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# STRUCTURAL CERAMICS PRODUCED FROM SOAPSTONE TAILINGS *

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**Abstract**

The use of tailings for the synthesis of new materials is a worldwide concern today. This paper approaches the utilization of tailings of soapstone (steatite) in order to produce ceramics. The results show that the addition of soapstone in a ratio over 20% in the ceramic mass has enhanced the bending resistance of the ceramic samples when they were fired at temperatures of 900°C or 1000°C.

**Keywords:** Soapstone, ceramic materials, sintering, tailings, clay.

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# 1 INTRODUCTION

Commonly known as soapstone, steatite has a metamorphic origin. The steatite (talc) is a phillosilicate of hydrated magnesium. The typical composition of talc is 31.7% MgO, 63.5% $SiO_2$ and 4.8% $H_2O$, forming $Mg_3(Si_4O_{10})(OH)_2$ (Filho, 1997) [1]. As talc is the most important mineral constituent of the soapstone, in terms of industry and trade issues, it is the basis of the main data in literature. Pontes and Almeida (2005) [2] mention that the use of talc in the ceramic industry is relatively wide, as it can be used in ceramic materials such as tiles, technical ceramics, industrial ceramics, tableware, bathroom fixtures, inserts, and in electric and thermal insulation. The main products of the structural ceramics class are bricks, blocks, tiles, pipes, roof slab, ornamental vases, light expanded clay aggregates and others. According to Motta et al. (2001) [3], the sector of structural ceramics basically uses ordinary clay. In order to produce this material, normally a mix of “heavy” clay is made, whose properties are high plasticity, fine particle size and composition of clay minerals, essentially; and “light” clay, which is less plastic and has high contents of quartz, classified as a plasticity reducing material.

Marino et al. (2000) [4] studied the thermal expansion of ceramic tiles with addition of talc. It was observed that the addition of talc caused a substantial increasing on values of bending resistance and thermal coefficient of linear expansion. On the other hand, Panzera et al. (2010) [5] studied the effect of the addition of remains of steatite over the physical and mechanical properties of clay composites. Experiments were conducted to evaluate the influence of particle size, steatite proportion, as well as the compaction pressure of the clay composites. The composite with 20% of steatite, with particle size between 100 and 200# and compaction pressure of 30MPa showed the best results. The incorporation of steatite to clay composites was shown to improve the mechanical properties. The particle size distribution of the steatite, between 100 – 200#, resulted in a significant increasing of the flexural strength when produced with 20-40% of steatite. This phenomenon is commonly attributed to the formation of crystalline phases such as the cordierite. When 20% of steatite was used, the results were higher in terms of density, porosity and mechanical resistance. Similarly, Strecker et al. (2010) [6] investigated the influence of the incorporation of steatite remains over the mechanical proprieties of cementitious composites. The parameters investigated were fraction, steatite particle size and compaction pressure (10 and 30MPa). The results indicated that the increasing of the fraction provided a raise of the bulk density and the superficial porosity of the composites due to the enlargement of the pores in the matrix–steatite interface. However, the addition of steatite provided a reduction of the compressive strength of the composites, also due to the interface conditions. The reduction of the particle size decreased porosity and increased compression resistance. The compaction pressure affected substantially the mechanical properties of the composites. The raising of the compaction pressure values from 10 to 30MPa not only provided a growth in the bulk density of the composites, but also raised the bending mechanical resistance and reduced the superficial porosity. Okada et al. (2009) [7] produced porous ceramics at low temperature using talc, glass wool and LiCl (supporting component of the sintering process). The mass proportions of talc/glass wool adopted were 7:3, 8:2, 9:1 and 10:0; furthermore, a 0.2 and 5 wt% of LiCl was added. In samples without LiCl, talc and glass wool were dry mixed in a ball mill, without the grinding elements. The samples with LiCl were wet mixed, then dried and mixed again, using an agate mortar and pestle, in order to neutralize any segregation during the drying, due to the density difference of the components. After drying at 100°C overnight, the powders were uniaxially pressed at 20MPa into pellets (ϕ10 mm) and test specimens were produced with the dimensions of 50mm x 5mm x 2mm. The samples without LiCl were fired at 800-

1000°C, meanwhile; the ones with LiCl were fired at 600-800°C, for 12 hours with a heating rate of 1°C/min for both cases. The results showed that porous ceramic with significant mechanical resistance can be prepared by firing at 600-800°C with LiCl, but cannot be prepared without LiCl, even when fired at 1000°C. The talc of these samples was converted into enstatite ($MgSiO_3$) under the influence of the liquid phase sintering by molten LiCl. The flexural strength (σ) of the samples varied from 6.3MPa to 16.3MPa. The maximum value registered was regarded for the sample with talc and glass wool in the ratio of 9:1, firing at 800°C and with the addition of 5 wt% of LiCl. This work is aimed at the utilization of the tailings of soapstone mineral processing for production of ceramics by its addition to clay.

## 2 MATERIAL AND METHODS

After sampling, tailings of soapstone and clay were homogenized and quartered. The particle size distributions of the soapstone tailings and of the clay were determined through homogenization; quartering and wet screening with the Tyler Series screens, starting with the 6# sieve (3360µm). The fraction under 325# (44µm) was characterized using a Cyclosizer model CC05. The mineralogical characterizations of the soapstone tailings and of the clay were made by X-Ray diffraction. The chemical analyses were performed by the X-Ray fluorescence. Lithium tetraborate ($Li_2B_4O_7$) was used to melt the material. In order to manufacture the ceramic samples, a fraction of the soapstone tailings with particle sizes smaller than 100# (149µm) was used, despite the fact that the tailings presented a high amount of large-sized particles. It was made in order to guarantee a better densification of the samples during the sintering process. The entire range of particle size of the clay was used for manufacturing the test samples, since the material presented 95% of the particles with sizes smaller than 6µm. The ceramic samples were produced as displayed in Table 1.

Table 1: Mixture composition of the ceramic samples

| Soapstone (%) | Clay (%) |
|---|---|
| 50 | 50 |
| 40 | 60 |
| 30 | 70 |
| 20 | 80 |
| 10 | 90 |
| 0 | 100 |

The test specimens were produced in steel molds with the dimensions of 6x2x0.5cm and compaction pressure of 30 MPa applied for 30s by a manual hydraulic press. The total of samples produced was 72, with 12 specimens for each composition.

The ceramic samples were dried for 24 hours at 110°C inside an oven, and then sintered at 900°C, 1000°C and 1200°C. Each set of 12 samples from the same composition was divided into 3 groups of 4 specimens. These groups were sintered separately at these temperatures. This procedure was repeated for the other sets of specimens with different compositions. Therefore, it was possible to investigate the influence of temperature and composition on the bending resistance. The heating rate of these samples was 3°C/min until the desired temperature was achieved and, then, the isothermal sintering for 30 minutes was carried out.

# 3 RESULTS AND DISCUSSION

## *3.1. Granulometric characterization*

The results revealed that 80% of the soapstone tailings had particle sizes over 44µm, Figure 1. As for the clay, it was noted that 95% of the material exhibited particle size of less than 6µm, so it was considered a very fine material, Figure 2.

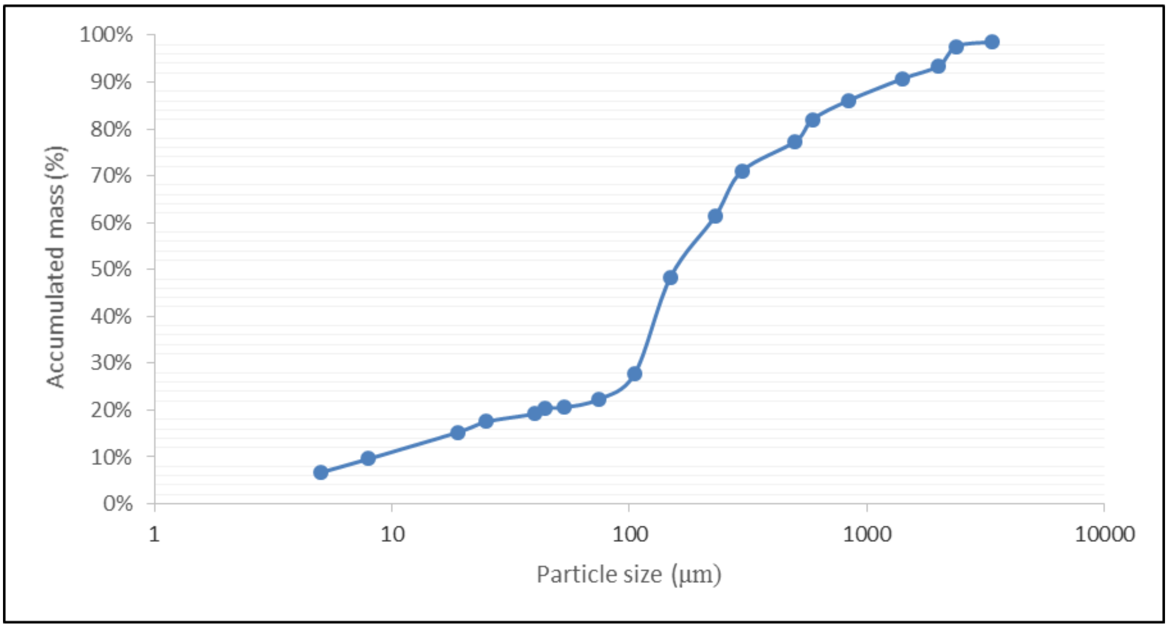



Figure 1. Particle size distribution of soapstone tailings

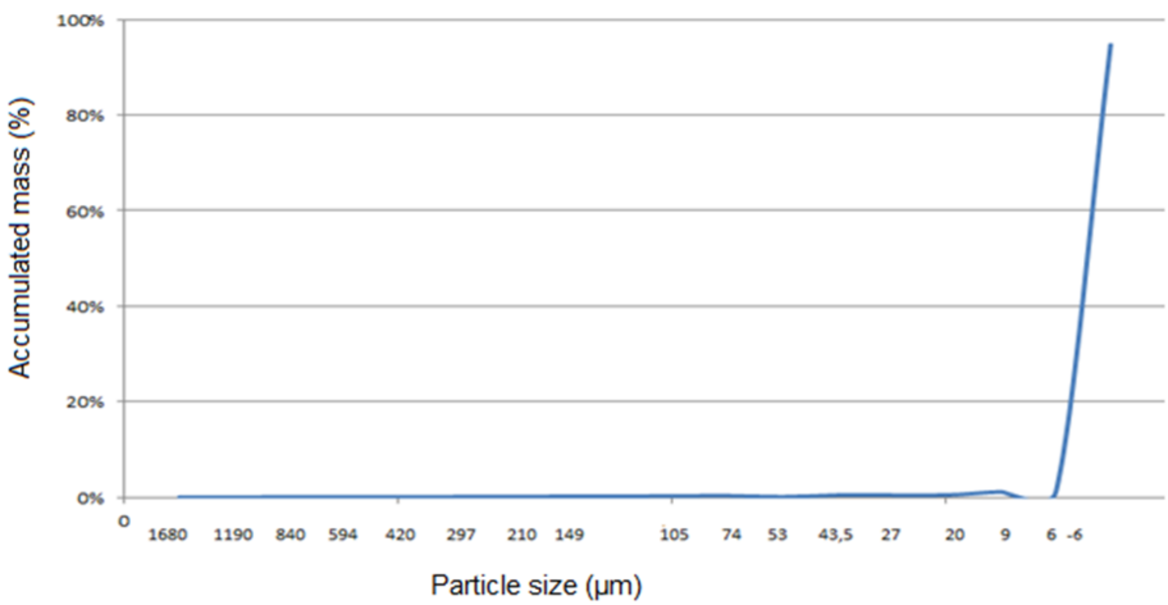
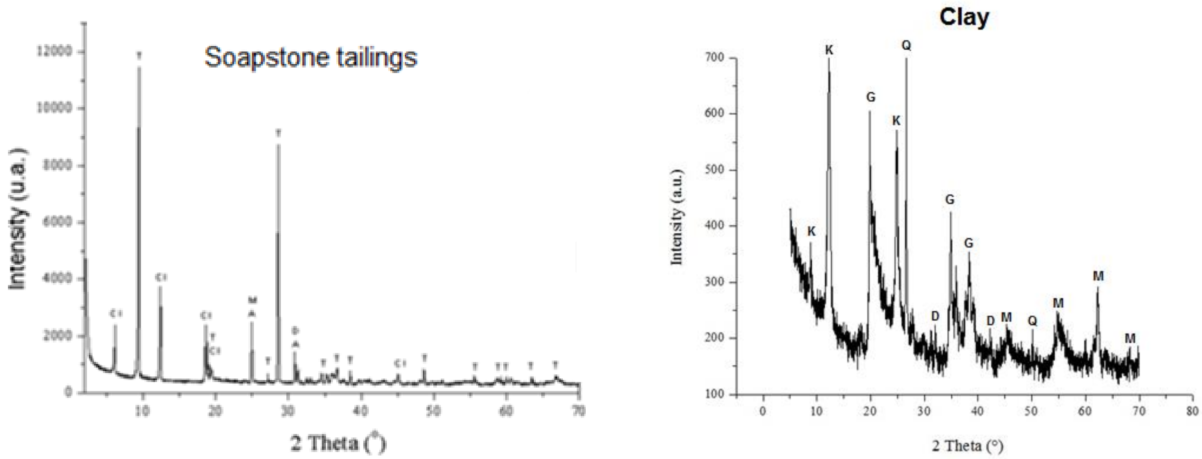



Figure 2. Particle size distribution of clay

*3.2. Mineralogical characterization*

The mineralogical characterization of the soapstone tailings, Figure 3(a), revealed the predominance of talc ($Mg_3(Si_4O_{10})(OH)_2$) and chlorite ($(Mg,Al,Fe)_{12}(Si,Al)_8O_{20}(OH)_{16}$) and, in a lower proportion, anorthite ($(Na_{0,1\text{-}0},Ca_{0,9\text{-}1})Al(Al_{0,9\text{-}1},Si_{0,1\text{-}0})Si_2O_8$), muscovite ($KAl_2Si_3AlO_{10}(OH,F)_2$) and dolomite ($CaMg\ (CO_3)_2$) were also found. The major presence of talc is consistent with the literature data, which states talc as the main constituent of the soapstone (Moreira, 1994) [8]. On the other hand, the clay, Figure 3(b), showed a prevalence of the phases kaolinite ($Al_2Si_2O_5(OH)_4$), quartz ($SiO_2$), goethite ($FeO(OH)$), muscovite ($KAl_2(Si_3Al)O_{10}(OH,F)_2$) and dolomite ($CaMg(CO_3)_2$).




(a) (b)

Figure 3. X- ray diffraction (a): of soapstone tailings and (b) of clay. K: kaolinite, Q: quartz, G: goethite, M: muscovite, D: dolomite, Cl: chlorite, T: Talc, A: anorthite

*3.3. Chemical characterization*

The elements present in the soapstone tailings were Mg, Al, Si, Ca and Fe, while the clay was formed basically of Al, Si and Fe. The results shown at Table 2 are similar to the ones shown by Panzera et al. (2010) [5]. In his article, the following chemical composition was observed for the soapstone tailings: 44.73% of $SiO_2$, 29.28% of MgO, 8.38% of $Fe_2O_3$, 3.70% of $Al_2O_3$ and 2.95% of CaO. For the clay, the composition observed was: 48.90% of $SiO_2$, 36.30% of $Al_2O_3$ and 1.09% of $Fe_2O_3$.

Table 2: Chemical Analyses of Soapstone Tailings (SST) and Clay

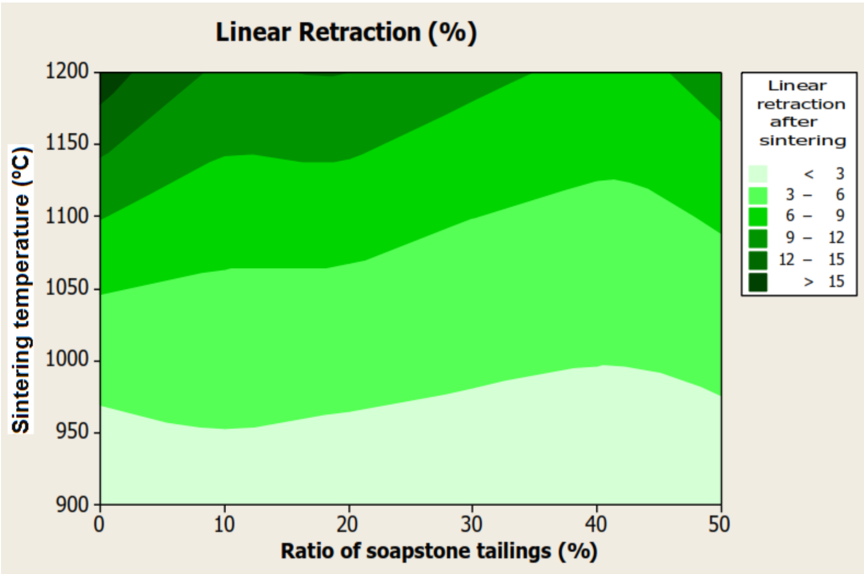
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $TiO_2$ | $P_2O_5$ | $Na_2O$ | $K_2O$ | MnO | Si | Fe | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | % | % | % | % | % | % |
| SST | 42.00 | 5.26 | 8.32 | 3.58 | 28.20 | 0.14 | 0.03 | <0.10 | <0.01 | 0.14 | 19.70 | 5.82 | 11.93 |
| Clay | 43.90 | 32.2 | 5.22 | 0.09 | 0.68 | 1.11 | 0.28 | <0.10 | 1.73 | <0.01 | 20.52 | 3.65 | 15.05 |

*LOI: Loss on Ignition

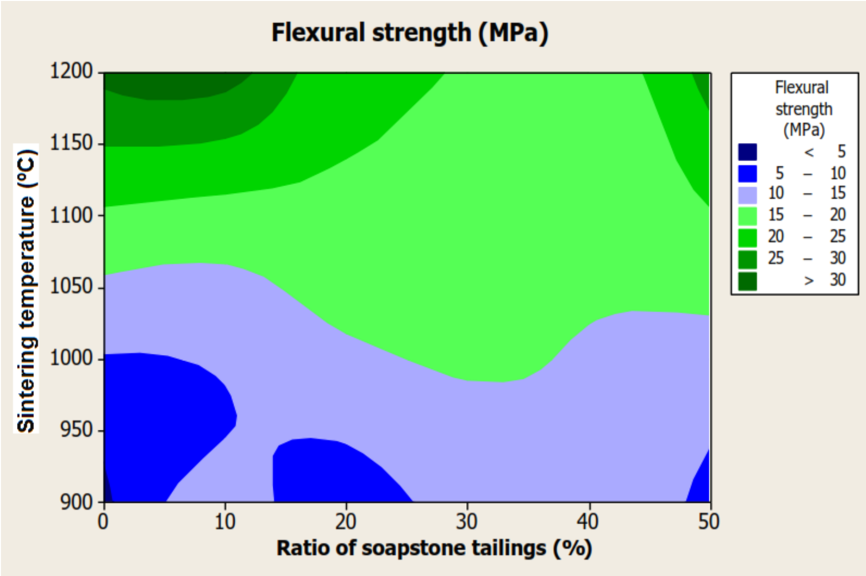
### *3.4. Linear retraction and flexural strength of the ceramic samples after sintering*

A temperature increase was incurred by eliminating the majority of the pores, consequently, raising the bulk density. The composition not only influenced the loss on ignition, but also led to the growth of the plasticity, and influenced the cohesion and mechanical resistance of the test specimens, as can be seen on Figure 4. Table 3 shows the flexural strength data of the ceramics produced with soapstone tailings. The abbreviations E0, E10, E20, E30, E40 and E50 indicate the ceramics test specimens produced with 0, 10, 20, 30, 40 and 50wt% of soapstone tailings added to the clay. It can be inferred from Table 3 that after 20wt% of soapstone tailings, the flexural strength values increase with the soapstone content and with temperature increase. This result can be correlated with the Panzera et al (2006) [5] data, which led to the conclusion that the flexural strength of ceramic is improved substantially when it is produced with 20 and 40% of steatite. Da Silva et al. (2014) [9] reported that the addition of iron ore concentration tailings to the ceramic mass increases its flexural strength, results which are very desirable to the ceramic industry. From that, it is possible to infer that the produced material can contribute to the reduction of rejects. Regarding the sintering temperature, a variation on the results was observed at the values of the flexural strength of ceramic samples.

Despite of the deviation in the flexural strenght measurements, a clear tendency of producing higher values with the addition of soapstone tailings can be noticed, at 900 and 1000°C. This is even more pronounced with additions between 20 and 40%, but is noticeable for all additions. Nevertheless, as the soapstone tailings are rejects produced from the beneficiation of the material, their use in the ceramic industry can be justified by its environmental benefits, even with no mechanical gain in the final material. This is the case for the ceramics fired at 1200°C, in terms of flexural strength, in which the addition of soapstone tailings did not increase the resistance of 31.49MPa that was reached for a sample produced without soapstone. Considering energy consumption during the ceramic parts production, Table 3 shows that parts with good flexural strength can be produced in lower temperatures, hence with lower energy costs.




(a)




(b)

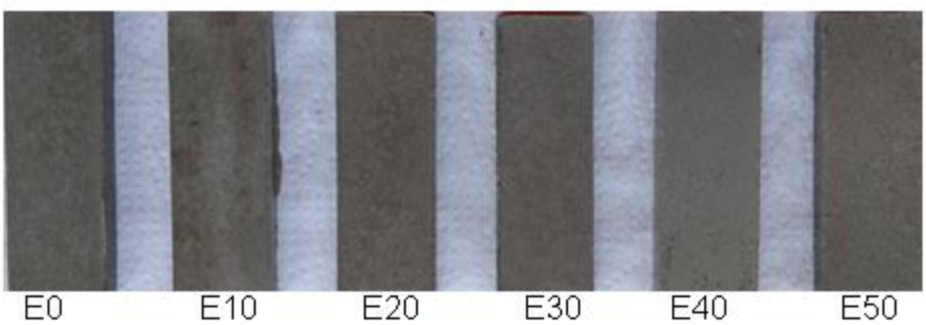
Figura 4. Results of: (a) Linear retraction and (b) flexural strength of ceramics sintered the 900ºC, 1000 ºC and 1200 ºC.

Table 3: Flexural strength of the ceramics samples (MPa): Composition x Sintering Temperature

| | E0 | E10 | E20 | E30 | E40 | E50 | Standard deviation |
|---|---|---|---|---|---|---|---|
| **900ºC** | 3.91 | 12.22 | 6.41 | 12.59 | 13.64 | 8.42 | 3.90 |
| **1000ºC** | 9.65 | 10.62 | 14.00 | 15.36 | 14.66 | 13.12 | 2.29 |
| **1200ºC** | 31.49 | 32.06 | 21.37 | 19.68 | 17.98 | 27.10 | 6.12 |

*3.5. Color of the ceramic specimens*

Figure 5(a) shows that the ceramic compositions before sintering presented a dark grey color and Figure 5(b) shows that after firing at the temperatures of 900ºC and 1000ºC the ceramic samples presented a reddish color that does not vary in different compositions. On the other hand at 1200°C the ceramic samples became dark green or orange/yellow. Note that the color obtained after firing the ceramics is a direct consequence of the composition of the ceramics (Da Silva, 2014) [9].




(a)

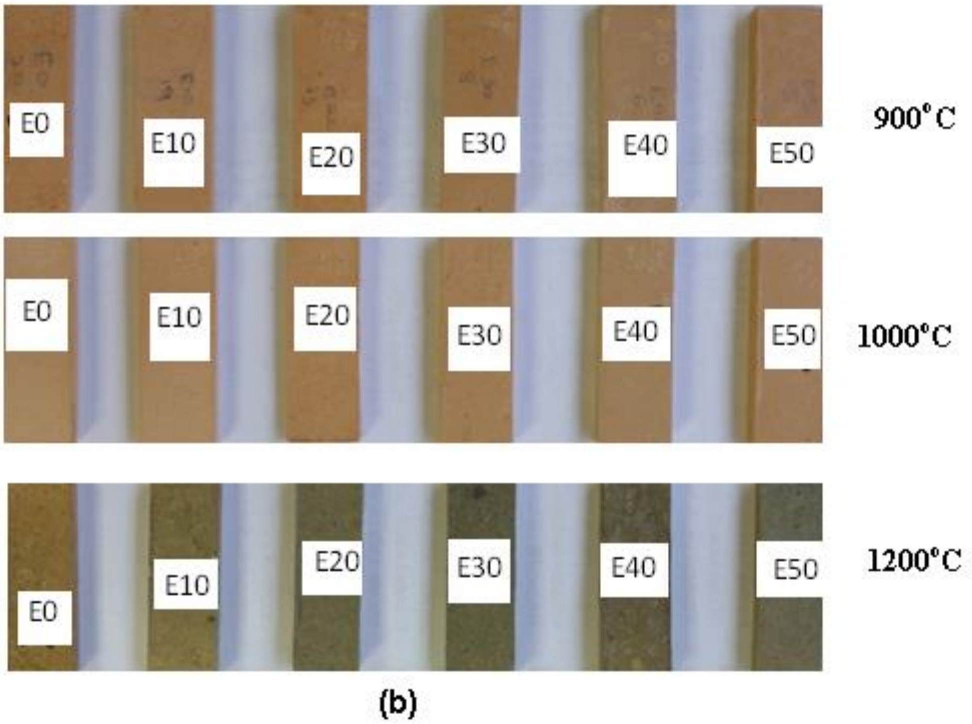



Figure 5. Colors of the ceramics: (a) after drying at 110ºC (b) sintered at 900ºC, 1000ºC and 1200ºC

## 4 CONCLUSION

The results showed the technical feasibility of making structural ceramics with the addition of soapstone tailings in excess of 20wt%, reaching good flexural strength after firing at 900°C or 1000°C. The recycling of soapstone tailings in the production of ceramics can contribute to the mitigation of environmental impacts of the soapstone industry and can enable the production of ceramic materials fired at relatively low temperatures, with good mechanical properties, leading to lower energy consumption.

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