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Evaluation of the use of polyurethane residue aggregated to the plaster of civil construction

Guilherme Moraes de Oliveira[1], Vittória Caroline Souza dos Santos[1], José de Souza[1], Tatiana Louise Ávila C. Rocha[2], Eduardo Henrique de Souza Cardoso[3]
[1, 2, 3]*Fundação Liberato – Novo Hamburgo, Brasil*
[4]*Universidade do Vale do Rio dos Sinos – São Leopoldo, Brasil*
[5]*Faculdade de Tecnologia – Novo Hamburgo, Brasil*
Corresponding Author: Guilherme Moraes De Oliveira

ABSTRACT: *The study deals with the reuse of polyurethane (PU) obtained from a kitchen sponge added to plaster for use in civil engineering. The kitchen sponge is an item widely used by the population in their daily lives, generating a significant accumulation of waste. Thus, from the analysis of the properties of the kitchen sponge, it was seeking possible reuse of the kitchen sponge using it as an aggregate in plaster. The objective is to evaluate the properties of the material and consequently the search for an alternative of reuse of the waste to reduce the impact of the waste on the environment from the disposal. The methodology is composed of the collection of kitchen sponges already used, the processing, its application as an aggregate to gypsum and water, the preparation of plates for the tests and the evaluation of the properties. In general, the mixture presents significant results, highlighting excellent impact resistance and maintaining characteristics of the plaster, such as its pick time and compressive strength.*
Keywords: *Polyurethane, Kitchen Sponge, Plaster, Reuse.*

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I. INTRODUCTION

The polyurethane sponge or kitchen sponge is present in our daily life being a tool that generates a significant accumulation of waste in landfills. In 2014, 360 million sponges were produced in Brazil, about 2520 tons of material. Because it is a polymer from the thermo-rigid family, it is difficult to recycle. The sponge can generate contamination in the groundwater because as responsible for recycling operations and takes about 90 years to decompose, in the meantime, animals feed on this waste, dying suffocated [1].

According to studies by researchers at Furtwangen University, Germany (2017), the sponge remains a "bacterium carrier" as it contains about 362 bacteria because the environment is very humid, is favorable for their development. Because of this, it specialists recommended that the item be replaced every ten days [2].

II. LITERATURE REVIEW

Synthetic double-sided sponges are intended in the kitchen for dishwashing. They are compound of a polymer called polyurethane. For the formation of the polyurethane polymer molecule to occur the reaction of the monomers (pure compounds) of diol (an organic compound with two hydroxyl groups) with diisocyanates (a functional group of nitrogen, carbon and oxygen atoms) [3].

There is a classification within the polymers that the kitchen sponge is inserted into, which is foam. About the kitchen sponge, the polyurethane foam used is the flexible one, in which for its manufacture different raw materials can be used, such as polyols (these of ether) [4]. Alternatively, ester, but in the case of a kitchen sponge, the polyol used is polyester), isocyanates, water, catalysts, blowing aids, and even flame retardants. Polyurethane foam exhibits a wide range of application as it has low bulk density, high-temperature capacity, and low thermal conductivity [5].

In addition to polyurethane, the double-sided sponge is also made of abrasive fiber. The recommended fiber for cleaning aluminum surfaces is composed of a synthetic fiber together with an abrasive mineral. Synthetic fiber is created with chemicals as raw material, without the participation of any natural fiber,

compounds usually derived from petroleum. The sponge for having a porous surface, after several studies showed that the sponge, are excellent transmitters of pathogens. Pathogens may, after spreading on the surface, favor outbreaks of foodborne diseases (DTAs) because contamination can last for hours or even days [6].

This is one of the most significant issues of concern for public health in recent years, there has been a significant increase in OTDs worldwide [7]. It is believed that this may occur due to several factors, according to data from such as keeping the sponge in containers with water, food scraps, detergent, and even grease, It also causes microorganisms to multiply [6]. In a microbiological analysis performed by Demarque et al. (2012) showed the presence of fecal coliforms in the sponge, a pathogen responsible for several diseases, including gastroenteritis [8].

Gypsum is found almost all over the world, the gypsum ore, the raw material from which the gypsum comes from, is calcium sulfate (CaSO4), with two water molecules, is seen in Brazil mainly in the region of Cretaceous terrain. As in the state of Ceará, Rio Grande do Norte, Piauí, and Pernambuco. Plaster consumption is growing in Brazil, due to the increase of new technologies in civil construction and the need for the fast delivery of buildings. The material can be used in wall coverings, boards, precast components, and even blocks [9]. The plaster of the calcined model, according to Barzotto et al. (2017) is characterized by dust obtained from calcination (chemical reaction of thermal decomposition), and the grinding of gypsum [10]. During the calcination stage, the temperature is around 125 °C and 180 °C, the gypsum ends up losing part of the crystallization water, passing, to form of calcium hemihydrate, ie, plaster. It is a medium grade insulator, protecting well mainly wooden structures from fire as it absorbs much heat [11].

Moreover, plaster plays an essential role in buildings primarily because it becomes the protection of the outer walls from the influence of weather conditions [12]. Its hardening process occurs from the chemical process called crystallization, and resistance to this step for Brachaczek (2018) is one of the most critical factors determining the durability of the plaster, this resistance crumbles under the influence of humidity [13].

Aggregate is all the material that is put together in the pure plaster mix (plaster paste and water only). Aggregates are sometimes added to improve features for a given application. As cited by Camarini et al. (2016), who added citric acid (C6H8O7) for use in component construction, resulted in decreased plaster consistency, increased flowability, increased grip time, and decreased compressive strength and hardness [14]. On the other hand, applied natural fibers in order to increase the lateral resistance outside the masonry wall plane, which cited: "Previous studies have shown that the addition of fibers to masonry elements (blocks, mortar, and gypsum) improved the mechanical properties of compression, shear and tensile strength by factors of 0.50, 4.25 and 3.0, respectively." [15]. Besides, the study by Li et al. (2016) who applied powdered red brick residue in the production of cement-based decorative plaster for walls, this experiment resulted in better compressive and flexural strength but also decreased the tensile strength of plaster [16].

III. LITERATURE REVIEW

The polyurethane sponge, is an indispensable item in the homes of the population, for washing kitchen utensils and cleaning in general. Because it is overused, it ends up being replaced with some frequency, generating a significant accumulation in landfills and dumps. Based on this analysis, this project was developed focusing on the reuse and recycling of this material.

For a better understanding of the defined percentage difference, the samples were named S1, S2, S3, S4 and S5, respectively, 0%, 5%, 10%, 15%, and 20%.

The project consists of developing material for civil engineering finishing application, using a ground kitchen sponge as an aggregate, in the mixture of plaster and water. The methodology is done in seven steps: the choice of material, chemical tests on new sponges to characterize them, the collection of kitchen sponges used for the project, the grinding of these, the making of molds for the manufacture of specimens, the making of samples and mechanical tests. To perform the practical part was used sponges from collection points in restaurants in the city of Novo Hamburgo, where there is a higher flow of item exchanges in their kitchens. Samples were placed in cardboard, with indicative papers glued on the top, explaining what the purpose of being there, and what would be the purpose of the project, because the Sanitary Surveillance, in its inspections, requires this procedure of restaurants. Also, a gathering was made at homes of friends and family, totaled 130 units of the item.

For grinding the material, a mill was used. Used sponges, thoroughly dried, were placed one at a time in the compartment above the equipment. After passing through the mill knives, the material had a small grain size. After that, a diversity of material size was verified. Because of this, the density of the kitchen sponge was calculated, obtaining 0.263 g/cm³ as its average density.

For the process of defining the amount of material to be used, it was necessary to establish the water/plaster ratio (C), we used the average of several relationships found in companies of calcined plaster, then, we arrived at the equivalent of C = 0.6 mL/g. That is, for each 600 mL of water, 1000 g of calcined plaster is

used. Based on the equations present in the MB 3470 standard, calculations were performed to find out the required amounts of gypsum and water for each mold made [17].

$$Mg = \frac{V}{C + 0.4} \quad \text{Eq. (1)}$$

Mg - Plaster Mass;
V - Volume;
C - Water / Plaster Ratio.

$$Ma = Mg \times C \quad \text{Eq. (2)}$$

Ma - Water Mass;
Mg - Plaster Mass;
C - Water/Volume Ratio.

For each test, different mold sizes are used. Calculations are performed five times, ie, one for each tested. The quantities determined from the calculations made are shown in Table 1, Table 2, Table 3, Table 4, and Table 5.

Table 1. Gypsum-kitchen sponge proportions – Humidity test.

	5%	10%	15%	20%
Sponge Volume (cm³)	2.34	4.6	7.0	9.3
Gypsum Volume (cm³)	48.0	46.0	44.0	42.0
Sponge Mass (g)	0.7	1.0	1.5	2.3
GypsumMass (g)	48.0	46.0	44.0	42.0
Water Volume (mL)	28.8	27.6	26.4	25.2
Water Mass (g)	31.5	28.3	24.9	25.4

Table 2. Gypsum-kitchen sponge proportions – Setting time.

	5%	10%	15%	20%
Sponge Volume (cm³)	22.0	44.3	66.4	88.5
Gypsum Volume (cm³)	425.0	407.0	390.0	370.0
Sponge Mass (g)	4.3	8.3	12.3	16.7
GypsumMass (g)	425.0	407.1	389.4	371.7
Water Volume (mL)	255.0	244.3	233.6	223.0
Water Mass (g)	238.2	230.2	210.7	200.4

Table 3. Gypsum-kitchen sponge proportions – Impact test.

	5%	10%	15%	20%
Sponge Volume (cm³)	60.0	120.0	180.0	240.0
Gypsum Volume (cm³)	1150.0	1100.0	1050.0	1000.0
Sponge Mass (g)	12.0	25.5	39.6	53.5
GypsumMass (g)	1150.0	1100.0	1050.0	1000.0
Water Volume (mL)	690.0	660.0	630.0	600.0
Water Mass (g)	670.5	635.6	601.2	571.9

Table 4. Gypsum-kitchen sponge proportions - Compression and Hardness.

	5%	10%	15%	20%
Sponge Volume (cm³)	5.85	11.72	17.58	23.44
Gypsum Volume (cm³)	120.0	115.0	110.0	105.0
Sponge Mass (g)	1.2	2.3	3.2	4.1
Gypsum Mass (g)	120.0	115.0	110.0	105.0
Water Volume (mL)	72.0	69.0	66.0	63.0
Water Mass (g)	61.8	55.3	51.7	47.8

Table 5. Gypsum-kitchen sponge proportions – Traction and Flexion Test.

	5%	10%	15%	20%
Sponge Volume (cm³)	12.8	25.6	38.4	51.2
Gypsum Volume (cm³)	245.0	235.0	225.0	215.0
Sponge Mass (g)	3.0	6.4	8.2	11.6
Gypsum Mass (g)	245.0	235.0	225.0	215.0
Water Volume (mL)	147.2	140.8	134.4	128.0
Water Mass (g)	124.5	123.2	116.0	106.0

Also, molding was performed three samples for each test compound only pure gypsum (gypsum + water), to have reference values for each test for further analysis of the results. The quantities of material required for each assay are in Table 6.

Table 6 . Gypsum-water proportions for Pure Plaster.

	Humidity	*Setting time*	*Impact*	*Compression and Hardness*	*Flexion Traction*
Gypsum Volume (cm³)	50.0	435.0	1200	125.0	256.0
Gypsum Mass (g)	50.0	435.6	1200	125.0	256.0
Water Volume (mL)	20.0	261.4	720	75.0	153.6
Water Mass (g)	28.8	245.0	704	64.1	132.6

For the sample molding step, all the molds needed to be separated and cleaned. Ortolan SEP 218 water-based release agent was placed on its surface with the aid of a brush to facilitate demolding. Before material separation, the kitchen sponge went through the sieving process using a 0.59 mm Granutest brand sieve to have a small grain size for better mixing of the mixture when ready. Then, in the next step, the materials were separated in the quantities described in the previous chapter and placed in separate containers.

For this moment, the MARTES scale, with a maximum capacity of 16.2 kg and a resolution of 0.01 kg, was used to weigh the necessary kitchen sponge, plaster, and water. Moreover, then, with the aid of a mixer, the compound was made. The paste was left in the blender for about 3 minutes until it reached a uniform appearance.

For the execution of the grip time test, a sample was molded for each percentage defined in the 177 cm³ non-corrosive and non-absorbent material mold, seen in Figure 1(a). For the impact test, 16 samples (3 of each set rate) of 1200 cm³ were molded, as shown in Figure 1(b). With six molds of 125 cm³, began the molding of samples for hardness and compression tests. Fifteen samples were molded for each assay (3 of each defined percentage) totaling 30 samples, as shown in Figure 1(c). Finally, for the flexural tensile strength test, 15 samples were molded with a 256 cm³ metallic prismatic mold. Three samples were made for each determined percentage, as shown in Figure 1(d), which shows the molding in one of the molds..

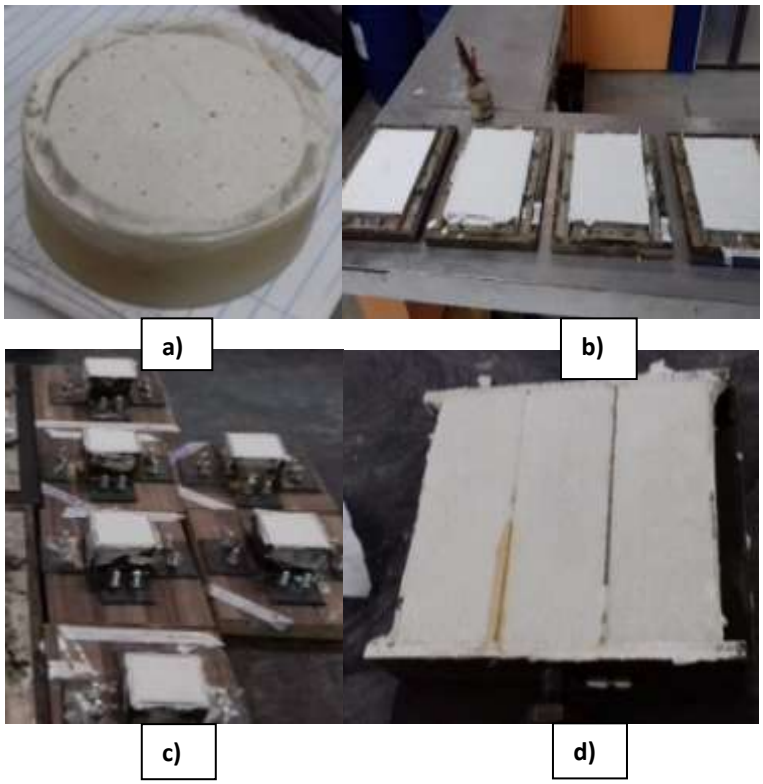

Figure 1. a) Sample setting time. b) Impact samples. c) Hardness/compression samples. d) Flexural tensile samples.

The procedures of the tests performed in the kitchen sponge for characterization and the molded plasterboards were TGA, DSC, and FTIR. The TGA test analyzes the thermal behavior of the material. The equipment has a thermobalance, and an oven, heated at 10 °C per minute, and from this, the loss of mass of the material was analyzed. The DSC (Differential Exploratory Calorimetry) test was performed on the same equipment as the TGA test and was heated to 10 °C per minute. However, in this essay, the mobility of the material was analyzed. For the Fourier Transform Infrared (FTIR) test, this is for characterization, in which the

equipment contains a crystal with an infrared beam that crosses the material. The equipment performs a mathematical treatment, resulting in bands that can serve to represent the chemical chain of the material.

The Granulometric Analysis test followed ASTM D1921-06: Standard test methods for particle size (sieve analysis) of plastic materials [18]. Which has been adapted for PU as the standard is for polystyrene (PE) and polypropylene (PP). Because the PU granulometry is similar to that of PE, the sieves for this material were used. These number 5, 7, 10, 18, 35, 120 and 200 and the bottom, with a thickness of 4000 µm, 2800 µm, 2000 µm, 1000 µm, 500 µm, 125 µm, 75 µm and 0, respectively. It was necessary to use 100 g of already ground sponge, and arrange the sieves in descending order on a sieve shaker and let it vibrate for about 20 minutes. After performing the test, it was possible to verify in percentages the amount of sponge retained in each sieve, according to the equation 3.

$$RM = \frac{(MF - MI) \times 100}{MA} \quad \text{Eq. (3)}$$

RM - Material retained in the sieve;
MF - Mass of each sieve as well as the bottom container containing its retained portion;
MI - Mass of each sieve as well as of the empty bottom bottle;
MA - Sample mass;
100 - Conversion factor.

After the granulometric analysis performed, it was possible to verify that the sieve number 120 µm, size 125 µm, retained most of the sponge, the results we can see in Table 7.

Table 7 – Granulometric distribution of kitchen sponge.

Screens (µm)	Weight (%)
4000	0.44
2800	0.20
2000	0.35
1000	2.21
500	30.47
125	50.37
75	8.64
0	7.33
TOTAL	100%

For the Humidity Test, we used as a base the dissertation Measurement of Humidity Content in Building Materials [19]. After the samples were molded into disposable cups, they were weighed on a analytical balance with a resolution of 0.0001. After this step, they were taken to a furnace at 40 °C. This procedure occurred four times, each for 1 hour. After every 1 hour in the furnace, the samples were left for 20 minutes in a desiccator and then weighed again. After the test performed, the humidity content was calculated with the equation 4:

$$w = \frac{m_h - m_s}{m_s - m_v} \times 100 \quad \text{Eq. (4)}$$

- Sample mass before going to the oven;
- Mass of the sample after oven drying;
- Mass of the container;
W - Humidity content (%).

Figure 2 shows the results obtained with the humidity content test of the samples..

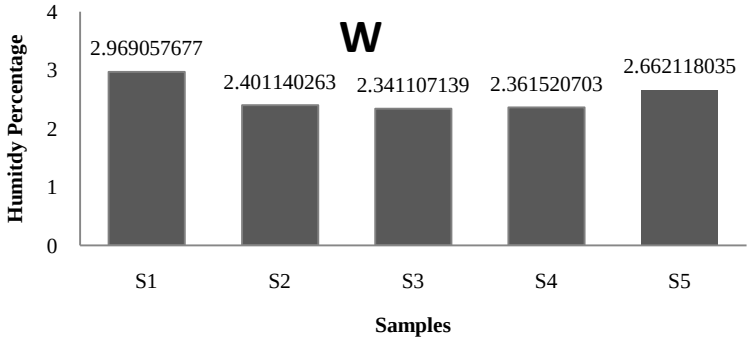

Figure 2 – Humitdy Percentage.

MB 3469 - Construction Plaster: Determination of the physical properties of the paste was performed based on the setting time test [20]. The Vicat device used for the analysis consists of a rod, which has a removable needle of 1mm² at its tip, and an adjustable indicator with its graduated scale in millimeters.

This test consists of determining, with the aid of a stopwatch, the start and end time of the paste. The start time of the grip was marked the moment the water comes into contact with the plaster and sponge, until the moment the appliance needle marks 1 mm from the base. Moreover, the final time of the handle just as the needle no longer penetrated the paste, leaving only a small impression. Figure 3 shows the values found in this test.

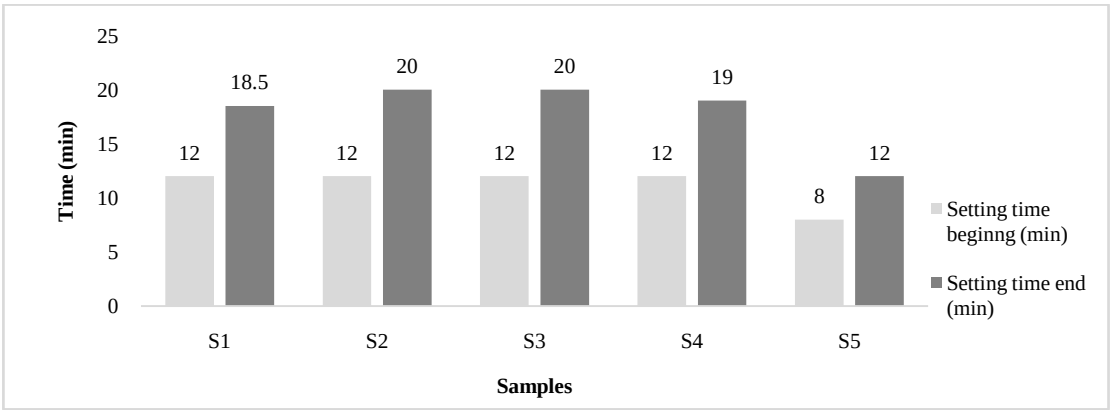

Figure 3 – Setting time.

Before the mechanical tests performed on the plates, after they were demolded, they were taken to a 40 ºC furnace for about five to seven days, as required by standards.

Besides, in the Impact Test, the procedure followed the same steps performed in the project Evaluation of the use of Ethylene-Vinyl Acetate E.V.A. Waste in Reinforced Gypsum Plaster Walls (MARTINS et al., 2015 [21]. The 1200 cm³ samples were struck in the center by a 6.3 N sphere projected from a height of 15 cm, which was increased by five cm by five cm until the rupture of the sample. Each fissure suffered during falls was measured with the aid of a fissurometer. This procedure has been performed 15 times. After that, it was possible to calculate the gravitational potential energy expended for the rupture of the sample from the equation 5:

$$Epg = m \times g \times h \qquad \text{Eq. (5)}$$

Epg – Gravitational Potential Energy;
m – Mass;
g – Gravity;
h – Height.

Figure 4 presents the graph with the results obtained with the impact resistance test.

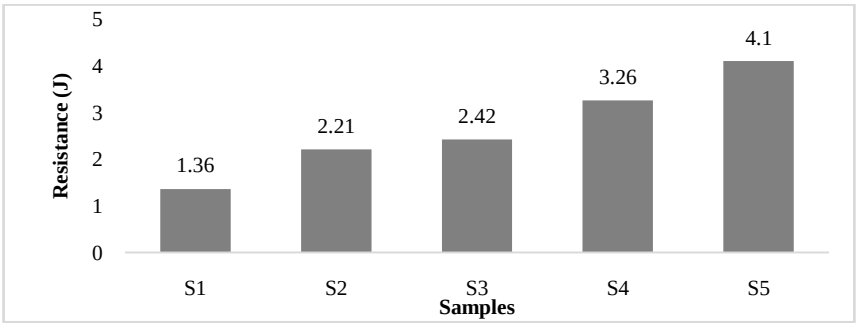

Figure 4. Results of Impact Test (J).

For the performance of the Compression Test, the procedure was by the standard MB 3470 - Plaster for construction: determination of the mechanical properties [19]. The machine used for the test consists of a press with a load capacity higher than 20000 N, a minimum accuracy of 200 N, with a minimum application area of 2500 mm² and a stroke of at least 100mm. For the test, the selected face was in the center of the test plate, and the load continuously applied at a ratio of 250 N/s to 750 N/s until rupture. The compressive strength resulted from the following equation:

$$R = \frac{P}{S} \quad \text{Eq. (6)}$$

R – Resistance to compression;
P – Load that produced the sample rupture;
S – Cross-sectional area of load application.
Figure 5 graphs the results of the compression test.

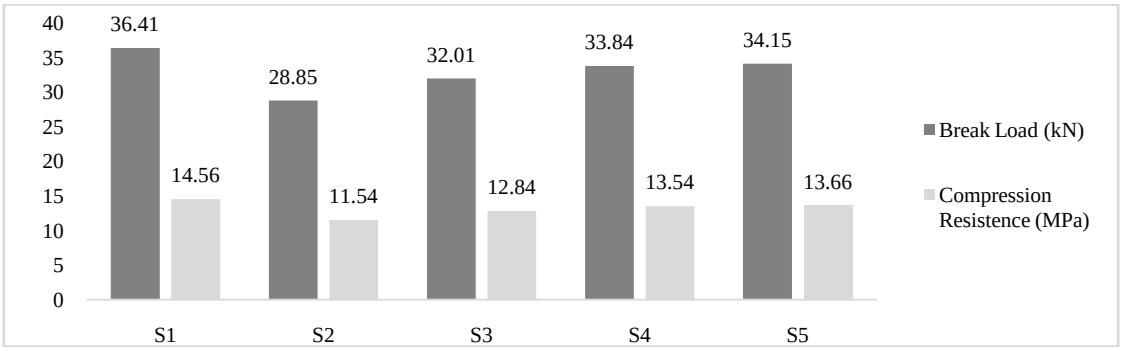

Figure 5. Compression Test.

The Hardness Test followed the same standard previously mentioned MB 3470 - Construction Plaster: determination of mechanical properties [19]. The preparation of the molds follows the same procedure; only the machine used is another. A three-dimensional optical measuring machine was used to measure the identification of the samples. After the procedure, the hardness of the material resulted from the equation 7:

$$D = \frac{F}{\pi \times \emptyset \times t} \quad \text{Eq. (7)}$$

D - Hardness of the material;
F – Strength (N);
$\emptyset$ - Ball diameter;
t – Average of the identifications..

Figure 6 shows the results obtained in the test..

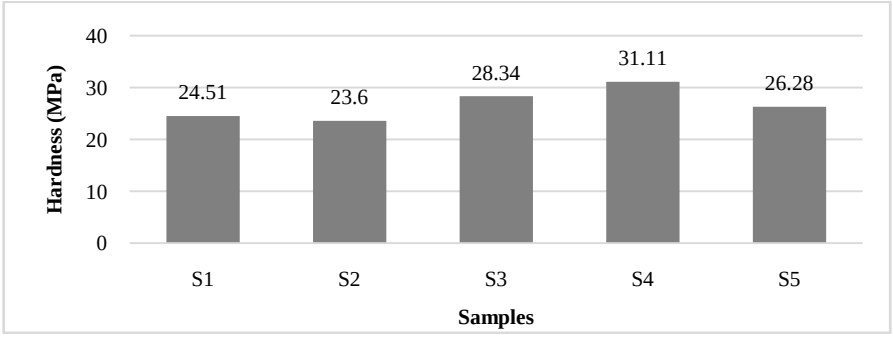

Figure 6. Hardness Test Results.

For the execution of this Flexural Tensile Test, the NBR 13279 standard was adapted for mortar [22]. The machine for the test consists of a press capable of placing the uniform and shock-free load of 50 N/s as required by the standard. The charge was applied from 50 N/s until the rupture of the sample. After the test performed the flexural tensile strength is calculated with the following equation 8:

$$R_1 = \frac{1.5 \times F_1 \times L}{40^3} \quad \text{Eq. (8)}$$

R_1 - Tensile strength of flexion;
F_1 - The load applied vertically in the center of the Sample;
L - Distance between brackets.

Figure 7 shows the results found in the tests.

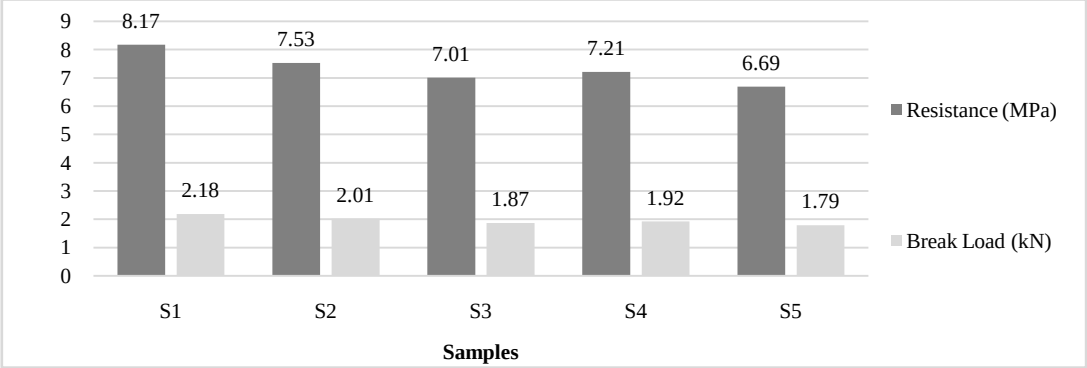

Figure 7. Results of the Flexion Test.

IV. RESULTS AND DISCUSSION

Regarding the humidity content test, it is worth noting that the samples with the sponge aggregate had a lower humidity content than the pure plaster sample, mainly S3 (10%), which presented a variation of 0.63%. Concerning the setting time test, all samples had a similar setting time, except for S5, which had a significantly low take-up time, ranging from 4 minutes from the beginning of the grip and 6.5 minutes from the end of the grip of S1. Because of this, it is interesting to note that, because of its shorter setting time, its handling is more complicated, since it is faster to dry.

There is a significant increase in the impact strength of the material with an increasing percentage of sponge in the sample. For the average breaking height of S1 was 21.67 cm, while that of S5 was 65 cm. It was resulting in an energy change required for breakage of 2.74 J.

Concerning the compression test, a decrease in the compressive strength of the sponge aggregate samples with the pure plaster sample occurred. Normally, the preferred foam for applications where compressive strength is crucial is polyether-based polyether foam, which generally has better compressive strength than polyester-based polyol. For, as stated in the literature review, the polyol used as the raw material of the polyurethane sponge is polyester [21, 23, 24].

Regarding the hardness test, it is worth noting that S2 presented a hardness lower than S1 (pure plaster), the other samples expressed an increase in hardness, mainly S4, which showed a difference of 6.6 MPa about S1.

In the case of the flexural tensile test, a loss of strength occurred in the samples with the aggregate. Mainly S5, which presented a variation of 1.48 MPa.

V. CONCLUSION

Humidity testing shows that decreasing humidity and increasing the percentage of sponge aggregate leads to reduced setting time. Given that the kitchen sponge has several bacteria, and that they spread in humidity, the result was beneficial. Besides, comparing with the parameters of MB 3469 Standard Plaster for Construction - Determination of Physical Properties of Pulp, which states that the value of the start of the handle should be greater than 10 minutes and the end of the handle of greater than 45 minutes. Its results that the plaster, with 5% aggregate, 10%, and 15% obtained the start time of the handle, compatible with the standard since it was 12 minutes. On the other hand, all samples had lower results than the norm, as they ranged from 12 to 20 minutes only. It is noteworthy that the sample with 20% achieved much more economical results in both the start and end times. Increasing the percentage of water in the mixture would increase the setting time.

The impact test presented satisfactory results, since it offered a resistance much higher than the pure plaster, thus allowing the application of this material in the civil engineering area. The mechanical performance related to compression presented satisfactory results. For comparing the results with the MB 3470 standard, it defines that the compressive strength must be greater than 8.4 MPa.

The mechanical performance related to hardness, presented unsatisfactory results, compared to the MB 3470 standard, which delimits the hardness of the plaster that should be greater than 30 MPa, except for the 15% sample, which presented a result of 33.84 MPa. The mechanical performance related to flexural traction, this was not found a reference standard in bibliographies, so it was considered as a reference only the result of the simple plaster test. Thus, it was possible to analyze that the results decreased, but with little variation from one sample to another.

It is also possible to state that the objectives and hypotheses mentioned in the research plan were achieved, for the polyurethane sponge was used as aggregate in the finishing plaster in the area of civil engineering, as a form of reuse of it. Moreover, after the mechanical tests performed the material presents

viability for the application, due to its evaluated resistances. It is also worth mentioning that both parts of the kitchen the polyurethane and the abrasive fiber were used in the form as an aggregate.

Finally, the importance of this application of the kitchen sponge as an aggregate, as an environmental benefit, is emphasized. Because its disposal in landfills and dumps will be lower, and also with the aggregate decreases the amount of gypsum used, making the mining of gypsum, less damaging the environment.

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