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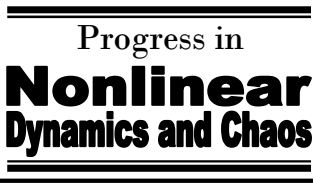

Performance Assessment of Ceramic Bricks Developed via Fly Ash and Waste Glass Admixing into Fire Clay

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Abstract. In quest for quality and sustainable developments, it is necessary to find alternative materials, methods of brick making construction materials. Porcelain represents one of the most complex ceramics, formulated from a mix of clay, feldspar and quartz are sintered to conform a glass-ceramic composite. Nowadays, research of new materials, for example non-hazardous wastes, that are able to replace the traditional fluxing agent without changing the process or quality of the final products has been realized. Development of products which can be produced from a country's natural resources is very important as for as the industrialization of a nation and saving foreign exchange is concerned. The aim of this work is to study the possibility of the use of glass powder and fly ash (waste materials), in ceramic mixtures, for manufacturing of ceramic bricks. It was prepared by mixtures containing different amount of fireclay, fly ash, glass waste, feldspar and quartz and the traditional manufacturing processes, particularly for manufacture of ceramic additive bricks have been discussed. The samples were fired reaching different maximum temperatures in the range 800-1200ºC, with a soaking time of 6 hour. The fired samples were characterized and the use of small amounts of glass powder and fly ash in addition with feldspar and quartz showed good results of mechanical technological properties.

Keywords: Coal power plants; fly ash; fired clay bricks; waste glass; technological properties.

1. Introduction

The establishment of an industrial symbiotic relationship similar to ecological symbiosis [1] through replacing clay materials with abundant and often recurring industrial waste is one key innovative approach in ensuring the sustainable material availability for construction [2]. Besides, the versatile polymineral constituents of clay materials specially offer boundless opportunities for further advantageous adulteration of their compositions with a wide-array of organic effluents into specialized tailor – made products [3, 4]. Moreover, the construction sector cardinal presents great potentials eco-friendly viable options for disposing industrial waste as well as the manufacture of

technological improved brick products [5]. Furthermore, from the socioeconomic viewpoint, the clay industry informally offers countless reliable job opportunities to the teaming unskilled or unspecialized but energetic youth for their dignified livelihoods: aside, the often highly weather dependent, seasonal reliant and laborious as well as fiddly underdeveloped agricultural sector in most emerging nations.

At present the issue of fly ash and waste glass which are generated from thermal power stations and industry management is one of the high – priority subject of governments. The present research therefore, examines the feasibility of developing fired clay bricks admixing fly ash and waste glass into fire clay materials with addition of feldspar as fluxes. The chemical and technological properties such as fired shrinkage of the developed bricks were assessed to determine the optimum development conditions for obtaining better technological quality of these ceramic bricks. Other quality determinants evaluated were water absorption, apparent porosity and compressive strengths at each sintering temperature. It is therefore, expected that this research could provide an eco-friendly, economic and sustainably approach towards enhancing effective utilization of waste materials stock piles.

Demands of ceramic bricks (porcelain bodies) are increasing day by day and researchers are becoming interested in developing porcelain bricks with high mechanical strength for household uses as well as for decoration purposes. Usually ceramic bricks (porcelain body) are manufactured by using clay quartz and feldspar but presently waste material such as waste glass and fly ash powder are used to make bricks. This waste glass powder is able to replace the traditional fluxing agents like feldspar without changing the process and quality of the final products. Ceramic product are manufactured using large amount of fluxing agent like sodium and potassium, feldspar, nefeline, talc and ceramic frits [6]. Ceramic bricks have various characteristics and it can be used in many different places because of high mechanical resistance and surface hardness [7, 8]. Glass is made from sodium oxide; calcium oxide and silicon dioxide are known as a soda lime-silica glass. In fact, soda-lime-glass is already vitreous silicate. The vitreous silicates are generated during the maturation of clay bodies which act as fluxing agent. The reducing clay body maturation temperature was evidence that addition of soda lime glass to clay body raw material could increase the efficiency of clay body firing and therefore be a value added application for recycled glass fines.

As an industrial waste, fly ash presents some environmental and storage problems; however, it has been used widely as an excellent mineral additive in the construction industry [9, 10]. The use of fly ash prevents environmental pollution, and it contributes to a reduction in the need for natural resources. Fly ash is available in different types, such as C and F. The F type has a low Ca content, and its content of SiO_2+Fe_2O_3+Al_2O_3 is greater than 70. There are many studies investigating fly ash and its use as an additive in cement mortars [11]. Fly ash is also used as an additive in the production of briquettes [12]. This study presents details about the utilization of fly ash that was collected from Neyveli Lignite Corporation, Neyveli, Cuddalore District, Tamilnadu, India. Production of briquettes that have shift compressive strength values for an effective utilization of glass waste as fly ash, it is necessary to determine their physical and chemical characteristics and to determine their effect strength developments on ceramic body-glass waste and ceramic body-fly ash mixtures.

2. Materials and method

Based on the extent of fly ash incorporation levels and their sintering temperatures, twenty (20) different brands of pressed ceramic clay bricks were selected for analysis. Table 1 shows the formulations, number of replicates and the firing schemes of all the selected brick samples. In order to minimize random errors associated with the manufacturing processes of these bricks, five replicates of each unique brick were similarly chosen for analysis. The materials used for this study included; dried glass waste powder, fly ash powder and porcelain composition (kaolin, quartz and feldspar). The equipment used for this study included furnace, mounting press, grinding mill, sieve shaker and set of sieves and compression strength tested. Dried glass waste and porcelain mixture obtained from government ceramic Institute Vridhachalam, Cuddalore District, Tamilnadu, India. The fly ash powder obtained from Neyveli Lignite Corporation (NLC) terminal power plant Neyveli, Cuddalore District, Tamilnadu, India. The chemical compositions of all the raw materials used are presented in Table 2.

A mixture of porcelain composition made with various proposition of glass waste 0-20 wt% group-I; (S_0-S_4) and various proportions of fly ash (0-25 wt% group-II; S_o, S_5-S_9). Each mixture was made thoroughly homogenized with the addition of optimum amount of plasticity water to both clay mixture and glass waste; (fly ash). The resulting mixtures (for each compositions of group I & II), were then compacted in a mounting press to obtain rectangular bar shape samples. These samples were placed in furnace and fired at various temperatures ranging from 800-1200ºC such that the additive powders burns off leaving some ash pores. A series of tests were formed on the fired samples. These tests included firing shrinkage, water absorption, porosity and compressive strength.

The selected fired brick samples were subjected to a number of tests to determine their technological properties. The linear fired shrinkage (L.S.) of each brick sample was ascertained via dimensional measurements with a veneer caliper (least count ±0.01 mm). Loss on ignition (LOI) values was determined with reference to secondary data and using a sensitive electronic balance with least count ±0.01 g to measure the fired brick weights. The LOI values were then standardized using equation (1). UNE67-027 standard procedures were observed in determining the water absorption levels of the fired brick samples. All samples were dried in hot air oven for 2 hours before recording their dried weights. Their respective wet weights were determined after a 24-hour total immersion in a water bath. The water absorptions values were then standardized using equation (2).

$$LOI\% = \frac{1}{N}\sum_{i}^{N}\left(1-\frac{W_{f,i}}{W_{g,i}}\right)100 \quad (1)$$

$$Water\ Absorption\% = \frac{1}{N}\sum_{i}^{N}\left(\frac{W_{w,i}}{W_{d,i}}-1\right)100 \quad (2)$$

Where N is the total number of bricks measured,
$W_{g,i}$ is the green weight of bricks,
$W_{f,i}$ is the weight of bricks after firing,
$W_{d,i}$ is the dried weight of bricks after firing and

$W_{w,i}$ is the wet fired weight of bricks after 24-hour total immersion in water.

Table 1: Composition of compounds

Sample No.	Fireclay (%)	Waste Glass (%)	Quartz (%)	Feldspar (%)
S_0	80	--	10	10
S_1	80	5	5	10
S_2	75	10	5	10
S_3	70	15	5	10
S_4	65	20	5	10
Sample No.	**Fireclay (%)**	**Fly ash (%)**	**Quartz (%)**	**Feldspar (%)**
S_5	80	5	5	10
S_6	75	10	5	10
S_7	70	15	5	10
S_8	65	20	5	10

Porosity of the brick samples were determined by the boiling water method. In this method, the saturated immersed weights of samples after 6 hours continuous boiling were recorded as (W_1) along with their wet weights (W_2). Similarly, the dried weights of the bricks were determined after 6 hours continuous oven-drying at 200°C (W_3). The porosity of each brick was evaluated using equation (3).

$$Porosity\% = \frac{1}{N}\sum_{i}^{N}\left(\frac{W_{2,i} - W_{3,i}}{W_{2,i} - W_{1,i}}\right)100 \quad (3)$$

Mechanical strength values were evaluated in accordance with UNE67 – 026 standard procedures using a UNITEK compressor model 94100 operating at a localized pressure of less than 20 Mpa/s until complete fracture of each brick unit. The micro structural evolution of ceramic materials on firing has been exhaustively studied over the fast fifty years. However because of the complex interplay between raw materials and firing kinetics, this type of ceramic materials continues to present many research challenges [13], the introduction of waste (glass & fly-ash) as partial replacement for raw materials leads to the formation of high temperature phases which play an important role in the micro structural development on firing ceramic bricks, thus affecting its performance. It is important to determine the new phases formed and correlate their existence to the starting materials and processing reaction between glaze and the near-surface materials and the glaze and kiln atmosphere have a significant effect on the bonding. Each raw material within the body formulation contributes different to the final

properties. The Field Emission Scanning Electron Microscope (FE-SEM) is uniquely suited for studying clays because it affords a magnified, three dimensional view of the unmodified (natural) clay surface with great depth of focus.

Table 2: Chemical compositions of the raw materials

S. No	Element composition	Fireclay	Fly ash	Waste Glass
1	SiO_2	59.60	63.020	69.320
2	Al_2O_3	18.62	23.470	2.080
3	BaO	1.41	-	0.110
4	CaO	0.670	5.513	11.750
5	Fe_2O_3	6.48	2.540	0.317
6	K_2O	0.030	0.055	0.928
7	MgO	0.00	1.250	1.370
8	Na_2O	0.00	0.425	13.740
9	SO_3	-	1.760	0.166
10	TiO_2	2.81	1.705	0.056
11	LOI (at 1000°C)	9.62	-	-

In the present study the crystalline structure and element composition of the ceramic brick samples were studied in a FEG Quanta 300 Field Emission Scanning Electron Microscope, equipped with an energy dispersive X-ray analyzer (FESEM-EDAX). The samples were mounted on Al stub with conductive glue and covered with a thin coating of gold to make them electrically conductive. A sputter coater (Bio RAD model Sc 502) was used, in which a vacuum of 3.0 nm atmosphere and 30KV current were applied for approximately 30 seconds.

3. Results and discussion

3.1. Chemical analysis

Table 2 shows the chemical and the normative mineralogical composition of the raw clay and additive (waste glass and flyash) samples respectively. The chemical data correlate well with the in mineralogical composition as the silica and alumina contents agree with the quartz and kaolinite contents**.** The main oxides are SiO_2, Al_2O_3, CaO and Fe_2O_3 whereas BaO, K_2O, MgO, SO_3 and TiO_2 are present only in small amounts. The oxides value for Na_2O is higher in waste glass (13.74%) but in respect of fly ash samples it is

present in minor amounts (0.425%). Considering the composition of Table 2 waste glass has higher SiO_2, CaO, Na_2O and MgO contents compared to the flyash sample. The relative abundance of SiO_2 indicates a rather high content of quartz, whereas Al_2O_3 can be correlated with clay minerals and feldspar. Varying amounts of quartz influence the plasticity and drying behavior of the clays. Relatively high iron oxide (Fe_2O_3) content provides a characteristic reddish–brown color to the fired body. However, Fe_2O_3 is not the only factor responsible for the coloring of ceramic wares [14]. Other constituents such as CaO, MgO and TiO_2 can appreciably modify the color of the fired body. The temperature of firing, relative amounts of Al_2O_3, and the furnace atmosphere all play an important role in the development of color in the fired clay products [15]. The main effects alkali in clays is to reduce their refractory temperature and therefore, they are called fluxes [16].

Lime melts silica in burning and binds the particle of brick together. It also reduces the shrinkage of brick during drying. Excess amount of lime cause the brick to fuse and the shape will be lost. Alkali and organic matter of small quantity assists burning of brick clay. It also reduces the fusion point. If excess amount is present and not burned properly the brick would be porous. Finally the chemical compositions of the raw clay, waste glass and fly ash were given in Table 2 in terms of chemical composition the SiO_2 was the most abundant component, followed by Al_2O_3, CaO and Fe_2O_3 contents, which was reaching upto 85.37 of fire clay, 83.46% of waste glass and 94.54% of fly ash. The main differences between the two samples (waste glass and fly ash) were the high CaO (11.75%) of waste glass and lower Al_2O_3 (2.08%) present. The high loss of ignition associated with low SiO_2 and high Al_2O_3 is due to the significant level of clay minerals. These differences suggest that highest amount of CaO in the firing step can give rise to higher porosity in the brick specimen prepared to waste glass, which is also suggested their higher thermal loss [17]**.** From the chemical composition (Table 2) the sum values of Fe_2O_3 and TiO_2 are 9.29% (Fire clay), 0.373% (waste glass) and 4.245% (fly ash). Many studies have described the influence of these minerals in enhancing the process of sintering of clay matrix as the formation of mullite [18, 19]. Ti^{4+} and Fe^{3+} play an important role either substituting Al^{3+} or by their integration into the structure intensities of the matrix.

The relative abundance of SiO_2 indicates (Table 2) a rather high content of quartz, whereas Al_2O_3 can be correlated with clay minerals and feldspar. Varying amounts 69.32% (waste glass) and 63.02% (fly ash) of quartz influence the plasticity and drying behavior of the clays. Relatively high iron oxide (Fe_2O_3) content provides a characteristic reddish- brown color to the fired clay. These physical, chemical and mechanical parameters are not only important to judge the quality of the product, but are also important to monitor the sintered body properties. Glass powder is a strong fluxing agent which has the capacity to form a lower melting silicate. Therefore the firing temperature range was relatively narrow and different from that of traditional ceramic body. The unfired ceramic bricks were prepared fired at different temperatures 800-1200ºC for 6 hours in electric furnace respectively. The firing shrinkage, water absorption and compressive strength of fired glass powder and fly ash added ceramic brick samples were tested to decide the sintering temperature.

3.2. Shrinkage of ceramic bricks (S_0, S_1-S_4 and S_5-S_8) samples

Measurements of firing shrinkage were performed at room temperature (for waste glass and fly ash added samples) are shown in Table 3 and Fig.1 In contrast, the rate of dissolution of quartz into the glass phase was somewhat influenced by quartz particle size, despite the fact that the specimens were fired at different temperatures to reach maximum densification. As clearly shown in Fig.1 progressive increase of heat-treated temperature causes changes in the firing shrinkage values of specimens. It can be seen that the specimens fired 800ºC and 1000ºC have shown similar behavior where a very small increase of linear variation between 0% and 15% of waste glass content is noticeable. From the group samples indicates a straight tendency that the firing shrinkage increases with waste content (15% at 1000ºC). In respect of fly ash added ceramic bricks (samples S_o and S_5-S_9).It can be seen that specimen fired at 900 and 1200ºC have shown similar behavior. The firing behavior shown by the composition S_5-S_9 presents increase shrinkage from 1100 to 1200ºC. This phenomenon only occurs from 1000 to 1200ºC in S_8 & S_9 (Fig.1), it means that highest amount of feldspar extends the firing range. It is noticeable that the fired specimens of all mixtures shrinked until 1000ºC (waste glass addded) and 1100ºC (fly ash added). After 1100ºC the specimens expanded (Table 4) with a corresponding increase of water absorption and decrease of compressive strength. The expansion perhaps is attributed to the negative role of silica as mentioned before. The expansion effect is supported with the increase of flyash added content (the source of silica) for batch S_5-S_9. Also, the expansion of the fired specimens decreases and the shrinkage increase with the increase of the flyash content upto S_8.

As normally observed, the shrinkage increases with heating temperature for all compositions (S_1-S_4 and S_5-S_8). The only waste glass additive body with higher amount of alkaline earth oxides show highest shrinkage at 1100ºC compared to fly ash added body, and the same sample at 1100ºC. Although there is no distinct relationship observed between shrinkage and alkaline earth oxide content, a correlation may be seen from Fig.1 that show the increase in shrinkage values due to alkaline earth oxide content beyond 1000ºC (waste glass added samples) and 1100 ºC (flyash added samples).

3.3. Water absorption of waste glass and flyash added ceramic brick samples

The internal structure of the building material must be compact enough to avoid the intrusion of water. Water absorption is used to estimate the pore ratio of ceramic brick samples. As depicted in Fig.2 and Table 3, the brick ceramic with 0% of waste glass powder has shown higher water absorption for the temperature of 800ºC than of 900-1100ºC.

The water absorption (for S_3 sample) decreases upto 48% for those samples with 15% of waste glass and it reaches a maximum for water absorption values. For samples with 5% and 10% of waste glass addition; increase the values with increase its temperature. The highest water absorption was 22.62% (at 800ºC) for sample S_0 and the lowest water absorption was 4.46% (at 1100ºC) for sample S_3. It is important to mention that the maximum allowed value of water absorption is 22% for commercial use of the bricks (7, 8].

Table 3: Mechanical properties of samples (S_0-S_4) group-I at different temperatures

Temp. °C	Samples	Firing shrinkage (cm)	Water Absorption (%)	Porosity (%)	Compressive strength in (Kgf)
800	S_0	7.14	22.626	30.41	224
	S_1	8.2	19.431	27.26	209
	S_2	7.1	18.917	26.43	212
	S_3	8.3	12.09	20.51	238
	S_4	6.3	16.15	24.83	230
900	S_0	6.71	18.949	26.81	226
	S_1	10	16.354	25.72	170
	S_2	10	14.387	22.76	220
	S_3	8.1	9.202	17.51	256
	S_4	6.8	9.569	18.06	227
1000	S_0	8.57	13.340	22.42	210
	S_1	11.2	7.723	16.25	226
	S_2	10.4	8.565	17.46	230
	S_3	12.8	6.46	13.1	280
	S_4	8.7	7.105	16.01	237
1100	S_0	8.42	10.77	19.53	207
	S_1	12.3	7.033	16.26	218
	S_2	12.5	6.490	15.74	224
	S_3	11.8	6.66	14.26	236
	S_4	10.98	6.96	16.88	217

Fig.4 shows the result of experimental bricks of fly ash added specimens (Table 4), aiming the comparison among waste glass added tested samples. It can be notices that the use of fly ash waste, dramatically changes the behavior of the ceramic brick, where a minimum is reached for values of 20% of mixture (S_8) fired at 1100ºC. However, the difference is not significant when compared to samples with 25% of waste content. The same can be said for samples fired at 1200ºC, ie., there is no significant difference among them. It can also be shown that the amount of 20% of waste increases considerably the water absorption at 900 and 1000ºC, indicating that, under this temperature is not suitable for use of any (fly ash) waste content due to the high water absorption values. At higher temperatures (T>1100ºC), the increase of the waste glass

caused an improvement of water absorption that can be attributed to an improvement, in the densification process.

Table 4: Mechanical properties of samples (S_0, $S_5 - S_9$) group-II at different temperatures

Temp. °C	Samples	Firing shrinkage (cm)	Water Absorption (%)	Porosity (%)	Compressive strength in (Kgf)
900	S_0	5.71	18.949	26.81	226
	S_5	4.2	19.68	25.86	223
	S_6	5.1	18.436	27.10	210
	S_7	6.4	18.86	26.84	220
	S_8	7.3	18.19	25.73	240
	S_9	6.4	18.876	25.84	230
1000	S_0	7.3	15.94	22.42	210
	S_5	8.4	19.46	21.35	240
	S_6	8.1	18.4	24.66	232
	S_7	8.2	18.318	23.15	224
	S_8	8.5	17.9	21.22	246
	S_9	7.0	20.684	25.73	233
1100	S_0	9.6	13.34	19.53	207
	S_5	7.3	12.12	20.96	205
	S_6	9.8	15.48	21.98	193
	S_7	9.2	14.71	23.52	186
	S_8	9.1	12.07	20.13	258
	S_9	9.6	15.69	22.27	198
1200	S_0	9.8	13.34	17.42	211
	S_5	10.2	14.46	15.69	206
	S_6	8.5	12.4	16.97	222
	S_7	8.2	12.1	18.71	217
	S_8	11.2	10.13	14.62	276
	S_9	9.4	15.94	19.69	216

The water absorption values obtained for ceramic mixtures with waste glass and flyash wastes are much better, for all temperatures as investigated in this work that the ceramic products that the ceramic industry produced at the same conditions.

3.4. Porosities of waste glass and fly ash added samples

The porosity of ceramic bodies determines other properties such as slag resistance and spalling resistance. When porosity increases, it normally leads to lower mechanical strength. This is because the number of regions of high stress concentration. The porosity and mechanical strength of a refractory can often be used as quality control factors for the manufacturing process and to evaluate the effect of various production factors on the properties of finished goods. Normal ceramic bricks have a porosity of about 15 to 28% where as high density products go down to 2 to 5%. A few special fabricated materials have zero porosity that is the true or theoretical density. During manufacture of ceramic bricks, except for insulating bricks, the aim is for a low porosity.

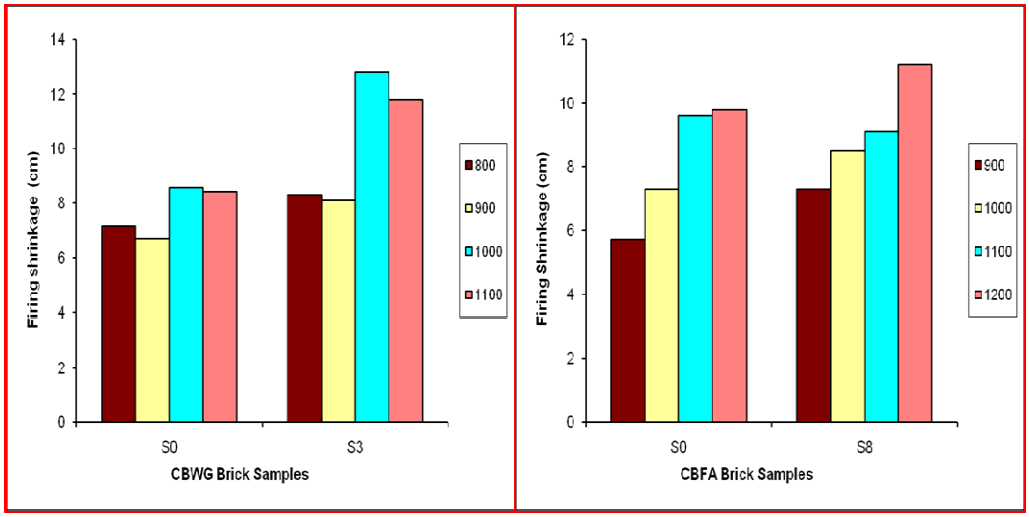

Figure 1: Firing Shrinkage of samples group-I (S_0 & S_3) and group-II (S_0 & S_8) Sintered at various temperatures.

This is because the mechanical strength is improved by good compaction of the brick mix. Other properties like density are improved by low porosity. The results obtained from the determination of porosity as a function of firing temperatures (Tables 2-3 & Fig.3) is very similar to that of water absorption. According to literature [14], the use of scrap-glass causes a general decrease in porosity besides the increase temperature range from 800ºC to 1100ºC. Partial replacement by waste glass and fly ash produces a decrease in intruded pore volume relative to that of the control (S_0) and the decrease turns to be somewhat greater for waste glass added samples. Also, the total intruded pore volume decreases with increasing replacement level and as might be expected, decreases with increase in temperature, although, there is quite a wide scatter in the data. In this case there is a clear difference in behavior relative to the control (S_0) between ceramic brick containing waste glass and fly ash. In both cases the early stages of firing

temperatures 800, 900, and 1000ºC, the percentage of fine pores is less than in the control (S_0) ceramic brick sample.

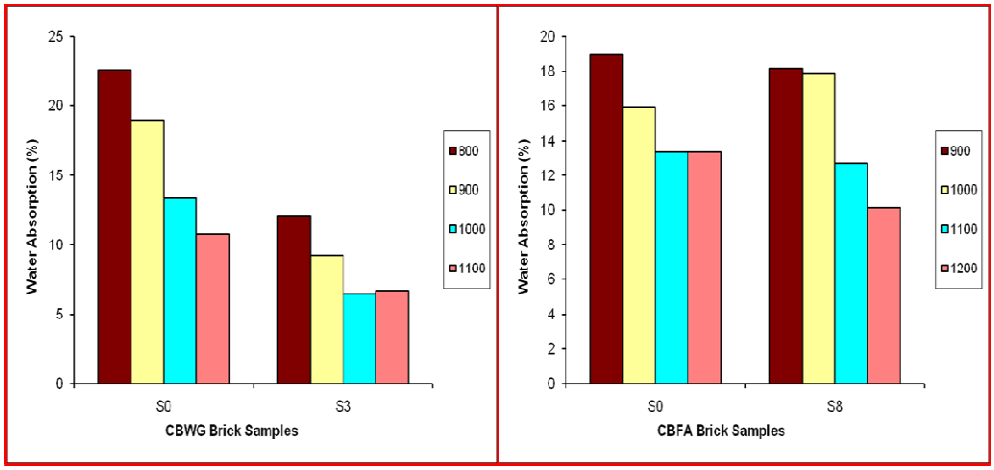

Figure 2: Water Absorption of samples group-I (S_0 & S_3) and group-II (S_0 & S_8) Sintered at various temperatures.

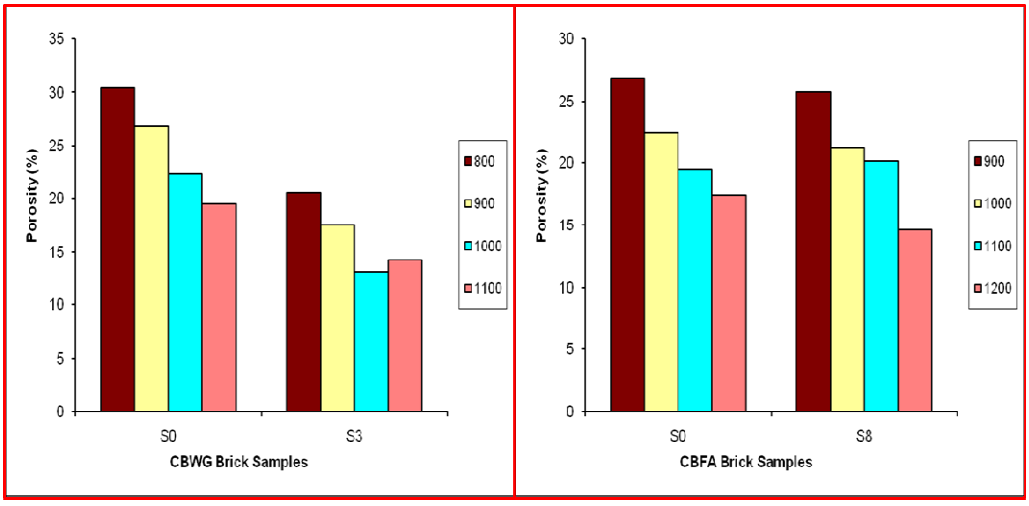

Figure 3: Porosity of samples group-I (S_0 & S_3) and group-II (S_0 & S_8) Sintered at various temperatures.

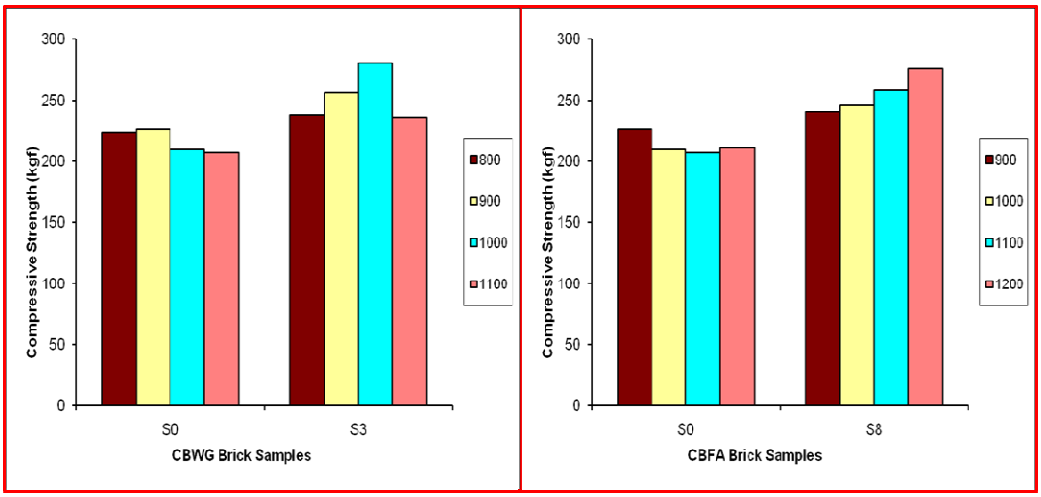

Figure 4: Compressive Strength of samples group-I (S_0 & S_3) and group-II (S_0 & S_8) Sintered at various temperatures.

When the sintering temperatures increased from 800 to 1000ºC for sample containing Waste glass (0 to 20%), the porosity values decrease from 20.51 to 13.1%. In case of 20% fly ash addition (Fig.3), the porosity of sintered specimens decreased from 25.73 to 14.62%, when the sintering temperature was increased from 900 to 1200ºC. The results also indicated that water absorption increased with increase in waste glass and fly ash addition ratio.

3.5. Compressive strength

The compression strength test is most important test that can be used to assure engineering quality in the application of building materials. The results of these Fig.4 indicates that the compressive strength values increase with the increase of firing temperatures until 1000ºC (for waste glass added specimen) and 1200ºC (for fly ash added specimen) and then decrease at 1100ºC (Tables 3-4). At 1000ºC, the polymorphism phenomenon of SiO_2 plays its negative role in forming a porous structure which weakens the body strength [20]. The compressive strength increased with increased sintering temperature and decreased with increased added waste glass. Compressive strength increased from 170 to 280 kg f/cm^2 in sample S3 (Table 3**)** and 193 to 258 kg f/cm^2 in sample S_8 (Table 4).

The sintering temperature was increased from 800-1100ºC for waste glass added specimens and 900 to 1200ºC for fly ash added samples containing wastes. In the 15% waste glass addition case, the sintered specimen compressive strength increased from 238 kg f/cm^2 to 280 kg f/cm^2 when the sintering temperature increased from 900 to 1100ºC. The higher compressive strength was developed at 1000 ºC sintering temperature with the waste glass ratio at 15%. In respect of fly ash added samples the compressive increased (for 20 % S_8 sample) from 240 kg f/cm^2 to 276 kg f/cm^2 when the sintering temperature increased from 900 to 1200ºC. The higher compressive strength developed at 1200ºC sintered temperature with the fly ash ratio at 20%.

3.6. Morphology

According to Nathan, 1976 [21], morphology refers to size, size distribution, shape, surface area ,and other parameters that may help to define how the powder will flow, pack, react and yield the microstructures of the finished ceramic body. Since, the driving force for converting a mass of discrete powder particles into a solid body is the reduction of surface energy, it is obvious that the shape and surface area of the particles define the thermodynamics and kinetic of densification. Particle size and particle size distribution are parameters which affects physical and chemical properties of all powders. Since, in any ceramic processing a starting point is a powder, particle size measurements has been recognized as a critical influence on processing and consolidation of ceramic powders. Parameters like packing density are critically dependent on particle size distribution and this has effects on fluidity, of slips, green porosity, fired shrinkage, forming rate and firing range. The morphology of the unfired sample (S_3) is displayed in Fig.5a. As seen, the unfired sample shows a highly layered structure of thin lamellae packed in larger aggregates.

FE-SEM image of ceramic bricks (S_3) sintered at 1000ºC is presented in Fig.5b. The micrograph (Fig.5b) indicates a denser more sintered microstructure. When compared with Fig.5a the sintered sample S_3 at (1000ºC) shows a dense matrix containing some isolated, small voids very few pores can be seen in the microstructure. Between 900 and 1000ºC a considerable decrease in the porosity occurs coinciding with the beginning of vitrification. As far as the porosity is concerned, a porosity value reduces from 17.51% (900ºC) to 13.92% (1000ºC). As agreed by Johari et al., 2010 [22], the purpose of the solid state sintering process is to develop atomic boding between particles by a diffusion mechanism.

The relation between mineralogy of the unfired minerals and phases changes taking place during their sintering under different conditions has been examined. It indicates that the unfired sample showed irregular plates are identified as kaolinite, showed isolated quartz crystal and amorphous Fe hydroxides (Fig.5-c&d). The sample S_8 composed of fire clay particles deposited in a phase to phase manner with voids, which show that clay contains iron impurity which convert the hematite during calcinations and is reached more efficiently. The porous microstructure leads to goods fire resistant performance. Some fly ash particles present as non active fillers between the porcelain body mixtures. The semi-spherical surface may be the interface of the ceramic brick material and the fly ash ball, where many needle or stripe-shaped particles may be due to the high concentration or abundant alkali solution surrounded the fly ash ball in the sample (ceramic material): the unreacted alkali precipitated after the tests and formed the needle or stripe shaped particles indicate that the ceramic products may have the capability for the growth of the compressive strength in the extended firing.

The fired specimen of 20 wt% of fly ash mixture (S_8) present in significant variation in the internal of 1200°C. The FE-SEM image of sample (S_8) demonstrates particles of different shapes and sizes (Fig.5c), which majority consists of solid particles. Different particles states of silica are responsible for the particles of irregular size. The well formed crystals seemingly develop only in pores and other voids. The surface texture of fly ash added ceramic brick shows (Fig.5c) that there have angular particles with a large rough surface area, which enhances the bond between aggregate particles and

fly ash matrix. It creates better interlocking between the particles and reduces the porosity. Because of this the strength and durability characteristics are improved. High fineness are spherical shape fly ash result in good filling effect clearly visible in Fig.5c when compared to Fig.5d sintering at 1200°C.

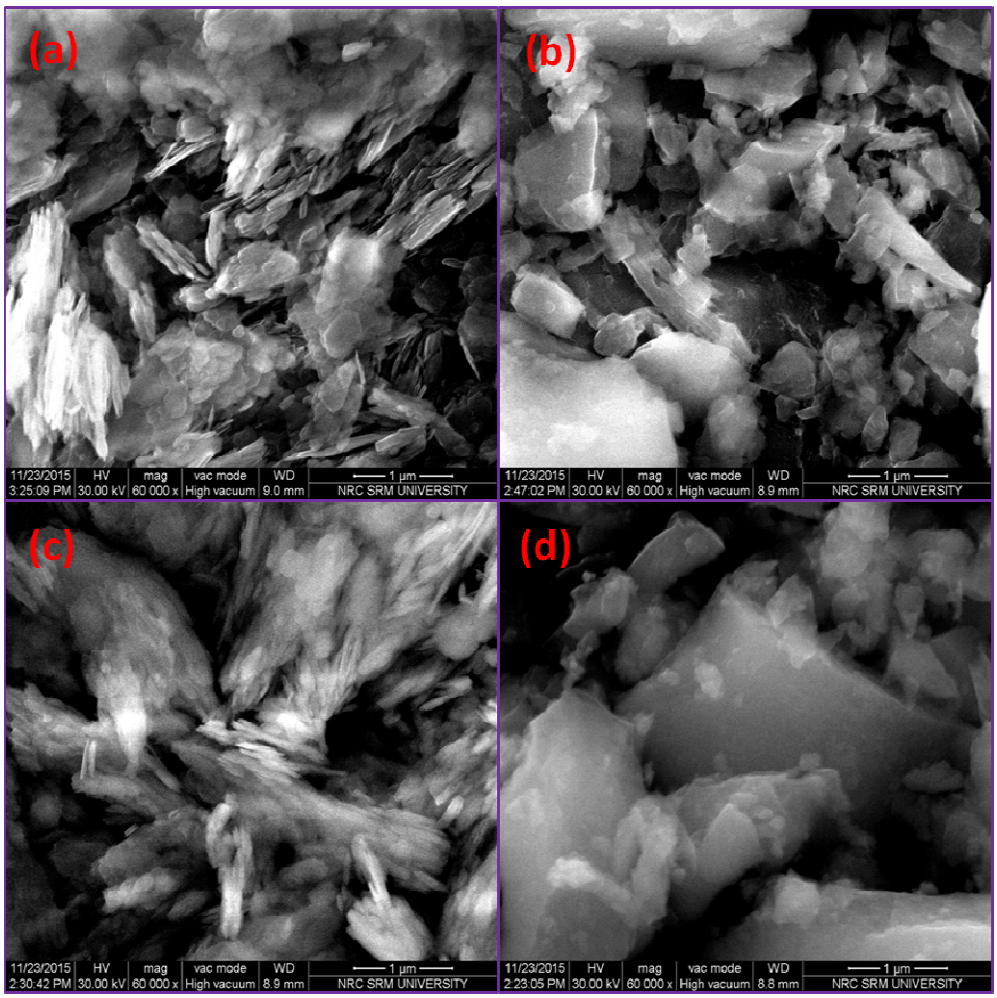

Figure 5: FESEM images of (a) unfired S_3, (b) fired S_3 (1000°C), (c) unfired S_8 and (d) fired S_8 (1200°C) samples.

4. Conclusions

This study represents an attempt to reveal the behavior of ceramic mixtures during firing. The experiments demonstrate the role played by the various mechanical properties in the formation of good quality bricks. The multi analytical approach could represent a tool to improve the knowledge on the dynamics of clay mineral transformation and on the composition of new ones. The possibility to increase the mechanical characteristics of the ceramic bricks is compared by the addition of waste glass and fly ash powders. The use

of small amount of waste glass (15%) and fly ash (20%) in association with ceramic mixture showed good results of mechanical properties. Experimental results from the characterization of formulated sample bricks indeed reveal the viability of manufacturing ceramic bricks from the waste addition (Waste glass, Fly ash). Formation of mullite, the strengthening component of ceramic additive bricks, has been confirmed by FE-SEM micrographs and mechanical properties of sintered samples. From the present study, among the various samples S_3 and S_8, which were fired at 1000ºC and 1200ºC alone have the high degree of mechanical strength and this led to the conclusion that it can be classified as ceramic brick bodies.

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