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Using Granite and Marble Sawing Power Wastes in the Production of Bricks: Spectroscopic and Mechanical Analysis

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Abstract: Granite and marble sawing powder wastes is widespread by-product of industrial process in India. Generally these wastes pollute and damage the environment due to sawing and polishing processes. Granite and marble wastes were collected from companies located in Salem district. Local clay and fired industrial brick materials were collected from Salem as well as nearby districts Namakkal and Erode, Tamilnadu, India. Fired industrial brick was characterized by using FTIR and Mossbauer spectroscopic techniques. Mixtures were prepared with 0, 10, 20, 30, 40 and 50 wt. % wastes incorporated into the raw clay material. For the briquette specimens fired in between 500 and 900ºC, the technological properties such as compressive and flexural strengths, water absorption, porosity and bulk density are determined and the same properties have also been obtained for industrial bricks. The results shows that granite and marble waste content upto 50 wt. % can be added into clay materials of Salem, Namakkal and Erode in the production of bricks with no major determinal effect on the properties of the sintered briquette specimens anticipating no costly modifications in the industrial production.

Key words: Clay, FTIR, granite waste and mechanical analysis

INTRODUCTION

Clay minerals are ubiquitous. Clays are not only an essential component of the soils to which we owe our survival, but also the most ancient and essential raw material of mankind used for artifacts-pottery, bricks and tiles. Clay deposits are exploited practically in every country in the world and they are used most extensively in the ceramic, paper, rubber and chemical industries.

Three elements, O, Si and Al, make up 82 wt. % of the crust, so it is hardly surprising that the world's most common minerals are silica and aluminosilicates. Now iron appears in fourth place. It is an important constituent in a great many aluminosilicates (Coey, 1980). According to Manoharan *et al.* (2008), the most common Fe minerals in clays are especially important in the determination of maximum firing temperature, firing atmosphere and colouring mechanism of any clay-based materials. Clay also contains small amounts of feldspars, carbonates, Ti, Mg, Mn, oxides, as well as soluble salts and organic matter.Clays are commonly understood to be fine-grained material that develops some ductile behaviour when mixed with sufficient amount of water and it hardens when dried or fired.

Now-a-days, generally, the making of brick involves different steps like collection and preparation of the clay, shaping, surface finishing, drying and hardening by heat treatment. Brick firing, if properly conducted, with respect to material and process, produces exceedingly durable brick materials.

Exposing the waste material to the environment directly can cause environmental problems. Therefore, many countries have still been working on how to re-use the waste materials. So that it causes fewer hazards to the environment. Developed countries strictly follow some rules to protect the environment whereas many developing countries have almost no rules to protect the environment against wastes. Waste materials can be used to produce new product or can be used as admixtures so that natural sources are used more efficiently and the environment is protected from waste deposits (Karasahin and Terzi, 2007).

Since the large demand has been placed on building material industry especially in the last decade owing to increasing population and has caused a chronic shortage of building material. The civil engineers have challenged to convert the industrial wastes to useful building and construction materials. Accumulation of unmanaged wastes especially in the developing countries has resulted in an increased 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 economical design of buildings. The increase in the popularity of using environmental friendly, low cost and

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durable construction materials in building industry have brought about the need to investigate how this can be achieved to benefit the environment as well as to maintain the material requirements affirmed in the standards (Algin and Turgut, 2008).

Marble and granite blocks are cut into smaller blocks in order to give the required smooth shape. During the cutting and polishing process about 25% marble and granite is resulted in dust, mainly composed of SiO_2, Al_2O_3, Fe_2O_3 and CaO, with minor contents of Mg, Ti, Mn and K oxides (Segadaes *et al*., 2005), which can cause serious damages to the environment, especially soil and underground water contamination, if not efficiently treated before disposal.

Marble and granite industries are some of the most promising business areas in 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 billions, taking into account tools, equipments, etc. (Menezes *et al*., 2005).

In India, about 6 million tonnes of wastes from marble and granite industries are being released through cutting, polishing, processing and grinding. The marble and granite dust is usually dumped on the riverbeds and this attracts major environmental concern. In dry season, the marble and granite powder / dust floats in the air, flies and deposits on crop and vegetation. All these significantly affect the environment and micro ecosystems (Pappu *et al*., 2007).

Now-a-days the cost of construction materials is increasing exponentially. In India, the cost of cement during 1995 was 1.25/kg and in 2008 the price increased by six times. In case of bricks the price was Rs.0.66 per brick in 1995 and the present rate is Rs.3.00 per brick. Similarly, over a period of 10 years from the year 1995 the price of sand has increased by five times. Also due to high transportation costs of these raw materials, demand, and environmental restrictions, it is essential to find functional substitutes for conventional building materials in the construction industry.

Therefore, the main objective of the present work is to study the possibility to incorporate granite and marble sawing powder wastes in brick products, with no major sacrifice of the mechanical properties of the final product.

MATERIALS AND METHODS

The laboratory study was conducted in Department of Physics, Annamalai University in 2008.The Mossbauer study was conducted at IUC-DAE Indore.

A typical clay material used in the brick industry, fired industrial brick and dry granite and marble sawing powder wastes, not beneficiated in any way, collected directly from the ornamental stone cutting industry from Salem District, Tamilnadu, India, were selected and characterized. The characterization included FTIR analysis (Avator-330 FTIR, Thermo Nicolet) and Mossbauer measurements (M/s WISSEL, Germany). To study the mechanical properties of wastes mixed bricks, the wastes were mixed with raw clay at 0, 10, 20, 30, 40 and 50 wt. % and briquettes samples of size (5.0x 2.5x2.5 cm) were prepared. Mixing was made in a planetary mill and minimum of 80 briquettes were manually shaped at workable consistency and the specimens were dried in an oven to 110ºC for 24 h. Briquettes specimens were sintered at temperatures between 500 and 900ºC for two hour in an oxidizing atmospheric condition with a heating rate of 10ºC/minute. After firing at selected temperatures, the specimens were subjected to several tests in order to verify their technological properties i.e., compressive and flexural strengths, water absorption, porosity and bulk density. The compressive strength was determined by dividing the maximum load with the applied load area of the brick samples. The flexural strength was measured with a universal testing machine in a three-point bending test of a constant cross-head speed of 0.5 mm/min. Water absorption, porosity and bulk density of the respective specimens were determined by using the Archimedes water displacement method.

RESULTS AND DISCUSSION

Ftir Techniques: The present investigation is aimed to determine the original firing temperature, firing condition, type of clay, minerals presence and colour mechanism of industrial brick collected from Salem, Namakkal and Erode District. It is also interested to study any structural changes takes place by mixing granite and marble wastes into raw clay material sintered at different temperatures. Fig. 1 to 6 shows the room temperature FTIR absorption spectra of clay material in the as received state and at different firing temperatures (100-900ºC). Fig. 7 to 9 shows the room temperature FTIR absorption spectrum of industrial brick (fired) in the as received state and refired in the laboratory at 900ºC. Fig. 10 to 12 shows the room temperature FTIR absorption spectra of 20 wt. % waste mixed brick sintered at 500, 600, 700, 800 and 900ºC.

Room temperature FTIR spectra of Salem, Namakkal and Erode clay materials in the as-received-state shows the presence of characteristic very weak hydroxyl bands at 3700 and 3620 cm^{-1}, which indicates that the above clay materials are belonging to disordered kaolinite type (Ramaswamy and Venkatachalapathy, 1992).Wagner *et al*. (1999) have reported that on firing the clays, kaolinite disappears at 400-450ºC. In the present investigation, it is noticed that on firing the above clay materials at 500ºC, the existence of the above two bands disappeared which indicates that the disappearance of kaolinite mineral. Room temperature FTIR absorption spectrum of industrial bricks collected from Salem, Namakkal and Erode in the as-received-state shows the

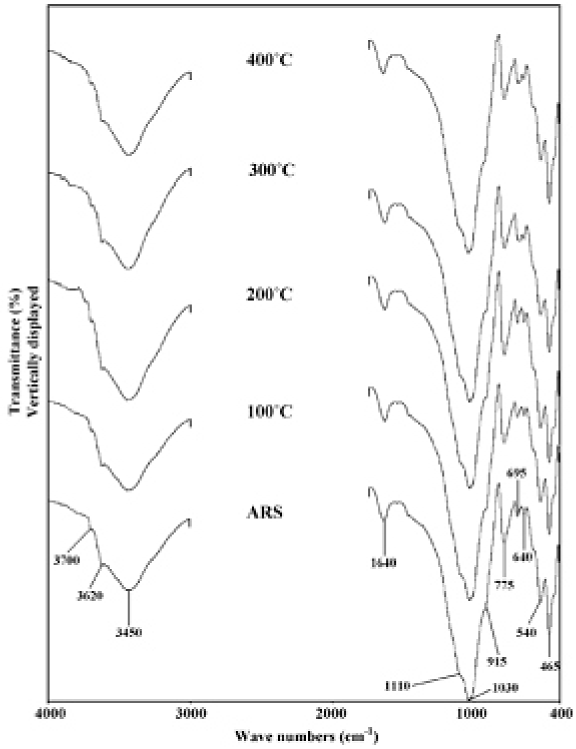

Fig. 1: Room temperature FTIR absorption spectra of Salem clay material in the as-received-state and sintered at 100, 200, 300 and 400ºC

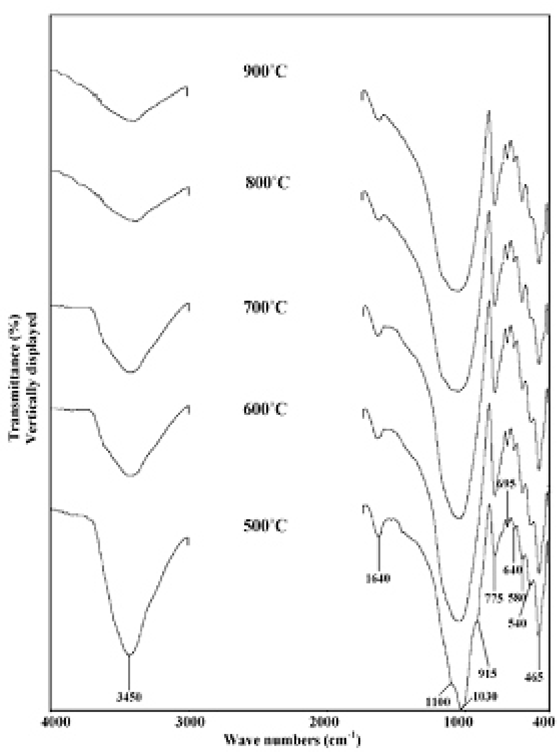

Fig. 2: Room temperature FTIR absorption spectra of Salem clay material in the as-received-state and sintered at 500, 600, 700, 800 and 900ºC

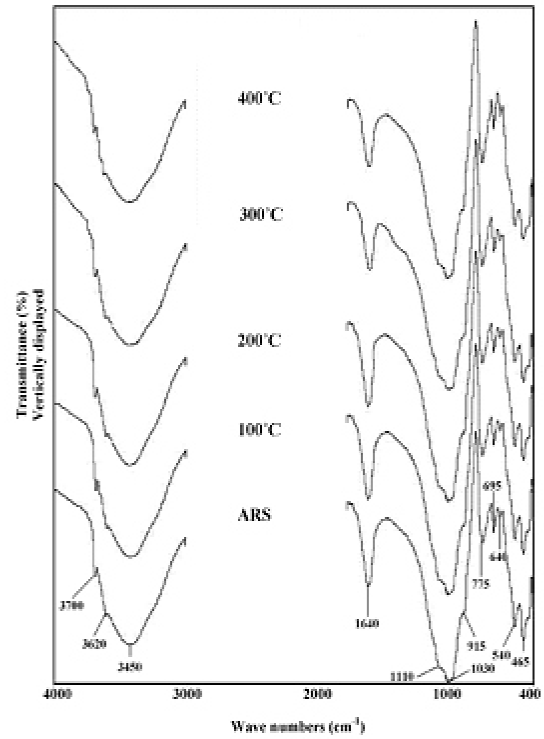

Fig. 3: Room temperature FTIR absorption spectra of Namakkal clay material in the as-received-state and sintered at 100, 200, 300 and 400ºC

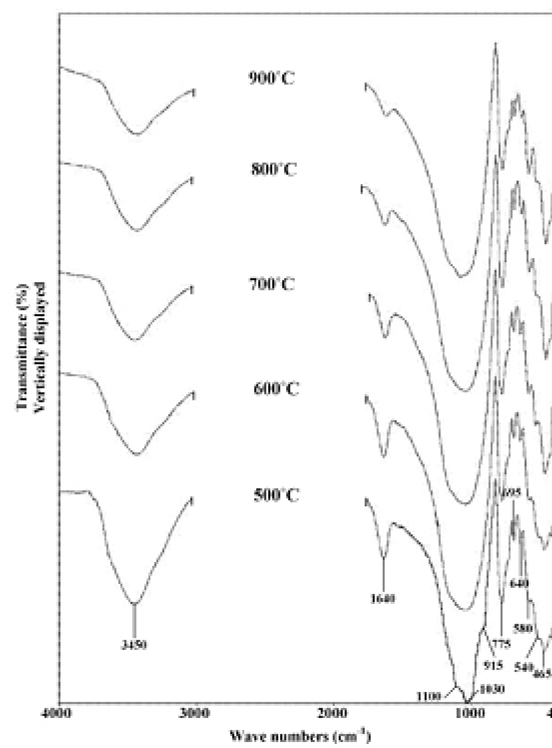

Fig. 4: Room temperature FTIR absorption spectra of Namakkal clay material in the as-received-state and sintered at 500, 600, 700, 800 and 900ºC

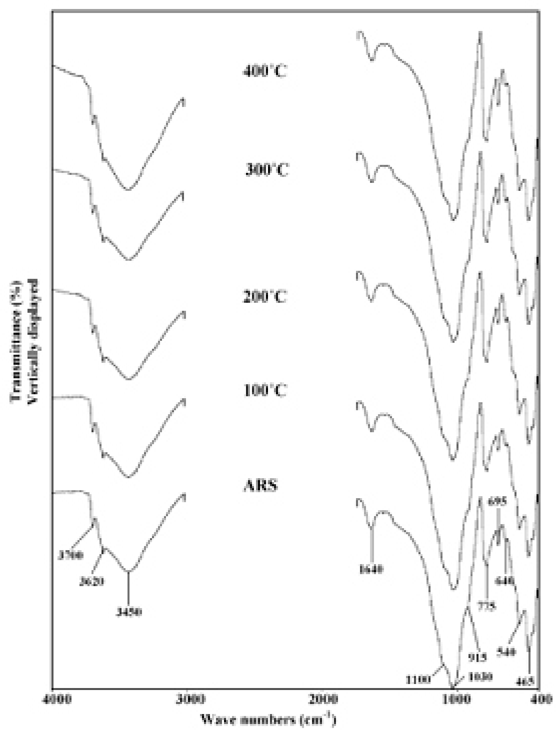

Fig. 5: Room temperature FTIR absorption spectra of Erode clay material in the as-received-state and sintered at 100, 200, 300 and 400ºC

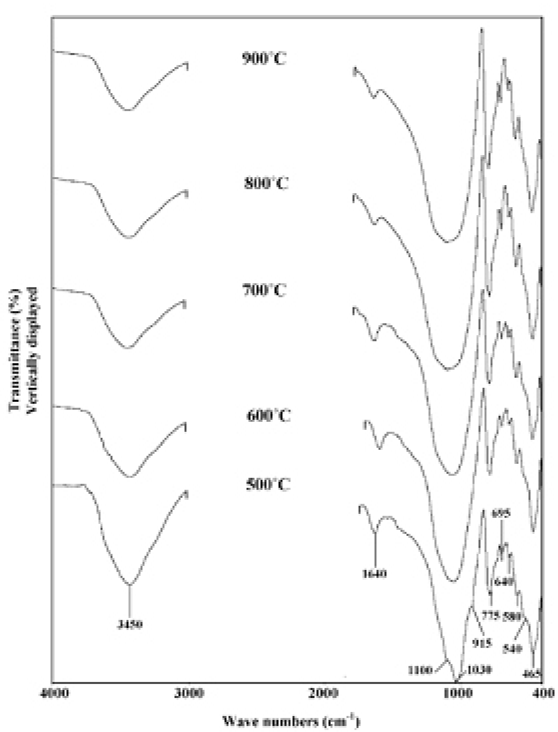

Fig. 6: Room temperature FTIR absorption spectra of Erode clay material in the as-received-state and sintered at 500, 600, 700, 800 and 900ºC

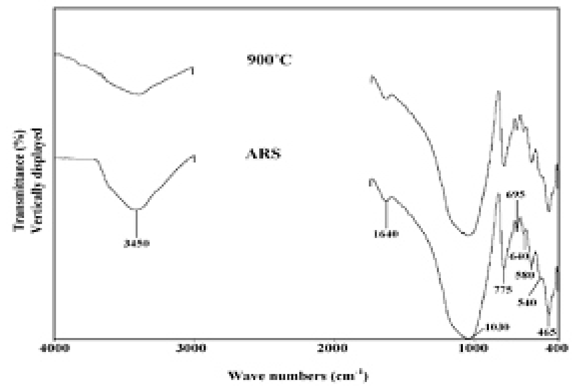

Fig. 7: Room temperature FTIR absorption spectra of industrial brick collected from Salem in the as-received-state and refired at 900ºC

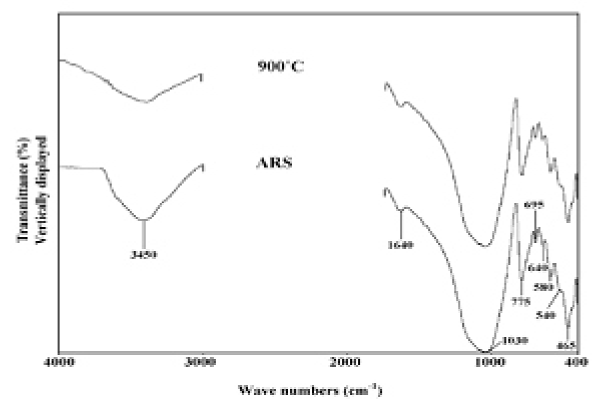

Fig. 8: Room temperature FTIR absorption spectra of industrial brick collected from Namakkal in the as-received-state and refired at 900ºC

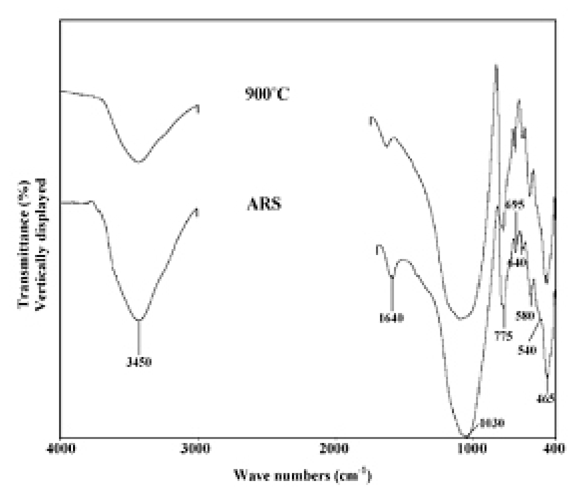

Fig. 9: Room temperature FTIR absorption spectra of industrial brick collected from Erode in the as-received-state and refired at 900ºC

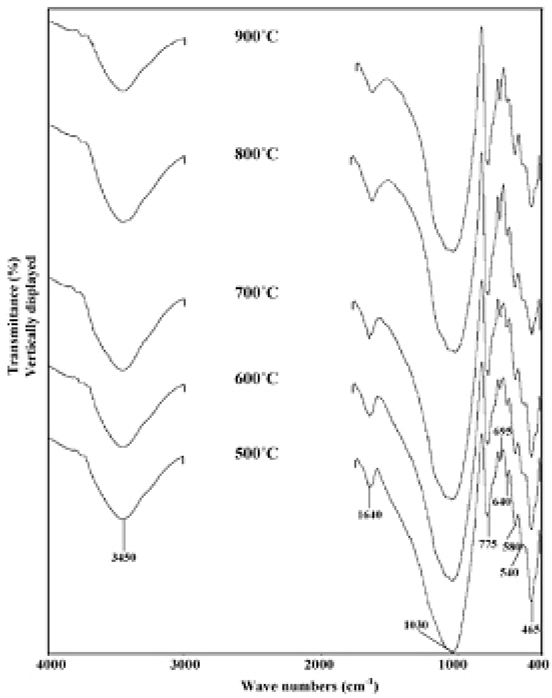

Fig. 10: Room temperature FTIR absorption spectra of Salem clay material +20wt. % waste incorporated briquette specimens sintered in between 500 and 900ºC

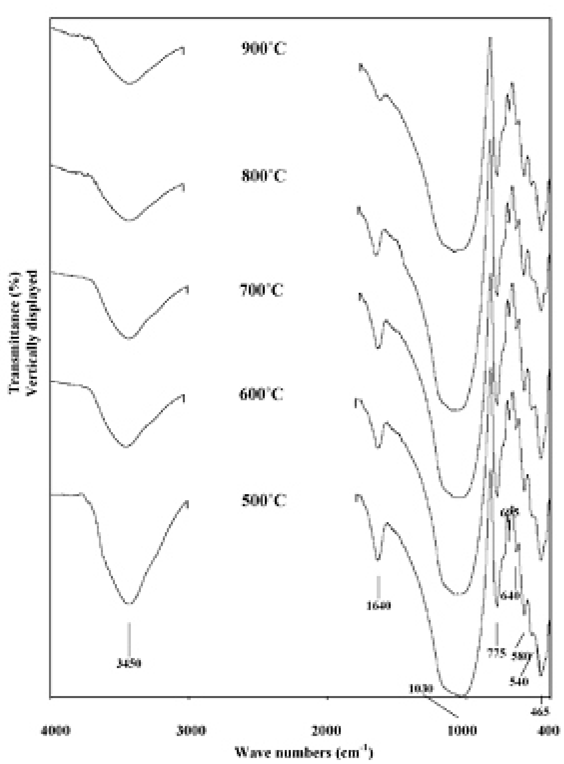

Fig. 11: Room temperature FTIR absorption spectra of Namakkal clay material +20wt. % waste incorporated briquette specimens sintered in between 500 and 900ºC

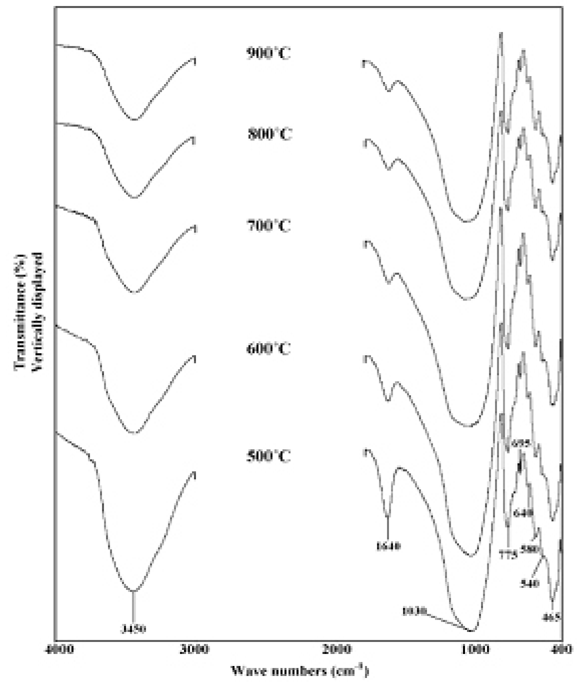

Fig 12: Room temperature FTIR absorption spectra of Erode clay material +20wt. % waste incorporated briquette specimens sintered in between 500 and 900ºC

absence of these bands (3700 and 3620 cm^{-1}). This confirms that they were fired above 500ºC during its manufacturing. In the FTIR spectra of the above clay materials, one can observe the presence of 1100 and 915 cm^{-1} bands as very weak shoulders centered at around 1030 cm^{-1}. These bands are attributed to O-H deformation and Si−O−Si modes. When firing the clay materials at around 600ºC, the expandable layer silicates collapse resulting the disappearance of the bands 1100 and 915 cm^{-1} and the appearance of the very strong and abroad symmetry band centered at around 1030 cm^{-1} for red clay and 1070 cm^{-1} for white clay (Wagner *et al.*, 1999; Manoharan *et al.*, 2002; Ghosh, 1978). In this work, the above clay materials when fired in between 500 and 600ºC, shows the disappearance of the bands 1100 and 915 cm^{-1} and the appearance of a strong and broad symmetry band centered at around 1030 cm^{-1}, which indicates that the above clay materials are belonging to red clay nature, out of which the industrial brick materials were produced.

It has also been noted that FTIR spectrum of industrial brick collected from three different places in the as-received-state shows the absence of the bands at 1100 and 915 cm^{-1} and the presence of a strong symmetry band at around 1030 cm^{-1}. So, it is confirmed that the above industrial bricks have been subjected to the firing temperature of above 600ºC during its manufacturing. In order to assess the maximum original firing temperature

(>600ºC) of any clay-based materials, the presence /absence or increase/decrease in intensities or shifting of the band position from 540 to 580 cm^{-1} is playing a vital role, which are attributed to iron oxides. In the present investigation, three clay materials in their as-received-state show the presence of a strong band at 540 cm^{-1}. This band may be attributed to goethite (FeOOH). During firing the clay materials upto 900ºC in steps of 100ºC, it can be observed that the intensity of the band 540 cm^{-1} is gradually decreased and particularly at 500ºC and above, it is noticed that a new band existed at 580 cm^{-1} which means that the band 540 cm^{-1} is gradually shifted to 580 cm^{-1} and its intensity is increased slowly at higher temperatures than that of 540 cm^{-1}. Manoharan *et al.* (2008) have reported that the existences of the band 580 cm^{-1} is attributed to magnetically ordered and well crystallized hematite present in the sample and this is possible when firing the clay-based materials above 750ºC under oxidising atmospheric conditions. This can also confirmed by subjecting the same sample to Mossbauer spectroscopic technique.

In the present investigation, the room temperature FTIR spectrum obtained for Salem industrial brick in the as-received-state shows the presence of the band 580 cm^{-1} as medium in intensity, while 540 cm^{-1} was observed as very weak shoulder. This indicates that magnetically ordered and well crystallized hematite (a-Fe_2O_3) is present in the sample. It is also found that FTIR absorption spectrum of Salem industrial brick obtained in the as-received-state is well compared with the FTIR absorption spectra obtained for Salem clay material fired at 800 and 900ºC. So, it is concluded that Salem industrial brick must have been fired above 800ºC under oxidising atmosphere during its manufacturing.

In the case of Namakkal industrial brick, the FTIR absorption spectrum obtained in the as-received-state is well compared with the FTIR absorption spectrum obtained for Namakkal clay sintered at 800ºC. So, it is concluded that Namakkal industrial brick must have been fired at around 800ºC under oxidising atmospheric condition during its manufacturing. The medium intensity of the band of 580 cm^{-1} in the Namakkal industrial brick in the as-received-state indicates that a-Fe_2O_3 is present in the material. When Namakkal industrial brick was refired at 900ºC, it was observed that the intensity of the band 580 cm^{-1} is increased further, which means that laboratory refiring temperature of the Namakkal industrial brick material exceeded its original firing temperature. But, in the case of Salem industrial brick no more changes were observed at the refiring temperature of 900ºC.

Room temperature FTIR absorption spectrum of Erode industrial brick in the as-received-state is well compared with FTIR absorption spectrum of Erode clay sintered at 600ºC in the laboratory. When refiring the Erode industrial brick at 900ºC, the intensity of 580 cm^{-1} is increased well than that of its intensity in the as-received-state. The reason is refiring temperature exceeded the original firing temperature of Erode industrial brick. So, it is estimated that Erode industrial brick must have been fired at around 600ºC under oxidising atmosphere during its manufacturing. The oxidising atmosphere is the main reason for reddish colour of the above three industrial brick materials (Wagner *et al.*, 1997).

The informations obtained in this study are in agreement with the informations obtained through Mossbauer spectroscopic studies. Therefore, the results are confirmed.

Apart from this, the presence of a sharp and medium band at 775 cm^{-1} coupled with weak band at 695 cm^{-1} are attributed to the presence of quartz mineral (Russell, 1987; Ojima, 2003; Greiner-Wronowa *et al.*, 1999). Generally, sufficient amount of quartz and feldspar are often present in clays and which make the clay self-tempered during firing process. The band occurring at 465 cm^{-1} is assigned to mixed Si-O-Si bending mode. This band is always free from temperature effect (Venkatachalapathy *et al.*, 2004a).

The characteristic bands observed at 3450 cm^{-1} and 1640 cm^{-1} are attributed to OH stretching and H-O-H bending vibrations of adsorbed water molecules. During sintering the clay-based materials, these bands will be diminished and disappeared (Wolff, 1963; Venkatachalapathy *et al.*, 2003). In the present study, the existence of these bands upto 900ºC might have been due to the absorption of moisture in the atmosphere by spectroscopic grade KBr while recording FTIR spectra.

It is interesting to note that the room temperature FTIR absorption spectra of granite and marble waste incorporated briquette specimens of Salem, Namakkal and Erode obtained by firing at 500, 600, 700, 800 and 900ºC are almost identical as the FTIR absorption spectra obtained for Salem, Namakkal and Erode clay materials fired at the same temperatures. This indicates that by mixing granite and marble wastes with raw clay materials of Salem, Namakkal and Erode at 10, 20, 30, 40 and 50 wt. % and sintered in between 500 and 900ºC, no major structural changes take place. This confirms that granite and marble wastes can be added to the raw clay materials of the above places for producing brick materials.

Mossbauer Techniques: Fig. 13 to 18 show the room temperature Mossbauer spectra of industrially produced bricks in the as received state and 20 wt. % waste incorporated briquette specimens sintered at 900ºC.

In the present investigation, the room temperature Mossbauer spectrum of Salem industrial brick in the as received state demonstrates the presence of a magnetic six line pattern i.e. the major phase is a-Fe_2O_3 (magnetically ordered and well crystallized hematite) with Mossbauer parameters as follows: Isomer shift (IS) = 0.382 mm/s, electric quadrupole splitting (DE_Q) = 0.225 mm/s with

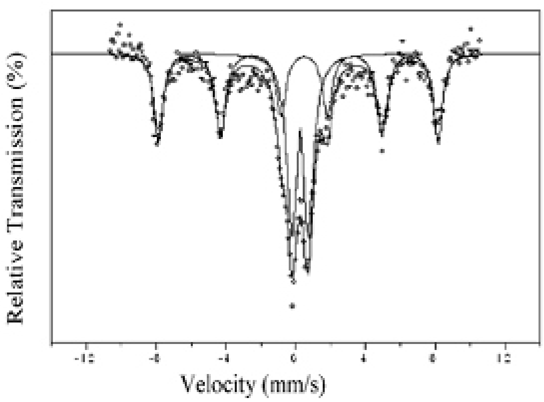

Fig. 13: Room temperature Mossbauer spectrum of Salem industrial brick in the as-received-state

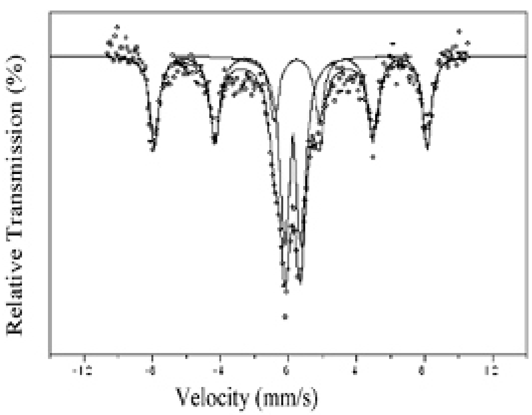

Fig. 14: Room temperature Mossbauer spectrum of Salem clay material +20wt. % waste incorporated briquette specimen sintered at 900ºC

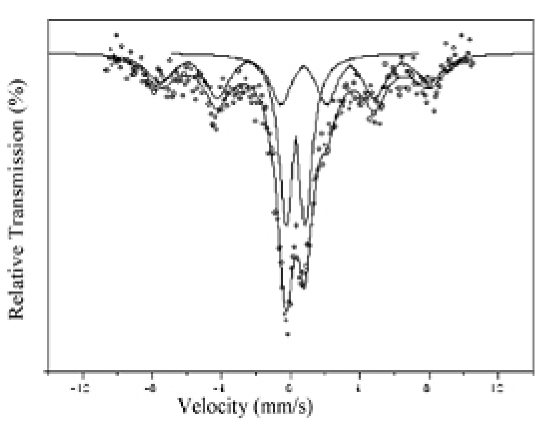

Fig. 15: Room temperature Mossbauer spectrum of Namakkal induterial brick in the as-received-state

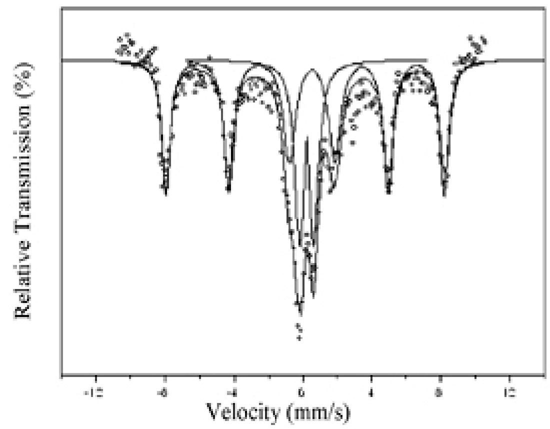

Fig. 16: Room temperature Mossbauer spectrum of Namakkal clay material +20wt. % waste incorporated briquette specimen sintered at 900ºC

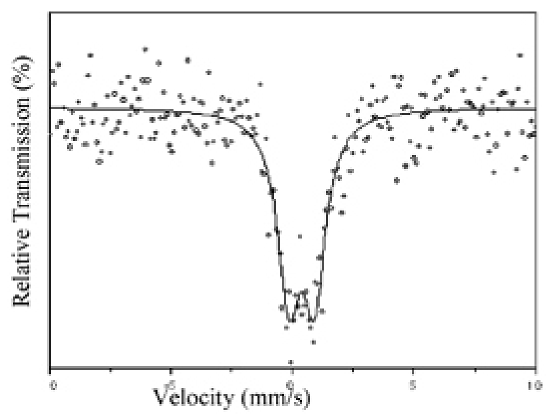

Fig. 17: Room temperature Mossbauer spectrum of Erode induterial brick in the as-received-state

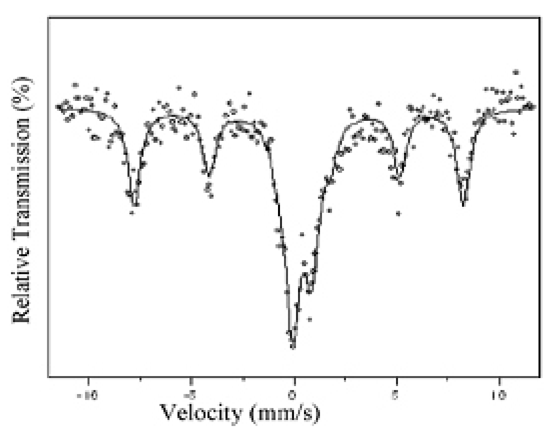

Fig. 18: Room temperature Mossbauer spectrum of Erode clay material +20 wt. % waste incorporated briquette specimen sintered at 900ºC

effective magnetic hyperfine field (H_{hf}) value of about 51 Tesla and area of about 50.5%. The second component observed is corresponding to Fe^{3+} species with parameters: IS = 0.412 mm/s, DE_Q= 0.911mm/s and area of about 40.78 %. The third component observed is corresponding to Fe^{2+} species with parameters: IS = 0.767 mm/s, DE_Q = 2.432 mm/s and area of about 8.70%. The presence of strong intensities of magnetic six-line pattern with effective field value of 51 Tesla and the revert quadrupole splitting value 0.911 mm/s strongly indicate that the industrial brick collected from Salem district must have been fired in between 800 and 900ºC during its manufacturing. The presence of a−Fe_2O_3 and the adoption of oxidising atmosphere are the reasons for reddish colour of the Salem industrial brick.

Room temperature Mossbauer spectrum of Namakkal industrial brick in the as received state shows the presence of a characteristic initial formation magnetic six-line pattern which is attributed to Fe_2O_3 (hematite) having isomer shift of 0.43mm/s and quadrupole splitting of 0.13mm/s with internal magnetic hyperfine field value of 502 kOe. Tominaga *et al.* (1978) characterized Ancient Japanese roofing tiles by using ^{57}Fe Mossbauer spectroscopy and reported that reddish clay-based materials will have the effective field value of 502 to 507KG, slightly smaller than the value (517KG) for the commercially available hematite (a-Fe_2O_3). The spectrum also shows the presence of second component as Fe^{3+} species having isomer shift of 0.30mm/s and quadrupole splitting of 1.07 mm/s. The fractional area of the sextet and doublet were calculated as 55 and 45%.

The initial formation of Fe_2O_3 (hematite), revert quadrupole splitting value 1.07 mm/s (Fe^{3+} species) and internal magnetic hyperfine field value 502 kOe indicate that Namakkal brick must have been fired in between 750 and 800ºC under oxidising atmospheric condition which reflects reddish colour of the brick.

Room temperature Mossbauer spectrum of industrial brick collected from Erode shows only the presence of paramagnetic doublet in the central part of the spectrum which is attributed to Fe^{3+} species having an isomer shift of 0.374 mm/s and quadrupole splitting of 1.205 mm/s. The presence of Fe^{3+} species in industrial brick indicating that brick was fired in an oxidising atmosphere which reflect red colour of the brick (Ramaswamy *et al.*, 1989). Wagner *et al.* (1999) reported that during heating in air, there is a strong increase of quadrupole splitting of Fe^{3+} species in the fresh clay from 0.66 mm/s to 1.05 mm/s on firing at 400ºC. Authors have also been pointed out that the splitting reaches a maximum of 1.35 mm/s on firing at 700ºC. From this information and the observed value of quadrupole splitting 1.205 mm/s, it is roughly estimated that the Erode industrial brick might have been fired at around 600ºC during its manufacturing.

Room temperature Mossbauer spectrum of 20 wt.% wastes incorporated briquette specimen of Erode sintered at 900ºC shows the presence of a characteristic six-line magnetic pattern (IS= 0.366 mm/s and DE_Q = −0.275 mm/s) associated exclusively with a paramagnetic Fe^{3+} doublet having an isomer shift of 0.386 mm/s and quadrupole splitting of 0.927 mm/s. The observed six-line magnetic pattern is assigned to a−Fe_2O_3 (magnetically ordered and well crystallized hematite) present in the sample (Wagner *et al.*, 1994). In addition, it is confirmed by the obtained effective internal magnetic field of 50 Tesla (Tominaga *et al.*, 1978).

Room temperature Mossbauer spectrum of Namakkal clay material plus 20 wt.% waste mixed briquette specimen sintered at 900ºC exhibits a characteristic of presence of large quantity of magnetic six-line pattern along with paramagnetic Fe^{3+} species. The observed isomer shift (IS) 0.340 mm/s and quadrupole splitting (DE_Q) 0.790 mm/s are attributed to paramagnetic Fe^{3+} species present in the material. The fractional area of Fe^{3+} species was calculated as 34%. It can also been notice that the observed parameters IS = 0.350 mm/s and DE_Q = −0.240 mm/s along with the effective magnetic hyperfine field of 508 kOe are attributed to well crystallized and magnetically-ordered hematite (a−Fe_2O_3) present in the material. The fractional area of a−Fe_2O_3 was calculated as 66%.

Room temperature Mossbauer spectrum of 20 wt. % wastes incorporated briquette specimen of Salem exhibits a doublet (IS = 0.310 mm/s and DE_Q= 0.900 mm/s) due to the presence of paramagnetic Fe^{3+} ion along with a magnetic sextet (IS=0.35 mm/s and DE_Q = -0.260 mm/s and Hhf = 506 kOe) is attributed to well-crystallized and magnetically ordered hematite (a−Fe_2O_3) present in the specimen. The fractional areas of the above iron compounds were calculated as 47.5 and 52.5%.

The Mossbauer parameters such as isomer shift, electric quadrupole splitting and magnetic hyperfine field values observed in this work are in agreement with the parameter values reported in literature (Venkatachalapathy *et al.*, 2003; 2004; Wagner *et al.*, 1998).

It is interesting to note that Salem industrial brick contains a−Fe_2O_3 along with paramagnetic Fe^{3+} ion. Similarly by incorporating 20 wt. % wastes with raw clay material of Salem and sintered at 900ºC in laboratory, one can observe the presence of a−Fe_2O_3 and Fe^{3+} species. The only difference observed in its fractional area might have been due to the difference in original firing temperature of industrial brick (in between 800 and 900ºC) and laboratory firing temperature (900ºC) of briquette specimen.

In the case of Namakkal industrial brick, one can observe the initial formations magnetic sextet (a−Fe_2O_3) and a paramagnetic Fe^{3+} species. Whereas 20 wt. % waste mixed briquette specimen sintered at 900ºC shows the intense peaks of magnetic sextet coupled with Fe^{3+} species. The intense peaks are due to the influence of higher temperature reached in laboratory. The room temperature Mossbauer spectrum of Erode industrial brick shows only the presence of paramagnetic Fe^{3+} ion and no Fe^{2+} and magnetic six-line pattern. This might have been due to the firing temperature of the industrial brick below 700ºC. Wagner *et al.* (1992) clearly reported that when firing the clay-based materials above 700ºC, the magnetic sextet will be formed. At 900ºC, the waste mixed briquette specimen of Erode exhibits the presence of a$-Fe_2O_3$ and paramagnetic Fe^{3+} ion. The absence of Fe^{2+} species on all waste mixed briquette specimens indicates that the laboratory firing condition is oxidising atmosphere in nature.

From the above information it is concluded that by mixing granite and marble sawing powder wastes into raw clay materials of Salem, Namakkal and Erode, no major changes can be observed in the presence of iron components. The results obtained in this analysis are in agreement with the results obtained in FTIR analysis. Therefore, the results obtained on both techniques are confirmed.

Mechanical Analysis:

Compressive Strength: The compressive strength is the most important test that can be used to assure the engineering quality in the application of building materials (Olgun *et al.*, 2005). In the present work, the compressive strength of compositions were determined by dividing the maximum load with the applied load area of the brick specimens. In order to compare the mechanical properties of industrially produced brick materials and granite and marble sawing powder waste mixed bricks produced in the laboratory at different sintering temperatures, it is necessary to measure the mechanical properties such as compressive strength, flexural strength, water absorption, porosity and bulk density of industrial brick (already fired in the brick industry) in the as-received-state. The compressive strength values of Salem, Namakkal and Erode industrial bricks were measured as 0.7501, 0.8461 and 0.3331 Mpa, respectively. The results of compressive strength testing of waste mixed bricks fired at different temperatures are shown in Fig.19 to 21. It could be seen in these figures that the firing temperature has a significant influence on the compressive strength of the compositions.

From figures, it was observed that the compressive strength values are directly proportional to the waste weight percentage as well as sintering temperatures except that the values obtained for 10 wt. %, where it could be noticed that the compressive strength values were decreased. Compressive strength value obtained for Salem brick at 0 wt. % at 800ºC is closely agreed with the values obtained for industrially produced brick material in the as-received-state, whereas in the case of Namakkal brick the compressive strength value obtained for industrial brick is closely agreed with the value of waste mixed brick (0 wt. %) obtained at 800ºC. In the case of Erode brick, the compressive strength value obtained at 600ºC for waste mixed brick (0 wt. %) is in close agreement with the value of industrial brick obtained in the as-received-state. Similar observations were made on other properties such as flexural strength, water absorption, porosity, and bulk density of Salem,

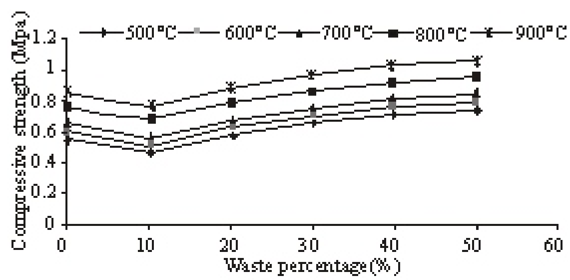

Fig. 19: Variation of compressive strength of waste incorporated briquette specimens of Salem as a function of sintering temperatures

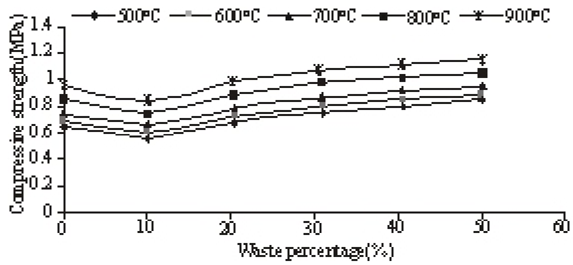

Fig. 20: Variation of compressive strength of waste incorporated briquette specimens of Namakkal as a function of sintering temperatures

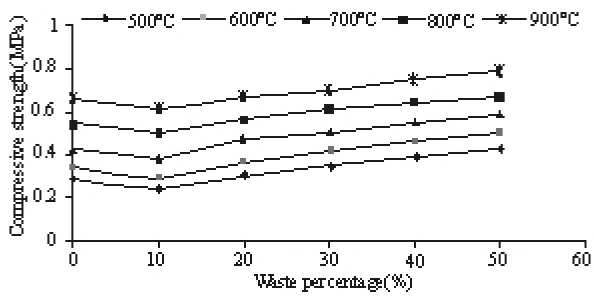

Fig. 21: Variation of compressive strength of waste incorporated briquette specimens of Erode as a function of sintering temperatures

Namakkal and Erode bricks in the as-received-state and waste mixed bricks fired at 800 and 600ºC respectively. These information indicate that the Salem and Namakkal bricks must have been fired at around 800ºC in the brick industry during its manufacturing, while Erode brick must have been fired at around 600ºC. These results are in agreement with the results obtained through FTIR and Mossbauer spectroscopic techniques. Further, when a 20, 30, 40 and 50 wt. % waste mixed briquette specimens sintered at the temperatures in between 500 and 900ºC shows that the compressive strength values increases gradually with waste wt. % and sintering temperatures. This indicates that the compressive strength of fired waste mixed briquette specimens depend on the porosity content, being decreased in the bricks containing organic wastes (Demir, 2008). However, the compressive strength values obtained at 40 and 50 wt. % at the temperatures in between 500 and 900ºC, are higher than that of the strength of the industrial building brick values. This indicates that granite and marble sawing powder waste addition clearly increased the strength of the clay body. An increase in the compressive strength is found to be very useful and suitability of addition of granite and marble sawing powder wastes in industrial brick formulations.

Flexural Strength: The quality of brick can be further measured by examining the flexural strength of brick. Flexural strength depends on the material compositions and dimension and morphology of the flows. The mechanical behaviour of the specimens can be explained taking into account the different microstructures developed during firing (Luz and Ribeiro, 2007).

Fig. 22 to 24 shows the results of the flexural strength values of fired compositions as a function of granite and marble wastes as well as temperature obtained from the test. The flexural strength is determined by the three point bending test of a constant cross-head speed of 0.5 mm/min. From Fig. 22-24 it could be noticed that all reformulated briquette specimens increase their flexural strength with temperature in approximately the same way except that the values obtained for compositions at 10 wt. % and at different temperatures. It is important to note that at higher temperatures especially at 800 and 900ºC, the increase of waste content has caused an flexural strength, that can be attributed to an improvement of the densification process, which is confirmed by the increase in the bulk density values (Acchar *et al*., 2006). The reason for the gradual increase in flexural strength of the above briquette specimens can also be attributed to the somewhat smaller particle size of granite and marble sawing powder and the resulting greater homogeneity of the material (Russ *et al*., 2005).

In the present investigation it is important to note that the average compressive and flexural strength values obtained for waste mixed briquette specimens are inversely proportionate with waste weight percentage especially from 20 wt.% to 50 wt.%. It has been clearly reported that BS6073 requires 0.65MPa as a minimum flexural strength for the building materials to be used in structural applications (Turgut and Yesilata, 2008). All the waste mixed briquette specimens and industrially produced bricks collected from Salem and Erode tested for flexural strength satisfy this requirement and shows the suitability of incorporation of granite and marble sawing powder wastes in brick production. Flexural strength values obtained for 50 wt. % waste mixed Namakkal briquette specimens satisfy this requirement at 900ºC only. However, gradual increases in their flexural strength at different wt. % and at different temperatures were observed.

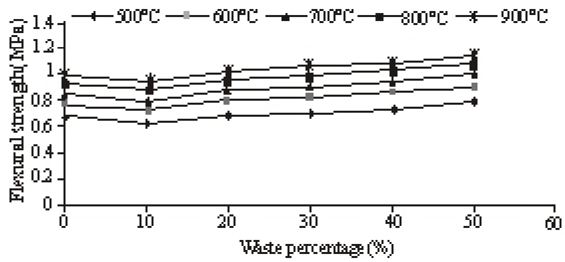

Fig. 22: Variation of flexural strength of waste incorporated briquette specimens of Salem as a function of sintering temperatures

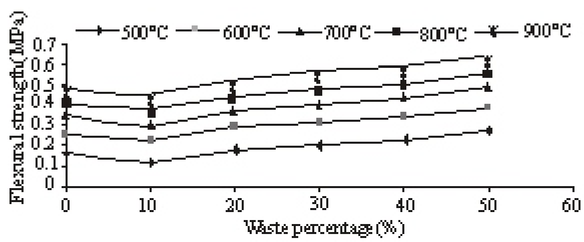

Fig. 23: Variation of flexural strength of waste incorporated briquette specimens of Namakkal as a function of sintering temperatures

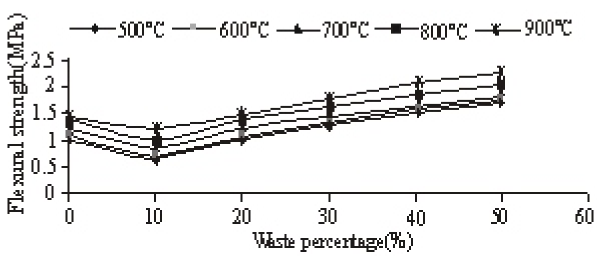

Fig. 24: Variation of flexural strength of waste incorporated briquette specimens of Erode as a function of sintering temperatures

It is very important to note that the average compressive and flexural strength values of briquette specimens obtained at 20 wt.% is higher than that of other wt.%. That is why FTIR and Mossbauer studies were carried out especially at 20 wt. % sintered at 900ºC in order to study its characteristics.

In the case of Erode briquette specimens, the compressive and flexural strength values obtained at 20 wt.% at 600ºC is higher than that of one obtained for the as-received-state industrial brick, whereas Salem briquette specimens exhibits higher values approximately at around 700ºC at 30 wt.%. In the case of Namakkal briquette specimens the compressive strength obtained at 30 wt. % at 700ºC is higher than that of the value obtained for industrial one, while flexural strength value obtained at 40 wt. % at 700ºC is the higher value than that of industrial one. All these information indicates that at low temperatures the effect of granite and marble sawing powder waste in brick products can be improved. Moreover, if the briquette specimens (clay material + 50 wt. % waste) are allowed to fire around 900ºC, better strength or quality brick materials can be produced.

Water absorption and porosity: The water absorption rate, which refers to the weight of moisture in the pores compared to the sintered specimens weight, is an effective index for evaluating the brick quality. The less water that infiltrates the brick, makes to expect greater durability and resistance to the natural environment are expected (Lin, 2006). So, the water absorption of bricks is measured to investigate the extent of densification in the fired body and also used as an expression to open pores (El-Mahllawy, 2008). Olgun *et al.* (2005) have reported that water absorption rate has been used as an indication for porosity of the brick. Authors have also been pointed out that the water absorption of the brick decreased with the increase of waste content. If cavities or porosity are more in the matrix, specimens will exhibit less density and absorb more water (Singh, 2007).

Sanchez *et al.* (2006) have reported that the technical characteristics of bricks are intimately related to the porosity of the product, while the high fracture strength is as a result of low total porosity. In the present work, the water absorption and porosity of waste mixed briquette specimens at different waste wt. % as a function of sintering temperatures are presented in Fig. 25 to 30. As shown in Fig. 25-30 one could observe that water absorption and porosity values of briquette specimens are inversely proportional to the sintering temperatures. That is, when the waste content and sintering temperature were increased the water absorption and porosity of the briquette specimens decreases. This indicates that the alkaline materials and feldspars present in the waste materials locked well or filled in the pores of the briquette body slowly by increasing the sintering temperatures and waste content which reflect the reduction in water absorption and porosity.

Bulk density: During sintering, open and closed pores are usually formed. The minimum density corresponds to the maximum volume of closed pores in the specimens. Densification is a pore-filing process that occurs during the liquid-phase flow and by pore shrinkage (Lin, 2006). The measurements of the bulk density of briquette specimens (Salem, Namakkal and Erode) with different proportions of granite and marble sawing powder wastes and fired at five different temperatures are shown in Fig. 31-33. The bulk density of the fired specimens is determined by dividing the volume over mass of fired briquettes (El-Mahllawy, 2008).

In the present investigation, the results indicate that increasing the temperature and waste content results in an increase in the bulk density. This indicates the extended densification of briquette specimens by mixing the wastes

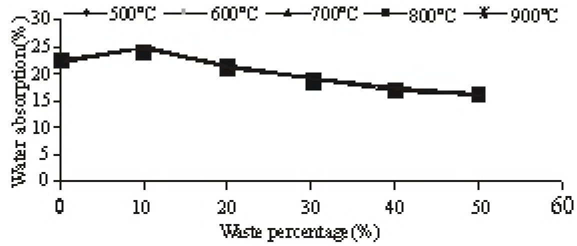

Fig. 25: Variation of water absorption of waste incoporated briquette specimens of Salem as a function of sintering temperatures

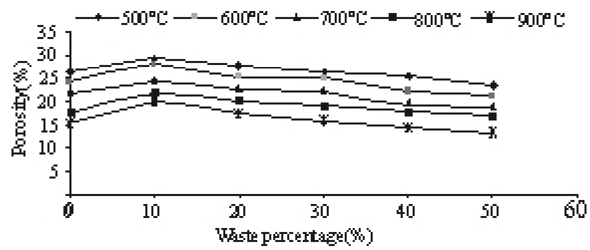

Fig. 26: Variation of porosity of waste incoporated briquette specimens of Salme as a function of sintering temperatures

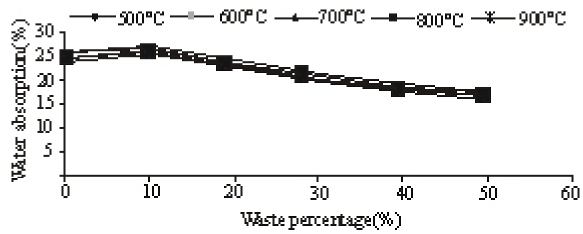

Fig. 27: Variation of water absorption of waste incoporated briquette specimens of Mamakkal as a function of sintering temperatures

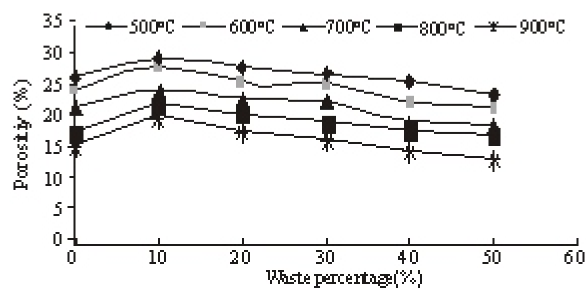

Fig. 28: Variation of water absorption of waste incorporated briquette specimens of Salme as a function of sintering temperatures

into the raw clay material. The heating temperature can also affect the bulk density of the briquette specimens. It is important to note that when comparing the bulk density values obtained at 10 wt. % and sintering at five different temperatures with 0 wt. % of Erode briquette specimens,

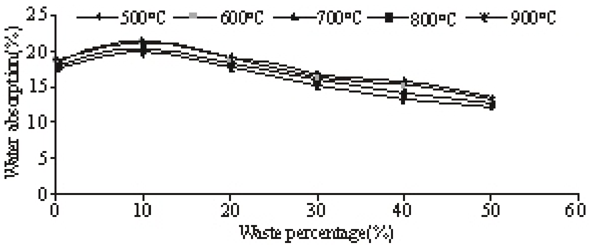

Fig. 29: Variation of porosityof waste incorporated briquette specimens of Salme as a function of sintering temperatures

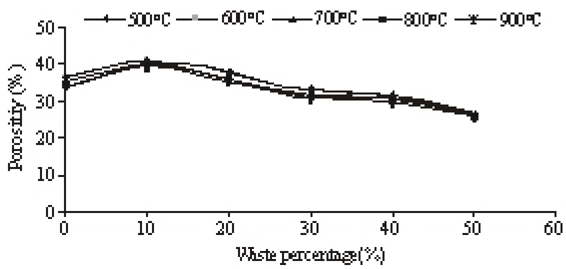

Fig. 30: Variation of water absorption of waste incorporated briquette specimens of Namakkal as a function of sintering temperatures

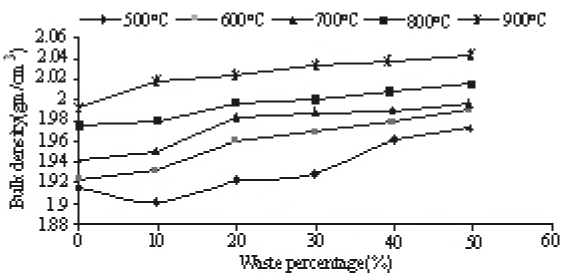

Fig. 31: Variation of bilk density of waste incorporated briqutte specimens of Salem as a function of sintering temperatures

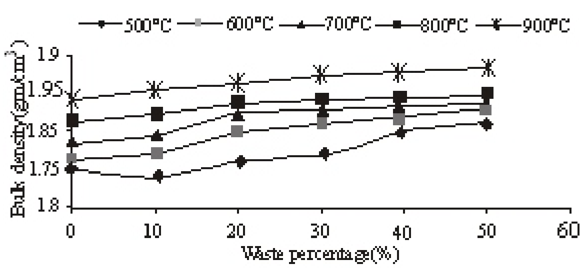

Fig. 32: Variation of bilk density of waste incorporated briqutte specimens of Namakkal as a function of sintering temperatures

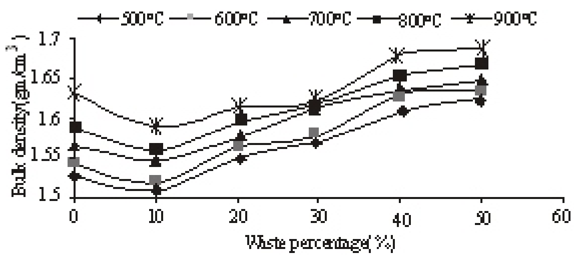

Fig. 33: Variation of bilk density of waste incorporated briqutte specimens of Erode as a function of sintering temperatures

the values are decreased. But this trend was not found in the other two briquette specimens (Salem and Namakkal). Lin (2006) has reported that clay bricks normally have a bulk density of 1.8-2.0g/cm^3. As for as Salem and Erode briquette specimens are concerned, the bulk density obtained at 20 wt.% at 700ºC is almost the same as one obtained for industrially produced bricks in the as-received-state and satisfy the requirement reported by (Lin, 2006). At the same time, when the amount of granite and marble wastes at 10, 20, 30, 40 and 50 wt. % and the briquette specimens were fired at 900ºC, the bulk density met desired criteria. The results indicate that the bulk density of the bricks increased as the waste content and sintering temperature increased.

CONCLUSION

Now-a-days the incorporation of industrial wastes or sub-products in bricks is becoming a common practice. Granite and marble process industry generates a large amount of wastes, which pollute and damage the environment. Therefore this work aims to characterize and evaluate the possibilities of using the granite and marble sawing powder wastes, generated by the process industries, as alternative raw materials in the production of bricks.

From FTIR spectroscopic technique, the original firing temperature of Salem, Namakkal and Erode industrial brick was determined as follows 800, 800 and 600ºC.The reddish colour of the above three industrial bricks indicates that oxidising atmosphere under which these bricks have been fired during its manufacturing. The presence of a broad and strong symmetry band centered at around 1030 cm^{-1} of the above three bricks in the as-received-state indicates that red type clay origin, out of which these bricks have been produced. Further, the presence high amount of quartz and hematite (Fe_2O_3 or a$-Fe_2O_3$) were also identified. The sufficient amount of quartz makes the clay self-tempered during firing process.

Mossbauer analysis of Salem and Namakkal industrial bricks shows the presence of Fe^{3+} species associated exclusively with magnetic six-line pattern. The magnetic six-line pattern is attributed to magnetically ordered and well-crystallized hematite (a$-Fe_2O_3$) present in the sample, while Erode industrial brick contains only Fe^{3+} species. The presence of Fe^{3+} species on the above three industrial bricks indicates that they were fired under oxidising atmosphere during its manufacturing. From the observed quadrupole splitting values for Salem, Namakkal and Erode industrial bricks it can be assessed that the range of firing temperature as 800 to 900ºC, 750 to 800ºC and at around 600ºC. These results are in agreement with the results obtained through FTIR spectroscopic technique.

It is clear that when the waste weight percentage and sintering temperatures are increased, the compressive and flexural strengths of briquette specimens increase whereas at 10 wt. % the same found to decrease. Further, in the case of Salem and Namakkal, the compressive and flexural strength values obtained at 30 wt.% sintered at 700ºC are in close agreement with the strength values of industrially produced bricks, while for Erode, the strengths obtained at 20 wt.% sintered at 600ºC are in perfect agreement with the strength values of industrially produced bricks. From this it can be concluded that incorporation of granite and marble wastes into raw clay material fired at low temperature, results energy saving as well as the relief of disposal of industrial wastes. At higher waste weight percentage and temperatures, the obtained strength indicates that the quality of the waste incorporated bricks may be further improved. Moreover, it is important to note that the average compressive and flexural strengths obtained at 20 wt. % is higher than that of other waste weight percentage.

The water absorption and porosity of the waste incorporated briquette specimens are inversely proportional to waste content as well as sintering temperatures, while bulk density is directly proportional to waste content as well as sintering temperatures. This indicates that the addition of wastes into raw clay material and fired at higher temperatures, the waste were filled in the pores of the clay bricks, which is the reason for reduction in water absorption and porosity and increase is bulk density.

From these informations it is concluded that granite and marble sawing powder wastes content upto 50 wt. % can be incorporated into raw clay materials of brick chambers available in Salem, Namakkal and Erode districts, without degrading their mechanical properties anticipating no costly modifications in the industrial production line. Further, it is found that the average strength value of waste mixed brick obtained at 20 wt. % is higher than that of other wt. %. Finally, granite and marble waste as an alternative raw material in brick production will induce a relief on waste disposal concerns. Further, the incorporation of granite and marble sawing powder wastes in brick production leads to a new method of wastes disposal and found to be an environmentally friendly recycling process in brick industries.

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REFERENCES

Acchar, W., F.A. Vieira and D. Hotza, 2006. Effect of marble and granite sludge in clay materials. Mater. Sci. Eng., A, A419: 306-309.

Algin, H.M. and P. Turgut, 2008. Cotton and limestone powder wastesas brick material. Construct. Build. Mater., 22: 1074-1080.

Coey, J.M.D., 1980. Clay minerals and their transformations studiedwith nuclear techniques. Atomic Energy Rev., 18: 73-124.

Demir, I., 2008. Effect of organic residues addition on the technological properties of clay bricks. Waste Manag., 28: 622-627.

El-Mahllawy, M.S., 2008. Characteristics of acid resisting bricks made from quarry residues and waste steel slag. Construct. Build. Mater., 22(8): 1887-1896.

Ghosh, S.N., 1978. Infrared Spectra of some selected minerals, rocks and products. J. Mater. Sci., 13: 1877-1886.

Greiner-Wronowa, E., C. Paluszkiewiez and L. Stoch, 1999. Applying FTIR spectroscopy in the study of archeometric sensor glasses. J. Mol. Struct., 511-512: 199-204.

Ojima, J., 2003. Determining of crystalline silica in Respirable Dust samples by Infrared spectrophotometry in the presence of interferences. J. Occup. Health, 45: 94-103.

Karasahin, M. and S. Terzi, 2007. Evaluation of marble waste dust Mixture of asphaltic concrete. Construct. Build. Mater., 21: 616-620.

Lin, K.L., 2006. Feasibility study of using brick made from municipal solid waste incinerator fly ash slag. J. Hazardous Mater., B137: 1810-1816.

Luz., A.P. and S. Ribeiro, 2007. Use of glass waste as a raw material in porcelain stoneware tile mixtures. Ceramic Int., 33: 761-765.

Manoharan, C., 2002. Spectroscopic and Ancient Geomagnetic field intensity studies on some South Indian archaeological artifacts. Ph.D. Thesis, Annamalai University.

Manoharan, C., K. Veeramuthu, R. Venkatachalapathy, Radhakrishnan and R. Ilango, 2008. Spectroscopic and ancient Geomagneticfield intensity studies on archaeological pottery samples, India. Lithuanian J. Phys., 48(2): 195-202.

Menezes, R.R., H.S. Ferreira, G.A. Neves, L. Lira H de and H.C. Ferreira, 2005. Use of granite sawing wastes in the production of ceramic bricks and tiles. J. Europ. Ceramic Soc., 25: 1149-1158.

Olgun, A., Y. Erdogan, Y. Ayhan and B. Zeybek, 2005. Development of ceramic tiles from coal fly ash and tincal ore waste. Ceramics Int., 31: 153-158.

Pappu, A., M. Saxena and S.R. Asolekar, 2007. Solid wastes generation in India and their recycling potential in building materials. Build. Environ., 42: 2311-2320.

Ramaswamy, K. and R. Venkatachalapathy, 1992. Infrared spectroscopic analysis of sedimentary formations of Neyveli Lignite Mine Cut-II. Indian J. Pure Appl. Phys., 30: 171-175.

Ramaswamy, K., M. Deenathayalu and S. Bharathan, 1989. Mossbauer study of some archaeological materials in Tamilnadu (India). Phys. Earth Planet. Inter., 56: 230-241.

Russ, W., H. Heinrich Mortel and R. Meyer-Pittroff. 2005. Application of spent grains to increase porosity in bricks. Construct. Build. Mater., 19: 117-126.

Russell, J.D., 1987. A Hand Book of Determinative Methods in Clay Mineralogy. M.J. Wilson and Blackie, (Ed.), London.

Sanchez. E., M.J. Ibanez, J. Garcia-Ten. M.F. Quereda, I.M. Hutchings and Y.M. Xu, 2006. Porcelain tile microstructure: Implications for polished tile properties. J. Eur. Ceramic Soc., 26: 2533-2540.

Segadaes, A.M., M.A. Carvalho and W. Acchar, 2005. Using marble and granite rejects to enhance the processing of clay products. Appl. Clay Sci., 30: 42-52.

Singh, I.B., K. Chaturvedi, R.K. Morchhale and A.H. Vegneswaran, 2007. Thermal treatment of toxic metals of industrial hazardous wastes with fly ash clay. J. Hazardous Mater., 141: 215-222.

Tominaga, T., M. Takeda, H. Mabuchi and Y. Emoto, 1978. Characterization of ancient Japanesh roofing tiles by ^{57}Fe Mossbauer spectroscopy. Archaeometry, 20(2): 135-146.

Turgut, P. and B. Yesilata, 2008. Physico-mechanical and thermal performances of newly developed rubber-added bricks. Energy Build., 40: 679-688.

Venkatachalapathy, R., D. Gournis, C. Manoharan, S. Dhanapandian and K. Deenadayalan, 2004a. FTIR and Mössbauer spectroscopic studies of archaeological potteries from Nathikudi, Tamilnadu. Indian J. Phys., 78: 1371-1375.

Venkatachalapathy, R., D. Gournis, C. Manoharan, S. Dhanapandian and K. Deenadayalan, 2003. Application of FTIR and Mossbauspectroscopy in analysis of some South Indian archaeological potteries. Indian J. Pure Appl. Phys., 41: 833-838.

Venkatachalapathy, R., C. Manoharan, S. Dhanapandian, T. Sundareswaran and K. Deenadayalan, 2004. FTIR studies of somearchaeological ceramics from Azhagankulam, Ramanathapuram District, Tamilnadu. J. Curr. Sci., 5(2): 695-700.

Wagner, J., R. Gebhard, E. Murad, J. Riederer, I. Shimada and F. Wagner, 1992. Archaeometry of Pro-Columbian Sites. In: Proceeding of a symposium organised the UCLA Institute of Archaeology and the Getty Conservation Institute, D.A. Scott and P. Meyers, (Eds.). Los Angels, California, March 23-27.

Wagner, U., R. Gebhard, E. Murad, G. Grosse, J. Riederer, I. Shimada and F.E. Wagner, 1997. Formative ceramics from the Andes and their production: A Mossbauer study. Hyperfine Interact., 110: 165-176.

Wagner, U., R. Gebhard, G. Grosse, T. Hutzelmann, E. Murad, J. Riederer, I. Shimada and F.E. Wagner, 1998. Clay: An important raw Material for Prehistoric man. Hyperfine Interact., 177: 325-335.

Wagner, U., R. Gebhard, W. Hausler, , T. Hutzelmann, J. Riederer, I. Shimada and J. Sosa and F.E. Wagner, 1999. Reducing firing of an early pottery making Kiln at Batan Grande Peru: A Mossbauer study. Hyperfine Interact., 122: 163-170.

Wolff, R.G., 1963. Structural aspects of kaolinite using Infrared absorption. The American Mineralogist, 48: 390-399.