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Effect of Different Types of Glasses as Fluxing Agent on the Sintering Temperature of Bricks

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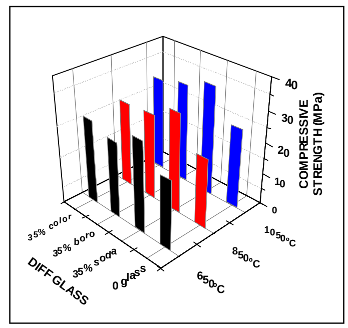
ABSTRACT

Generally conventional bricks of Bangladesh are sintered at 950^o to 1050^{o}C temperature. These bricks have compressive strength between 2600 and 3000 psi. To lower the sintering temperature, waste glass powder (borosilicate glass, coloured glass and sodalime glass) was used in the production of bricks and sintering temperature was successfully lowered to 650^{o}C. Among the glass powder used, sodalime glass produced the best result. Compressive strength of the brick made with 50% sodalime glass was around 31.36 MPa (4550 psi), which was much higher than that of conventional brick. Higher percentage of sodalime glass resulted in degraded quality of bricks. Other physical properties of bricks like bulk density, apparent porosity, water absorption and shrinkage were also better than those of conventional one. Longevity of bricks increases when they contain both glassy and crystalline phases. While conventional bricks possess no or less amount of glassy phase, XRD patterns of the prepared brick sample showed prominent glassy phase along with crystalline phase in it.



[Keywords: Waste glass, Sintering temperature, Compressive strength, Conventional bricks, XRD]

Introduction

To evaluate different types of waste glass as fluxing agent to reduce the sintering temperature of bricks is the main target of our present work. For the past few years extensive research works were carried out to utilize waste materials to produce bricks for environmental protection and sustainable development.[1–18] Usually conventional bricks are produced from clay with high temperature kiln firing or from ordinary Portland cement (OPC) concrete. Both the processes consume lots of energy and release CO_2 due to high temperature firing. Fluxing agents can facilitate melting i.e. lower the melting points of mixtures compared to the pure components and also facilitate deposition of particular components, which, in turn, reduces the sintering temperature. The aim of this study is to find out the type and optimal level of fluxing agent for using in production of bricks.

Waste glass is being used in the production of building materials (such as bricks) as it can reduce both the consumption of natural resources and the cost of waste disposal while protecting the environment from harmful effects of waste materials. Many researchers successfully used glass as a binder and fluxing agent in ceramics and bricks to lower softening temperature, firing time and energy consumption[19–23] and also studied the effects of waste glass as a fluxing agent, which lowers the sintering temperature, on the physical and microstructural properties of expanded clay aggregates (ECA).[24]

In Bangladesh conventional bricks are sintered at 950^o to 1050^{o}C temperature and these bricks have compressive strength ranging from 2600 to 3000 psi. In the present study we tried to lower the sintering temperature as well as increase the compressive strength of bricks by using waste glass powder (borosilicate glass, coloured glass and sodalime glass) in the production of bricks. We also studied different physical properties, like bulk density, apparent porosity, water absorption and shrinkage, of the prepared bricks in comparison to the conventional bricks.

Experimental Details

Raw Materials

The main raw materials used for the production of low temperature fired brick were local red clay (Mirpur clay), available in Pollobi, Mirpur-12, Dhaka, Bangladesh, and different types of waste glass powders, viz. sodalime glass (mainly used in window and sheet glass), coloured glass (from thai aluminium colour glass) and borosilicate glass (from laboratory glassware).

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Material Preparation

For making bricks, at first waste glasses were crushed into pieces. Then crushed glasses and red clay were ground into powders separately by using a grinder. These fine powders were passed through 20 mesh (+20 to –20) sieve. Returning the sample on –20 mesh, the sizes of granulated particles were at most 0.85 mm. These two raw materials were mixed together and ball milled for 6 h. After that, adequate amount of water was added to the mixture to make proper mould size. The prepared mixtures were compacted in laboratory type mould under 5 ton pressure with a hydraulic press (Weber-pressen Hamburg, Germany) for the perforated rectangular shape (50×50×50 mm^3). The pressed samples were taken out from the mould and held in open air for overnight followed by oven drying at 110°C for 24 h. These dried brick samples were fired at 650°, 850° and 1050°C for 3 h in a laboratory type electrical furnace at the rate of 5°C/min and soaking period was 15 min.

Characterization

All the fired samples were characterized by apparent porosity (ASTM C-29), bulk density (ASTM C-29) and linear shrinkage (ASTM D-4943). Chemical analyses of raw materials were characterized by ASTM C-114. Compressive strengths of the brick samples, made with red clay and different types of fluxing agent with dimensions of 50×50×50 mm^3, were determined by using Carver laboratory press (model –C), USA. Crystallographic analyses of bricks and raw materials were carried out on powdered samples by X-ray diffraction (XRD) (PAN Analytical X'Pert Pro XRDPW 3040) using CuKα radiation. Powder samples were prepared by quartering and grinding.

Results and Discussion

Chemical composition of red clay was investigated by ASTM C-114 method and the results are listed in Table I. The major constituents of this clay are silica, alumina and iron(III) oxide with minor contents of calcium, magnesium, sodium, potassium and sulfur oxides. According to Maniatis and Tite,[24] clay with CaO level <6% has been named as noncalcareous clay. As the clay material consists of only 0.05% CaO (Table I), it is nancalcarious clay. Waste glass materials consist of high amounts of fluxing oxides such as Na_2O and CaO. If the fluxes concentration (K_2O, Fe_2O_3, CaO, MgO and TiO_2) are more than 9%, the clays are termed as low refractory and referred to as high refractory if the fluxes in the sample are less than 9%.[25] As can be observed from Table I, even only Fe_2O_3 content is ~14%, the brick raw material (red clay) can be referred to as noncalcareous clay with low refractory properties.

Characterization with Sintering Behaviour

Sodalime glass influences the densification process by increasing firing shrinkage and decreasing open porosity and bulk density in respect to the reference bodies, especially when the glass content is higher than 10%. It also influences mechanical and tribological performances. However, waste glass promotes effective melting of quartz and partial dissolution of mullite, so that it can lead to a more abundant and less viscous liquid phase, thereby accelerating sintering kinetics.[26–28]

Technological Properties of the Brick Bodies

In this study, at least 12 samples were prepared for all types of compositions and were used at each test, the average of which was considered.

Replacement of waste glass in the clay brick influences the mass loss or loss of ignition. Usually when the waste glass content is low, i.e. 10% or lower, then most of the clay mixture contains chemically bonded water and organics inside, and the mass loss continuously decreases with the amount of waste glass addition.[29] However, if the waste glass content is higher than 10%, the phenomena is just opposite, i.e mass loss continuously increases with the amount of waste glass addition (Table II). This may happen because of the fact that when the glass content is high, it promotes more effective melting of quartz and a partial dissolution of mullite. Quartz decreases slowly for increasing temperatures; the amount of residual silica is inversely proportional to the addition of sodalime glass.[28] This, in turn, affects the mass loss and linear firing shrinkage, as shown in Table II and Fig. 1. Figure 1 shows that the linear firing shrinkage increases with increasing temperature and with increasing amount of sodalime glass. Sodalime glass has different effects on firing shrinkage behaviour depending on the composition of the clay brick mixture. Sodalime glass basically accelerates the densification process, increasing the linear firing shrinkage with increasing amount of glass content, especially when the glass addition is as high as 10%.[28] Furthermore, an increase in the linear firing shrinkage value with increasing amount of waste glass leads us to choose an optimum condition (% content of waste glass) considering the other parameters, which can help us to choose the best condition for making brick with lower firing shrinkage value.

Table I : Chemical composition of raw materials

Raw materials	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	Na_2O	K_2O	SO_3	Loss on ignition (LOI)
Red clay	46.53	22.45	0.05	0.44	14.85	0.2	0.19	0.1	8.38
Sodalime glass	77.20	2.24	8.21	2.67	0.21	8.27	0.28	–	–
Borosilicate glass	70.27	2.23	11.12	1.61	0.09	14.016	0.31	–	–
Coloured glass	73.62	2.53	8.36	1.06	0.25	13.27	0.63	–	–

Table II : Linear shrinkage and mass loss values of brick samples containing different amounts of fluxing agent

Sodalime glass content (%)	Linear firing shrinkage (%)			Mass loss (%)		
	650°C	850°C	1050°C	650°C	850°C	1050°C
0	0	0.37	1.87	6.83	7.48	7.82
20	0	0.49	2.91	7.10	11.01	20.31
35	0.03	0.63	3.78	7.29	19.49	29.41
50	0.05	0.84	3.97	7.47	24.22	31.07

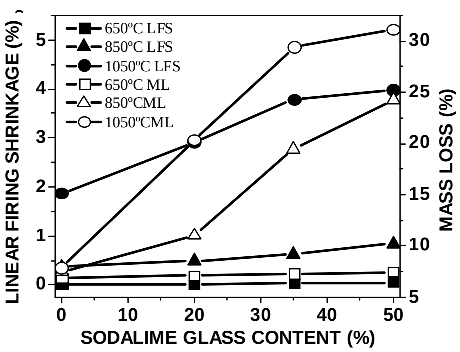

Fig. 1 – Dependence of linear firing shrinkage and mass loss on the %content of sodalime glass at different temperatures

When the waste glass (sodalime glass) content is lower than 10%, the bulk density of the samples are almost independent on either the content of waste glass in the mixture, or the chosen firing temperatures.[29] When the glass content is 20% or more, the bulk density increases significantly with the increasing amount of waste glass addition and also with the increasing firing temperature (Fig. 2 and Table III).

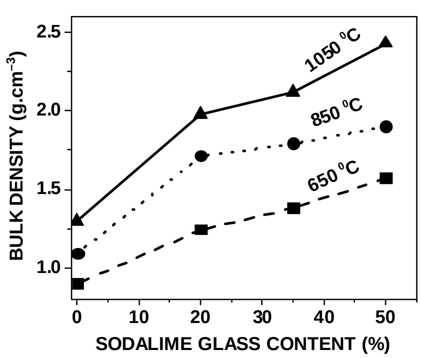

Fig. 2 – Dependence of bulk density on the %content of sodalime glass at different temperatures

Table III : Bulk density of the brick samples containing different amounts of fluxing agent

Sodalime glass content (%)	Bulk density ($g.cm^{-3}$)		
	650°C	850°C	1050°C
0	0.90	1.09	1.30
20	1.24	1.71	1.98
35	1.38	1.79	2.12
50	1.57	1.90	2.43

Another important property is the water absorption for the durability of the bricks. When water infiltrates into the brick, it decreases the durability and so the internal structure of the brick must be dense enough to avoid the intrusion of water.[29] Water absorption and apparent porosity are directly related to each other and the results are listed in Tables IV and V, and Fig. 3. Both the values decrease with increasing sintering temperatures and amount of sodalime glass content in the clay brick mixture.

Table IV : Apparent porosity of the brick samples containing different amounts of fluxing agent

Sodalime glass content (%)	Apparent porosity (%)		
	650°C	850°C	1050°C
0	41	37	21
20	37.44	29.05	16.93
35	33.21	26.04	16.06
50	29.91	24.65	14.68

Table V : Water absorption values of the brick samples containing different amounts of fluxing agent

Sodalime glass content (%)	Water absorption (%)		
	650°C	850°C	1050°C
0	13.65	13.52	11.41
20	9.48	8.30	3.14
35	5.71	5.32	1.84
50	4.73	4.71	1.40

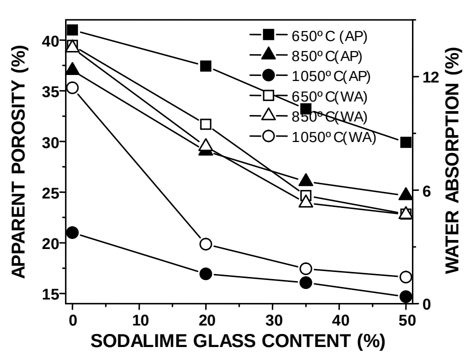

Fig. 3 – Dependence of apparent porosity and water absorption on the %content of sodalime glass at different temperatures

The compressive strength test is the most important test for assuring the engineering quality of a building material. Table VI and Fig. 4 show that compressive strength directly depends on the content of sodalime glass in the brick samples and also on sintering temperature.

Table VI : Compressive strength of the brick samples containing different amounts of fluxing agent

Sodalime glass content (%)	Compressive strength (MPa)		
	650°C	850°C	1050°C
0	21.88	22.22	25.62
20	26.84	26.85	34.02
35	28.88	31.79	35.14
50	31.36	32.42	37.18

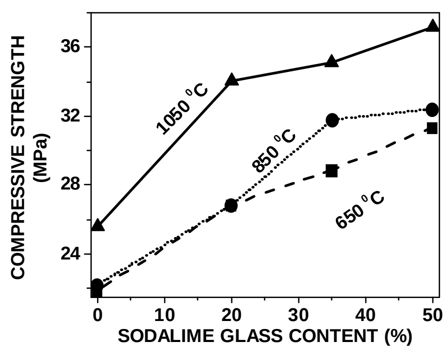

Fig. 4 – Dependence of compressive strength on the %content of sodalime glass at different temperatures

It has been already reported by other researchers that the compressive strength increases with increasing amount of fluxing agent and sintering temperature.[29–32] Percentage of waste glass is the most influential variable in the increase of the compressive strength. Fired clay brick, without any added fluxing agent in the control experiment, showed the lowest strength at the given temperatures. This was due to the increased porosity of the clay brick samples compared to those of the samples that include fluxing agents.

Figures 5a and 5b show that the compressive strength depends on various types of fluxing agent and the strength is lowest if no fluxing agent is added. 35% sodalime glass as a fluxing agent shows compressive strength better than that of other two with same content of fluxing agent. From Table VII one can conclude that sodalime glass containing brick material gives higher strength than those of borosilicate and coloured glass. From Table I it can be observed that sodalime glass contains optimum amount of Na_2O and CaO with a higher amount of SiO_2, which can lower the sintering temperature than the other waste glasses (borosilicate and coloured glass). From this study it is clear that Na_2O and CaO promotes more effective melting of quartz, as well as lesser crystallization and/or a partial dissolution of mullite which can lead the liquid phase

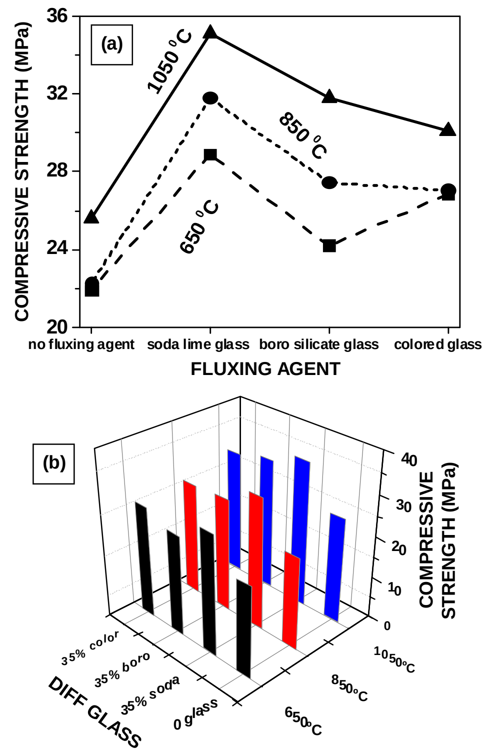

Fig. 5 – Variation of compressive strength as a function of different types of fluxing agent (35% content) at three different temperatures: (a) 2-dimensional view, (b) 3-dimensional view

Table VII : Compressive strength of the brick samples containing different types of waste glass

Different types of waste glass content (%)	Compressive strength (MPa)		
	650°C	850°C	1050°C
0	21.88	22.22	25.62
35% sodalime glass	28.88	31.79	35.14
35% borosilicate glass	24.18	27.44	31.78
35% coloured glass	26.84	27.04	30.08

to a saturation in SiO_2, Al_2O_3, Na_2O and CaO.[34] As a matter of fact, sodalime glass seems to modify the equilibria between the coexisting glassy and crystalline phases in the prepared brick samples.

XRD Analysis

X-ray diffraction patterns show the glassy and crystalline phases of clay materials and brick samples with varying amounts of sodalime glass, at 1050°C sintering temperature (heating rate 5°C/min) (Fig. 6). Usually kaolinite, illite and quartz are detected in the clay raw material, and when fired new phases are identified as oxides, hydroxides and silicates, in addition to the residual quartz.[33] It can be observed from Fig. 6 that a new peak appears for the brick sample with 35 wt% sodalime content at ~20 2θ angle, which gets intensified with higher amount of sodalime glass. However, with the higher sodalime

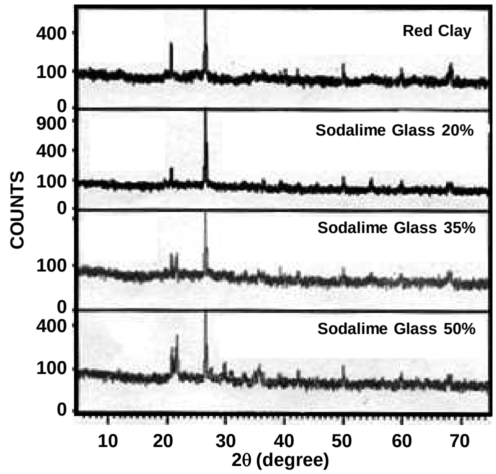

Fig. 6 – XRD patterns of the brick samples containing various amounts of sodalime glass at 1050^{o}C sintering temperature

content, the glassy phase becomes more prominent than the crystalline phase, and the increased crystallinity leads to higher shrinkage. Hence, although the compressive strength is higher for those compositions, the shape of the brick sample is changed. So from overall study it can be concluded that bricks made from the mixture of red clay and 35% sodalime glass is the best choice.

Conclusions

As clay materials reserve their original structures, which vary only slightly at low temperatures, the lowest strength comes at 650^{o}C, and improves at 850^o and 1050^{o}C. Generally conventional bricks of Bangladesh are sintered at 950^o to 1050^{o}C temperature These bricks have compressive strength between 2600 and 3000 psi. Compressive strength of the brick made with 50% sodalime glass was found around 31.36 MPa (4550 psi), which was much higher than that of conventional brick. Other physical properties of bricks like bulk density, apparent porosity, water absorption and shrinkage were also found better than those of conventional one. The heating rate of sintering temperature was also found to play an important role to get the desired physical properties of the finished bricks. XRD patterns of the prepared brick sample showed prominent glassy phase along with crystalline phase in it.

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