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PROPERTIES OF CLAY-BASED CERAMICS ADDED WITH CONSTRUCTION AND DEMOLITION WASTE

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Abstract

The accelerated growth of urbanization processes and current environmental concerns brought to light the existing enormous quantity of construction and demolition waste (C&DW). Considering the frequent lack of adequate landfill areas available for the disposal of these materials, their use in the manufacture of ceramic products has been attracting a growing interest from researchers and is becoming common practice, with the consequent relief in public administration concerns for the C&DW appropriate management.
This work describes the study of clay-based products added with C&DW collected directly from the construction industry. Samples containing up to 50 wt.% C&DW were uniaxially pressed and sintered in air in an electric furnace (950-1150 °C, 1 hour). Sintered test pieces were characterized by X-ray diffraction, apparent density, open porosity and flexural strength. The results showed that up to 50 wt.% C&DW can be added to the clay material, with no degradation in the final product properties.

Introduction

The industrial activities produce a remarkable amount of waste materials. Nowadays the industries have optimized their processes, reducing the quantity of waste materials, and are looking for alternatives to waste dumping.

Clay-based ceramic materials show an extensive range of chemical composition, resulting in products with heterogeneous characteristics. This attribute enables easy incorporation of different types of waste materials into clay-based products [1-12]. However, some industrial waste materials have chemical compositions and characteristics similar to those of natural ceramic raw materials and can thus be upgraded to alternative raw materials and used in the fabrication of ceramics products. Some waste materials have already been shown to improve the properties of the clay products or the processing parameters. When compared to the traditional clay material, the addition of granite and marble rejects and coal fly ash caused a reduction in the sintering temperature [1-4].

The construction industry is closely related to the clay-based ceramics industry, consumes vast amounts of natural resources and produces a significant quantity of construction and demolition waste (C&DW) [13].

There is no detailed information about the amount of C&DW produced in Brazil. In large cities, such as São Paulo, Rio de Janeiro and Salvador, the C&DW production has been estimated in 0.49 kg per inhabitant/day, corresponding to around 31 % of the total collected domestic waste [14]. Since 2002, all Brazilian municipalities were forced to implement strategies for sustainable management of C&DW. However, there is no sufficient research in Brazil to prove the technical and economic viability of C&DW recycling centres. Hence, there are very few C&DW recycling centres in Brazil and most of the waste is sent to waste dumps or to landfill sites [14].

The objective of this work is to study the effect of the incorporation of C&DW materials on the sintering/densification and mechanical behaviour of a commercial clay-based ceramic material.

Experimental Procedure

A typical clay mixture used in the ceramic industry in Rio Grande do Norte-RN, Brazil, and a C&DW material collected directly from the construction industry were selected and characterized. The C&DW material consists basically of ceramic rejects (bricks, cement, tiles, etc). The characterization of the both materials included chemical composition (X-ray fluorescence, XRF, Philips PW 1400), mineralogical composition (X-ray diffraction, Smimadzu XRD 600), thermal behaviour (dilatometry, BP Engineering, and DTA and TGA, Schimadzu), and particle size distribution (Laser Granulometer, Micromerits). Selected mixtures containing 0, 10, 20, 30, 40 and 50 wt.% of reject were prepared and homogeneized for 4 hours in a planetary mill with alumina grinding balls. The powders were uniaxially pressed into test bars (50 x 4 x 4 mm^3) under a load of 20 MPa. Powder compacts were sintered at temperatures between 1050 and 1150 °C during 1 hour. The mechanical strength of the sintered samples (average of five specimens for each value) was measured with a universal testing machine (Zwick-Roell) in three-point bending tests at a constant cross-head speed of 0.5 mm/min. Apparent density and water absorption were determined by using the Archimedes water displacement method, as specified by the European Standard EN 99, and the crystalline phases present after sintering were identified by X-ray diffraction.

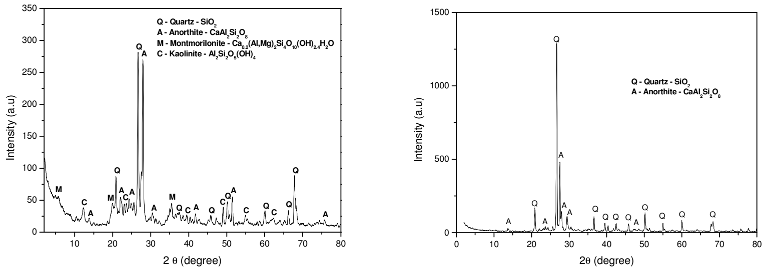
Results and Discussion

Table 1 gives the chemical composition of the original clay mixture and the C&DW material. The clay mixture shows the expected typical composition: rich in silica and alumina (minor contents of Mg, Ti, Ca, Na and K oxides), accompanied by 4.5

wt.% iron oxide. In terms of oxides, the C&DW material consists basically of SiO_2, Al_2O_3 and CaO, with minor contents of MgO, Fe_2O_3, K_2O and Na_2O. The high CaO content (16 wt.%) is associated with the presence of cement in the waste material and will influence the sintering behaviour of the clay product.

Table I. Chemical composition (wt.%, XRF) of the materials used in this work.

	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	Na_2O	TiO_2	MgO	BaO	P_2O_5	SO_3
Clay mixture	60.2	24.9	4.5	4.1	3.0	0.9	0.4	0.8	0.3	0.1	—
C&DW material	64.6	10.7	1.5	4.4	16.0	0.9	0.3	0.4	0.0	0.2	0.6

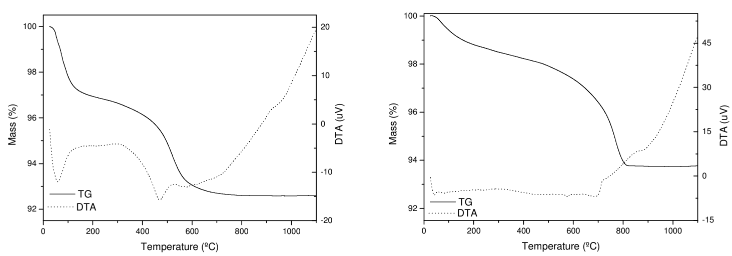


(a) (b)

Figure 1. X-ray diffraction patterns of: (a) clay mixture, and (b) C&DW material.

Table II. Particle size distribution.

	Amount in the size class (wt.%)			
	< 2.0 µm	2.0 – 20 µm	> 20 µm	Average particle size (µm)
Clay mixture	12	50	38	22.83
C&DW material	11	46	43	24.13



(a) (b)

Figure 2. Thermal behaviour (TG and DTA) of: (a) clay mixture, and (b) C&DW material.

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Figure 1 shows the X-ray diffraction patterns of the original clay mixture and the C&DW material. It can be seen that the clay mixture contains quartz and anorthite, and minor amounts of kaolinite and montmorilonite. The C&DW shows the predominance of quartz and anorthite, which is in agreement with the chemical composition shown in Table 1.

Table 2 gives the particle size distribution of the clay mixture and the C&DW material. The average particle sizeof the clay and waste materials are approximately 22.83 µm and 24.13 µm, respectively. Although green processing was not the objective of this work, one must bear in mind that differences in particle size distribution and the non-plastic character of the reject, particularly for high reject contents, might introduce some difficulties in the shaping process (usually, extrusion). Although any mixture of particles of different sizes should reach a higher packing density than that of the individual components [14], the non-plastic character of the C&DW material might give rise to lower green density values.

Figure 2 shows the thermal behaviour of the clay mixture and the C&DW material. The thermogravimetry (TGA) of the clay mixture (Fig. 2a) shows a two-step small weight loss (~7%) from 40 to 600°C (adsorbed and structural water). Endothermic peaks in the DTA curve (respectively at ~80 and ~480°C) correspond to both weight losses. The TGA curve for the reject shows a smooth weight loss up to 800°C, which can be related to water and volatiles evolution. The DTA curve shows a small peak at 700°C that can be associated to the dissociation of calcium carbonate and a very small exothermic peak at ~900°C, suggesting the formation of crystalline phases (possibly more anorthite).

Figure 3 depicts the results obtained from the dilatometric study. The original clay mixture shows a uniform expansion up to ~900°C, which slows down up to ~1050°C, and is then followed by a strong shrinkage. On the other hand, the C&DW added mixture (30 wt.%) shows a similar behaviour with a small delay on the beginning of the shrinkage (from 1050 to 1100°C), which can be attributed to the presence of pre-sintered materials and also the high silica content (64 wt.%) that act as inert materials.

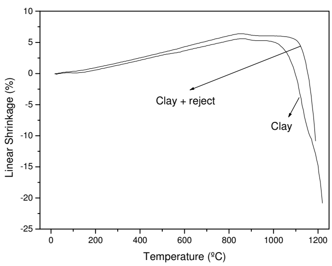
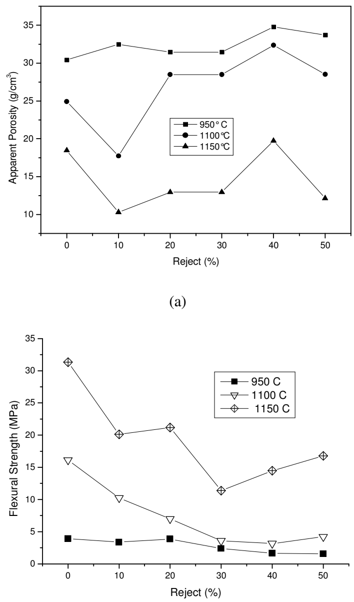


Figure 3. Dilatometric behaviour of the original clay mixture and the C&DW added material (30 wt.%).

Figures 4a and 4b show the changes in porosity and strength values, respectively, observed with the sintered specimens as a function of the C&DW content and the sintering temperature. When comparing the experimental values, it must be noted that, as mentioned before, the starting green body density was not necessarily kept constant. The non-plastic character of the reject might give rise to lower green density values for the reject-added compositions, given that a constant compaction pressure was used throughout the work.



(b)

Figure 4. Changes in porosity (a) and flexural strength (b) of the sintered bodies, as a function of the C&DW content and the sintering temperature.

As expected, at each firing temperature, the C&DW acts as an inert material, causing a general increase in the porosity. However, the negative effect of the addition of an inert material on the sintering behaviour is initially (*i.e.* for C&DW contents up to 10 wt.%) counteracted by the fluxing effect of the addition of CaO, which improves the sintering behaviour at higher firing temperatures (1100 and 1150°C).

These results are in agreement with the dilatometric behaviour (Fig. 3) that shows the beginning of the shrinkage of the clay + C&DW materials at temperatures above 1100°C.

This effect is also observed in the flexural strength of the sintered materials, as shown in Figure 4. After firing at 950°C, the flexural strength is hardly affected by the C&DW additions; at higher temperatures (T ≥ 1100°C), a significant improvement becomes evident for C&DW additions above 30 wt.%. The porosity and flexural strength values obtained in this work satisfy the ISO and EN standards, making the construction and demolition waste a potential raw material to be used in the traditional red ceramic industry.

Conclusions

The results obtained in this work show that high content (~50 wt %) of a construction and demolition waste can be incorporated into an industrial clay mixture requiring no changes in the processing routines and causing no detrimental effects on the final products properties. Such a large usage of the construction and demolition reject will translate into a much welcome relief on waste disposal concerns.

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