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CHARACTERIZATION OF CERAMIC COMPOSITE FROM WASTE FOR THE MANUFACTURE OF A SOLAR OVEN

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Abstract. *Solar energy is a sustainable and growing alternative in Brazil. One of the applications of these energy is using solar ovens, which contributes to reducing environmental impacts and have been tested and used in food preparation. However, for these ovens to reach the desired temperature, a study of the material is necessary, in order to improve its thermal insulation. With this in mind, this work seeks to perform the characterization of a ceramic composite that will be used in the fabrication of the device for testing welding electrodes. For this, Red Ceramic Waste (RCW) were used to produce a mix of low thermal conductivity mortar. These tailings were ground and sieved, later a standard reference mix was defined, incorporating RCW contents of 10%, 20% and 30% as a partial replacement for the sand. Tests were carried out to determine specific mass, tailings grain size, chemical composition, consistency test and thermal conductivity. The results obtained in the consistency test were in accordance with the current standard and the thermal conductivity of the mortar was lower at the 30% RCW content. Thus, it is concluded that the proposed composite material is suitable for the proposed application, as it presented an adequate consistency index, in addition, it presented a good thermal insulation.*

Keywords: *Solar Energy, Solar oven, Red ceramic waste, Thermal Insulation.*

1. INTRODUCTION

The sun is a major source of inexhaustible free energy for the planet Earth. Currently, new technologies are being employed to generate electricity from harvested solar energy, and the development of these technologies is considered to be one of many key solutions toward fulfilling a worldwide increasing demand for energy (Kabir *et al.*, 2018). The use of solar energy has been increasingly regarded in many countries as an alternative to reduce the environmental impacts associated with climate changes and dependence on fossil fuels (Ferreira *et al.*, 2018). The Brazil, as a country located mostly in the intertropical region has great potential for solar energy utilization throughout the year (Henrique Rossa *et al.*, 2015). The “Figure 1” shows the global average daily radiation in Brazil.

One of the applications of solar energy is its use in solar ovens. These devices capture sunlight and convert it into thermal energy inside the oven, allowing the device’s internal temperature to rise (Cuce and Cuce, 2013). Solar ovens are ecological as they do not depend on gas or electricity; they are economical as sunlight is enough, so in a long period of time, money can be saved and; they are easy and safe to use (Jebaraj and Srinivasa Rao, 2015) (Shahzad *et al.*, 2013).

The first solar collector in history was developed by the Swiss scientist Horace de Saussere in 1767 (Saxena *et al.*, 2011) and since their creation, they have been widely used and studied, especially in relation to cooking food (Ayub *et al.*, 2018) (Hernández-Luna and Huelsz, 2008) (Suharta *et al.*, 1998) (Nandwani, 1989). However, there are also other applications of this technology, such as in the sterilization of instruments in rural health clinics (Jørgensen *et al.*, 2002), in drying processes (Cetina-Quiñones *et al.*, 2021) (Ebadi *et al.*, 2021) (Bailey *et al.*, 2018), in the food processing industries (Barba *et al.*, 2019), in the heat treatment of titanium alloy (Chicos *et al.*, 2018), among other applications.

Many studies were carried out with the purpose of increasing the production capacity of the ovens and reducing the limitations present in it. Guidara *et al.* (2017) managed that his project for a solar box cooker achieve high temperatures

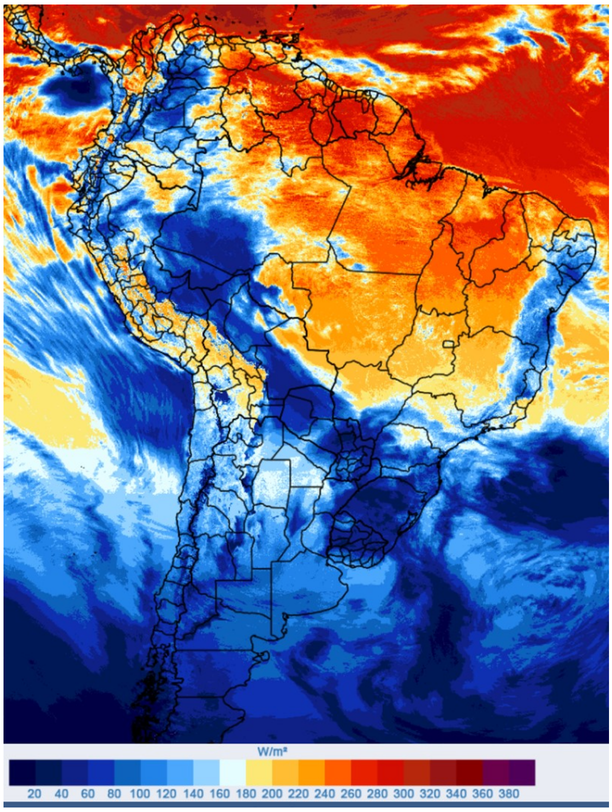

Figure 1. Global average daily radiation in Brazil. Source: Solar Radiation and Terrestrial 2021 (INPE, 2021)

during days of low solar incidence, this due to the presence of four external reflectors. Geddam *et al.* (2015), in his work, carried out a modification of the cooking space to improve the thermal efficiency and consequently guarantee a shorter food production time in his solar oven. Other authors added in their work a heat storage system, so that the device could be used at times of low solar radiation (Lecuona *et al.*, 2013) (Liu *et al.*, 2012). Cuce and Cuce (2013) also emphasize in their study the importance of using and investigating the geometric parameters and materials used to manufacture solar ovens, since these devices use thermal energy storage, therefore, to prevent the transmission of this energy from within outside the box, it is mandatory to provide thermal insulation. Composite materials have been shown to be present in studies with this purpose.

The incorporation of ceramic waste as composite materials in the manufacture of mortars has been shown to be an alternative that minimizes the accumulation of solid waste in the construction process Lima *et al.* (2016). Brazil wastes 8 billion reais a year because it does not recycle your products. The numbers indicate that 60% of solid waste in cities comes from civil construction and 70% of this total could be reused (Morand, 2016). According to National Environment Council (CONAMA), the reuse of waste is subdivided into three distinct approaches, presenting reuse as one of the alternatives (Brasil, 2002). Therefore, this work aims to characterize a ceramic composite, from Red Ceramic Waste (RCW), which will be used in the manufacture of a solar oven for testing welding electrodes.

2. METHODOLOGY

2.1 Materials

Red ceramic waste samples were collected at Cerâmica located in Itajá - Rio Grande do Norte. The collection of waste was carried out in dumpsters and in tailings deposit sites. The RCW acquired was composed of solid brick pieces that were not approved in the company's quality control for commercialization, whether due to burning failure, improper handling, defects in dimensional and geometric tolerances or intrinsic fragility of the piece.

The residue was collected in pieces of different sizes, from smaller pieces to whole bricks ("Fig. 2A"). They were crushed with a soil compaction mallet into objects approximately 20 mm long ("Fig. 2B"). This crushing procedure was carried out in order to optimize and homogenize the material for the next refinement step, which consisted of reducing the granulometry of the material in the ball mill equipment – at 33.7 rpm. "Figure 2C" illustrates the appearance of the material after its comminution process.

In the ball mill, large (5 cm), medium (2.5 cm) and small (1.5 cm) spheres were used in quantities, respectively, of 8, 64 and 33, corresponding to 3 kg of spheres. These spheres were mixed with 2.5 kg of RCW for a period of 6 hours.

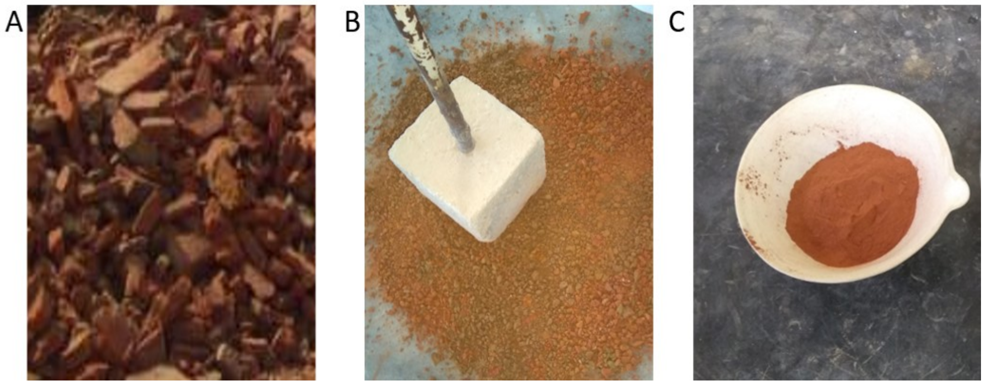

Figure 2. Material comminution process. A) Brick materials (whole). B) Material after being crushed. C) Final appearance after comminution.

Fifteen tests were carried out in the ball mill, resulting in a total of approximately 36 kg of waste produced and 1.5 kg of material not passing through the 4.8 mm sieve. From this process, a material with fine aggregate particle size was obtained. The “Figure 3” presented a flowchart of the synthesis of ceramic waste processes from pottery bricks.

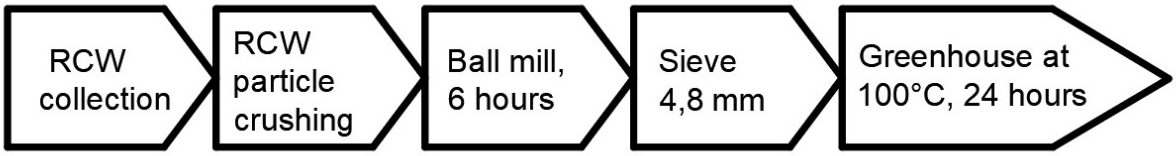

Figure 3. Flowchart of the steps in the processing of ceramic waste from pottery bricks.

Portland cement

The cementitious material used in the study was CP V ARI MAX Portland cement, from the Nacional brand, from the same quality control batch. This type of cement was chosen because the manufacturer guarantees approximately 95% of its strength in just 7 days after molding the mortar bodies.

Sand

The sand used was of medium granulometry, available in local commerce, this grain size was chosen because the RCW has a similar condition, that is, both grain sizes are approximately equal to improve the mixture and homogenize the mortar. The sand was dried under study at a recorded temperature of approximately (105 ± 5°C).

Lime

The mortar plasticizer was the high purity CH-I hydrated lime from the Ouro Branco brand. Lime or calcium hydroxide participates in the proportion of the mortar to improve the workability of the mixture, it went through a maturation process meeting the requirements of the Brazilian standard NBR 13276, according to Brazilian Association of Technical Standards (ABNT, 2005).

2.2 Methods

Particle size analysis by sedimentation

Red ceramic waste was characterized by determining the particle size by sedimentation (distribution and grain size) over a period of 12 hours as recommended by Brazilian standard NBR 7181 (ABNT, 2017).

X-ray fluorescence (XRF)

Five samples of the ceramic material collected in the ceramic industries were used. The XRF analysis was obtained by X-ray fluorescence using a Shimadzu brand EDX-720 spectrometer, exposed to a vacuum atmosphere with a 10mm collimator and capable of quantifying all the chemical elements present.

Specific mass of materials

Tests were carried out to determine the specific mass of all materials that made up the mortar. For this, the procedures described in the Brazilian standard NBR 9776 (ABNT, 1987) for sand were adopted - for the determination of the specific mass of the sand, the solvent was used as water using a Chapman flask as suggested by the standard. For materials that act as binders such as Portland cement, RCW and hydrated lime, the Brazilian standard NBR NM 23 was used (ABNT, 2000). The specific masses of cement, lime and RCW were determined using kerosene to ensure no chemical reaction between the solvent and the solute materials – here the Lê Chatelier flask was used as recommended by the standard.

Setting the proportion of mortar

In order to mix the materials that will form the ceramic composite, a standard mix of 1:1:6 was defined, that is, one portion of cement, one portion of lime and six portions of sand in volume. This trait was defined with the help of the Brazilian Association of Portland Cement – BAPC. The mortar confections used in this study were produced by the partial replacement of different sand contents by RCW. The data in "Tab. 1" show how mortars with replacement contents of 0%, 10%, 20% and 30% of residue in sand were formed.

Table 1. Percentage of waste and volume trace

Percentage of waste (%)	Volume Trace (cement: RCW: lime: sand)
0	1: 0.0: 1: 6
10	1: 0.10: 1: 5.4
20	1: 0.20: 1: 4.8
30	1: 0.30: 1: 4.2

Testing of thermal properties

The portable equipment from Decagon Devices model KD2 Pro was used to test the thermal properties. Five thermal conductivity measurements were carried out for each configuration – 0%, 10%, 20% and 30%. The test procedure was performed according to American Society for Testing and Materials (ASTM) D5930 – 17 (ASTM, 2017), which is technically demonstrated in its manual.

2.3 Statistical analysis

The statistical study was carried out using the Statistical Package for the Social Sciences (SPSS) statistical software. For statistics, an Analysis of Variance – ANOVA followed by a Tukey post hoc test – was performed for independent samples. Results were shown as mean ± standard deviation (SD). The level of significance was equal to 5%. ANOVA compares more than two groups (0%.10%, 20%, 30%) and the post hoc test makes all the combinations between the RCW percentages to find out how much one differs from the other.

3. RESULTS AND DISCUSSION

3.1 Especific mass

The values calculated according to the normative experiments were, in terms of average: 2.67 [g/cm³] for RCW, 2.36 [g/cm³] for lime, 3.15 [g/cm³] for cement and 2 .63 [g/cm³] for sand ("Fig. 4"). The graph is the result of the average of five values for each material calculated according to the norm. The values found in our results are within the expected range for each of the substances according to what is seen in the literature (Bauer, 2010) (Lima *et al.*, 2016) (Santos *et al.*, 2018).

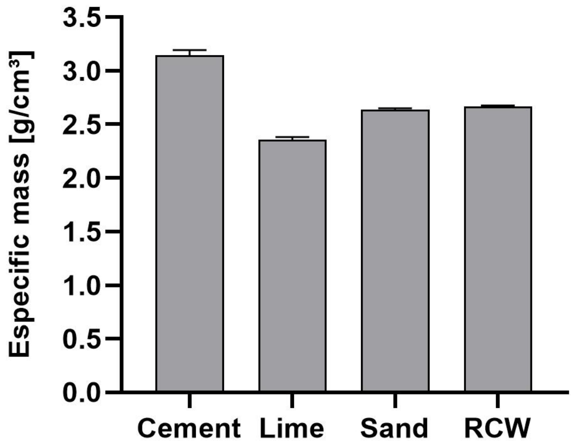

Figure 4. Average of the specific mass values of the materials used.

3.2 RCW Granulometry

The analysis of the particle size distribution curve obtained by sedimentation shows that the RCW presented particle size corresponding to ranges of: 53.45% of thin sand (0.06 - 0.2 mm) of grain diameter, 44, 70% silt (0.002-0.06 mm), 2.27% medium sand (0.2 – 0.6 mm) and 1.08% coarse sand (0.6 – 2 mm) ("Fig. 5").

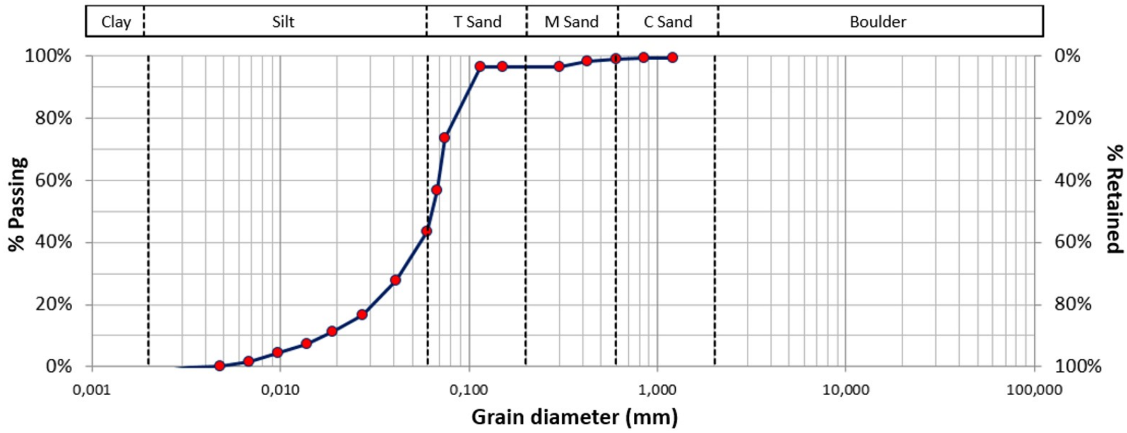

Figure 5. Average of the specific mass values of the materials used. T sand = Thin sand, M sand = Medium sand, C sand = Coarse sand.

In view of this granulometric behavior in the graph with a predominance of fine sand and silt, it is observed that the material is, on average, uniform in its entirety because its uniformity coefficient is 3.998 (Isaia, 2010). The graph also shows that the average diameter of the RCW for a passing percentage corresponding to 50% is approximately 0.060 mm. For this reason, the percentage load of RCW added to the mortar will be a replacement for the sand, as they have grain sizes similar to what has been observed in studies carried out (Lima *et al.*, 2016) (Silva *et al.*, 2010) (Corinaldesi and Moriconi, 2009).

3.3 RCW chemical composition

The chemical composition of the residue demonstrates all the chemical elements present in the sample, ten samples from different batches of RCW collected in the ceramic industry were analyzed ("Fig. 6"). It can be seen from this graph that the chemical elements with the highest percentage is the iron atom followed by the silicon and aluminum atom. This was expected, since the ceramic residue has a red color – pottery bricks – thus confirming a greater presence in a greater amount of iron atoms that when oxidized will form iron oxide according to Nociti (2011).

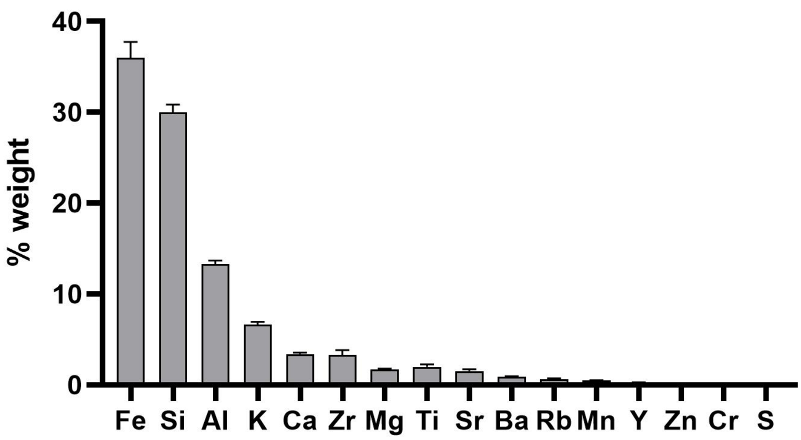

Figure 6. Chemical composition of the RCW binder.

3.4 Consistency index and Thermal conductivity property

For the characterization of the mortar consistency index, our results showed that there was no difference in the average spreading diameters between the RCW replacement contents, $p > 0.05$. All contents (0%, 10%, 20% and 30%) are within the tolerance required by the Brazilian standard NBR 13276 (ABNT, 2005), which is 260 ± 5 mm ("Fig. 7A").

For the thermal conductivity analysis, the average thermal conductivity at 30% was 0.746 W/mk, at 20% it was 1,110 W/mk, at 10% it was 1.070 W/mk and at 0% it was 1.061 W /mk, the 30% content was lower than all others, $p < 0.05$ ("Fig. 7B"). The results show that the thermal conductivity decreases when higher percentages of residue are added to the mortar, which gives them a certain thermal insulation through Fourier's law of thermal conduction. This result reveals that for higher levels of RCW in the mortar, the thermal insulation will be better, this difference for the 30% was expected because they are waste from refractory bricks, that is, they resist high temperatures. As the RCW perception increased and the sand in the mortar decreased, there was a greater thermal resistance of this material.

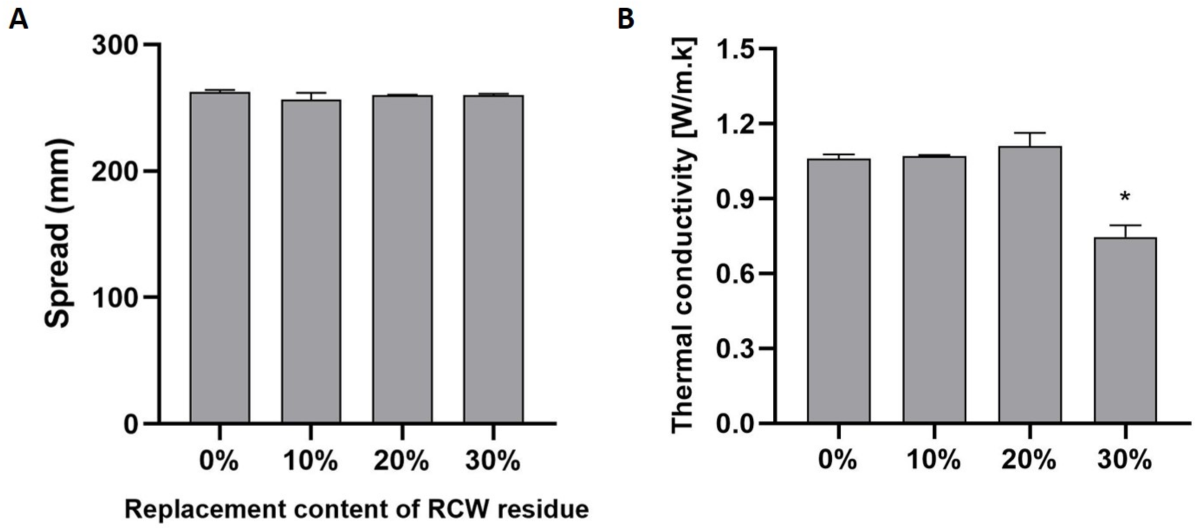

Figure 7. A) Average of the spread obtained for the consistency index test. No statistical difference. B) Average thermal conductivity at all RCW residue replacement grades, the 30% grade was less than all others. (*: $p < 0.05$)

4. CONCLUSION

Thus, it was found that the mortar - ceramic composite material - was approved for use in the construction of the solar oven, as its consistency index is in accordance with the standard, that is, the mortar is neither dry nor very wet, and can be avoided cracks in the solar device. In addition, it was observed that the most suitable mortar to be used in the oven is the one with the highest thermal resistance and, therefore, better thermal insulation for the solar oven - providing lower thermal losses to the environment. In our results, the mortar with 30% RCW content will be chosen for the construction of the oven, both because of its better thermal insulation and its consistency.

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6. RESPONSIBILITY NOTICE

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