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### DEVELOPMENT OF COMPOSITES WITH SOAP STONE WASTE

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**Abstract.** *The soap stone is a mineral that is abundant in the Ouro Preto - MG region and it has an important role in local economy, since its major destination is in the local production of craftsmanship and vases and other decorating utensils. However, there's a problem regarding the disposal of the waste material generated in those activities, that is usually thrown away without any control. Such materials can be harmful to the environment and to the health of local residents. Therefore, studies that evaluate other purposes for the waste are necessary. This work has as main objective to characterize the soap stone waste, and to manufacture polymer matrix composites using the waste as reinforcement and to evaluate the mechanical properties of these composites. The materials used in this work were high-density polyethylene (HDPE) as matrix and the waste of soap stone as the dispersed phase. The composites were made in three compositions: 90/10, 80/20 and 70/30. The characterization of the soap stone was done with x-ray diffraction. The tensile properties were used to characterize the mechanical behavior. The results were used to compare the properties obtained to those of the neat polymer used. The XRD revealed a monoclinic crystalline structure with crystalline peaks characteristic of the talc mineral. The composites had a more brittle mechanical behavior than the neat HDPE with a lower tensile strain at break, but presented higher tensile strength.*

**Keywords:** *soap stone, polyethylene, polymer composites, characterization.*

## 1. INTRODUCTION

The soap stone is a compact, plastic, metamorphic rock with low hardness and fine grain (Lippmann *et al.*, 2007). Regarding physical characteristics, the soap stone is not affected by acid or alkaline substances and it's capable of resisting extreme temperatures from zero to about 1000°C (Santos *et al.*, 2009). The composition of the soap stone can vary according to the region it was extracted from, but it is usually composed mainly by talc (35%) and over 25% of chlorite, quartz, calcite, dolomite, magnesite, tremolite, amphibole, pyroxene and hematite minerals (Garcia *et al.*, 2014). The talc is a hydrated magnesium polysilicate, its crystalline structure consists of octahedral structures of magnesium hydroxide between tetrahedral layers of silicon-oxygen (Rodrigues, 2010). This crystalline structure is shown in Fig. 1 (Gruner, 1934; Momma and F. Izumi, 2011).

The major production of this mineral occurs in the Ouro Preto region, in Minas Gerais state and the main destination of the soap stone is in local production of craftsmanship and manufactures (Assis *et al.*, 2006). These activities foment the local economy by generating jobs and income, but they also generate a considerable amount of waste that is usually thrown away with no control (Rodrigues, 2010). Since the waste can be harmful to the environment and to the health of the local residents, the search for alternative purposes for this material is an important issue.

A possible destination to the soap stone waste is as reinforcement to polymer-matrix composites. This type of composites is known as particulate composite, a class of materials that consist of particles suspended in a matrix. Polymeric composites reinforced with rock wastes are vastly used in the auto industry and recent studies have shown good results as a low cost alternative for 3D-printed orthopedic prostheses (da Silva *et al.*, 2013; Eiriz *et al.*, 2018). This type of composite can also be adapted to produce abrasion resistance functionally graded composites using mineral wastes (J. R. M. d'Almeida and Alves, 2009).

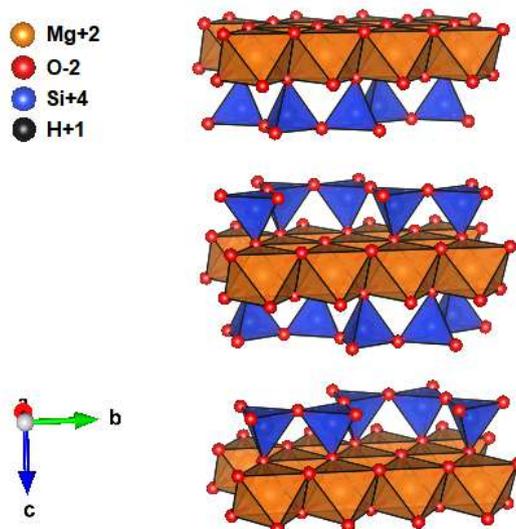


Figure 1. Crystalline structure of the talc mineral obtained with VESTA software (Gruner, 1934; Momma and F. Izumi, 2011)

The mechanical properties of a composite material vary according to the relative amount of each constituent phase (matrix or particles) and are different from the neat materials. Therefore, the mechanical characterization of the resulting composite is relevant to determine whether its production could be interesting from the market point of view.

The objective of this work is to characterize the soap stone waste, to produce polymer matrix composites with the waste and to characterize the mechanical behavior of the composites obtained. The materials used were HDPE and the soap stone waste. The composites were made in three polymer/particle compositions: 90/10, 80/20 and 70/30. The characterization of the soap stone was done with x-ray diffraction and the mechanical characterization of the composites was obtained with uniaxial tensile tests. These results were used to compare the properties obtained to those of the neat polymer matrix.

## 2. MATERIALS AND METHODS

### 2.1 Materials

The materials used in this work were high density polyethylene (HDPE) and soap stone waste (SSW), as showed in Fig. 2. The HDPE was received as pellets with the specification IA59U3 and it was produced using the solution process by BRASKEM company. Some of the HDPE's properties provided by the manufacturer are presented in Tab. 1.

Table 1. Properties of the HDPE used in this work.

Properties	ASTM Method	Values
Fluidity Index (g/10min)	D1238	7.3
Density (g/cm <sup>3</sup> )	D792	0.960
Resistance to Flowing (MPa)	D638	28
Tensile Strength (MPa)	D638	25
Shore D Hardness (-)	D2240	58
Impact Resistance (J/m)	D256	73
Softening Temperature (°C)	D1525	129

The soap stone waste was obtained with craftsmen in Ouro Preto, MG. The waste consists of a orange fine powder and it was used without any kind of processing.

The composite production was done in three compositions of HDPE/SSW: 90/10, 80/20 and 70/30. Twenty specimens of each composition were made, eight of those were used in the tensile test. The composites were produced in a mini parallel double-screw extruder (DSM Xplore 5cc), in which the inlet, homogenization and exit temperatures were set at 180, 190 and 200°C, respectively. The rotation used for the mixture was 160 rpm. The homogenization time was about three minutes in the extruder, under constant flux of N<sub>2</sub>. After the extrusion, the tensile specimens were injected in a mini injector (DSM Xplore 5,5cc), with the injection nozzle at 200°C and the mold at 80°C. The specimen used were V type as per ASTM D 638. The extruder and injector used are shown in Fig. 3, while the specimen used in the tensile test and

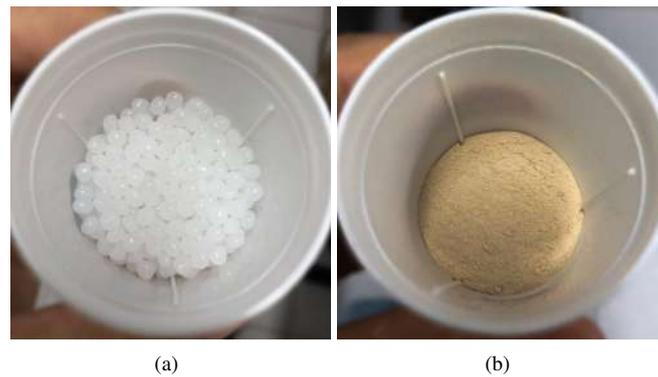


Figure 2. HDPE pellets (a) and soap stone waste (b) used in this work.

the mold are presented in Fig. 4.

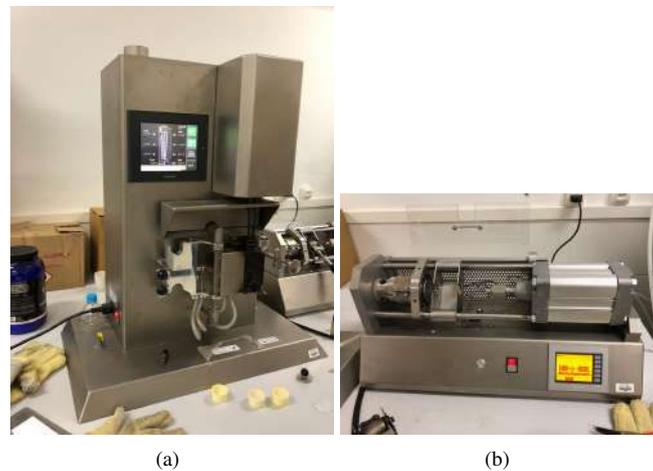


Figure 3. Extruder (a) and injection molding machine (b) used in this work.

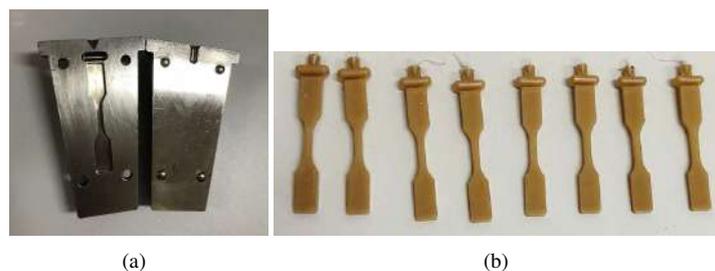


Figure 4. Mold (a) and tensile test specimens of type V (b) used in this work.

## 2.2 Methods

### 2.2.1 Tensile testing

Eight specimens were selected to be used in the tensile tests. Mechanical properties were measured using a universal testing machine, Oswaldo Filizola ASME 2kN, as shown in Fig. 5. The tests data were obtained by the Dynaview software and the properties were calculated using Excel. The tensile tests were performed at 50mm/min and with initial distance between grips ( $L_0$ ) of 25mm. All tests were performed at room temperature ( $23 \pm 2^\circ\text{C}$ ).

### 2.2.2 X-ray diffraction (XRD)

The x-ray diffraction tests were performed with a D8 Discover diffractometer from Bruker manufacturer with copper radiation operating at 40 mA and 40 kV and with Lynxeye detector. The radial scan of intensity vs. diffraction angle ( $2\theta$ )



Figure 5. Tensile testing machine.

was recorded in the range  $5 - 90^\circ$  with a step of  $0,02^\circ$  and 1 second by step. The software TOPAS was used to obtain the crystalline structure and to determine the crystalline peaks and the respective diffraction angles.

### 3. RESULTS AND DISCUSSION

#### 3.1 Tensile testing

Stress-strain curves were obtained for each specimen of each composition tested. Figure 6 shows a comparison of the curves obtained for one specimen of each composition and for the neat HDPE.

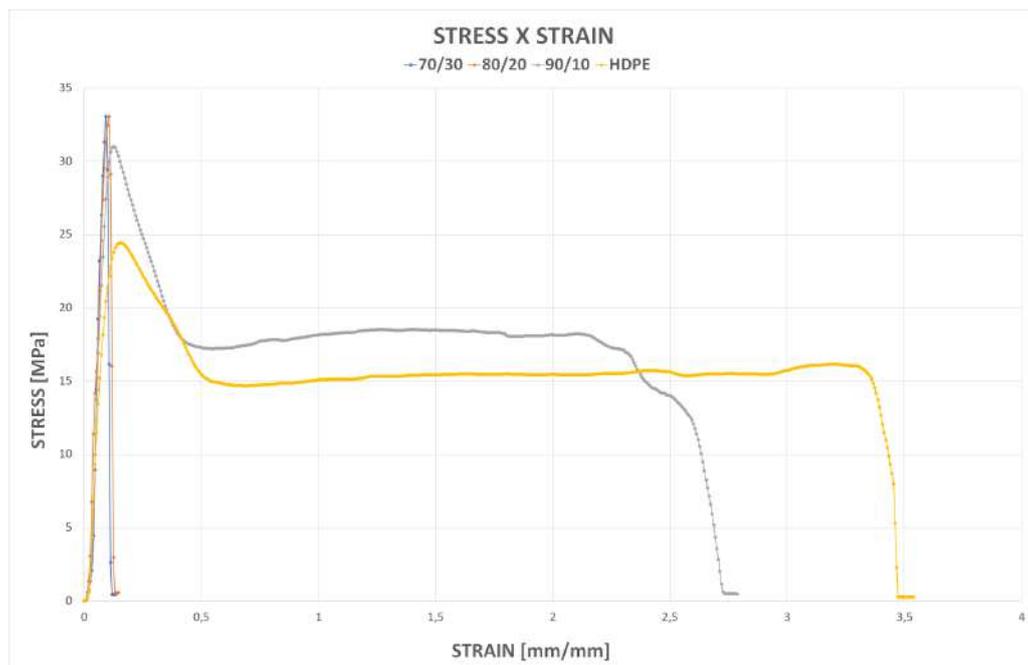


Figure 6. Stress-strain curves for the HDPE and the 90/10, 80/20 and 70/30 composites.

From Fig. 6 it is possible to observe a loss in ductility and tenacity as the volume fraction of soap stone increases in the composites compositions. This loss is even more evident in the 80/20 and 70/30 composites, that showed stress-strain curves characteristic of brittle fracture. Another important observation can be made regarding the stress-strain resistance. The composites, specially the 80/20 and 70/30, showed higher values of tensile strength and therefore, were more load-resistant.

The mechanical properties obtained for the three compositions tested and for the neat HDPE are listed in Tab. 2. The properties of the neat HDPE were included in the table for comparison.

Table 2. Mechanical properties of the HDPE and the 90/10, 80/20 and 70/30 specimens determined by the tensile test.

	HDPE	90/10	80/20	70/30
Yield strength (MPa)	$25.75 \pm 2.20$	$29.74 \pm 0.64$	-	-
Tensile strength (MPa)	$19.57 \pm 3.81$	$17.50 \pm 0.50$	$32.93 \pm 1.37$	$33.89 \pm 0.81$
Strain to failure (mm/mm)	$4.44 \pm 1.84$	$1.62 \pm 0.63$	$0.11 \pm 0.01$	$0.09 \pm 0.01$
Elastic modulus (MPa)	$331.32 \pm 32.17$	$381.54 \pm 33.93$	$379.98 \pm 40.08$	$583.93 \pm 60.79$
Tenacity (MJ/m <sup>3</sup> )	$90.93 \pm 40.78$	$44.14 \pm 12.98$	$3.40 \pm 1.55$	$1.64 \pm 0.18$
Resilience (MJ/m <sup>3</sup> )	$2.32 \pm 0.15$	$2.17 \pm 0.20$	-	-

For better visualization of the variation of the mechanical properties with the increase of the amount of soap stone, box-plots of some relevant properties were made using the data from the Tab. 2. The strain to failure and tensile strength box-plots are shown in Fig. 7 and the elastic modulus and tenacity box-plots in Fig. 8. Figures 9 and 10 show the composite specimens after the tensile test.

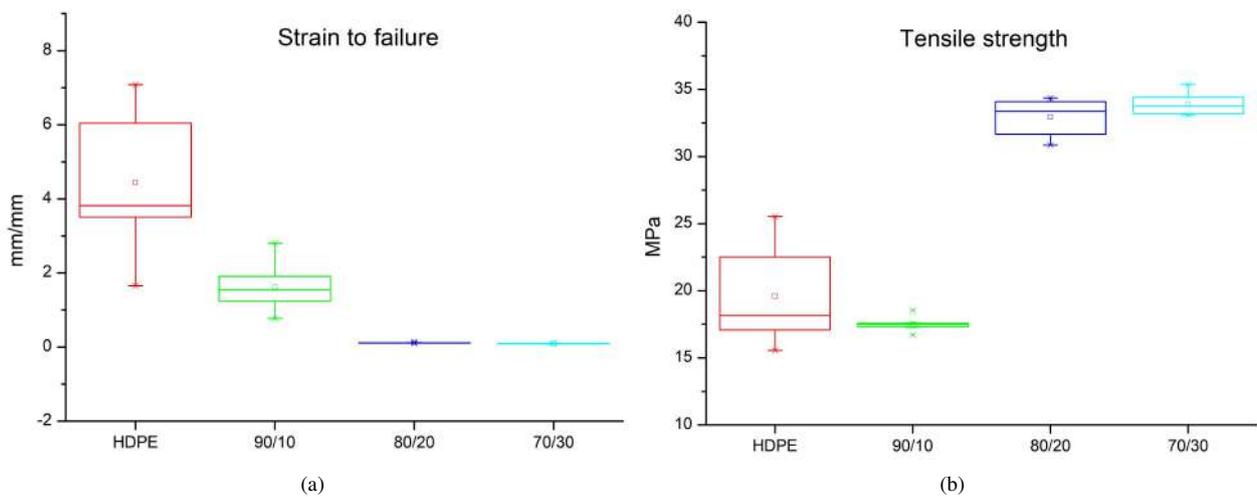


Figure 7. Strain to failure (a) and tensile strength (b) box-plots.

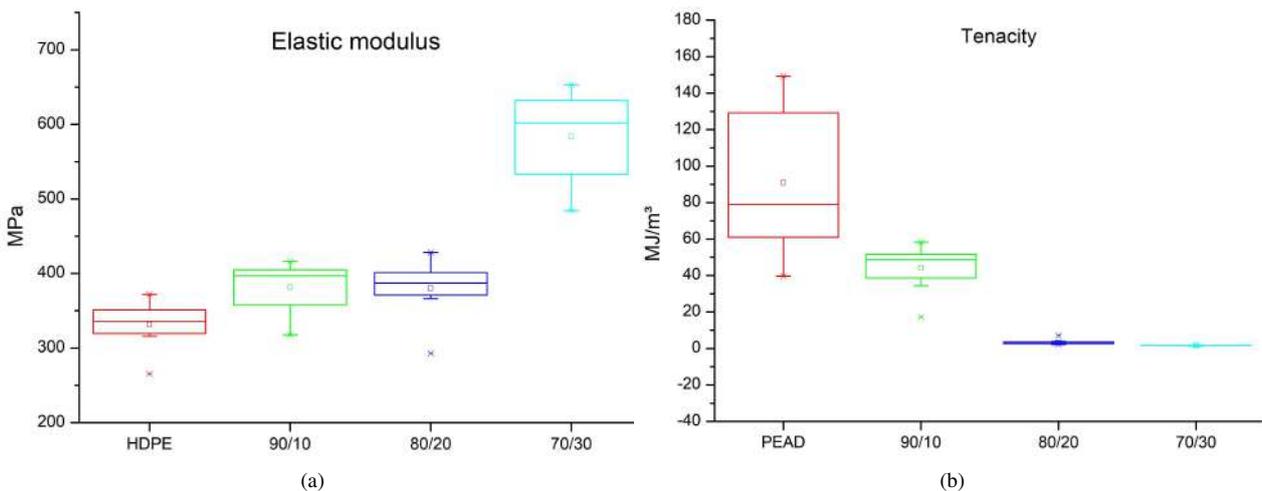


Figure 8. Elastic modulus (a) and tenacity (b) box-plots.

In the box-plots, it's possible to observe that the composites, specially the 70/30 specimens, had higher elastic modulus than the neat polymer, which implies in higher rigidity. It's also possible to observe that the tenacity values decreased as the volume fraction of soap stone increased, implying in a loss of ductility. This loss of ductility can be noted when comparing the tested specimens shown in Fig. 9 and Fig. 10. The 90/10 specimens had visually significant plastic deformation while the 80/20 and 70/30 showed little or no deformation before failure, presenting a brittle fracture, as mentioned before.



Figure 9. Tested specimens of the 90/10 composites.



Figure 10. Tested specimens of the 80/20 (a) and 70/30 (b) composites.

### 3.2 XRD

The X-ray diffraction analysis determined that the crystalline structure of the soap stone waste was monoclinic and the crystalline peaks obtained were characteristic of the talc,  $Mg_3Si_4O_{10}(OH)_2$ , as shown in Fig. 11. The approximate diffraction angles,  $2\theta$ , of the peaks are listed in Tab. 3 for better identification.

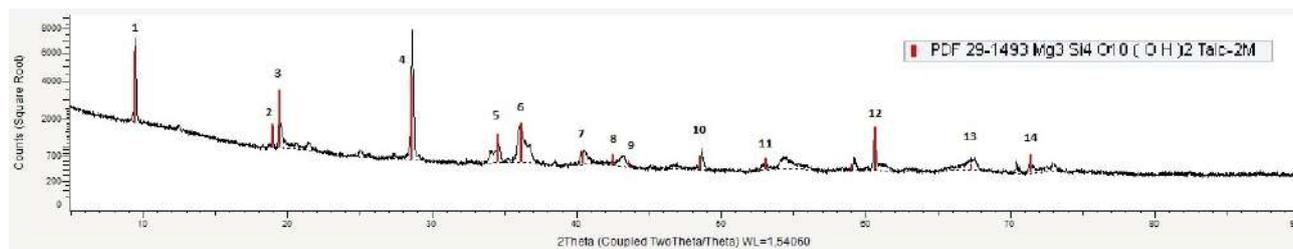


Figure 11. X-ray diffraction of the soap stone waste.

Table 3. Values of the diffraction angles,  $2\theta$ , of the crystalline peaks.

Peaks	$2\theta$
1	9.3°
2	19°
3	19.4°
4	28.5°
5	34.5°
6	36.1°
7	40.2°
8	42.5°
9	43.5°
10	48.5°
11	53°
12	60.7°
13	67.2°
14	71.2°

#### 4. CONCLUSION

From the results obtained it was concluded that the soap stone waste has a monoclinic crystalline structure and presented crystalline peaks characteristic of a talc mineral ( $Mg_3Si_4O_{10}(OH)_2$ ). The tensile testing showed that an increase in soap stone waste concentration results in more brittle and rigid composites, but with higher values of both yield and tensile stress.

The results show that the soapstone is a promising reinforcement for HDPE composites. Possible applications can be found in the auto and aeronautic industries along with other applications that require low density materials with high tensile strength.

#### 5. ACKNOWLEDGEMENTS

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