THE USE OF WASTE MATERIAL IN THE MANUFACTURING OF CLAY BRICK

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ABSTRACT

Fired clay bricks are produced when clay particles bond to one another at high temperatures, forming a glassy material, which, upon cooling, displays high strength and durability properties. High temperatures required to melt SiO_2 mean high energy cost associated with brick production. In addition to cost, challenges facing the modern brick industry include shortages of raw material and environmental impacts of production. The feasibility of using waste material as a brick body was investigated, where several possible waste additives, including slag, biological waste, and waste container glass, were considered. A literature review was conducted in order to assimilate past work and experimental results. The results of several testing programs were compared and the feasibility of further work in the addition of waste additives to bricks was discussed. Due to its soda content, amorphous glassy structure, and availability, waste glass was determined to be a feasible option for addition. The specimens with glass additions exhibited an increase in compressive and flexural strength, a decrease in the initial rate of absorption, and an increase in firing shrinkage. The determination of feasibility of adding slag or biological waste to bricks was hindered by a lack of comparable data; however, the limited comparison available suggested the necessity for additional, directly comparable testing programs. As a result, an experimental program was developed to investigate potential benefits in terms of strength, absorption, and durability of bricks associated with the addition of waste glass, as well as economic and environmental gains as a result of the process.

KEYWORDS: brick; clay; waste material; slag; glass

INTRODUCTION

The brick industry in North America relies on abundant natural reserves of clay and shale, which are mined from the ground and used to produce bricks with minimal use of additives. Although this method of production is currently cost effective, the availability of raw material and cost of production are becoming a concern to the industry. One of the possible remedies is the use of waste material, having a chemical composition similar to that of natural clay or shale, to replace a percentage of the raw material. The possible benefits are threefold: economic benefits due to a reduction in the volume of raw material required per unit produced, as well as a reduction in the firing temperature required; environmental benefits due to the diversion of solid waste from landfills, and placement of waste in a sound, inert and useful medium; and strength benefits due to the possibility of increased strength and durability of the fired bricks by using appropriate waste material to act as a fluxing agent within the brick.

A literature review to assess the feasibility of adding waste material to fired clay has been conducted. The review included additives such as waste container glass, fly ash, biological waste, and furnace bottom slag. The assessment of adding such materials to fired clay bricks are based on the reported test results for strength, durability, appearance, compatibility in production facilities, environmental, and cost benefits. Parameters investigated included the chemical composition of the base material, combinations of waste material, percentages of waste material, particle size and distribution of waste additive, and kiln firing temperature. These variables are expected to affect not only strength and durability properties, but also have direct influence on absorption, appearance, both drying and firing shrinkage, and distortion.

This paper will present the results of the literature review. The raw materials used in the production of standard clay bricks, as well as in the preparation of sample test specimens, will be discussed and compared based on chemical composition. Some of the potential waste additives will be discussed with respect to their composition, source, current uses, properties, and possible beneficial properties as additives. The results of experimental work performed using the potential additives will be summarized, with a focus on strength, absorption, and volumetric stability. Conclusions drawn from this comparison will lead to a discussion of future testing requirements for the determination of the feasibility of waste addition to clay bricks.

CLAY

The type and source of clay used in the production of bricks varies greatly depending on geographical location of the production site. In Southern Ontario, clay used for brick production is surface mined from shale deposits along the Niagara Escarpment, which are identified by their depth below the surface and approximate age of formation. Local producers use Queenston Shale, while British production uses Carboniferous Shale and Glacial Lacustrine Clay [7]. The chemical compositions of these and several other types of brick making clay and shale are provided in Table 1. The main difference between clay body types will be the silicon dioxide (SiO_2) content, as well as the aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3) contents.

Table 1 - Chemical Composition Of Several Common Types Of Brick Making Clay And Shale

Compound %	Etruria Marl[7]	Carboniferous Shale[7]	Quatrenary Glacial Lacustrine Clay[7]	Queenston Shale	Westerwald Ball Clay[3]	Egyption Body Mass[6]
SiO_2	61.1	58.48	68.71	46.83	61.06	62
TiO_2	1.27	0.95	0.48	0.77	1.57	traces
Al_2O_3	18.74	19.32	11.73	16.33	25.24	21
Fe_2O_3	9.58	7.73	3.61	5.83	1.2	4
CaO	0.3	0.61	2.7	9.9	0.18	2
MgO	0.51	1.61	1.84	2.96	0.46	<1
Na_2O	0.1	0.68	0.33	0.25	0.18	0.5
K_2O	1.96	2.5	3.02	4	2.21	2
LOI	6.16	7.82	6.57	12.5	7.9	6.5

The ability of clay to form a ceramic bond upon firing is due to the large amounts of silicon dioxide present in its particles. Upon heating, this compound softens into a glassy form, which bonds the remaining particles to one another where they are in contact in a process known as sintering, which is depicted in Figure 1. The strength, durability, and absorption of the resulting product are dependent on the state and nature of sintering within the brick. For the purpose of producing fired clay bricks, a silicon dioxide content of between 55 and 70 percent is ideal. Too little will lead to incomplete sintering and a weak finished product, while too much will cause unnecessary deformation and volumetric instability. For the purpose of comparison, most glass contains between 60 and 75 percent silicon dioxide.

The properties of the resulting product, including green and fired colour, shrinkage and deformation, extrusion characteristics, strength, and durability, may be influenced by the chemical composition of the clay; however they also vary depending on the unique microscopic composition of the material. Specifically, the amount of aluminum oxide in clay will increase the firing temperature necessary for sintering due to the relatively high melting temperature of this material, while the colour of the fired brick will depend heavily on the amount of iron oxide in the clay.

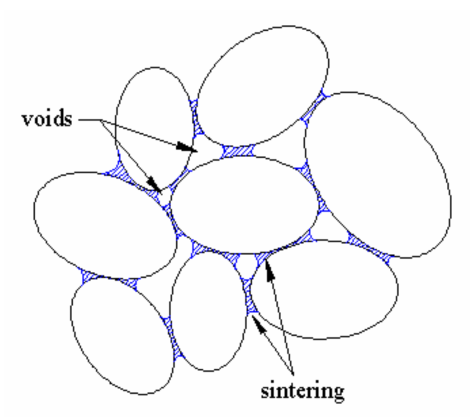

Figure 1 - Sintered Clay Particles

ADDITIVES

The literature review revealed that waste materials such as container glass [1-7], float glass waste [3], blast furnace slag [8,9,14], fly ash, sewage sludge ash [10], waterworks sludge [10], and municipal solid waste (MSW) incinerator fly ash [11] have all been tested as possible additives in clay brick. Although the testing programs were often specifically designed for an existing production facility, the results obtained were comparable in terms of the preliminary findings and possible future use as a brick additive.

Waste container glass consists of common soda-lime glass, or bottle glass. Container glass can be manufactured in a number of colours based on the addition of oxides. Common container glass colours include green, amber, and clear. Although all three types of glass have the ability to be recycled, commonly only clear glass, which has the highest value, is retained for recycling purposes. Amber container glass gains its colour from the addition of Fe_2O_3 (Ferric Oxide) and FeO (Ferrous Oxide), while green glass is coloured with the addition of Cr_2O_3 (Chrome Oxide) [11]. During the recycling process, these additives may cause difficulty in obtaining a consistent required end product, and are therefore undesirable. This waste glass has many possible uses outside of bottle production, and is often processed into sand sized particles for use in such applications. Glass has a high SiO_2 content, and has a chemical composition comparable to that of natural shale and clay. The highly vitreous state of glass increases its potential as a sintering agent in clay brick.

Blast furnace slag is a by-product of the steel making industry, and is abundant locally. Slag produced from a variety of metal working furnaces is used extensively as an aggregate in civil engineering applications such as for roadways and cement. Slag consists of dicalcium silicate (C_2S) and dicalcium ferrate (C_2F), with a SiO_2 content ranging from 10% to 18% [12]. The high content of lime can lead to volumetric instability as a result of hydration; however, treatments are available to minimize this effect. Despite the volumetric concerns, lime can act as a very effective flux in the vitrification process [13], and it is therefore beneficial to optimize its content. However, the temperature required to melt slag is very high, at approximately 1600°C [12], which may limit its use within the brick making process.

The remaining materials represent the use of biological waste as additives to brick body material. Biological waste can take many chemical compositions, as there are several point sources, such as water and wastewater treatment facilities, capable of producing a volume of waste that would support the constant supply required for addition into brick. Disposal of biological waste is demanding, as the volume of the waste is large and unstable. Current methods of disposal include landfill and agricultural land spreading. Although some form of pre-treatment is required to remove excess moisture, the incorporation of biological waste into bricks would help ease the current spatial demand for its disposal.

Table 2 - Chemical Composition Of Several Possible Waste Additives

Compound %	Waste Container Glass	Waste Float[3]	Waste Container Glass[5]	Steel Slag[14]	Granulated Slag[9]	BOF Slag[12]	Water Treatment Residue[10]
SiO_2	63.79	71.92	63.64	19.15	36.75	12-18	9.06
TiO_2	0.2	0.06	0.43	-	-	-	1.1
$Al2O_3$	3.02	1.22	2.16	1.18	17	<3	2.85
Fe_2O_3	1.57	0.36	0.14	7.64	0.6	14-20	83.9
CaO	9.9	7.45	0.66	41.98	39	45-55	0.92
MgO	0.89	3.95	0.22	1.16	5.2	<3	0.4
Na_2O	11.72	14.15	6.9	2.32	-	-	<0.05
K_2O	0.54	0.36	7.36	2.89	-	-	0.18
LOI	4.55	0	0	15.73	-	-	51.5

Table 2 contains the chemical composition of several possible waste additives. As can be seen from Tables 1 and 2, although the shale and clay compositions for each trial are comparable, the waste compositions vary greatly in chemical content, especially silica and ferric oxide, and as previously mentioned, the slag has very high lime content.

EXPERIMENTAL WORK

Several experimental procedures and scopes have been explored as a result of research initiatives dating back as early as the mid 1970s. Generally, a sample of both clay and waste material from various sources are combined in different concentrations by mass and waste particle sizes. The resulting strength, absorption, and durability properties of the bricks are then compared with a control brick to gage the resulting effect. Often temperature effects are also studied, where the temperature for a constant composition is varied in order to find the optimal firing temperature for the mixture. Although the experimental procedures are not exactly comparable, the results of the addition of the different types of waste material can be interpreted for comparison in order to establish the feasibility of production.

WASTE GLASS

The addition of waste glass ranged from 0.5% [10] to 94% [12] by mass; however, most studies tended towards a range from 5% to 20% glass by mass. The glass particle sizes ranged from 600µm to 45 µm. For all studies, shrinkage was noticed to increase as glass addition increased, as well as with increased temperature of firing. Figure 2 and Figure 3 depict the results obtained by Sanders [5], Matteucci [3] and Smith [7] for shrinkage effects. For lower percentages of added glass, shrinkage effects were dependant on particle size.

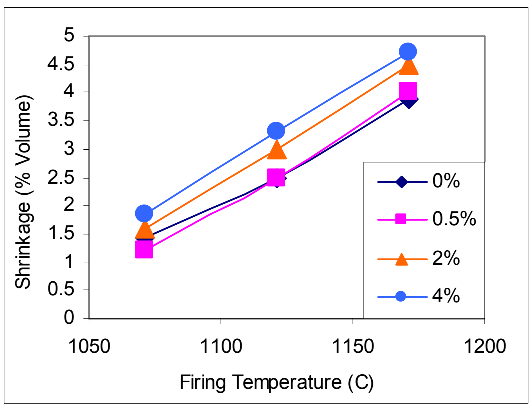

Figure 2 - Effects Of Glass Addition On Shrinkage [5]

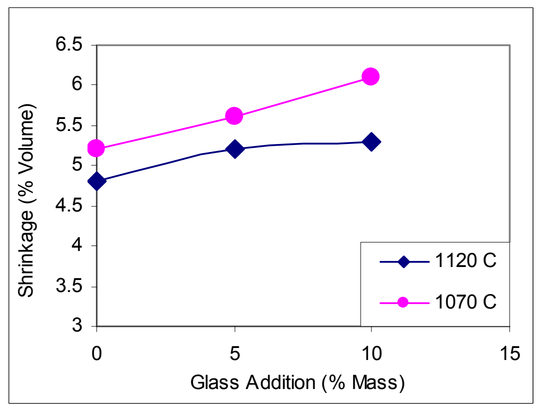

Figure 3 - Effects of glass addition and temperature on shrinkage [3,7]

Sanders [5] indicated that while a glass particle size of less than 75 µm added at 4% mass produced similar shrinkage values to a control brick, the addition of coarse glass, with particle sizes ranging between 132 µm and 150 µm at 4% caused shrinkage to decrease. According to the National Brick Research Council (NBRC) [13], larger particle sizes lead to incomplete sintering, where glass particles act more as an aggregate with sintered edges than a completely sintered medium.

The strength properties were determined for both compressive strength and modulus of rupture. Figure 4 illustrates some of the results achieved for various additions of waste glass [1,4,6,7]. The range of compressive strength values varies between specimens, which may be attributed to slight variations in particle size, specimen size and firing temperature for each testing method. The trend for all results, however, clearly indicates an increase in compressive strength with increased addition in waste glass, especially addition between 10% and 30% by mass. Values obtained for modulus of rupture demonstrates a similar trend. As can be seen in Figure 5, the actual MOR values obtained by two methods [4,5] are not necessarily similar due to differences in methodology; however the trend follows an increase in strength with increased waste glass addition.

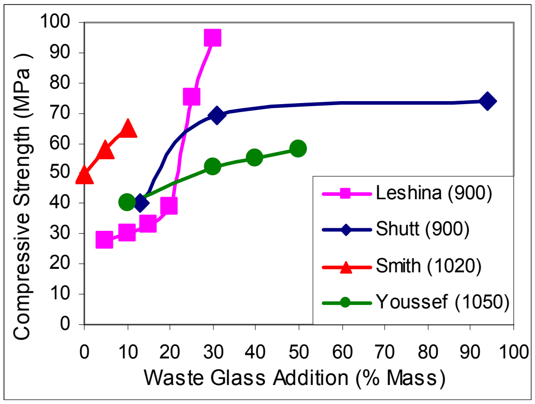

Figure 4 – Effects Of Glass Addition On Compressive Strength [4,1,7,6]

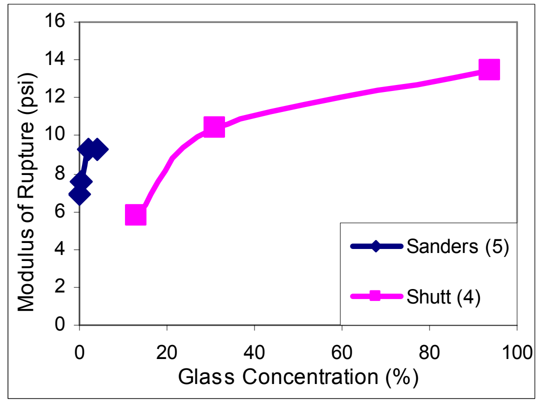

Figure 5 – Effects Of Glass Addition On Modulus Of Rupture [4,5]

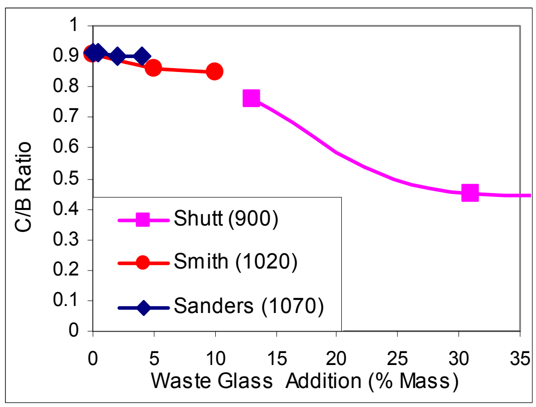

Figure 6 - Absorption Coefficient For Various Waste Glass Additions [4,5,7]

There is a lack of comparable data available with respect to durability testing of bricks with waste glass additives. The only results presented came from Leshina [1], who used sodium sulfate to simulate freeze thaw testing. Samples containing at least 5% waste glass were resistant to at lease 70 cycles of freeze thaw, a value beyond current code requirements. Since freeze thaw tests can be time consuming to perform, often absorption properties are used to establish the expected durability of a brick, as well as its performance in construction applications. The absorption coefficient (C/B), a ratio of the cold water absorption to the boiling water absorption, is often provided as a means of determining durability, where a lower C/B value may indicate greater durability and performance. Several C/B ratio studies were available for comparison [4,5,7]. Figure 6 indicates an apparent decrease in C/B ratio with increased waste glass addition, which further suggests increased durability.

SLUDGE

Sludge in the form of water treatment residue (WTR), industrial wastewater residue (IWR) and wastewater treatment residue (WWTR) has been added to fire clay bricks in various percentages by mass, and with several additives required to overcome processing complications. Work by Anderson et al. [10] considered addition of sludge ranging from 0% to 6% by mass, with addition of incinerated sewage sludge ash and carpet yarn in order to control excess moisture and improve plasticity [10], while work by Liew et al. and Weng et al. considered only sludge. While the procedure followed by Weng [15] seemed comparable to industrial processes, the specimens prepared and tested by Liew [16] used manual pressing methods for brick formation, and therefore, comparison was limited.

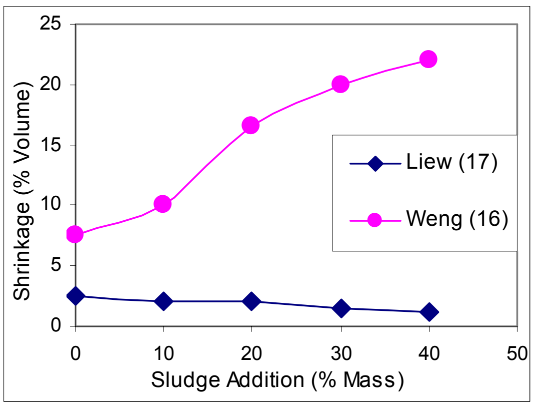

Figure 7 - Effects Of Sludge Addition On Shrinkage [16,17]

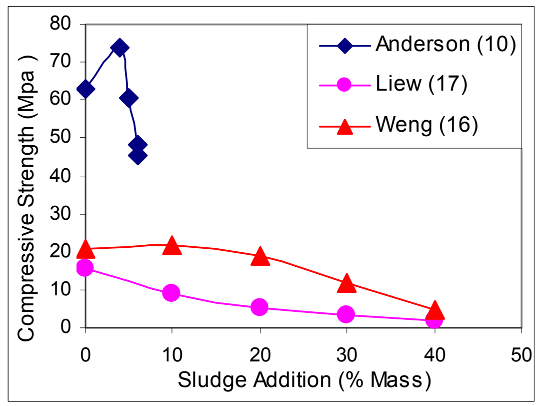

Figure 8 - Effects Of Sludge Addition On Compressive Strength [10,17,16]

Values reported for shrinkage were not comparable, and may be due to differences in preparation of specimens. While Liew reported an apparent decrease in firing shrinkage, quite the opposite result was recorded by Weng, who attributed the increase in the degree of shrinkage to the higher swellability of the organic matter in the sludge [15], as can be seen in Figure 7. According to Liew, work by Alleman (1987) and Ang (1982) demonstrated a similar contradiction of results. This contradiction could be a result of any number of factors, including sludge or clay chemical composition or particle size.

Testing of specimens prepared in a full factory setting tend to exhibit overall higher strength properties due to the highly pressurized extrusion process, as can be seen in Figure 8, where the resulting compressive strength of specimens tested by Anderson et al. are not comparable to those reported for the laboratory specimens. The trend in compressive strength of the specimens is, however, comparable, where an increase in sludge addition tends to decrease compressive strength, albeit at varying rates.

Figure 9 shows the similar trend in absorption values in fired clay bricks with waste sludge addition. Although the manually pressed bricks are observed to have absorption values 30% to 80% higher than mechanically produced bricks, the general trend of increased absorption is similar for addition of sludge between 10% and 40% by mass. Results presented by Anderson [10] with additional additives noted a similar trend. Durability results were also discussed by

Anderson, where some difficulties were observed in meeting durability requirements without the addition of alternative additives, including incinerated sewage sludge ash and carpet yarn. There are no data presented for those specimens to comment on the durability performance.

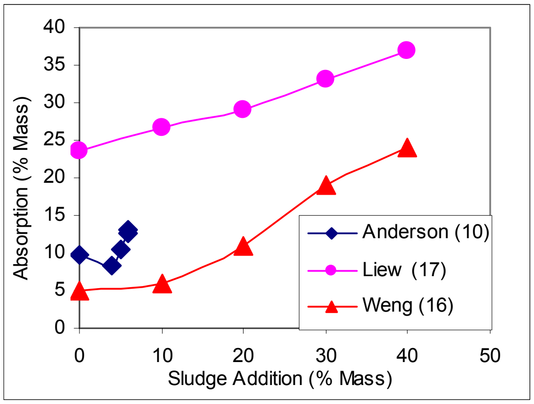

Figure 9 - Effects Of Sludge Addition On Absorption [10,17,16]

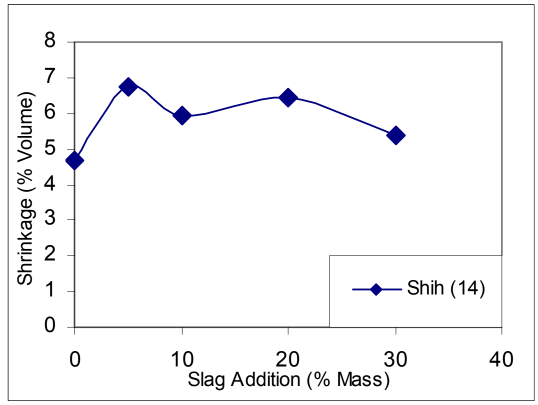

Figure 10 - Shrinkage For Various Slag Additions [14]

BLAST FURNACE SLAG

The high lime content in slag (Table 2), which can often cause volumetric instability in hydrating environments, tends to act as a sintering agent within fired clay bricks. Therefore, the application of slag in clay bricks may be appealing. Testing in this area has not been explored to the extent of waste glass; however, the following results discuss some attempts to incorporate slag specifically into clay bricks, where addition of slag varied from 5% to 30% by mass, and was often incorporated with other waste materials [8,17] to optimize benefits.

Work by Arkhipov [8] and Nishigaki [17] suggests reasonable values of shrinkage, acceptable in a production environment, are achievable with addition of 20% slag, and it was shown by Shih [14] that values of shrinkage varied only moderately with increased slag addition (Figure 10). Results presented for compressive strength indicate that values remain relatively consistent with addition ranging from 5% to 30% [14]; however, values were low in comparison to those achieved through the addition of waste glass. Unfortunately, the remaining comparable strength, absorption, and durability properties presented for slag addition to bricks include combinations of additional materials such as glass, grog, and coal [8,17]. However, the values presented do indicate that the addition of slag up to 20% by mass does not affect the properties of interest negatively, and has the advantages of replacing the non-renewable body material clay and potentially lowering firing temperature [14]. Results generated by a comparable process should be pursued in order to better interpret feasibility.

CONCLUSION

Review of the literature has led to the following conclusions:

Waste Glass:

1) Addition of waste glass showed an increase in strength, and decrease in C/B ratio.
2) Addition of waste glass in an industrial setting in the order of 10% to 15% by mass can be adopted to produce acceptable quality bricks.
3) Addition of glass tends to improve the quality of the bricks using lower firing temperature, thus significantly decreasing energy requirements.
4) Addition of waste glass reduces emission by lowering Hydrogen Fluoride by 33% [7].

Sludge:

1) Addition of wastewater and water treatment sludge to bricks demonstrated possible benefits to clay brick.
2) Inconsistency in the tested results and processes, as well as a lack of information with respect to actual chemical composition, consistency in materials, and product durability creates a need for additional laboratory testing representative of production facilities in order to determine whether or not this process is possible and would be desirable in North American industry.
3) Despite processing and product success, this concept may be beyond current legal and public acceptance.

Blast Furnace Slag:

1) Reported data lacked comparisons specific to slag addition without the combination of other waste materials and additives.
2) A testing program focusing solely on the addition of slag is necessary before any firm conclusions can be drawn on the influence of adding slag to clay bricks.

The data presented on the use of waste materials as additives in fired clay brick with the expectation to improve quality while reducing resource depletion and production cost, are only a narrow sample of possible alternatives and combinations thereof. It is recommended that at least one process of waste addition suitable for an industrial process be fully tested to adequately appreciate the benefits from waste diversion, cost reduction, and quality improvement perspectives.

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