TOWARDS A GREENER BRICK – CASE STUDIES ON THE FLUXING PROPERTIES OF INDUSTRIAL AND QUARRY FINES IN CLAY BRICK MANUFACTURE

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Abstract

The results of works based trials of alternative raw materials with fluxing properties in the clay brick industry are discussed. Two trials have led to ongoing cost benefits in a commercial setting at two separate brickworks using different base clays. In the first example, the addition of glass powder to a glacio-lacustrine clay results in the improvement of technical and aesthetic characteristics. This has led to increased market share over two years and European Standards are now complied with. The product market is no longer restricted. In the second case, the factory was already using a low temperature clay as a flux to reduce the firing temperature by 50°C but limestone present in the clay was increasingly causing problems. Again, glass powder was assessed with successful results. Full scale production is scheduled to begin in January 2011. As an alternative, a quarry water process filter cake was trialled successfully on a small scale and can act as a substitute for the glass powder.

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Introduction

Brick making is an ancient industry. The range of techniques is wide, from hand making in a cottage style setting for mainly local needs or specialist niche markets to highly mechanised and computerised mass manufacture for national and even international markets. Particularly in the latter case, it is highly energy intensive especially when using kaolinitic clays with a high natural firing temperature. Whether the driving force is economic, carbon reduction or both, attempts have been and continue to be made to produce bricks with a lower firing temperature and reduced energy consumption.

This paper focuses on the beneficiation of the raw clay by blending with two alternative materials; quarry filter cakes and recycled glass powder. The former is generated in hard rock quarries where clay and silt fractions are separated from waste water prior to re-use of the water or discharge off-site. The latter is generated by the recycling of glass bottles, which have silica, soda and lime as their main components and have a low melting point compared with clays used in brick-making. Filter cake and glass both possess fluxing characteristics that enable a lowering of the vitrification point of the mix and thus the firing temperature of the product. Two case histories are reported here. Firstly, a situation where the product was of relatively poor quality, and secondly, a lower firing temperature clay had previously been blended in to reduce the firing temperature but had ultimately caused other problems. This necessitated a replacement fluxing material to be found so that the lower firing temperature and attendant cost savings could be maintained.

The case studies presented are subject to client confidentiality restrictions. As a result the authors are unfortunately not permitted to present certain data especially regarding the type, origin and location of the clays used.

Brick making processes

The brick making process uses clay, mudstone or shale as the basic raw material. This is first ground to a powder, usually <0.5mm, mixed with water to achieve plasticity and formed into shape. It is then either stacked in static kilns or loaded onto transfer cars for passage through tunnel driers and kilns. Heat for drying is increased slowly so that moisture is removed without causing the brick to crack. The constituent grains are drawn into close contact during this drying process resulting in some shrinkage. Once dry, the rate of heating is increased and chemically combined water is gradually released from the crystal lattice, resulting in further shrinkage of the ware. During firing quartz and clay minerals eventually start to break down and the components recombine to form a glassy matrix. Other, principally iron bearing minerals are locked into the glass and give the brick its characteristic colour – the more iron, the darker red the colour is likely to be. This vitrification process is accompanied by further shrinkage, and is the process that ultimately gives the final product its hardness, strength and durability. The mineralogy is now permanently changed with a range of mainly alumina, calcium and potassium silicate glasses formed in relatively small quantities, but sufficient to bind together the residual minerals such as quartz and any new minerals formed. As a result of this process, when cool, the brick is hard and fixed to the moulded shape. There are several other important mineralogical changes but the most noteworthy results from the decomposition of carbonates, either as calcite or dolomite. Heat drives off CO_2 to produce CaO (lime), which can then take up moisture from the atmosphere in an expansile process known as slaking. If particles of lime larger than nominally 0.5mm are present at or close to the surface of the brick, the expansion can force the skin away to leave unsightly white or grey spots known as lime blows.

Experimental procedures

The chemistry and mineralogy of the clays and additives were determined using X-Ray Fluorescence (XRF) and whole rock X-Ray Diffraction (XRD). Related to fluxing action, XRF would show higher silica, potash and soda content along with lower alumina content for a better fluxing material (allowing a lower firing temperature). XRD would show greater proportions of quartz, illite, chlorites and/or feldspars. A higher proportion of very fine material (<5 microns), would increase the reactivity of a fluxing material in a blend. Particle size was measured by sedigraph.

Shrinkage is the most important property by which fluxing effect is measured in ceramic products. Laboratory samples are made with marks indented at a set distance apart. The distance between them is measured after drying, and again after firing. Drying and firing shrinkage is customarily calculated from the measurements on a dry basis, and total shrinkage on a wet basis (respectively, wet-dry/dry, dry-fired/fired and wet-fired/wet). The greater the fired shrinkage, the greater the fluxing effect. An additional benefit in drying is often noted, whereby greater additions of glass powder show a reduction in drying shrinkage. The Lime Index is an industry empirical test whereby a 10g sample of clay is submerged in dilute (10%) Hydrochloric acid in a petri-dish. The acid reacts with any carbonates present and the CO_2 produced results in effervescence. Small particles less than 0.1mm in diameter, and particles showing a very weak reaction are usually not counted as experience shows that they would not be expected to produce lime blowing in the fired product.

Case study 1: Product Improvement

Clay A is an illite rich glacio-lacustrine clay with a relatively low firing temperature but also a low clay mineral content resulting in a brick of low strength, high porosity and poor durability. The product failed to meet various European Standard tests and so had a market limited to sheltered locations and mild climates. The challenge was therefore to find a material capable of reacting with the clay mineral to bring the onset of vitrification earlier, at a lower temperature. In this way, the firing temperature could be maintained at its original level but the technical characteristics of vitrification would be enhanced, giving greater strength and durability and a better quality brick.

Previous research at the works had demonstrated the potential of glass powder to achieve this but had not progressed to full scale production. Glass powder of nominally less than 250μm in size was readily available. Laboratory scale trials were carried out first using the base clay as a control, then adding glass powder in increments of 2.5%. These samples were fired together to the same temperature, and subjected to a number of tests, principally fired shrinkage, see Table 1. The samples were also fired under load to assess the effects of the added proportions of glass, see Figure 1. This demonstrated that the more glass that is added, the greater the firing shrinkage. A secondary benefit demonstrated in this case is that the dry glass powder acts as a filler during the drying process, so the drying shrinkage decreases with more glass (Table 1). This reduces the strain on the brick during drying and has improved waste levels due to cracking in the dryer. The under load test is particularly revealing, giving a continuous temperature vs. shrinkage trace (Figure 1). The Red line shows that without glass addition shrinkage commences at just under 1100°C and with increasing proportions of glass powder, shrinkage starts at a lower temperature and is greater at any given temperature. In this case only ceramic tests were carried out and no chemical or mineralogical tests as the client wished to keep testing costs to a minimum, and was concerned only with the effects of the glass additions and not the causes.

It was decided that the addition of 5% powder and maintaining the same firing schedule should produce tangible benefits at a cost effective price. A small scale works trial was then carried out to prove the theory under practical conditions, and the bricks were found to be stronger and more durable. (Actual data cannot be presented due to client confidentiality restrictions). This trial gave the confidence to attempt a full scale works trial in 2008. Glass fluxing powder has been added to almost all products since that time enabling the customer confidently to sell the product into more lucrative markets whilst reducing the number of complaints received due to inferior quality. The brick also has a brighter, more vibrant colour which has enhanced sales further.

Addition	Drying Shrinkage (%)	Firing Shrinkage (%)	Total Shrinkage (%)
Control	9.0	0.7	9.6
2.5% glass	8.2	1.0	9.1
5% glass	7.7	1.4	9.0
7.5% glass	6.0	1.7	7.6

Table 1. *Effects of glass powder additions on shrinkage of Clay A showing decreasing drying shrinkage and increasing firing shrinkage.*

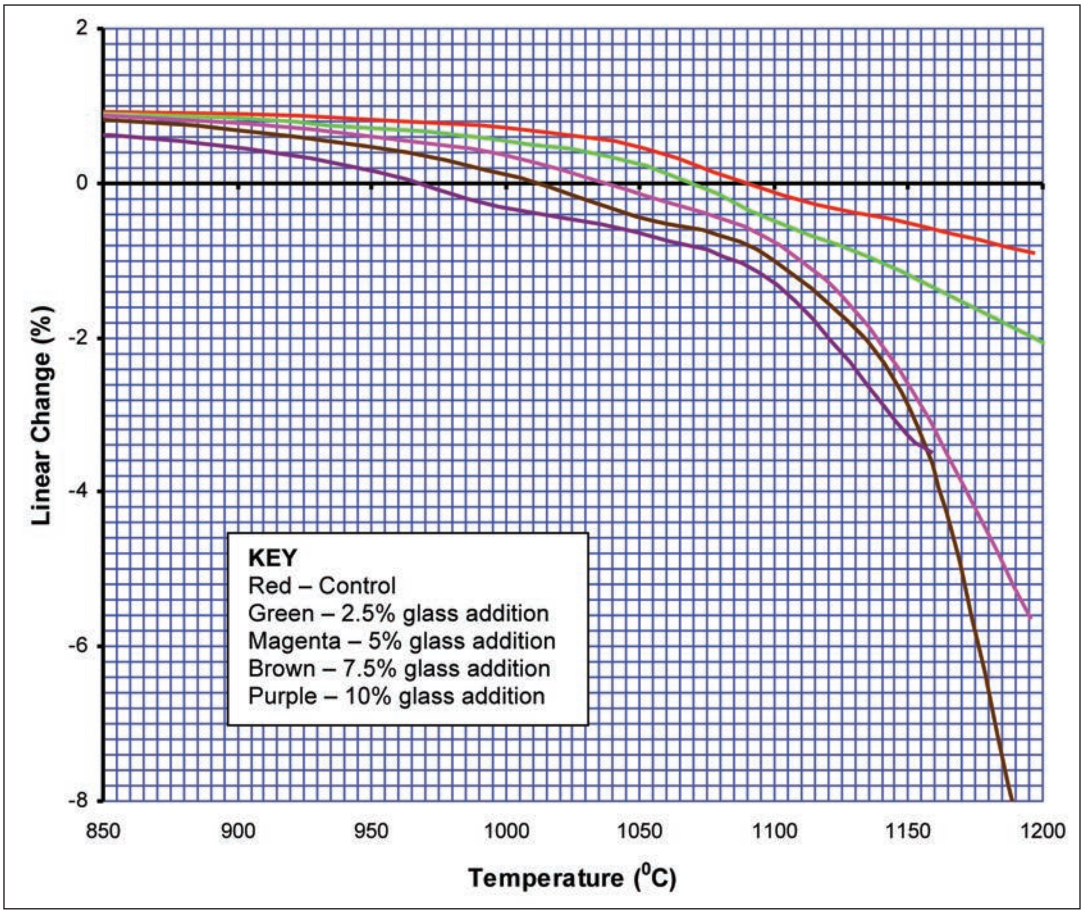

Figure 1. *Firing under load curves showing progressively earlier onset of vitrification with increasing glass powder additions.*

Case study 2: Energy Saving

This works used a kaolinite rich Carboniferous clay, Clay B, with a higher firing temperature than Clay A. Attempts had been made to reduce the firing temperature, and thus make savings on gas consumption in the kiln, by adding a lower firing temperature clay, Clay C, in a blend at a rate of 20-25%. Clay C contains more illite and less kaolinite than Clay B. Illite contains a higher proportion of potassium compared with kaolinite which is alumina rich (Table 2). The net result is that this blend requires a lower firing temperature. Initially this was successful, enabling the top temperature to be reduced by 50°C, but it was found in time that lime blowing was becoming a serious and gradually worsening issue, resulting in increased wastage along with the danger of complaints should the phenomenon occur after the product had left the factory. The lime index is an empirical quality control test where 100g of ground clay is immersed in dilute hydrochloric acid and the number of effervescing particles counted. Figure 2 shows that the problem became worse with every stockpile in which Clay C was used.

In this case, the manufacturer had previously assessed glass powder without success and was convinced that it would not be a suitable replacement for Clay C. There were also doubts as to whether consistent addition of glass powder to the clay mix would be possible, potentially resulting in unacceptable variability of the product. Following success with Clay A, there was confidence that these issues could be overcome, but none the less attention was focussed on seeking an alternative solution as well. We were aware of the potential fluxing properties of some quarry filter cakes, and obtained a number of such materials from quarries within economic haulage distance. Laboratory scale trials indicated which of these was likely to give the best results at the most economical price.

Using Clay B as a control, laboratory trials were conducted using glass powder additions at 2.5% increments and quarry filter cake at 10% increments. All the samples were fired together and tested in the same way as the Clay A laboratory trials. This proved that both the glass powder and the filter cake gave the desired effects as shrinkage increased, and that 2.5% glass powder was broadly equivalent to 10% filter cake and 5% equivalent to 20%, see Table 3, dry to fired results. These samples were all fired at the same temperature and the fluxing effect was indicated by darker fired colours and increased firing shrinkages. Matching the colour of the control sample was a critical factor, so using a fluxing additive enabled a reduction in firing temperature which would therefore save energy costs. A slightly better performance was achieved with glass powder than with filter cake. Further, the 5% glass and 20% filter cake additions were both comparable in terms of fired colour with the blend of Clays B and C, allowing continuity of product characteristics.

A limited mineralogical analysis was carried out (see Table 2) and there are several significant factors to note; kaolinite has refractory properties (it requires a higher

Element	Clay B	Clay C	B + 25% C	Filter Cake	B + 20% FC	Glass	B + 5% glass
SiO_2 (%)	59.18	50.74	56.01	59.32	59.13	72.20	59.83
Al_2O_3 (%)	20.06	14.77	19.15	17.24	18.78	1.50	18.69
K_2O (%)	1.76	3.56	2.13	1.71	1.78	1.65	1.68
Na_2O (%)	0.22	0.27	0.10	2.58	0.60	13.30	0.73
CaO (%)	0.72	5.02	1.57	4.81	1.36	10.90	1.17
MgO (%)	0.84	6.12	1.89	3.67	1.39	0.45	0.93
Fe_2O_3 (%)	8.47	5.52	7.81	6.34	7.70	0.07	7.74
LOI (%)	7.50	12.96	10.00	3.39	7.95	2.00	7.98
Illite/smectite (%)	7.1	10.3	7.3	ND	6	NA	6.9
Illite + mica (%)	13.3	31.8	13.3	ND	12.6	NA	12.6
Kaolinite (%)	24.2	5.4	24.4	ND	19.3	NA	19.3
Chlorite (%)	12.6	6.2	8.4	ND	12.0	NA	12.2
Quartz (%)	33.7	21.2	30.5	ND	35.0	NA	36.5
K feldspar(%)	0.0	3.1	1.7	ND	2.0	NA	2.0
Plagioclase (%)	0.0	2.3	1.1	ND	4.2	NA	1.5
Calcite (%)	0.0	4.3	2.0	ND	1.2	NA	0.0
Dolomite (%)	2.0	10.4	4.5	ND	1.5	NA	1.1
Haematite (%)	7.0	2.0	6.8	ND	6.2	NA	6.5
XRD Total (%)	99.9	97.0	100	ND	100	NA	98.6
Lime Index	54 [1]	ND	29 [2]	ND	12	NA	9
<5 microns (%)	71	ND	72	ND	64	ND	71

[1]: Mostly very fine particles, quality control results indicate an expected figure of 10
[2]: Coarse particles
ND = Not Determined. NA = Not Applicable (XRD cannot be carried out on non-crystalline substances).
(Results presented are mean of several samples)

Table 2. *Comparison of technical properties measured by XRF, XRD (whole rock analysis), Lime Index and particle size.*

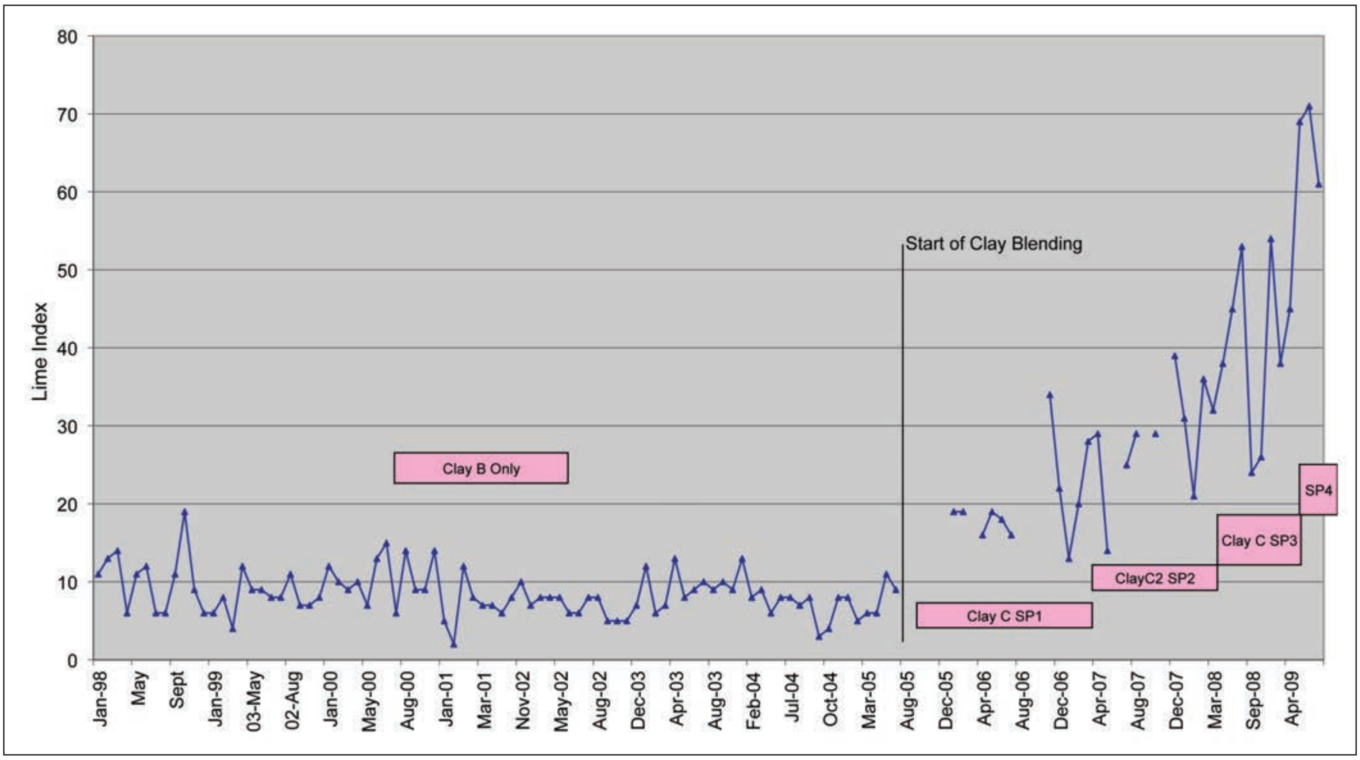

Figure 2. *Progressively increasing incidence of lime blowing, from four stockpiles containing Clay C.*

Blend	Drying Shrinkage (%)	Firing Shrinkage (%)	Total Shrinkage (%)
Clay B	3.7	2.2	5.7
B + 2.5% glass	3.3	2.5	5.7
B + 5% glass	3.4	3.0	6.3
B + 7.5% glass	3.5	3.3	6.7
B + 10% filter cake	3.0	2.9	5.8
B + 20% filter cake	3.1	3.0	5.9

Table 3. *Effects on shrinkages of glass powder and filter cake additions.*

firing temperature than other clay minerals) so reducing the proportion of this mineral compliments any active flux addition. Silica and quartz are both low in Clay C, the fluxing effect coming from increased illite/mica and reduced kaolinite content and very fine grained carbonates which can form calcium and magnesium silicates at relatively low temperatures. Coarser particles of carbonate result in lime blowing, and result in a higher lime index. The lime index for Clay B in this sample is disproportionately high, but the particles were noted to be very small and we know from factory quality control results that the average figure is around 10. The high LOI (Loss on Ignition) figure shows the breakdown of the calcite and dolomite carbonates as CO_2 is lost. Overall, the blends of Clay B with glass powder and filter cake are very similar, confirming the ceramic results observed. There is increased quartz and decreased kaolinite in both. The slightly better performance of the glass can be explained by a higher proportion of the sub 5 micron fraction in the particle size distribution, which increases reactivity of the powder and thus enhances its fluxing characteristics.

Short production runs of 1000 bricks each were carried out with 20% filter cake and 5% glass additions and fired in a small kiln to see how they performed in a small scale production run. The client reported that the results were not quite as good as hoped, but good enough to justify introducing the glass powder to the mix. Shrinkage was greater for the glass addition, and porosity (as measured by water absorption) correspondingly lower. Although the glass blend never quite achieved the same degree of fluxing as Clay C, it was always slightly better than filter cake blend. Actual test results were not disclosed to the authors.

Due to the better results and a slightly lower overall delivered cost, the manufacturer decided to introduce the glass into full scale production. Issues of powder handling and addition to the mix have been addressed by installing a silo (also enabling delivery by bulk tanker) with a screw feed system to control addition rates to the mix. The effectiveness of a screw feed was demonstrated during the pilot trials. Again, client confidentiality restrictions prevent further detail being presented here, and the authors have had to rely on the comments received from the client which have been confirmed by installation of equipment as described.

Production is due to be moved over to the glass blend at the beginning of 2011, 12 months later than originally anticipated due to the effects of the economic recession.

It is the manufacturer's intention, once the glass additions have been fully proven in a production environment over a period of time, to carry out further work to introduce quarry filter cake as well as glass powder in an attempt to further reduce the firing temperature. It is thought that this may be more economically and technically viable than relying on increasing the proportion of glass powder addition slightly. Utilising quarry filter cake precludes the reliance on a single ceramic reaction for the fluxing effect. Rather, adding a clay based fluxing material to the blend with a high proportion of elements such as silica and potassium present as very fine grained quartz, feldspar and illite-mica may enhance the effect of the glass powder.

Conclusions

Glass powder, produced as fines from the manufacture of higher value products from recycled glass bottles, has been proved to reduce the fluxing temperature of two very different clays in a full scale production environment. The cost benefit has been demonstrated clearly by two different brick manufacturers, each taking the decision to incorporate 5% glass powder into their mix. One has benefited from improved product technical characteristics allowing increased sales into a wider market, the other from a reduced firing temperature and attendant financial savings as less gas is used in firing the ware. On a laboratory scale, it has been demonstrated that a quarry filter cake generated from a water purification process also produces fluxing effects. The filter cake trialled in this case compared well with glass powder, a linear relationship being observed as additions of each alternative raw material to the same control clay were tested. 20% filter cake addition gives comparable results to a 5% glass powder addition. Further trials using filter cake will be undertaken in 2011, with a view to further reducing the firing temperature by adding both alternative materials together.

By employing a methodical, scientifically controlled approach to the addition of alternative materials it is possible to ensure that product quality is not compromised and that the cost benefit is fully understood. In this manner, it is possible significantly to reduce the production cost and carbon footprint of this essential building commodity, and move towards a greener brick.