Creating markets for recycled resources

R&D Report: Glass

Glass Addition Trials:
York Handmade Bricks Co Ltd.

Project code: GLA 0037

Date of commencement of research: September 2004
Finish date: January 2005

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Published by:

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Date (published): February 2005

ISBN: 1-84405-203-6

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1. Summary

1.1 Research Objectives

Following on from the success of the WRAP funded project [1], York Handmade are keen to continue the assessment of the benefits that recycled glass could bring to their product range. The purpose of this project is therefore to undertake a trial and testing programme that will maximise the information gathered enabling commercial decisions to be made as to whether or not the use of recycled glass powder will be economically viable for York Handmade in the future.

York Handmade produce 2 main body types, basically the same clay but one with coke breeze (fine grained coke recovered from the coke washing process), and those without. It was decided, in consultation with York Handmade to undertake the trials on the body that did not contain the coke breeze, therefore the reactivity would be directly proportionate to the interaction between the clay and the glass, rather than with the added variables presented by the coke breeze addition.

The baseline against which the results were to be measured is routine production firings of the Hambleton range of bricks. These products are typically fired to 1000°C in the 2 natural gas fired moving hood kilns that York Handmade have. Figure 1. Shows the Hambleton Blend product specification sheet copied from the York Handmade website [3].

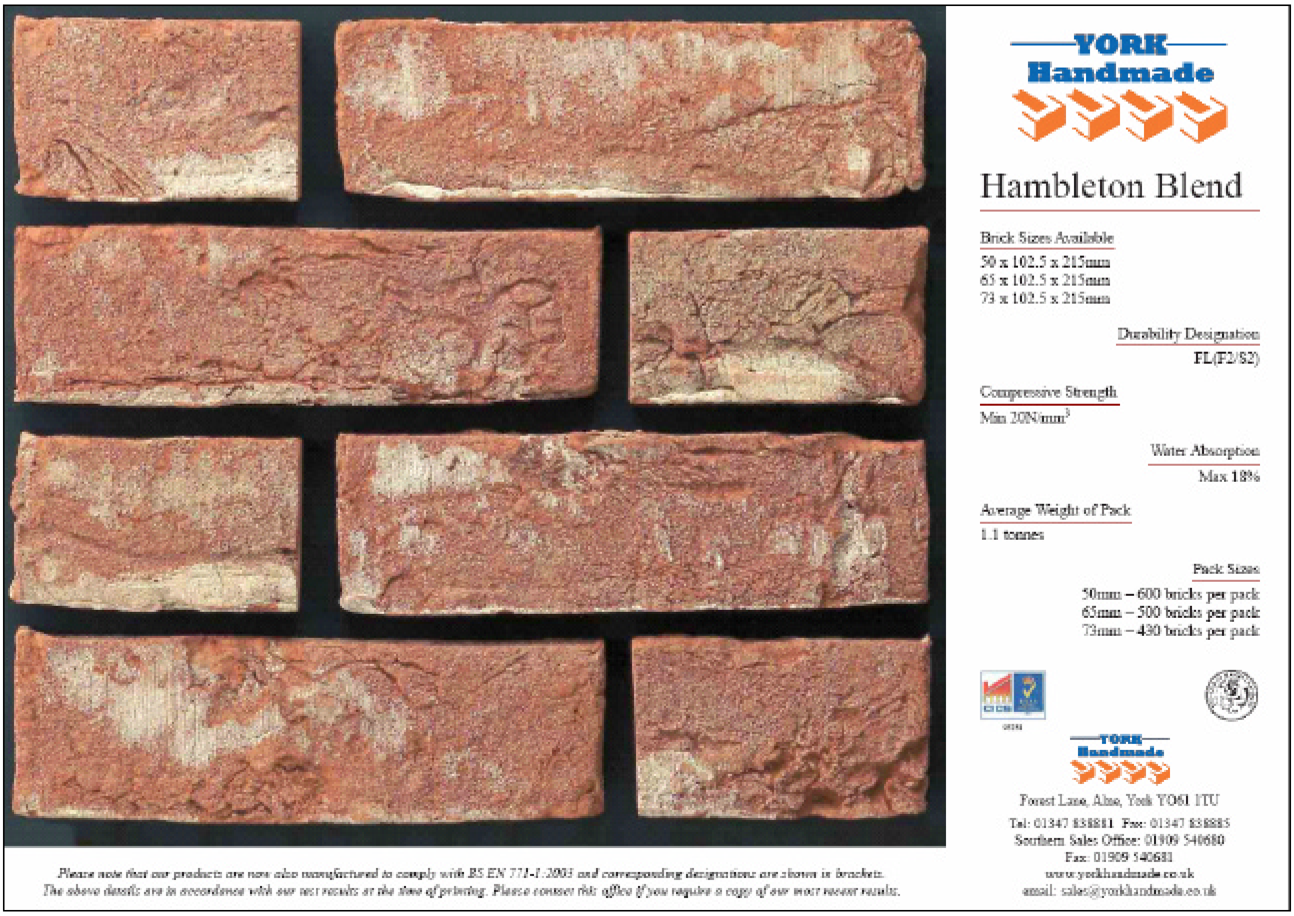


Figure 1. Hambleton Blend product specification sheet (downloaded from the York Handmade website)

The project was designed to test the quality and measure the technical performance of bricks containing 5% and 10% replacement of the clay by powdered recycled glass, and subsequently fired at 970°C and 950°C (-30°C and -50°C from normal firing conditions) for the same duration. Lowering the firing temperature will reduce the energy requirements for the firing, and the benefits or modifications to the technical properties of the bricks are measured against the possible energy savings.

1.2 Results

In all cases the addition of glass to the body, both at 5% and 10% addition levels has resulted in an improvement on the clay alone results for the comparable firing temperatures and duration. From this it can be clearly seen that the addition of the glass has been beneficial, resulting in a modified pore structure and increased compressive strength.

Of the physical properties measured as part of this investigation, water absorptions, both 24 hour cold water and 5 hour boiling water results have improved, against the controls, though only marginally different between the 5% and 10% glass addition values in both trial firings.

Compressive strengths have increased in all glass addition bodies, again the increase corresponds to the level of glass addition, but like the water absorption values, the benefits of 10% glass addition are only marginally better than the 5% glass addition values.

The only property where there was a clear advantage in the addition of 10% glass over 5% was that of freeze-thaw durability. In this case the results clearly show that the 10% glass addition bodies both passed the requirements for the severe exposure classification (F2) (prEN 772-22), where as the controls and 5% glass additions only met the requirements for moderately exposed (F1).

Overall, colour appears not to be significantly affected by the glass additions, at the firing temperatures trialled.

Analysis of the energy consumption of the two trial firings shows that there is a potential saving of 18.7% in crude gas metered volumes with a reduction of 50°C from the normal firing soak temperature. There is additionally a saving in the length of the firing of up to 3.5%.

The overall result of the two trials shows that there is only a marginal benefit in adding 10% glass over 5%, but this would on the face of it leave the bricks less frost resistant. This could be countered by maintaining the normal firing duration, and increasing the soak time with a modest reduction in firing temperature, 20-30°C. This would generate the required amount of heatwork, and would also benefit from reduced firing temperature, still returning an energy saving.

2. Introduction

The UK brick industry manufactures in the region of 2.85 billion bricks per annum (2004 figures), consuming approximately 8 million tonnes of raw materials, primarily clays, marls, silt- and mud-stones from across the UK. The raw materials are highly variable in their characteristics and give rise to bricks and pavers of wide ranging technical performance. Planning constraints for new quarries and stricter environmental impact conditions of the working of clay pits and quarries means that the value of the workable reserves in the ground are as high as ever. Raw materials are the 'life blood' of the brick industry, and the deposits are a major financial and strategic factor in the operation of the brick manufacturing industry. An alternative to using virgin raw material, even at a level of 5% potentially reduces the year on year consumption of the clays by 350k-400k tonnes.

As a very significant energy user, the UK brick industry, has a yearly consumption of approximately 4.06 billion kWh equivalents of natural gas, (= c. 138.7 million therms, = c. £52 million) based on fourth quarter 2004 energy prices. Any potential savings on the volume of the energy used to manufacture the bricks would therefore offer significant financial savings.

Powdered recycled glass has been shown to be a very active body additive, even at levels of 5% (wt/wt), CERAM Report published by WRAP 2004 [1]. Even at such moderate addition levels, as a direct replacement for raw clay, recycled glass powder can result in significant reductions in both energy consumed during manufacturing, and the emission of pollutant exhaust gases, such as Hydrogen Fluoride, but also can result in benefits to the technical and physical properties of the bricks.

York Handmade Brick Co Ltd were one of the 4 original manufacturing partners in the initial WRAP project. Following the results of the project, York Handmade were keen to investigate further the potential benefits of powdered recycled glass for their manufacturing process. In order to evaluate this CERAM Building Technology, the Project Managers in the WRAP 2004 report were commissioned to undertake a bespoke investigation.

The investigation consists of 2 trial firings each containing equal amounts of bricks containing no glass (controls), 5% glass, and 10% glass, and fired to 2 different top temperatures, namely 970°C (30°C below the normal firing top temperature, 950°C (50°C below the normal firing top temperature). During each firing, total energy, in terms of total gas volume consumed was recorded.

3. Raw Materials

3.1. Powdered Glass

The powdered glass for this trial was provided by Glass Recycling Group Ltd (GRG) from their milling plant in Longport, Stoke on Trent. The glass is almost exclusively from the processing and milling of mixed colour cullet derived from container glass. GRG employ a primary crusher followed by a VSI (variable speed impactor) to produce the powdered glass, which is then subsequently screened through a mesh screen and finally air classified to achieve the required particle size distribution as specified in PAS 102: 2004. [2]. Table 1. Shows the particle size distribution requirements as specified in PAS 102: 2004

3.1.1. Particle Size Distribution

Particle Size (μm)	Percentage Passing (%)
150	100
75	90
45	50

Table 1. Supply specification for powdered recycled glass for use as a fluxing additive in clay brick manufacture. Taken from PAS 102:2004.

Particle size is a critical parameter in the level of reactivity and as such requirements for the use of powdered recycled glass as a fluxing additive in clay brick manufacturing has been specified in PAS 102:2004 in order to safeguard the "quality and reactivity" of the materials supplied into the Brick Industry.

The level of reactivity is principally governed by the surface area to volume ratio, therefore the finer the particle size the greater proportionally the surface area. This is important, as with such relatively low addition rates, 5%, it is important that most if not all the glass is "active" in the formation of the melt phases during the firing process.

3.1.2. Chemical Analysis

	Clay Alone (Control)	Clay +5% Glass	Clay +10% Glass		GRG Average Glass
SiO_2	63.00	63.97	63.98		69.97
TiO_2	0.59	0.53	0.52		0.12
Al_2O_3	14.10	13.14	12.86		3.03
Fe_2O_3	4.45	4.18	4.06		0.51
CaO	3.24	3.87	4.03		10.41
MgO	2.31	2.20	2.19		1.65
K_2O	3.08	2.90	2.85		0.65
Na_2O	0.35	1.26	1.65		12.58
P_2O_5	0.11	0.10	0.10		0.02
Cr_2O_3	0.01	0.02	0.03		0.12
Mn_3O_4	0.06	0.06	0.06		0.03
LOI	8.62	7.73	7.55		0.44
Total	99.92	99.96	99.88		99.40
Calc Glass %	-	6%	10%		-

Table 2. Chemical Analysis of the Clay, Glass and Clay-Glass Mixes (Major Element Oxides Percentages determined by XRF)

In order to check the amount of glass added to the bricks during the manufacturing process, X-ray Fluorescence analysis has been employed to determine the major element oxides. The results are presented here in Table 2.

The results show that on the basis of the average composition of the glass supplied by Glass Recycling Group RG Ltd, the addition rates for the glass are 6% for the nominally 5% addition rate and 10% for the 10% addition rate, therefore within the range of control available by the addition method, in this case a variable speed discharge belt from a hopper.

3.2. Clays

3.2.1. Quaternary Glacial Lacustrine Clay (York Handmade)

York Handmade Brick Co Ltd are sited in the Vale of York, to the NNW of York on the outskirts of the village of Alne. Historically, and still to date, the principle raw material is the local glacial lacustrine clay (as described by the British Geological Survey) won from the adjacent quarry. The quarry is currently operated by a local landfill operator, and clay is won on an intermittent basis, typically when a new cell is required for the landfill operation. The brickworks currently maintains a substantial stockpile between the factory and the quarry.

The glacial/alluvial lacustrine clay is a deposit of Recent age (in Geological Timescales). The deposits are lake deposits laid down during the last major glacial period (11,000 yrs bp). The clays are made up of thinly layered sequences representing annual deposits from meltwaters entering the lake during the summer months.

The clays are made up of predominantly silt sized quartz, disordered kaolinite and illite, with variable amounts of chlorite and the carbonate minerals calcite and dolomite. The clays tend to be plastic in nature and thus lend themselves to the hand throwing process used at York Handmade.

4. Works Trials

4.1. Trial Parameters

The trials were undertaken on the Hambleton body type, clay without the addition of any body fuel/colourant in the form of coke breeze. This body, following drying, is normally fired over a period of 94.5 hours including a 10 hour soak period (top temperature) at 1000°C.

All the bricks have been made in the same way, with the exception that 5% and 10% substitution of the clay has been undertaken for the 2 glass addition trial bodies under investigation. 25,000 bricks were fired in each of the 2 trials, and each firing contained approximately 1/3 - control samples, 1/3 - 5% glass additions and 1/3 - 10% glass additions.

The kiln hearth uses a setting pattern of 25 stacks each containing 2 packs of bricks (500 per pack) set in a 5x5 pattern. Figure 2. shows a partially dehacked hearth from a “normal” firing.

Figure 2. Hearth setting pattern for the moving hood kiln used in the trials.

4.2. Firing Regimes

It was agreed at the initial project meeting that in order to simplify the interpretation of the results of the trials, the only factor (variable) that would change would be the soak temperature. In practice both temperature and duration were changed. The first trial reduced the soak temperature to 970°C, and the second to 950°C. A diagrammatic representation of the firing regimes used is presented here in Figure 3 and 4. As a result of this the actual firing time is marginally reduced, by 2 hours for the 970°C firing and 3.32 hours for the 950°C firing, due to reductions in the ramp time. There is therefore a cumulative effect on the heatwork done on the bricks during the reduced temperature firings, that of temperature and time.

The firing regime is fairly standard for most intermittent kilns such as the ones used at York Handmade, the ability to programme in relatively long “dwells”, periods at constant temperature, is a distinct advantage for clays that contain high clay mineral content, such as the lacustrine clay used by York Handmade, or where body fuels are used in the body mix to aid even firing, or more typically to modify the fired colour of the bricks. These dwells allow for even burnout and temperature development throughout setting, which results in a more even heat distribution and therefore quality.

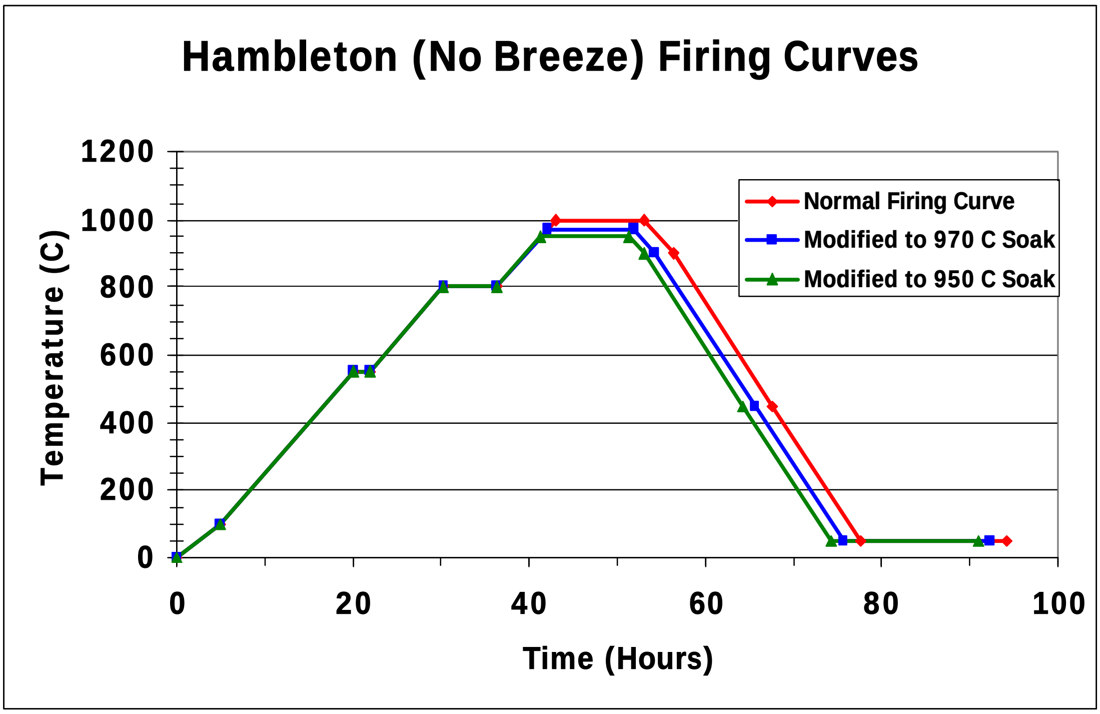


Figure 3. Diagrammatic representation of the firing regimes used in the trials.

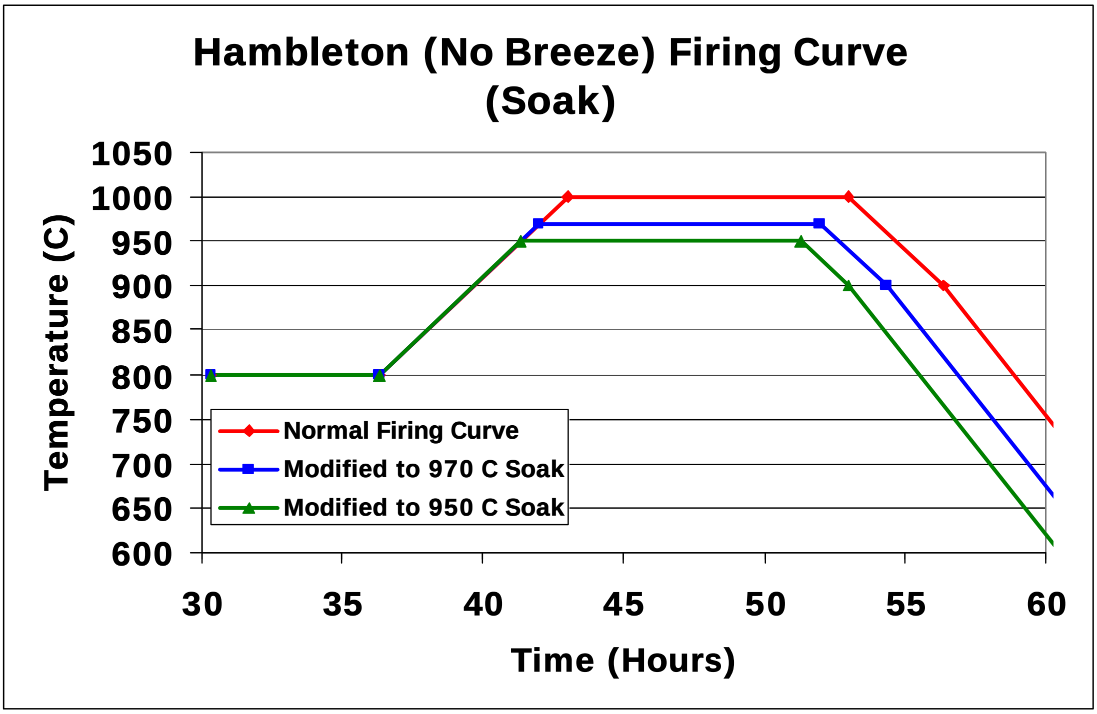


Figure 4. Expanded diagrammatic representation of the high temperature range of the trial firing regimes.

4.3. Underload Firing Curve

Underload firing curves are determined are laboratory firings under highly controlled conditions, and are designed to simulate the level of deformation resulting from the densification (through vitrification) of a clay body with an applied load. The 34kN/m^2 load used in the tests undertaken at CERAM, replicate the typical load the brick at the bottom of a 16 brick high setting pattern would be expected to experience through the firing process. This load is typical for the setting patterns used in UK brick works using high setting height kilns, typically seen on the larger works producing +2 million bricks per week.

The test is conducted on 6 briquettes cut from the production made bricks, in order to maintain the manufactured compaction and structure of the dried bricks. Each briquette is nominally 75x35x25 mm (lxwxh) and set in a 2x2x2 crossed setting pattern, and fired at a constant rate of 60°C/hr, up to a predetermined set point, or degree of linear shrinkage, which ever occurs first.

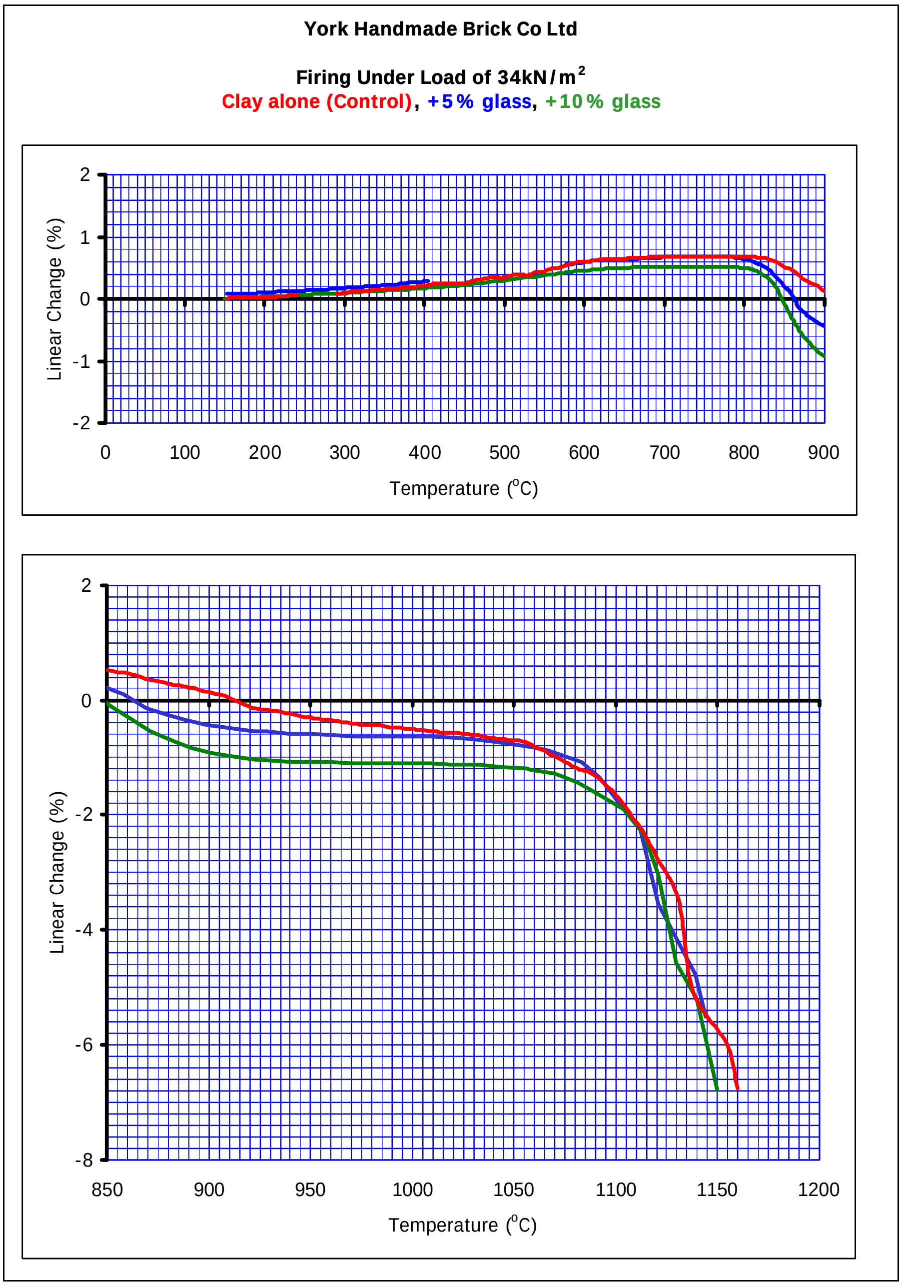


Figure 5. Underload Firing Curve

Figure 5. shows the Underload Firing Curve for the three York Handmade bodies under investigation. On initial heating, and then up to approximately 800°C the clay bodies all expand by between 0.5% and 0.7%. This is typical for nearly all clays, and is the result of the expansion of the mineral phases that make up the body, prior to the point at which the temperature controlled mineral reactions and transformations take place, normally above 650°C-800°C. Once these reactions start, and includes the formation of the glassy melt phase, that subsequently binds the brick minerals together to give the physical property characteristics, the body of the briquettes starts to shrink, a process known as sintering and then densification.

The lacustrine clays used by York Handmade typically show a very marked initial stage of shrinkage, as seen 840°C (clay alone), which crosses the point of neutrality (zero expansion) at about 910°C and then continued shrinkage with increasing temperature is very slight or sometimes nil, as seen by a plateauing of the shrinkage curve. Here, continued slight shrinkage continues until 1060°C when the curve steepens showing rapid shrinkage with a minor increase of temperature.

The 2 glass addition bodies can be seen to behave in a slightly different way, with the onset of initial shrinkage starting at 800°C (5% glass) and 790°C (10% glass). Neutrality is reached at 860°C (5% glass) and 845°C (10% glass), indicating that between 800°C and 860°C a significant amount of glass fluxing is occurring, resulting in these rapid shrinkages of the briquettes. Following this initial early shrinkage, both glass containing bodies stop shrinking (plateau) at about 930°C, the 5% glass addition at a shrinkage of 0.6 % and the 10% glass addition at 1.1%, and no further significant shrinkage takes place until the onset of the second phase of shrinkage at 1050°C (for both glass addition levels, and as previously reported the clay alone). This would tend to indicate that the mineral assemblage that makes up the lacustrine clays used by York Handmade, are very temperature stable up to about 1100°C, after which the curves become very steep. This tends to indicate that the glass additions are having an effect early on in the firing process, but little or no significant effect above 900-930°C.

4.4. Fired Properties

Ultimately the quality of bricks produced are measured against physical and chemical properties. Within the UK there are currently 2 quality standards in co existence at present, BS 3921:1985 [4] the current British Standard, and BS EN 771-1:2003 [5] the current European Standard. From the end of 2005, all UK manufactured bricks will be required to be manufactured to the European Standard, part of the process of lowering the barriers to trade across the EU. The European Standard for bricks, will therefore become the definitive standard for the whole of Europe.

BS EN 771-1:2003 is the specification standard for clay masonry units, and reference is made against the test methods for determination of the specification, which are known as the BS EN 772 suite of test methods. In order to compare the quality and physical properties of the bricks made during the trials 4 European Standard test methods have been used;

BS EN 772-1:2000 Compressive Strength [6]
BS EN 772-7:1998 Water Absorption (5 hr boiling water method) [7]
BS EN 771-1:2003 Annex C Water Absorption (24 hour cold water method) [5]
pr EN 772-22 Freeze-Thaw Durability (under development) [8]

4.4.1. Compressive Strength

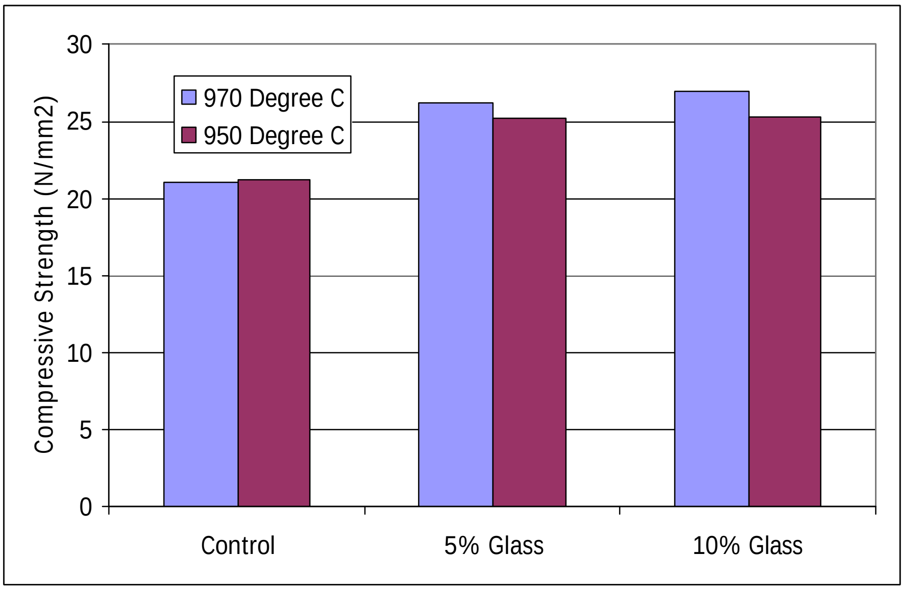


Figure 6. Compressive Strength Values (N/mm^2)

The results of the compressive strength measurements, shown in Figure 6, to BS EN 772-1:2000, which includes surface grinding, shows that the strengths of the bricks in both firings increases with increasing glass content. The degree of increase varies in absolute values, but the general trend is that a greater increase in strength gain is attained between

0% and 5% glass, than is seen between the 5% and 10% glass bricks. This would tend to indicate that in terms of strength, the greatest gains in physical performance are achieved at lower glass addition levels, rather than at the higher levels.

In general, the strengths quoted here for the trial bricks are slightly greater than the minimum strengths quoted in York Handmade's literature (Figure 1), but it should be noted that the strength quoted in the literature are based on BS 3921 test method values, and not the BS EN 772-1 test method.

4.4.2. Water Absorptions

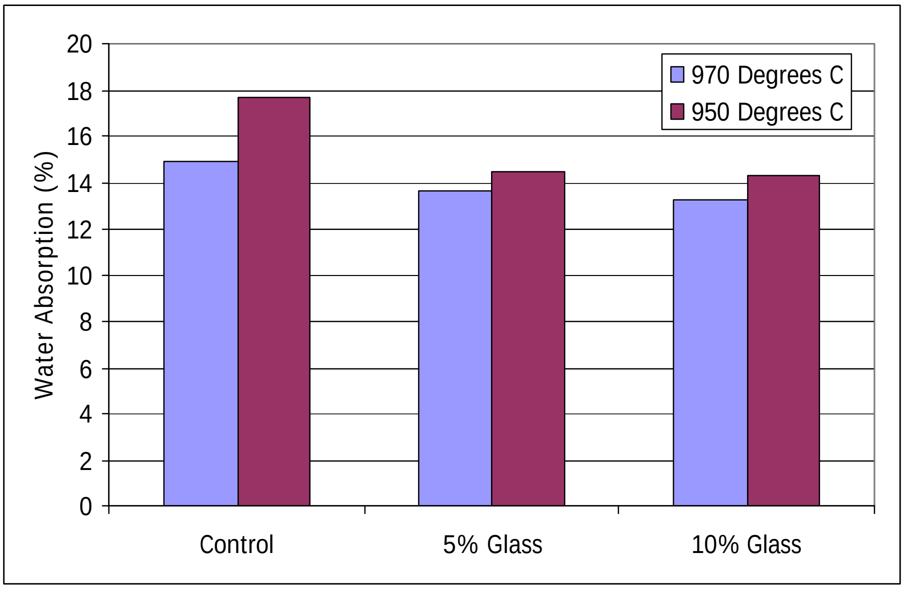


Figure 7. 24 Hour Cold Water Absorption Values (%)

Figure 7. shows the 24 hour cold water absorption values for the three bodies at the two firing temperatures. At both top temperatures increasing glass content reduces the water absorption values measured. Overall the lower of the two firing temperatures gives the higher water absorption values. This is as would be expected as there is less heatwork being done on the bricks with the reduced firing temperature. It is common for manufacturers to declare water absorption values greater than those typically measured routinely at the factory. This allows for some of the natural variation in the raw materials and the brick making process. Routine production at York Handmade typically fall below the manufacturers declared value of 18% for the 24 hour cold water absorption value. York Handmade typically measure a 24 hour cold water absorption value of around 12% for the Hambleton product.

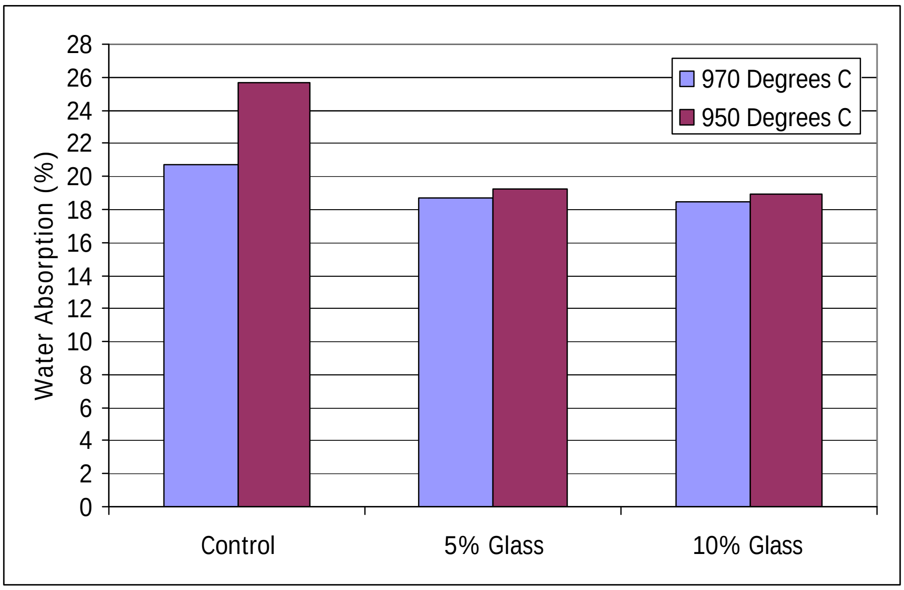
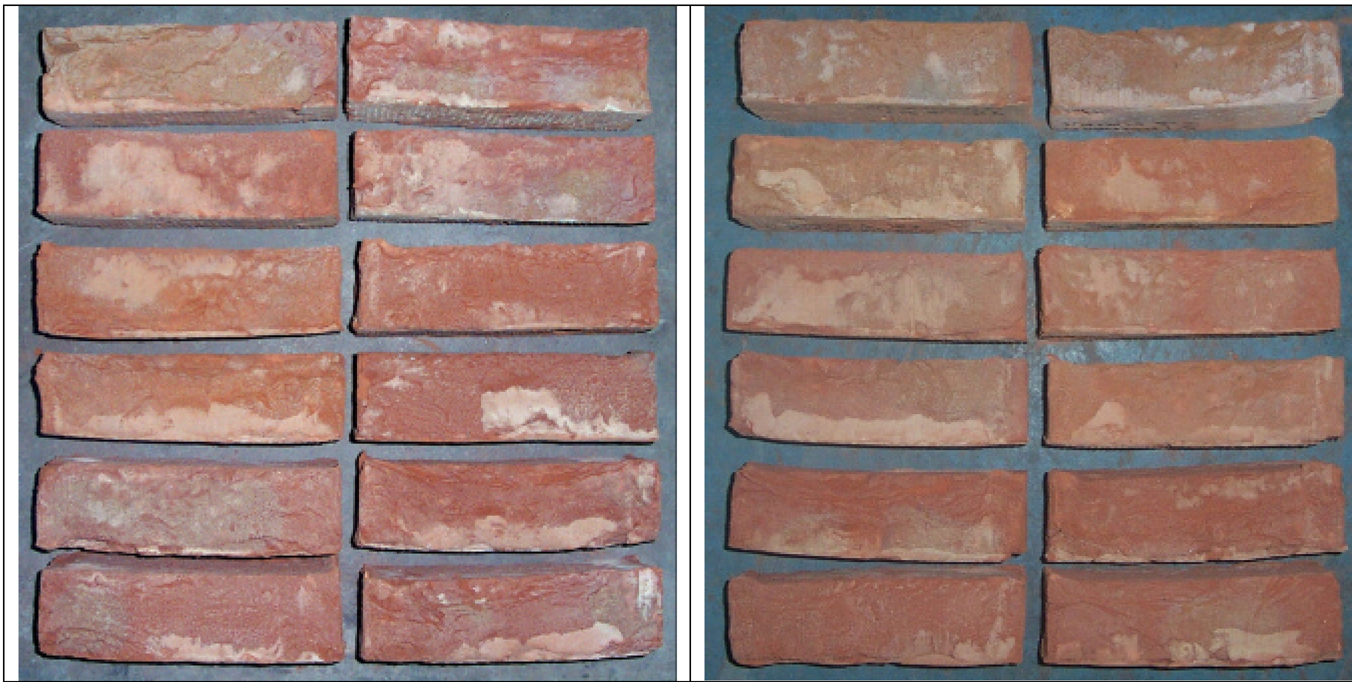


Figure 8. 5 Hour Boiling Water Absorption Values (%)

Similar trends are seen in the higher 5 hour boiling water absorption values, Figure 8. Again it appears that the pore structure of the bricks have been modified, with the greatest benefit being seen between 0% and 5% addition than between 5% and 10%.

This would tend to indicate that the pore structure of the brick is more open than that of the typical Hambleton product, normally this would be attributed to the lower firing temperature, but with the addition of glass it would be expected that the level of vitrification would increase, as seen in the Underload Firing Curves (Figure 5.). In reality it would appear that the distribution of the melt phase has modified the pore structure of the bricks, resulting in a stronger bond between the cemented grains, as shown by the compressive strength values, but with bigger, more open pore structure.

4.4.3. Colour



970°C Trial. Top 2 rows Controls Middle 2 rows 5% glass Bottom 2 rows 10% glass	950°C Trial Top 2 rows Controls Middle 2 rows 5% glass Bottom 2 rows 10% glass

Figure 9. Fired colour comparisons of the bricks from the 2 trial firings, and with variable glass additions.

In previous trials with different clay raw materials and higher firing temperatures, modification to the fired colour has been seen as a possible issue. Figure 9. shows the range of colours created from the different body compositions fired under the two trial regimes. In both trials there appears to be little colour difference between the range of colours produced, but some of the main face colours have been muted by the large "scuff" marks where the clay has been thrown into the mould, and has no sand coating. This though is a feature of hand made bricks and is therefore not seen as a major issue, but adds to the "rustic" natural look of the product.

4.4.4. Freeze-Thaw Durability

Durability, especially in relation to freeze-thaw resistance, in the UK market place is a critical factor. Failure to achieve the declared level of freeze-thaw durability often leads to significant compensation and remedial claims against the manufacturer. In the light of this, the lowering of the firing temperature would normally be seen as a factor that would lead to the reduction in the freeze-thaw durability of the product. This is borne out by the results shown in Table 3.

Currently freeze-thaw resistance is by manufacturers declaration, based on experience, but with the provision of declaring a durability on the basis of the CERAM Freeze-Thaw Test Method, as per BS 3921:1985. Over recent years, with progression towards European Standard harmonization for standards, harmonised test methods have been developed and published, of which freeze-thaw durability for clay masonry units is one. At the date of writing this standard prEN 772-22 is still a provisional standard, but is based on the methodology of the CERAM Method currently in use in the UK. The only modification to this is a 6 hour pre-freeze prior to the 100 cycles of freezing and thawing. It is this standard that has been used to test the York Handmade bricks, on the basis that the test is slightly more severe that the current UK method, and that in the near future it is likely that this will become the UK standard test method.

Firing Temperature	Controls	5% Glass Additions	10% Glass Additions
970°C	2/35 Failed (F2) but Passed (F1) – Delamination on Defrost (100 Cycles)	2/35 Failed (F2) but Passed (F1) – Delamination on Defrost (100 Cycles)	Passed (0/35 Failed)
950°C	6/35 Failed (F2) but Passed (F1) – Delamination on Defrost (100 Cycles)	3/35 Failed (F2) but Passed (F1) – Delamination on Defrost (100 Cycles)	Passed (0/35 Failed)

Table 3. Freeze-Thaw Resistance results of the trial firings (prEN 772-22 test method).

The test method identified the resistance to repeated freezing and thawing and results in a classification, which currently identifies the suitability of the bricks to different levels of exposure. Severe Exposure is regarded as able to be used anywhere, where as Moderate Exposure requires the brick to be used in a mode that will minimise the risk of the bricks becoming saturated for long periods of time. The classifications and cycle thresholds are as follows:

F2 – Severe Exposure – all must pass 100 cycles
F1 – Moderate Exposure – all must pass 15 cycles
F0 – Passive Exposure – no testing required

The results of the testing of the York Handmade bricks at the two firing temperatures clearly shows the need for heat work and the resultant formation of ceramic fluxes to achieve freeze-thaw durability. As expected lowering the firing temperature resulted in failures in the control samples in respect to F2 classification (suitable for Severe Exposure), and resulted in a greater number of failures at the lower of the two firing temperatures.

The 5% glass addition trials, whilst still failing to meet the requirements for F2, either maintained or improved upon the number of failures. All the 10% glass addition trial bricks, at both firing temperatures, successfully passed the requirements for F2 Severe Exposure uses.

The results also show that the mode of failure of the bricks was by delamination, a category 8 (highest) mode of failure, but upon inspection at 80 cycles all were still intact. This indicates that the final 20 cycles are where the delaminations have propagated, typically within 5-10mm of the exposed face of the bricks.

4.5. Energy

One of the key driving forces behind the interest in the use of powdered recycled glass is the potential savings on energy costs, specifically that of natural gas. As Natural Gas is by far the commonest fuel used in the UK, the recent sharp increases in gas prices (Qtr 3 and 4 of 2004) and the projected continued increases through 2005, savings on gas consumption play a significant role in the business drivers for the heavy clay industry.

York Handmade were keen to establish a “real” benchmark level for gas savings, in order to measure the quality, measured in terms of physical properties, that the use of glass additions may offer. The results presented in Table 4. show that for the two trial firings savings in uncorrected volumetric usage of gas, up to 18.7% reductions are possible by firing to 50°C below the normal soak temperature of 1000°C. Even a modest 30°C reduction in firing soak temperature has resulted in a 13.2% reduction in gas consumption. These values are complicated by the slight shortening of the firing duration, by up to 3.5%, but still offer a significant potential saving in gas consumption.

In true terms the savings financially can be regarded as modest, and certainly do not account for the total cost of the glass additive, which based on £30.00 per tonne delivered, works out at roughly £4.50 for a 5% addition rate into each 1000 bricks produced. There is therefore a cost of £1.00 per 1000 bricks for the addition of this amount of glass at a firing temperature of 30°C below normal and a faster firing. Balanced against the other physical property benefits, this £1.00 cost could easily be recovered with increased throughput (productivity) by the reduction in firing times, of 2%, which equates to approximately £6.00-8.00 per 1000 bricks.

Firing		**Normal Firing**	**970°C Firing**		**950°C Firing**	
		Measured	**Measured**	**Saving**	**Measured**	**Saving**
Volume (Natural Gas uncorrected for STP)		5,091 m^3	4,418 m^3	673 m^3 (-13.2%)	4,141 m^3	950 m^3 (-18.7%)
Energy - kWh	kWh	62,365 kWh	56,253 kWh	6112 kWh	52,726 kWh	9639 kWh
	kWh/t (based on 75t per firing)	832 kWh/t	750 kWh/t	82 kWh/t	703 kWh/t	129 kWh/t
Energy - therms	therms	1,884 therms	1,635 therms	249 therms	1,533 therms	331 therms
	therms/1,000 bricks (25,000 bricks)	75.4 therms/'000	65.4 therms/'000	10.0 therms/'000	61.3 therms/'000	14.1 therms/'000
Energy Savings per Firing	Based on average 35p/therm	£659.40	£572.25	£87.15	£536.55	£115.85
Energy Savings per 1000 bricks				£3.50		£4.94
Firing Time	hrs	94.24 hrs	92.24 hrs	2.00 hrs (-2.1%)	90.92 hrs	3.32 hrs (-3.5%)
CO_2 Emission	$kgCO_2$	11,849	10,688	1,161	10,018	1,831
CO_2 Market Value under EU ETS	£4.83/t CO_2 (€7.00/t CO_2)	£53.23 (€82.94)	£51.62 (€74.82)	£5.61 (€8.13)	£48.39 (€70.13)	£8.84 (€12.82)

Notes. January 2005 Natural Gas prices are approximately 35p/therm for yearly contracts, but spot prices have been reported at nearly double that for the futures markets.
Powdered Glass is costed at £30.00 per tonne delivered.
CO_2 price (€)/tonne based on trading price mid Feb 2005 (Telegraph Business Section)
Exchange rate used £1=€0.69

Table 4. Gas consumption and firing time duration for the trials compared to the normal firing regime.

It is clear that increasing the glass addition to 10% would incur a glass additive cost of £9.00, but would only recover a saving of just under £5.00 in pure energy costs. Other savings though can be achieved by the reduction in primary raw material costs, reduction in CO_2 emissions, and the potential to sell the unused carbon credits on the open market in line with EU ETS (European Union Emissions Trading Scheme). The last two rows in Table 4. gives an indication of the potential value of the reduction of CO_2 emissions, should they then be sold as part of the Emissions Trading Scheme. The values are per firing, and therefore account for 25,000 bricks (nominally 75 tonnes of bricks).

5. Conclusions

The results of the trials in terms of the measurables used (physical properties) clearly show improvements in both firing temperatures by the addition of glass to the body. In all cases the benefits, with the exception of freeze-thaw durability, in terms of improvements, there is only a slight benefit in adding 10% glass rather than 5% glass into the body. By far the greatest benefits are to be gained by the initial addition of the 5% glass.

As mentioned the exception to this is the freeze-thaw durability, where 10% glass additions in both trials resulted in fully frost resistant bricks suitable for use in severe exposure situations. This is currently the status of the Hambleton Range of bricks manufactured by York Handmade, and therefore a reduction in the durability aspect of the bricks would not be acceptable for the target market and applications in which these bricks are used.

In addition it was noted, both by York Handmade staff that some of the bricks were "dunted". Dunting is a term used in the brick industry to describe a hairline crack in the brick that results in a dull ring when the bricks are knocked together. This is often a result of the cracking of the brick during the cooling part of the firing curve. At 573°C the mineral quartz undergoes a volumetric change due to the reordering of the crystal lattice. This reduction in volume can be sudden, and if uncontrolled sets up stress cracking in the glassy matrix of the brick. The surface of a crack caused by dunting, typically has a very glossy/glassy surface, showing that the crack has propagated through the minerals and glass phase rather than around the grains.

Dunting is viewed as a problem, which would require a redesign of the cooling part of the firing curve, lengthening the firing time between 650°C and 500°C to allow for the gradual, rather than sudden change in the volume of the quartz grains.

Dunting was not noted on the samples tested at CERAM, and has not therefore been regarded as a significant factor in the absolute values attained from the physical testing nor the interpretation of the results.

Overall the results are very positive, the issue with dunting has known solutions, but this would increase the firing time, and slightly increase the energy usage. Concern at York Handmade have been that the bricks are a little underfired, but in terms of physical properties this is clearly not the case, and the physical properties have been modified.

6. Recommendations

The original agreed firing curve was designed to not reduce the overall firing time, but as a result of altering the ramps to the top soak temperatures, time was saved, on the ramps, and thus a led to a corresponding reduction in heatwork. The true benefit of reducing the temperature is therefore complicated by the associated reduction in firing time. Only by increasing the soak time by the length of time lost in the ramps, would address for this factor, and therefore identify the true saving based on temperature only.

On the basis of these results it appears possible that York Handmade could reduce the firing soak temperature of the Hambleton Range (no coke breeze body) by 20-30°C (to 980-970°C) whilst adjusting the time the brick spends above 800°C to match that of a current firing regime (ie increase by about 2 hours on top temperature soak) and achieving both energy savings and maintaining product physical properties, by the addition of 5-10% glass. The increase in soak will aid in the increasing of freeze-thaw durability, even at 5% glass addition levels.

The coke breeze free brick body only makes up about 40% of the York Handmade range, therefore further work into the body containing coke breeze, and typically fired to 1040°C would be worthwhile, and have the potential to offer similar if not greater energy benefits.

7. References

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