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MECHANICAL STRENGTH OF SYNTHETIC STONES OBTAINED FROM SOAPSTONE RESIDUES IN OURO PRETO REGION – BRAZIL

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Abstract. *Soapstone waste recycling is still a problem for handcrafters in Ouro Preto, MG, Brazil. In order to solve it, synthetic soapstone samples were produced from soapstone waste. Mechanical tests were done in laboratories and handcrafters' evaluation was considered as well. From these synthetic soapstone sample analyses it was confirmed that it is possible to have a low cost alternative in order to solve the soapstone waste disposal in Ouro Preto.*
Keywords: soapstone, waste, synthetic soapstone, mechanical tests.

Keywords: *- soapstone waste; synthetic soapstone; recycling, environment*

1. INTRODUCTION

Soapstone rock (steatite) is one of the softest rocks found in nature and it has always been used in artistic works and industrialized products as can be seen in Figure 1 (Jones et al., 2007; Torres et al., 2015, Souza et al, 2016).

Figure1. Artistic works produced by handcrafters.

Soapstone rocks are basically compounded of mineral talc which Mohs hardness is 1 (Almeida, 2006; Torres et al, 2015, Souza et al, 2016, Huhta et al, 2016). Indian tribes already employed this rock before the Portuguese arrival in Brazil in 1500 (Silva and Roeser, 2003). Soapstone rocks became famous in Europe because of Aleijadinho's artistic works (18th century). In Brazil, soapstone rocks are mostly found in Ouro Preto, Congonhas do Campo, São João Del Rei, Diamantina, Tiradentes and some others cities in the state of Minas Gerais and it is the main economic activity of handcrafters (Farias, 2005). However, only Ouro Preto was recognized by UNESCO in 1980 as "Humanity International Artistic Patrimony".

Nowadays, there are two problems concerning soapstone rock use: (a) handcrafter social and economical conditions and (b) environmental problems related to soapstone waste. The Figure 2 shows two kinds of soapstone waste.

(a) (b)

Figure 2. Soapstone waste produced by (a) pan industries and (b) handcrafter workshops.

Handcrafters are responsible for the incorrect soapstone waste disposal. According to a survey, carried out by Almeida (2006), it was found out that soapstone waste was: piled up in the workshops (30%); thrown out at the outskirts of the city (21%), in vacant lots (28 %), into rivers and dams, which can cause silting (6%), or on plantations (3%); taken to uncertain destinations (2%) and removed by the City Hall (10%) (Almeida, 2006). This work proved that it is possible to recycle the soapstone waste disposal.

According to Torres et al. (2015), new products can be manufactured from soapstone waste. Some time ago, handcrafters could explore soapstone rocks freely. Today, their entrance into the mines is restricted, due to the soapstone rock shortage. As a result, handcrafters purchase soapstone rocks which are not used by industries at approximately US$ 117.00 (88.00 €) per 1,000 kilograms.

2. MATERIALS AND METHODS

During the visit to Ouro Preto in 2009, it was possible to evaluate the problems that handcrafters have to produce their work. So, synthetic soapstone samples were developed in order to meet handcrafters' needs and such samples have to fulfill the following criteria:

1 – soapstone waste recycling procedure adoption which can be copied by handcrafters, in order to avoid heat and chemical treatments or any other sophisticated high-cost process;

2 - synthetic soapstone and soapstone rocks should have similar characteristics;

3 – synthetic soapstone manufacturing should not harm the environment.

Based on these criteria, soapstone waste was mixed with some additives and conformed by uniaxial pressing.

Soapstone rocks are found in nature in spherical shape and their diameters range from 3 m to 20 m. Their outer layer is yellowish, soft and fragile and it is frequently used by handcrafters. The central layer varies from gray to green; it is stiff and is used for making pans and objects produced for the civil engineering.

Two kinds of yellowish soapstone waste were collected from two workshops and a greenish-gray one, saturated with water, was collected from a pan factory. Some soapstone rock samples used by handcrafters were collected for laboratory analyses A specific terminology was adopted in this work in order to label soapstone waste, which is presented in Table 1.

Table 1. Soapstone waste terminology.

SOAPSTONE WASTE	COLOR	ORIGIN
SW 1	Yellowish	Workshop 1
SW 2	Yellowish	Workshop 2
SW 3	Greenish-gray	Pan factory

Plaster, Portland cement (CPII), polyvinyl alcohol solution at 5 wt% (PVal) and white glue (PVA) were experimented as additives. Liquid petroleum jelly, mineral and vegetable oil were experimented as lubricants.

Grain size analysis and X-ray diffraction were used to characterize the soapstone waste. The methodology used for the preparation and evaluation of the samples followed the fluxogram shown in Figure 3. The synthetic soapstone sample manufacturing was performed in steps. If the results obtained in laboratories had good mechanical strength, the samples were sent to the handcrafters; if not they were rejected.

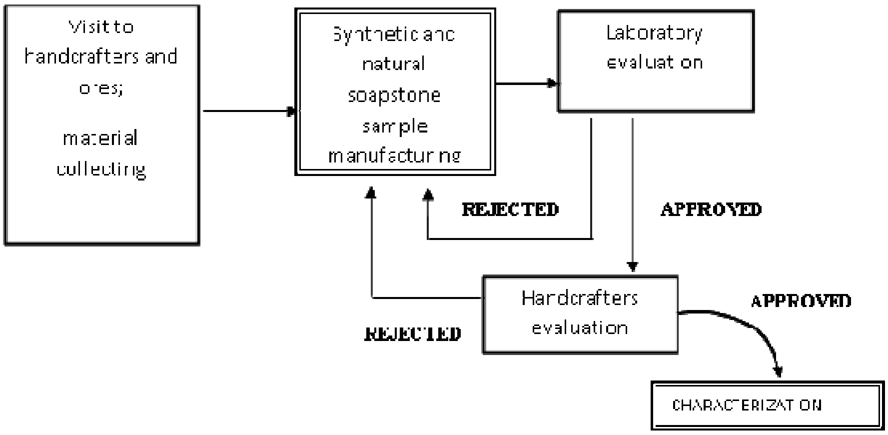

Figure 3. Fluxogram adopted for manufacturing and analyzing synthetic soapstone samples.

According to Figure 4, at the end of the process, both synthetic soapstone samples and soapstone rock samples showed the same shape, although the first ones have been formed by uniaxial pressing at 40 MPa and the second ones have been machined (Reynaud et al., 1992; Vieth et al., 2005).

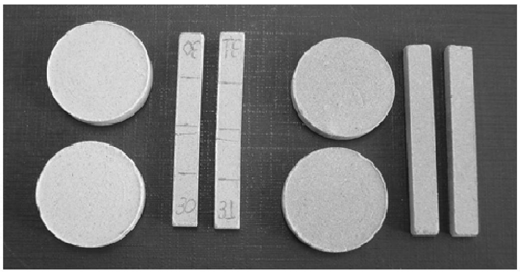

Figure 4. Synthetic soapstone and soapstone rock samples.

The samples were characterized by analyzing their porosity and apparent density (according to ASTM C20-00) to find out how they interact with water and varnish; contact angle, to compare the wettability; mechanical strength under three point flexural test (according to ASTM C1161-02C), to check their handling and tooling capacity; and roughness. Weibull statistics was employed to analyze mechanical strength results (Wu et al., 2006).

Questionnaires were sent to handcrafters, so that they could evaluate the samples according to their daily use at the workshops. Some questions were made in order to clarify some aspects, such as:

I – if the samples broke during manufacturing;

II – if it was easy for handcrafters to machine the samples using their habitual tools (knives, spoons, chisels etc);

III – if it was possible to use sand paper, paint and varnish to obtain good visual appearance.

Two groups of samples were produced: the first one (SW3) was manufactured with plaster as binder, and the second one manufactured with Portland cement (CPIII). Both were produced with Pval and distilled water (10 wt%). These samples were not approved by the handcrafters because, according to them, they were “too dry” and as a consequence they did not show greasiness, which is the soapstone peculiar characteristic. They also reported that the synthetic soapstone, when sanded, resulted in an abrasive wearing with no significant change in texture. Another aspect reported by handcrafters was that machining made between the synthetic soapstone and the soapstone rock was similar.

Based on these results, the second part of the project started. In this phase, plaster was discarded as binder, because the samples degraded when they were in contact with water. A lubricant was added to the mixture in order to give the samples greasiness appearance. Vaseline, mineral and vegetable oil were experimented as lubricants. The results obtained were not positive because besides being expensive, these lubricants did not facilitate the pressing process and did not provide the desired greasiness.

During the third phase, grain wax was mixed and rubbed with the soapstone waste and additives. After that, it was sieved and separated from the mixture in order to be used again in the future. This process allowed the sample desired greasiness obtaining. Distilled water was replaced by tap water and Pval was replaced by white glue (PVA). This new sample group was taken to laboratories for analyses and sent to the handcrafters for a second evaluation.

Different binder and additive percentages were experimented during the third phase of the work. Mixture variations are described in Table 2.

Table 2. Sample mixture during third phase.

Sample	Glue (wt%)	Cement (wt%)
	5	10
W1	10	10
Yellowish	15	10
Workshop 1	10	5
	10	15
	5	10
W2	10	10
Yellowish	15	10
Workshop 2	10	5
	10	15
	5	10
W3	10	10
Greenish-gray	15	10
Pan industry	10	5
	10	15

3. RESULTS AND DISCUSSION

Figure 5 shows the three X-ray diffraction patterns (XRD) extracted from the soapstone waste: SW1, SW2 and SW3. It was observed that the soapstone waste have the same mineralogical phases; however they have some spectral lines intensity differences. SW1, SW2 and SW3 contain hydrated magnesium silicate; Torres (2015) and Assis (2006) also observed these characteristics in their works. The greatest diffraction peak (28.92°) corresponds to $Mg_3Si_4O_{10}(OH)_2$, that is, talc. XRD patterns of SW1 and SW2 are similar (little intensity variation at 28.92°), since they are originated from the same kind of soapstone rock. SW3 XRD patterns show a great intensity peak at 25.03°, which corresponds to $Mg_3Si_2\ O_5(OH)_4$, that is, mineral serpentine, which is responsible for the soapstone greenish-gray color.

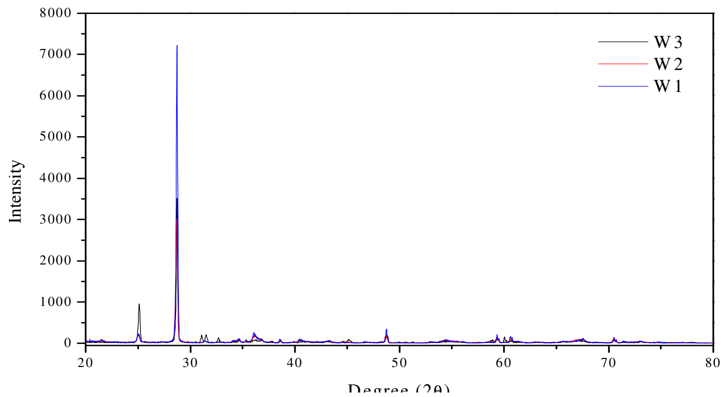

Figure 5. SW1, SW2 and SW3 XRD patterns.

Table 3 shows three point flexural test results for the different glue and cement percentages. Figure 6 shows σ50 results of Table 3.

Table 3. Three point flexural tests.

1	Sample	σ_{50}	σ_0	m
	Green Rock	10.41	11.73	3.1
	Yellowish rock	3.02	3.35	3.7
W1	5% glue	4.07	4,23	12.4
	5% cement	2.80	3.00	6.9
	10% allmaterials	3.75	4.02	6.7
	15% glue	7.09	7.52	8.1
	15% cement	4.08	3.58	6.5
W2	5% glue	4.12	4.29	12.9
	5% cement	3.63	3.79	12.3
	10% allmaterials	3.94	4.14	9.4
	15% glue	7.35	7.63	14.0
	15% cement	3.92	4.12	9.8
W3	5% glue	4.60	4.96	6.2
	5% cement	6.04	6.40	8.5
	10% allmaterials	7.13	7.51	9.5
	15% glue	6.79	6.59	16.9
	15% cement	6.84	6.84	8.1

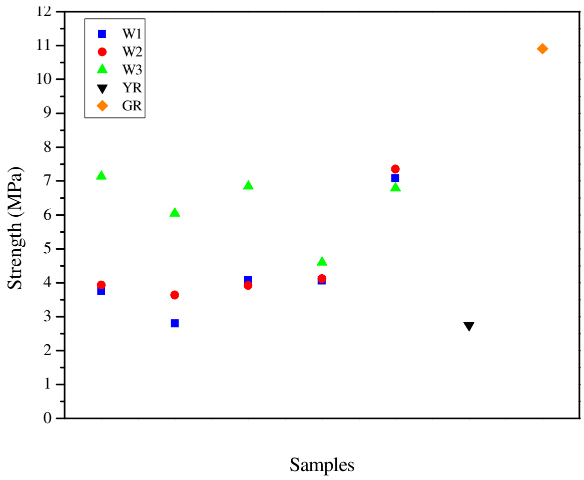

Figure 6 - Three point flexural tests.

Based on Weibull module (m), it was observed that synthetic soapstone mechanical strength dispersion was smaller than the soapstone rock one. It was also verified that all synthetic soapstone samples had much lower mechanical strength than the green soapstone rock and all of them had much higher mechanical strength than the yellowish soapstone rock.

All synthetic soapstone which were manufactured with 15% of glue had higher mechanical strength than the ones manufactured with 5% of glue. Therefore, it can be concluded that synthetic soapstone mechanical strength is related to the glue amount added to the mixture. The same result was observed in relation to the cement amount added to the mixture, but the mechanical strength variation was smaller. So, it is not necessary to add 15% of cement to the mixture in order to obtain relevant higher mechanical strength. On the other hand, synthetic soapstone which was manufactured with only 5% of glue showed higher mechanical strength than the yellowish soapstone rocks. It was also observed that synthetic soapstone samples produced from green soapstone waste, showed higher mechanical strength than the synthetic soapstone samples manufactured from yellowish soapstone waste, except the ones produced with 15% of glue.

Figures 7 and 8 show some tests made by handcrafters in their workshops.

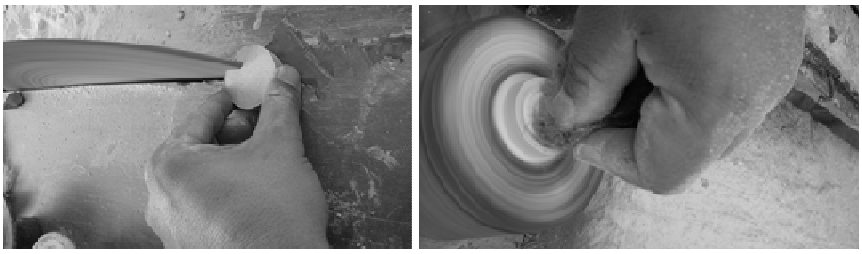

Figure 7. Cutting, machining and polishing tests.

Figure 8. Painting and finishing tests.

According to the answers given by the handcrafters, it was concluded that it is possible to use synthetic soapstone to produce arts and crafts because they have the same advantages as the soapstone rocks, such as workability, softness and traditional tool usage. It was also possible to find out that the synthetic soapstone showed satisfactory finishing, glazing and painting.

4. CONCLUSION

It was concluded that all synthetic soapstone which were manufactured with different percentages of glue and cement, can replace soapstone rocks in arts and crafts, especially in small objects, while the soapstone rocks cannot be replaced by synthetic soapstone in civil engineering and pan manufacturing.

Summarizing, it was stated that it is possible to manufacture synthetic soapstone from soapstone waste discarded by industries and handcrafter workshops. Since this synthetic soapstone manufacturing process is relatively easy and inexpensive, new researches and programs in this area could be developed by government or private institutions to help handcrafters continue producing their arts and crafts.

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6. RESPONSIBILITY NOTICE

The authors Maria Gabriela Araújo Ranieri, Carlos Eduardo Silva de Amorim, Elson de Campos and Francisco Cristovão Lourenço de Melo are the only responsible for the printed material included in this paper.