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Evaluation of the use of Ethylene-Vinyl Acetate E.V.A. Waste in Reinforced Gypsum Plaster Walls

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Abstract: *This paper presents an evaluation for the reuse of ethylene-vinyl acetate E.V.A. discarded by the footwear industry. With the objective of obtaining an alternative to reduce the environmental impact generated by remains of the material and reduce the accumulation in landfills. The study presents an evaluation of the possibility of using the E.V.A. as a composite in reinforced gypsum plaster walls. Different proportions of E.V.A. mixed with gypsum were used. The tests of hardness, compression, flexure, impact, water absorption, setting times, particle size distribution and ignitability were performed. In addition, the composite structure was evaluated through the Scanning Electron Microscope (SEM). The results demonstrate the feasibility of using the composite.*

Keywords: *Ethylene-vinyl acetate E.V.A., Gypsum plaster walls, Reuse, Finishing coat.*

I. INTRODUCTION

Ethylene-vinyl acetate (EVA) copolymer, has wide application in the footwear industry for its applicability in the manufacture of soles and midsoles. It is used in cut-out expanded plates that generate residues in excess of 200 tons per month in southern Brazil [1]. The residue of E.V.A. from the footwear industry represents 12 to 20% of the total consumption of this copolymer [2]. The volume varies according to the process used in the cut, the average production of this type of waste is around 400 tons per month in Rio Grande do Sul. The biggest aggravating factor is that this material is non-biodegradable, generating accumulation in landfills and deposits [2].Ethylene-vinyl acetate (E.V.A.) copolymers offer excellent mechanical properties and has good clarity and gloss, barrier properties, low-temperature toughness, stress-crack resistance, hot-melt adhesive and heat-sealing properties and resistance to UV radiation [3].

Ethylene-vinyl acetate (E.V.A.) copolymer, a commercially available thermoplastic has extensive industrial applications [4]. Because of its high versatility, EVA has a wide range of applications, for films, adhesives, shoe soles/midsoles/pads, carriage tires and toys [5]. During molding the E.V.A. compound expands uncontrolled, being able to vary its properties during the process. The properties of E.V.A. depend on the molecular weight and vinyl acetate content. With up to 30% presents predominantly thermoplastic properties, with higher levels the E.V.A. presents elastomeric or "rubbery" characteristics. E.V.A. has excellent resistance to animal, vegetables and minerals oils.

The gypsum is one of the three mineral agglomerates most used in construction, the other two being cement and lime. It is characterized - chemically - as a Calcium Sulfate hemihydrate ($CaSO_4 \cdot 0.5H_2O$) [6]. Gypsum is a compact, low-hard mineral - usually at 2 on the Mohs Scale. Usually it is white and due to impurities it can appear grayish, yellowish, rosy or even brownish. It is poorly soluble in water and very soluble in Hydrochloric acid (HCl). After the extraction, the gypsum goes through some processes of beneficiation, to fit the type of furnace where it will be calcined. This processing is a manual selection followed by crushing, coarse grinding, storage, drying, fine grinding and packaging. Calcination is the thermal process by which the gypsum is dehydrated and may occur through a dry or humid way. If the gypsum is dry calcined under atmospheric pressure or low pressure, the β-hemihydrate will be obtained with the lowest production cost, which leads it to predominate within the civil construction area [7].

II. EXPERIMENTAL

The company that generates the E.V.A. residues manufactures soles for shoes with a "manual" cutting process and then generates the remains used in the design study (Fig. 1), which are the patchwork of the stamping process.

Figure 1. Ethylene-vinyl acetate (E.V.A.) patchwork resulting from the footwear production process.

This material was ground and sieved for 20 minutes in sieves of different sizes obtaining the final granulometry (Fig. 2). The final granulometry of the used material was the result of a mixture of several sizes and was evaluated by a particle size analysis.

Figure 2. E.V.A milled and milled.

The process of preparing the material consisted of three steps. The first step was the evaluation of the relation between water and gypsum (C). The average of various ratios used by calcined gypsum manufacturers was used. The equivalent was C = 0.6 mL / g. For each 600 mL of water was used 1000 g of calcined gypsum. The second step was to calculate the proportions between gypsum and E.V.A. and their respective masses. For that, it was necessary to evaluate the density of E.V.A.. The average density found was equivalent to 0.173 g per cm³, according to table 1.

Table 1. Density of E.V.A.

	Volume (cm³)	Mass (g)	Density (g/cm³)
1	60	9.9	0.165
2	60	10.6	0.176
3	60	10.6	0.176
4	60	10.3	0.171
5	60	10.6	0.176
Average	60	10.4	0.173

For the calculation of gypsum mass, a procedure was used as indicated by NBR-12129 and NBR 13279 [8-9]. The values found for the Impact CP for volume and mass are described in Table 2.

Table 2. Proportion gypsum and E.V.A. Impact test.

	0%	5%	10%	15%	20%
E.V.A. Volume (cm³)	-	60	120	180	240
Gypsum Volume (cm³)	1200	1140	1080	1020	960
E.V.A. Mass (g)	-	10.38	20.76	31.14	41.52
Gypsum Mass (g)	1200	1140	1080	1020	960
Water Volume (ml)	720	684	648	612	672

The values for compression test are described in Table 3.

Table 3. Proportion gypsum and E.V.A. Compression test.

	0%	5%	10%	15%	20%
E.V.A. Volume (cm³)	-	6.25	12.5	18.75	25
Gypsum Volume (cm³)	125	118.75	112.5	106.25	100
E.V.A. Mass (g)	-	1.1	2.2	3.3	4.4
Gypsum Mass (g)	125	119	113	106	100
Water Volume (ml)	75	72	68	64	60

The calculations were redone. The values corresponding to the masses for the flexion test have been shown in Table 4.

Table 4. Proportion gypsum and E.V.A. Flexion test.

	0%	5%	10%	15%	20%
E.V.A. Volume (cm³)	-	12.8	25.6	38	51.2
Gypsum Volume (cm³)	256	243	230	217	204
E.V.A. Mass (g)	-	2.2	4.4	6.6	8.8
Gypsum Mass (g)	256	243	230	217	204
Water Volume (ml)	153	145	138	130	122

And finally, for the ignitability test [10] the data were presented in Table 5.

Table 5. Proportion gypsum and E.V.A. Ignitability test.

	0%	20%
E.V.A. Volume (cm³)	-	135.02
Gypsum Volume (cm³)	675	540
E.V.A. Mass (g)	-	23.3
Gypsum Mass (g)	675	540
Water Volume (ml)	405	122

The characterization of the E.V.A was performed to obtain more information about the residue. A granulometric analysis was performed. This is the study of the distribution of the various grain sizes present in the granular material in different sieves. The test was performed based on Method 01 of the standard ASTM D1921 (2010) – 06 Standard Test Methods for Particles Sizes (Sieve Analysis) of Plastic Materials [10]. The result of the granulation analysis is shown in Table 6.

Table 6. Granulometric distribution of E.V.A.

Screens	Lost Mass (g)	Weight (%)
4.75 mm	0.23	0.6
3.35 mm	1.56	3.9
1.70 mm	24.02	60.5
850 µm	8.36	21
600 µm	1.59	4
425 µm	1.55	3.9
212 µm	1.61	4
150 µm	0.36	0.9
106 µm	0.27	0.75
75 µm	0.14	0.45

Through the data obtained the data obtained in Table 6, a comparison chart of the distributions found was developed. The data have been shown in Figure 3.

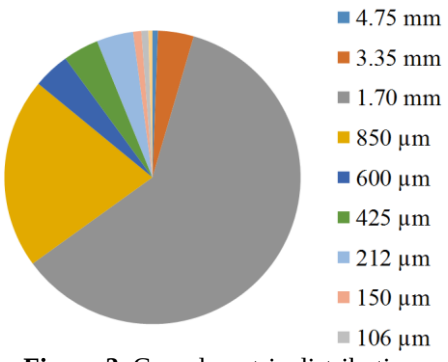

Figure 3. Granulometric distribution.

With the evaluation of the granulation finished, the measurement of the humidity of the E.V.A. was started [11]. This test is based on the elimination of water through controlled heating and the verification of the difference between the initial mass and the final mass. Table 7 shows the moisture content of the material in three different containers according to the standard, which presented an average value of 0.4914%.

Table 7. Data for calculating humidity.

	Container 1	Container 2	Container 3
Container Mass (g)	43.7702	47.1030	43.6665
Sample Mass (g)	4.9986	4.9999	5.0016
Residue Mass (g)	4.9731	4.9736	4.9797
Humidity (%)	0.5101	0.5260	0.4379

After the characterization of the E.V.A., the setting time – the time until the beginning and end of the gypsum setting time - was evaluated. This test consists basically in the evaluation of the time from the contact of the gypsum and the water to the beginning of the setting time – when the needle of the equipment no longer penetrates the bottom of the paste - and the end of handle – when the needle no longer penetrates the paste. This test was carried out according to NBR 12128 [13] and Table 8 shows the times found for the time of 0% for gypsum and 20% for the composite.

Table 8. Setting time.

	0%	20%
Beginning of the Setting time (min)	25	26
End of the Setting time (min)	43	41

III. RESULTS

The results obtained were the results found in the tests performed. The project aims at the development of a composite with the E.V.A. and calcined gypsum. The results of the tests performed were of the final material and not of the characterization of an individual. In addition to quantitative data, the research and experience gained during project development is considered as a result. The results obtained in the Hardness Test are shown in Table 9.

Table 9. Hardness Test Results (Mpa).

	0%	5%	10%	15%	20%
Resistance	27.09	30.9	49.4	29.23	23
	35.8	29.23	23.7	39.78	31.1
	33.3	26.5	28.8	31.83	37.7
Average	32.04	28.87	33.72	33.61	30.63

The Table 10 shows the results obtained through the Compression Test. The highlighted values were not considered due to the fact that they have more than 20% change in relation to others.

Table 10. Results of the Compression Test.

	0%	5%	10%	15%	20%
Resistance	11.1	7.55	6.72	5.6	4.9
	12.02	5.82	7.5	7.9	5.9
	11.5	6.17	4.59	6.8	6.8
Average	11.54	6.51	7.11	6.8	5.9

In Figure 4, it is possible to analyze the difference presented between the compression tests, with the lines referring to the samples (S_1, S_2 and S_3), the values found in the tests, and the line referring to the average, the value found as resistance of the percentage.

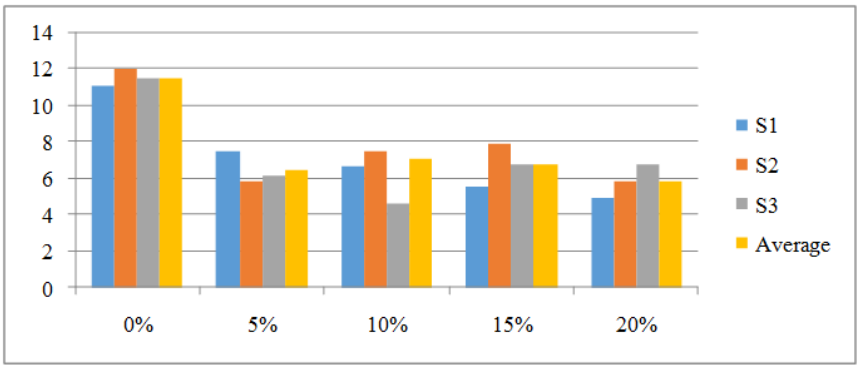

Figure 4. Comparison of results obtained in the Compression Test.

The results found in the impact test are showed in Table 11.

Table 11. Results of Impact Test (J).

	0%	5%	10%	15%	20%
Resistance	1.29	2.26	1.61	3.54	3.87
	0.96	1.61	2.9	4.51	3.87
	1.29	1.61	3.22	4.19	4.51
Average	1.18	1.8	2.58	4.08	4.08

Figure 5 shows the increasing improvement in impact resistance as the percentage of E.V.A. increases, with the lowest resistance being 0% and the highest of 20%.

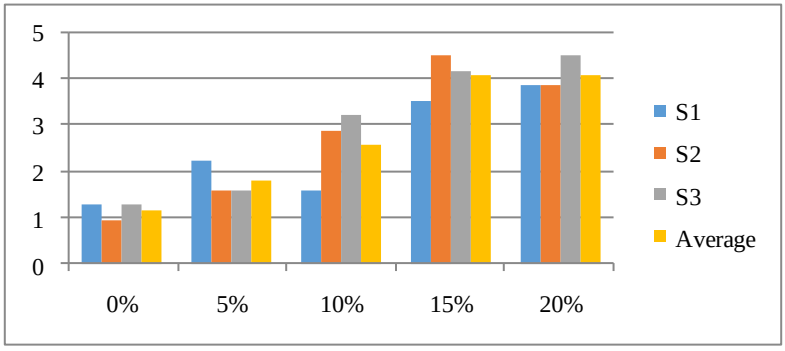

Figure 5. Comparison of results obtained in the Impact Test.

On Table 12, the results of the Flexion test are shown.

Table 12. Results of the Flexion Test (Mpa).

	0%	5%	10%	15%	20%
Load	0.396	0.400	0.380	0.280	0.240
	0.405	0.432	0.400	0.300	0.330
	0.500	0.400	0.410	0.310	0.220
Average	0.430	0.410	0.400	0.300	0.260

The percentage of water absorption obtained is shown in Table 13.

Table 13. Results of the Water Absorption Test (%).

	0%	5%	10%	15%	20%
Absorption	29.8	39.9	53.6	32.1	38.2
	30.6	42.2	55.0	31.4	40.1
Average	30.2	40.1	54.3	31.7	39.2

The Figure 6 shows the difference between the percentage of water absorption of the samples. In this case, is possible to evaluate that only one composite – the 15% sample - is viable to apply in humid environments, since the other ones shows a high absorption of water, which may cause unwanted results.

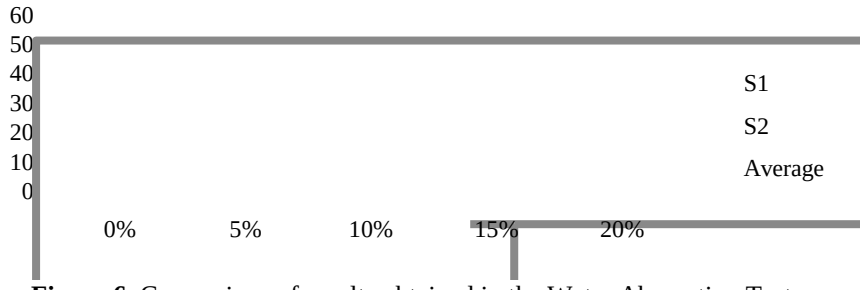

Figure 6. Comparison of results obtained in the Water Absorption Test.

In addition to the tests an important result is the evaluation of the weights of the samples of the composite (Table 14). These data were used to compare the values found in a 100% calcined gypsum material and the developed composite.

Table 14. Results of the Composite Weight Evaluation (g).

	0%	5%	10%	15%	20%
Weight	151.6	137.6	133.4	123.2	121.5
	148.7	139.5	134.6	142.0	127.5
	153.8	136.2	116.6	138.5	130.5
Average	151.4	137.7	128.2	134.6	126.5

The results concerning Ignitability, performed with the percentages of 0% and 20%, to analyze the presented difference (Table 15), all the results are negative.

Table 15. Results of the Ignitability Test.

Kind	%	Weight	Exhaustion	Ignition	Height	Particles
Edge	20%	822.9 g	0.71	No	No	No
	0%	885.6 g	0.73	No	No	No
Surface	20%	803.1 g	0.7	No	No	No
	0%	908.3 g	0.74	No	No	No

The images obtained for analysis through the SEM, Scanning Electron Microscope, are compared in Figure 7, in order of percentage, from lowest to highest. As can be seen, the E.V.A. presented a good wrapping with the plaster, not increasing considerably its porosity.

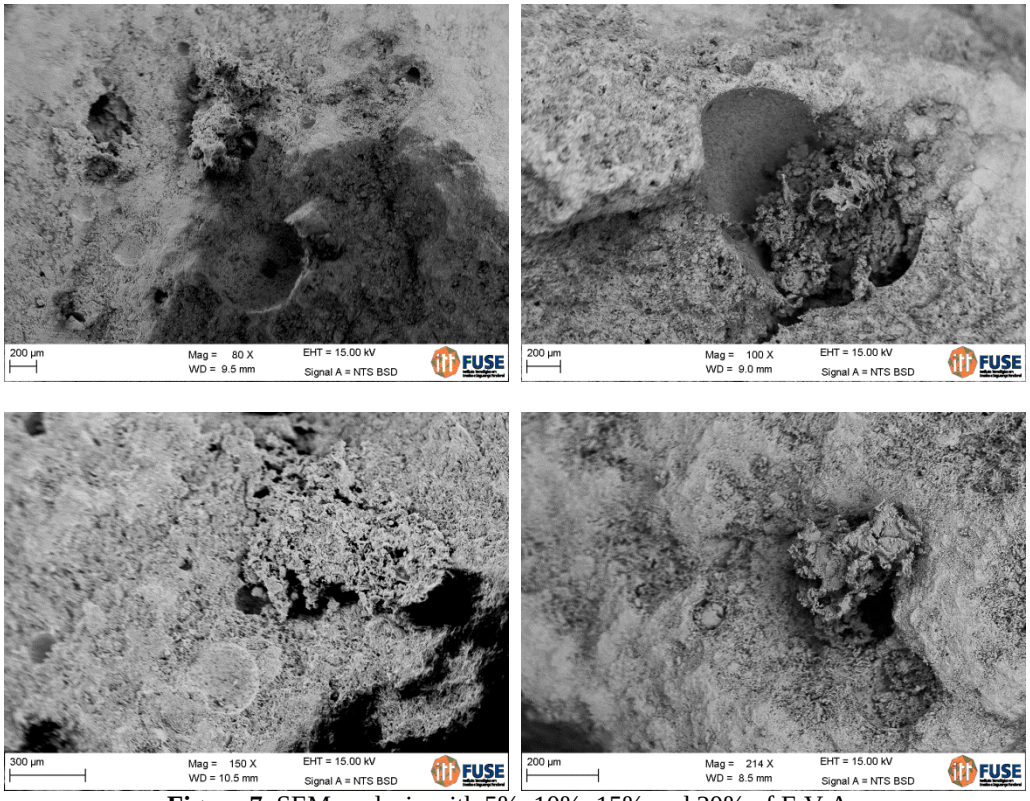

Figure 7. SEM analysis with 5%, 10%, 15% and 20% of E.V.A..

IV. CONCLUSION

It was observed that the temperature of the furnace used in the composite affected its resistance directly, since the lower the temperature, the lower the resistance results.It was also observed that the granulation may have been influencing the results, because the higher was the granulation, higher was the porosity, and consequently, less was the adhesion to the gypsum. Due to this uncontrolled granulation, the composite was not satisfactory. However using different granulations simulated the state that the material would be when generated in the industry. It was concluded that the design is feasible, and the compressive strength presented is lower than the limited by the NBR 12129 standard of 8.4 MPa, the highest equivalent being 7.11 MPa - referring to the composite of 10% E.V.A. In the Impact test, however, the results were satisfactory, since they presented a resistance much more than that of the simple gypsum (0%), in the case of the composite (15% and 20%) thus enabling the application of this Material in the construction area. Finally, the hardness and water absorption index - of the composite of 15% - were higher when related to the values found in the composite of 0%, demonstrating the feasibility of its use.

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