addition of fibers on the thermal conductivity of mortars. There was an insignificant increase in conductivity in mixtures with MGCW. The fiber did not influence because only 4g per kilogram of cement was added.

The thermal (and acoustic) characteristics of floor systems that separate rooms are very important. The self-leveling mortar has a disadvantage compared to a conventional mortar, which is more porous. In comparison with the conventional mortars, self-leveling mortars have a higher thermal conductivity due to their particular composition. This is due to the high compactness of the product and the absence of air entrained (insulating) in the mass, which limits the conductive capacity of conventional mortar. Corinaldesi [30] found thermal conductivity for conventional mortar of 0.73 W/mK.

4. Conclusions

(1) The MGCW had no pozzolanic activity.

(2) The formulated mortars did not show flow retention in the period of 30 minutes, while the TCOMMERCIAL mortar reduced about 30% of the spreading capacity in the same period. All dosages prepared had a setting time of more than 5:00 hours, enough to perform the material pumping, if necessary.

(3) The dosages developed were superior to commercial mortar, when analyzing the compressive strength, water absorption, voids index, linear shrinkage and tensile adhesion strength. The T01 ARI mixture showed the greatest compressive strength at 1, 7 and 28 days, with its final strength being 43.14% higher when compared to the commercial mixture. The TCOMMERCIAL dosage showed the highest percentage of water absorption, voids index, linear shrinkage and its tensile adhesion strength was 27.45% lower than the value obtained for the T01 mixture (50%).

(4) The linear shrinkage values remained below 1.0 mm/m, except for T01 (50%) mortar, which obtained a shrinkage of 1.054 mm/m at 28 days. In comparison with the T01 mixture (50%), the TCOMMERCIAL dosage obtained 85.56% greater shrinkage. The linear shrinkage contributes to subfloor pathologies such as debarking and cracks.

(5) The mortar with the incorporation of polypropylene fibers, T01 FIBER dosage, obtained results of linear shrinkage lower than the T01 mixture (50%). At 7 days there was a reduction of 68.92%, at 14 days 42.51%, at 21 days 46.48% and 47.63% at 28 days. The fiber action effectiveness in reducing the linear shrinkage of mortars was proven at all ages tested.

(6) MGCW and fiber did not influence thermal conductivity, which is higher in self-leveling mortar compared to conventional subfloor.

(7) Most of the mortars developed in this research, when evaluated for physical properties in the fresh and hardened states, had higher results when compared with the tested commercial mortar, indicating the

possibility of applying the dosages in civil construction as a subfloor layer.

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