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ORIGINAL ARTICLE

Physico-mechanical investigations on mineralogical clay-based ceramic bodies with rock residue

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Abstract Waste recovery is very important for public health and from environmental and industrial perspectives. The use of waste as useful raw material is strongly recommended, since it reduces the negative environmental impact associated with landfill and preserves non-renewable nature. This paper describes the usability of rock residue powder as an additive raw material in ceramic product. In the present study, qualitative analysis was carried out to determine the major and minor constituent minerals present in ceramic bodies made from rock residue powder by X-ray diffraction and FT-IR spectroscopic techniques. Also to study the mineralogical and physico-mechanical characterization of ceramic bodies made from rock residue powder. The present study demonstrates the usefulness of the physico-mechanical properties and spectroscopic techniques in determining the quality of the ceramic samples made from 10–50 wt.% of rock residue additives.

1. Introduction

The industrial activities produce a remarkable amount of solid waste materials. Accumulation of industrial solid waste materials can be considered as one of the main sources of environmental pollution. Recycling of solid waste materials by incorporating them into ceramic material is a practical solution to environmental pollution. In the last decades, many researchers were interested in studying the problem of solid

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waste materials. Rock waste residue powders which result from cutting, polishing, crushing and machining operations in the rock quarries have a notable and serious effect on their surroundings. The rock waste is largely pollutant, only some part is discarded. In most of the cases illegally dumped in land and in the surrounding environment. This causes negative effects on the environment and human health, mainly inhalation of suspended fine powder with a range of 25% of total formation (Rego et al., 2001; Torres et al., 2004; Menezes et al., 2005). The aim of the present research work is on the use of the waste material (rock residue) for manufacturing ceramic product and some polymers (Arifuzzaman Khan et al., 2016). The objective of this work is to study the possibility to incorporated rock residue powder in ceramic product, without degrading their properties.

2. Experimental procedure

A typical ceramic body formulated using a rock residue in the form of powder was selected as one raw material and mixture of another raw material is fire clay. The rock residue powder was collected from a private rock-crushing plant located in Thuraiyur, Trichy (South India, Asia) India and the fire clay material was collected from Government Ceramic Institute, Virdhachalam, Cuddalore, Tamilnadu, India. The raw materials, rock residue powder and fire clay material were dried and ground in an agate mortar. The various percentages from 0% to 50% in steps of 10% were mixed with Fire clay material on weight basis. The formatted samples [RW0, RW10, RW20, RW30, RW40 and RW50] are allowed to dry in air and oven at 110° for 72 and 24 h respectively.

The raw materials, rock residue powder and fire clay material were dried and ground in an agate mortar. The various proportions of rock residue 0% (control), 10%, 20%, 30%, 40% and 50% were mixed with fire clay material on weight basis. Five series of batches (RW10–RW50) and a clay only mixture batch (RW0) were used as a reference specimen. The ceramic specimens were moulded into ASTM standard rectangular bars using a uniaxial pressing technique. After forming, the ceramic body specimens were dried in air (3 days) and then in an oven dried for 24 h at 110 °C.

Then sintering of dried ceramic specimens was performed in a laboratory muffle furnace at 800, 850 and 900 °C. The heating rate was 5 °C/min. with 1 h soaking at maximum temperature. Then cooling occurred by natural convection inside the furnace after it was turned off. As a result, rectangular standard fired ceramic bodies were obtained.

The samples were powdered finally using agate mortar and the samples are subjected to FTIR and XRD studies. The XRD – pattern are recorded by Bruker – XRDiffractometer [D8] with the source of CuKα radiation was used in the 2θ range from 5° to 70° with a step size of 0.02° and a scanning speed of 1° per minute. The XRD peaks observed in the diffractogram were assigned with reference to the 2θ values and corresponding *d*-spacing. It is used to identify mineral phases in all the samples.

The infrared spectra were recorded in the mid IR region 4000–400 cm^{-1} using Perkin Elmer FTIR interferometer. The KBr pressed pellet technique was used by mixing the powdered samples with KBr in weight proportion of 1:20. The precision of the FTIR instrument is $\pm 4\ cm^{-1}$ in 4000–2000 cm^{-1} region and $\pm 2\ cm^{-1}$ between 2000 and 400 cm^{-1}. The ceramic bodies were tested to determine the plasticity, density, cold crushing strength, flexural strength, and drying shrinkage by standard procedures (Norsker, 1987; Demir, 2008; Gupta, 1994).

The plasticity of the samples were tested by using the following form,

$$\%\ \text{of plasticity} = \left(\frac{(W_W - W_d)}{W_d}\right) \times 100$$

where, W_w is the wet state weight of the sample (gram) and W_d is the dry state weight of the sample (gram).

The density was evaluated (Monteriro et al., 2004; Vijayaragavan and Mullainathan, 2011) by dividing accurately measured mass of the dry/sintered samples by external volume (dimensional method).

Flexural strength was calculated from the breaking load using the formula (Chesti, 1986; ASTM C674-77, 1977).

$$R = \left(\frac{3WL}{2bt^2}\right)$$

where, R – the flexural strength (Mpa), L = the distance between knife edges (mm), b = the breadth of the specimen (mm), t = the thickness of the specimen (mm), and W = the load at which the specimen failed (N).

The drying shrinkage, firing shrinkage and the total shrinkage were calculated for each test specimen using the following formula (Norsker, 1987).

$$\text{Average drying shrinkage is } \left(\frac{OL - DL}{OL}\right) * 100$$

where: OL means the original length; DL stands for the dry length and FL is the fired length.

3. Results and discussion

The clay minerals are the essential and basic raw materials for making ceramic products. Knowledge of the structure of the clay material goes a long way in characterizing the quality of such materials. Of the various well known methods of analysis, infrared spectroscopic is found to be a potential tool in investigating the structure of clay mineral (Ramaswamy and Kamalakkannan, 1987). Among all techniques available, X-ray diffraction technique has been used most frequently for qualitative identification of mineral components of ceramic materials. Strength is the ability of a material to resist failure under the action of stresses caused by a load. The study of this property of material is the concern of a special science i.e., the strength of materials (Komar, 1987; Vijayaragavan and Mullainathanm, 2013). Strength test is the most important test for assuring the engineering quality of a ceramic material.

3.1. X-ray diffraction analysis

The rock residue powder mixed ceramic bodies (RW0–RW50) were subjected to powder X-ray diffraction study and the XRD patterns are presented in Fig. 1. And it's showing that the samples contain both amorphous and crystalline phases. The X-ray diffraction pattern of the sample (RW0) of the ceramic body without rock residue additive is shown in Fig. 1. The identified minerals are: Kaolinite – (1.542 Å 1.790 Å, 1.902 Å, 4.456 Å and 7.181 Å), Montmorillonite – (1.491 Å), Quartz –