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Investigation of granite waste incorporated clay brick as a building material

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Abstract

The incorporation of various industrial waste materials as additives in the manufacture of clay-based products has been attracting a growing interest from researchers in recent years and is becoming common practice. The present work reports the changes in the behaviour of the clay material used in the brick industry due to additions of a granite sawing powder wastes, generated from ornamental stone processing industry in Madurai region, South India. The raw materials were characterized with respect to their chemical composition by XRF, mineralogical composition by XRD, particle size distribution and plasticity. Mixtures of clay and waste material (10-50 wt. %) were moulded by extrusion and sintered at temperature ranging from 600 to 900°C. Results of technological tests indicated that the granite waste proportion and firing temperature were the two key factors determining the quality of bricks. With 30 wt. % granite waste content, the reformulated briquette specimens sintered at 900°C exhibited better values of water absorption, porosity, bulk density and mechanical strength than the normal clay bricks produced in the industry.

***Keywords*: Granite waste; Clay; Brick; Mechanical properties**

1. Introduction

In India, today the population has crossed 1 billion and houses available are a mere 185 million. Further, the migration of rural families to urban areas abandoning their houses in villages and settling in cities has made the problem of housing much more severe.

Conventional construction materials namely bricks, tiles, cement, lime, timber etc will fall considerably short of their demand despite improved production. Therefore, the search for cost effective processes in the manufacture of existing building materials and substitutes for these will assume a special significance.

Accumulation of unmanaged wastes especially in developing countries like India has resulted in an increasing environmental concern. Recycling of such wastes as building materials appears to be viable solution not only to such pollution problem but also to the problem of economic design of buildings.

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The increase in the popularity of using environmentally friendly, low-cost and light weight construction materials in building industry has brought about the need to investigate how this can be achieved by benefiting to the environment as well as maintaining the material requirements affirmed in the standards.

Marble and granite mining and process industry are one of the most promising business areas of the mining sector, with a mean growth in the world production of approximately 6% per year in the last 10 years. The international trading is approximately US$ 6 billions per year and around US$13 billion, taking into account tools, equipment, etc. (Menezes et al., 2005). In India, the cost of cement during 1995 was Rs. 1.25/kg and in 2009 the price increased around five times. In case of bricks the price was 0.66 per brick in 1995 and the present rate is Rs. 4.00 per brick. Similarly, over a period of 15 years from the year 1995 the price of sand has increased six times. Also due to high transportation costs of these raw materials, demand, environmental restrictions, it is essential to find functional substitutes for conventional building materials in the construction industry. In India, about 6 million tones of wastes from marble and granite industries are being released from marble and granite cutting, polishing, processing, and grinding (Pappu et al., 2009). During sawing and polishing of marble and granite rock blocks, a large amount of wastes are generated, basically composed of SiO_2, Al_2O_3, Fe_2O_3 and CaO (Segadaes et al., 2005; Acchar et al., 2006). The marble and granite wastes are usually disposed in sanitary landfills or dumped on the riverbeds and this possesses a major environmental concern. Marble and granite wastes cause serious damages in the environment, such as soil and underground water contamination, if not efficiency treated before disposal (Menezes et al., 2005). The incorporation of marble and granite sawing powder wastes in the production of bricks and tiles is becoming common practice and have been done successfully in many countries (Saboya Jr. et al., 2007; Monteiro et al., 2004; Acchar et al., 2006).

Therefore, the main objective of this work is to study the prospective use of granite sawing powder wastes as additives and their effect on the sintering and mechanical properties of brick.

2. Materials and methods

A typical clay material used in the brick industry from Ramanathapuram region and granite waste from sawing operations, collected directly from the ornamental stone cutting industry from Madurai region, Tamilnadu State, South India, were selected for these investigations (Fig. 1) and characterized. The characterization included chemical composition [X-ray fluorescence (XRF), Philips PW 1400], mineralogical composition [X-ray diffraction (XRD), Rigaku Geigerflex D/max-Series)], particle size analysis (HORIBA LA-910) and plasticity. Mixtures containing 0, 10, 20, 30, 40 and 50 wt. % granite sawing waste were homogenized for 4 h in a planetary ball mill and a minimum of 50 briquette specimens ($5.0 \times 2.5 \times 2.5$ cm) were manually shaped at workable consistency. The specimens were then dried at 110°C for 24 h in an aerated oven. The firing of the specimens was performed at 600, 700, 800 and 900°C in an electric muffle furnace. This range of temperature is normally used in the fabrication of clay bricks in Tamilnadu State, India. The heating rate of the electric muffle furnace used for firing was 10°C/min with 2 h at the maximum temperature. Cooling occurred by natural convection inside the furnace after it was turned off.

The mechanical strength of the sintered specimens coverage of the five specimens for each combination of mix composition was measured with a universal testing machine (Shimadzu Autograph 25TA) in three point bending test at a constant cross-head speed of 0.5 mm/min. Water absorption and porosity were determined by using the relative displacement method. The bulk density was calculated as the ratio of mass of the specimen to its volume. Fracture surfaces were observed by Scanning Electron Microscopy (JEOL-JSM-5610LV, at 20 KV, after gold coating) and qualitative EDS was used to identify the various phases observed.

3. Results and discussion

Table 1 shows the chemical composition of the raw clay material and the granite sawing powder waste. The clay material shows the expected typical composition: rich in silica and alumina, with minor contents of Ca, Mg, K and Na oxides, accompanied by a significant amount of iron oxide, which is responsible for a reddish colour of the clay bricks after firing (Monteiro et al., 2004, 2008; Das et al., 2005). The loss on ignition is (6.63%) within the usual range for clay material and is most likely associated with volatile components and organic matter (Acchar et al., 2006). In terms of oxides, the reject material consists basically of SiO_2, Al_2O_3 and CaO, with minor contents of MgO, K_2O, Fe_2O_3 and Na_2O. The loss on ignition (LoI) is slightly higher than the clay material and results from the decomposition of calcite and dolomite. Few peaks were identified for calcite and dolomite in the XRD analysis. The significant amount of alkaline earth oxide content particularly CaO and K_2O observed in the present work will act as a fluxing agent during the sintering process (Acchar et al., 2006).

Fig. 2 shows the X-ray diffraction patterns of the clay material and the granite waste. It can be seen that the clay material contains quartz and plagioclase (albite and anorthite) and minor amounts of orthoclase, kaolinite and hematite. The reject also contains quartz as predominant, together with plagioclase, calcite, dolomite and hematite. The crystalline phases identified by XRD are in agreement with the results obtained by XRF (Table 1).

The particle size distributions of the clay material and granite waste are depicted in Fig. 3, where it can be seen that, for granite waste, 84% are of silt size and 16% are of fine sand size, indicating that this material can be classified as a silt clay-like material. These results pointed out that the granite wastes have a granulometry similar to the processed conventional non-plastic raw materials such as quatz, and feldspar, without additional grinding, suitable for the use in raw material of clay brick.

For the clay material, it can be seen that 50% of the particle size distribution are of clay fraction where 33% are of silt size, indicating its suitability for use in fired ceramic body (Saboya et al., 2006). The fine and coarse sand proportions are 14 and 3%, respectively. This is a typical particle size distribution of local alluvial-sedimentary clay deposit.

An important parameter for the production of structural clay brick is plasticity. If the plasticity is inadequate, extrusion failures and heterogeneities develop in the moulded clay body which consequently lead to weak mechanical properties (Demir, 2005).

Table 1 Chemical composition of the raw materials as determined by XRF (wt.%)

	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	TiO_2	P_2O_5	MnO	LoI
Clay material	60.93	21.58	3.82	2.92	0.52	1.89	1.60	0.02	0.01	0.08	6.63
Granite waste	54.23	19.25	4.20	5.62	1.70	3.18	2.45	0.96	0.01	0.02	8.38

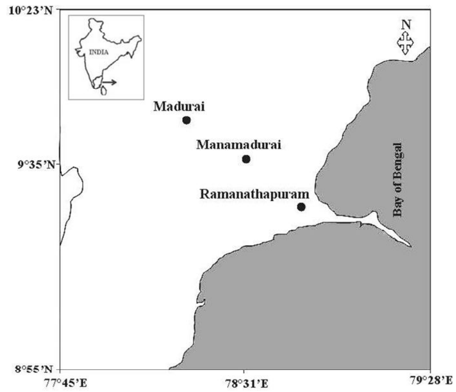

Fig. 1. Location Map of clay bricks and granite waste investigated [Ramanathapuram and Madurai]

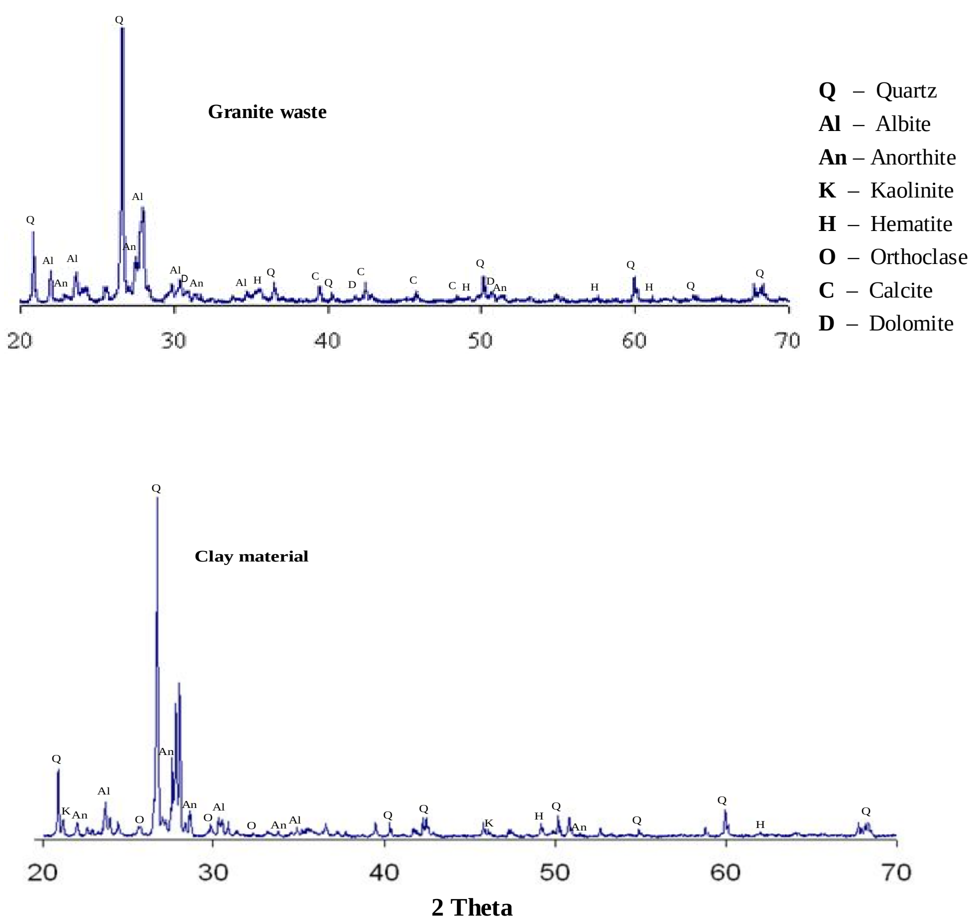

Fig. 2. X-ray diffraction patterns of the raw materials

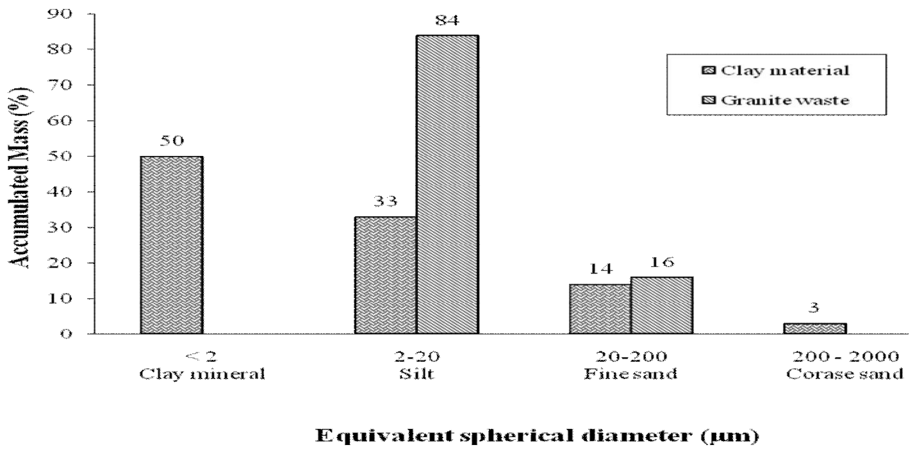

Fig. 3. Particle size distribution of the raw materials

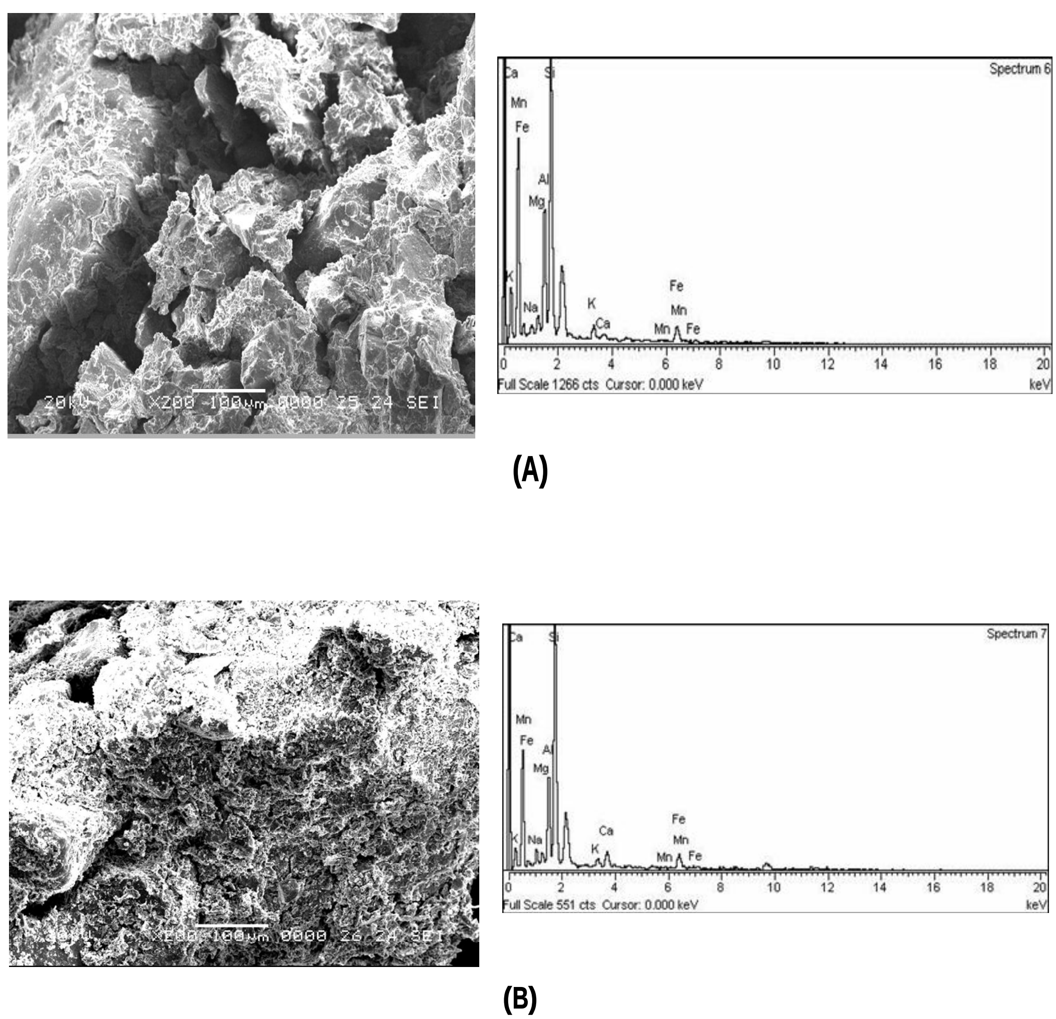

Fig. 4. SEM micrographs and EDS spectrum of the fracture surfaces of samples sintered at 900°C: (A) Clay material; and (B) Clay material + 30 wt. % granite waste

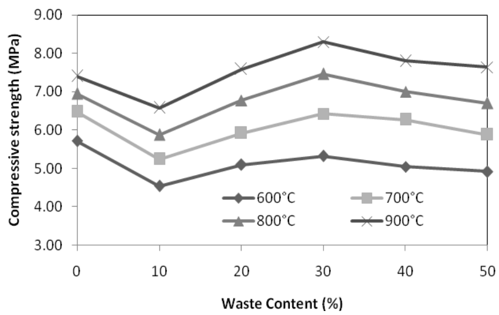

Fig. 5. Changes in compressive strength as a function of the waste content and the sintering temperature

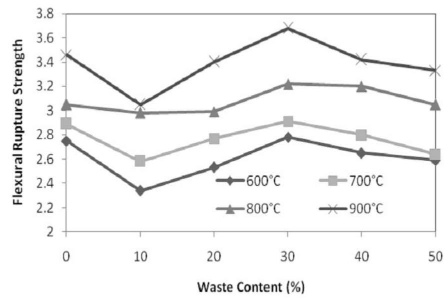

Fig. 6. Changes in flexural rupture strength as a function of the waste content and the sintering temperature

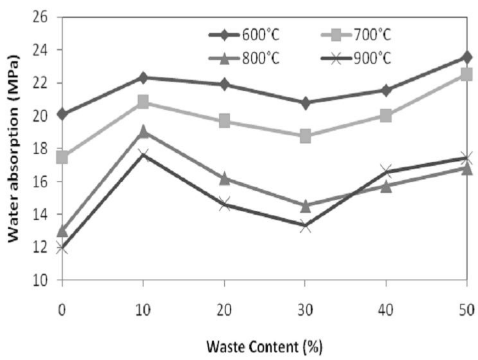

Fig. 7. Changes in water absorption as a function of the waste content and the sintering temperature

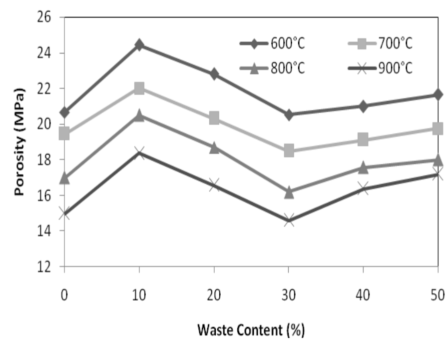

Fig. 8.Changes in porosity as a function of the waste content and the sintering temperature

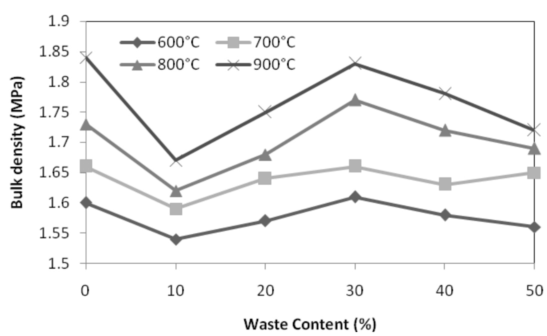

Fig. 9. Changes in bulk density as a function of the waste content and the sintering temperature

Monterio et al. (2008) have reported that for practical purposes the value of plasticity index must be about 10%, whereas lower than 10% are not appropriate for clay brick production due to the risk of developing problems during the extrusion process. These problems are related to a possible variation in the amount of extrusion water, causing in appropriate dimensional changes and even cracks in the pieces.

In the present work, it was observed that the plasticity index of clay material is 17.9% . When increasing the granite waste addition with upto 50 wt.% to the clay body decreases the plasticity, but not lower than 10%, indicating that the typical clay material collected from Ramanathapuram region maintain the required plasticity and suitable for brick products.

Fig. 4 illustrates the fracture surface of sintered briquette specimens, as observed by SEM. The sintered clay material still displays large quartz grains (strong peak in the XRD in Fig. 2) with insignificant bonding between particles and lot of interconnecting porosity at higher firing temperature investigated. On the contrary, the samples containing waste additions show clear signs of vitrification and a higher degree of closed porosity. The EDS analysis fits well with the results of chemical analysis, with the presence of Si, Al, Fe, Ca, K, Mg and Na.

Fig. 5 shows the compressive strength of the compositions as a function of waste and firing temperature. The compression test is the most important test that can be used to assure the engineering quality in the application of building materials (El-Mahllawy, 2007). In the present work compressive strength of the compositions were determined by dividing the maximum load with the applied load area of the brick samples. The results indicate that the strength is greatly depend on the amount of waste in the brick and the firing temperature. The fired clay bricks collected from the industry had a compressive strength of about 7.28MPa. As shown in Fig. 5, with up to 30 wt. % waste added to the bricks, the strength achieved at 900°C can be as high as the normal clay bricks produced in the industry. With up to 40 and 50 wt. % waste added to the bricks, the strength measured at the temperature of 900°C, met the required strength can be used for wall construction and other domestic purposes.

The quality of brick can be further measured by examining the flexural strength. In this work the flexural strength of the compositions were determined by the three-point bending test at a constant cross-head speed of 0.5mm/min. Flexural strength is one of the property which is strongly dependent on the porosity and microstructural defects of the specimen. The fired clay bricks collected from the industry had a flexural strength of about 3.34 MPa.

In the present work, the reasons for the increase in flexural strength (Fig. 6) of the compositions (with up to 30 wt.%) can be attributed the somewhat smaller particle size of granite waste and the resulting greater homogeneity of the material.

The water absorption and porosity are an effective index in evaluating the quality and densification of building brick. During sintering, open and closed pores are usually formed. The minimum density corresponds to the maximum volume of closed pores in the sample. Densification is a pore-filling process that occurs during the liquid-phase flow and by pore shrinkage (Lin, 2006). According to Singh et al. (2007), if cavities or porosity are more in the matrix, specimens will exhibit less density and absorb more water. The measurements of water absorption, porosity and bulk density of briquette specimens with different proportions of granite waste and fired at four different temperatures are shown in Figs. 7 – 9. The bricks made with clay normally have a bulk density of 1.8 – 2.0 g/cm^3 (Weng et al., 2003).

Figs. 7 and 8 shows that the water absorption and porosity of the briquette specimens decreases with increased granite waste addition (up to 30 wt. %) and firing temperature, thereby increasing its weathering resistance. The results indicate that increasing the waste content (up to 30 wt. %) and firing temperature results in an increase in the bulk density (Fig. 9). When the mixture contains a rather higher amount of granite waste (40 and 50 wt. %), the adhesiveness of the mixture decreases, therefore the internal pore size of the briquette specimen increases resulting the quantity of absorbed water increases. As shown in Figs. 5 – 9, when the mixture contain 30 wt.% waste and is fired at 900°C exhibits better values of water absorption, porosity, bulk density and mechanical strength than the industrially used. The brick materials produced with the replacement of clay material by 40 and 50 wt.% of waste and fired at 900°C met the required mechanical properties, can be used for wall construction purposes and suggested not for the building construction purposes.

4. Conclusion

The physical and mechanical properties of brick samples with granite sawing waste are investigated. The results obtained in this work show that high contents particularly 30 wt.% of a non-beneficiated and fine grained granite waste can be added to an industrial clay material, already in use in the production of bricks, with no major sacrifice of the properties of the final product, anticipating no costly modification in the industrial brick production line. On addition of 40 and 50 wt.% of waste into clay material, the adhesiveness of the mixture decreases, however, when sintered at 900°C, the material attain the required mechanical strength, can be used for wall construction, much welcome relief on waste disposal concern.

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