PRODUCTION OF SUSTAINABLE MASONRY PRODUCTS USING VEGETABLE OIL BASED BINDERS AND RECOVERED/RECYCLED AGGREGATES

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ABSTRACT

Vegetable oils are increasing becoming a sustainable source of raw materials for the production of biopolymers. These same oils have been used extensively in paints and varnishes for hundreds of years to provide coatings. Oxidation of vegetable oils is a reaction which is well understood and it is this reaction which allows drying oils to harden when exposed to air. The heating of thin layers of oil in combination with oxygen causes the formation of polymers, which continue to increase in polymer chain length with increased exposure to heat and oxygen. This same reaction can be used to produce masonry products such as blocks, bricks and brick slips from a combination of recovered or recycled aggregates and a wide variety of vegetable oils from different sources. The addition of colouring and texturing allows facsimiles of traditional clay bricks to be manufactured. The carbon footprint for bricks and brick slips can be significantly reduced by the use of vegetable oil binders. This paper outlines the testing carried out on a brick manufactured from recycled lightweight aggregate and vegetable oil.

KEYWORDS: vegetable oil, polymerization, bricks, recycled, furnace bottom ash, pulverised fuel ash

INTRODUCTION

Up to now masonry products e.g. blocks and bricks require, to a large degree, raw minerals to be bound within processes requiring high temperatures. There are different types of masonry products used within the construction industry; concrete blocks, concrete coursing bricks, clay bricks, clay brick slips, roof tiles and pavers. The construction of buildings is of course not limited to these products. Concrete is primarily used to form pillars and beams reinforced with steel to provide the necessary skeletal framework. Blocks, bricks and slips are then used to allow the construction of internal/external walls around the reinforced concrete framework and also to provide an aesthetic look.

Bricks have been manufactured using the same process for over thousands of years. Clay, extracted from the ground, is moulded into shape before undergoing drying and firing. The temperatures required to fire the bricks in order to vitrify the minerals present within the clay, can be in excess of 1000 °C. The firing time varies depending on the minerals present within the clay, desired colour and texture and method of production but is usually between 24-72hrs. The energy consumption and subsequent CO_2 emissions from firing bricks are on average around 1.84-2.8kJ/kg [1] and 184-244kg CO_2 per ton of bricks [2], respectively.

In comparison, concrete products are manufactured from aggregates extracted from the ground and cement. Cement production around the world currently accounts for about 8% [3] of all man-made emissions of CO_2. The production of cement is an energy intensive process as it requires a temperature of 1450 ^{O}C in order to produce the required silicates and aluminates of lime. It is these silicates, when in the presence of water that forms products of hydration, which can then be used to bond aggregate particles together to form concrete. Based on molar calculations of the cement production process, for every 1 ton of cement produced, approximately 1 ton of CO_2 is emitted to atmosphere. Concrete blocks and coursing bricks are an important masonry product used in the construction of many types of buildings. On average for each concrete block/brick, 6-10% of the mass is made up of cement.

With energy availability declining, energy costs rising and the drive to reduce global CO_2 emissions, there is a need to use alternative technologies to produce a product which has the aesthetic appearance and physical properties of a brick but with a lower carbon footprint. Using a patented process, Encos are developing the production of bricks (Encobrick) using recovered/recycled aggregate and vegetable oil binders. The technology behind it is a follow on from the development of Bitublock [4], where bitumen was mixed with aggregate to create a block with a compressive strength ranging from 8-10MPa. By replacing bitumen with vegetable oil, it is possible to achieve the same compressive strengths but using a binder which is sustainable. Vegetable oils contain a combination of mono-, di- and triglycerides, with triglyceride the most dominant. The triglyceride molecule has three long chains attached to a central backbone molecule. Along these chains are, at various points, carbon–carbon double bonds which are susceptible to chemical reactions. The application of heat causes the addition of oxygen at adjacent sites to the double bonds, forming highly reactive molecules called free radicals. The free radicals can then attach themselves to other triglyceride molecules, building up long, highly branched chains to form irregular polymer-type structures, which are both solid and durable. The process is known as oxypolymerization. Mechanically, the properties of the unit are modified from an elastic – plastic (viscous) behaviour (uncured condition) to an elastic – brittle behaviour (cured condition) similar to that of traditional clay bricks. Effectively, the viscous nature of the oil is removed by the heat curing process.

This paper details the development of bricks using a combination of aggregates commonly used in block making, i.e. furnace bottom ash (FBA) and pulverised fuel ash (PFA). There are no natural aggregates present in the material matrix (the bricks are composed of 100% recycled / secondary aggregates). Currently, FBA is wholly used in the UK by industry, most significantly by the concrete block industry. However, in the UK of the approximately 6 million tonnes of PFA produced each year, only 40 - 50% is currently utilised. The remainder is landfilled or used for quarry / land restoration projects adjacent to power stations. As mentioned, incorporation of PFA in concrete masonry units is already standard practice for the majority of block manufacturers in the UK (aggregate blocks - approximately 6%). However, it is envisaged that PFA can be utilised as filler material at replacement levels of at least 20% by mass in these new units if required.

MATERIALS AND EXPERIMENTAL PROCEDURE

Furnace bottom ash, graded below 10mm and pulverised fuel ash, manufactured to EN450, were obtained from Power Minerals, UK. Particle size distribution of the FBA is shown in Figure 1. Voided bricks measuring 215mm x 102mm x 65mm, with three 33mm diameter voids running the length of the brick were manufactured from a mix of 95%FBA/5%PFA using 10% w/w pure canola oil as the binder. The bricks were manufactured on a standard block machine using a vibratory-compaction method of production.

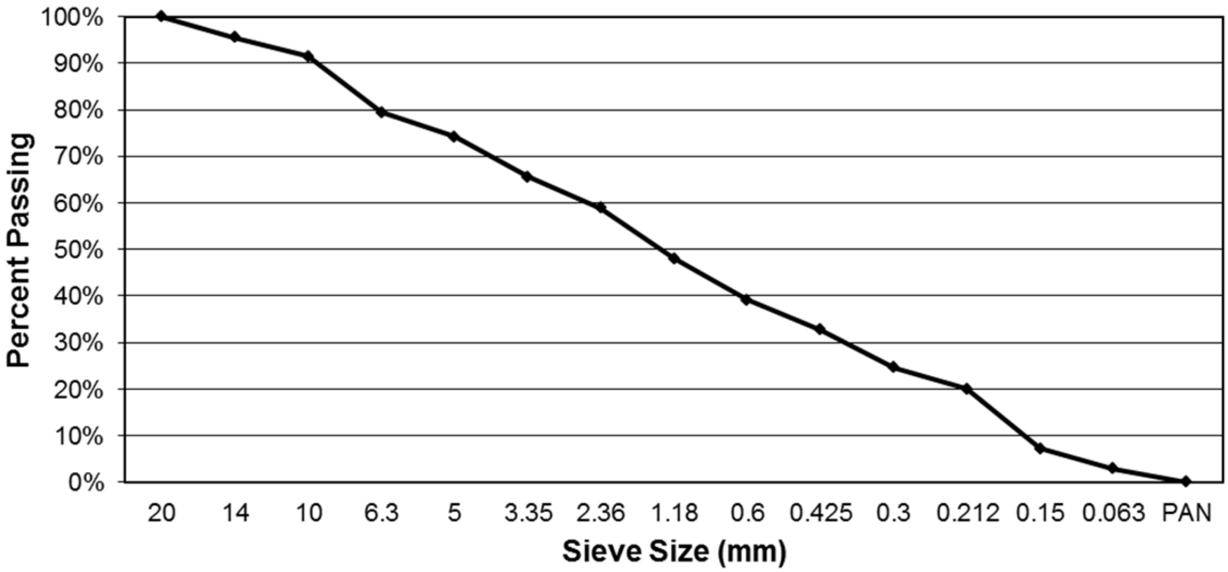

Figure 1: Particle size distribution for furnace bottom ash

The moisture content within the bricks, before curing, was 5%. This was from the water present in the FBA aggregate, as no additional water was added.

After the bricks were manufactured, they were cured in a recirculating box oven for 24hrs at 150^{O}C. During the curing cycle the oil polymerized, forming a bond between aggregate particles. The result was a grey brick which was hard and easily handled. After the bricks were cured, physical testing to the appropriate European standards was undertaken. New test procedures were developed by the Building Research Establishment [5] to compare the performance of the Encobrick against a ‘London Stock’ brick and a class B engineering brick. Figure 2 illustrates a range of Encobricks.

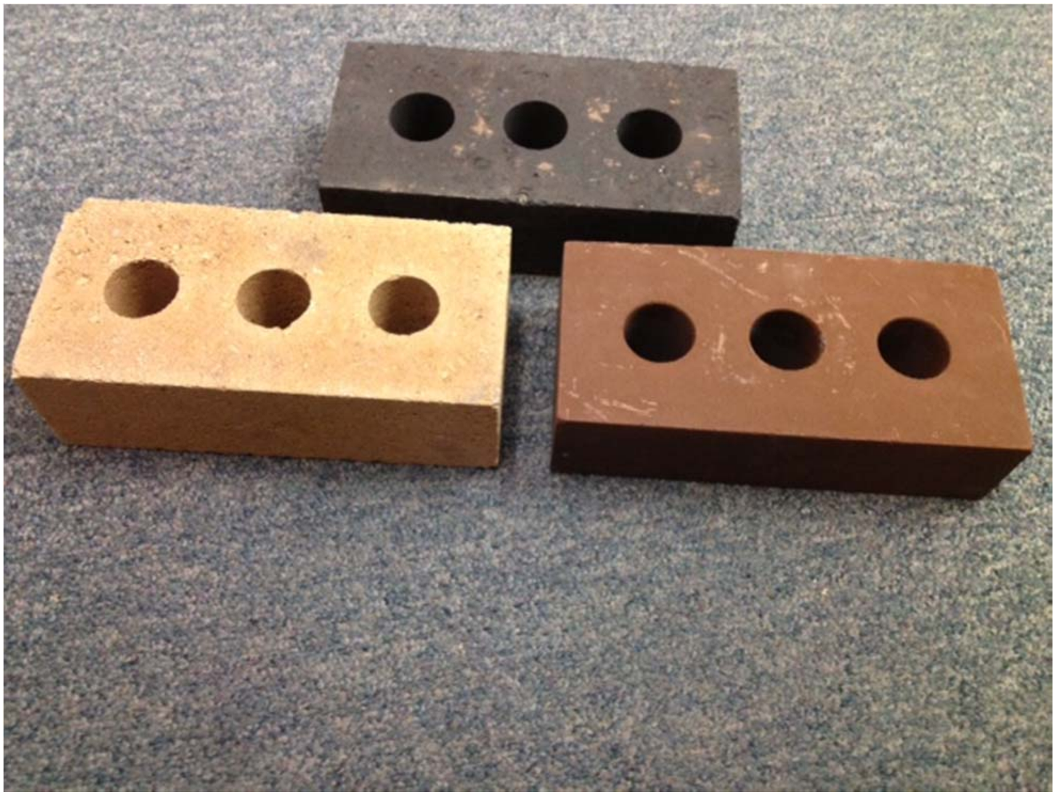

Figure 2: Examples of the range of Encobrick

PHYSICAL TEST METHODS

To gain an understanding of the physical properties of the FBA/PFA bricks, they were subjected to several physical tests. The tests carried out and the relevant British Standard are shown in Table 1.

Table 1: Physical test methods [5]

Test	British Standard
Density	BS EN 772-13:2000
Water absorption	BS EN 771-1 Annex C
Initial rate of water absorption	BS EN 772-11:2011
Compressive strength	BS EN 772-1:2011
Freeze-thaw	DD CEN/TS EN 772-22:2006
Durability (comparative freeze-thaw)	BS EN 12371:2010
Fixings	In house test
Composite/plastering	BS EN 1542:1999

The aim of the fixings test was to examine the comparative pull-out resistance of screw fixings in different masonry products. A 6 mm diameter hole was drilled to a depth of 30 mm, a standard ‘red’ wall plug inserted and a ‘1¼ inch’ screw fixed into place. The maximum force required to remove the screw was then determined using a universal test machine.

RESULTS

The results for each test shown in Table 1 are shown in Table 2. The number of bricks tested for each physical property shown in Table 1, was dependant on the requirements of the appropriate test standard. The results below show the mean values of those tests [5]:

Table 2: Test results from the suite of tests listed in Table 1

Test	Results		Notes
Density	1190kg/m^3(net)	1370kg/m^3(gross)	
Water absorption	16%		Comparison: London Stock brick - 23%, Class B - 4%
Initial rate of water absorption (5 minutes)	0.0038kg/(m^2.min)		Comparison: London Stock brick – 0.0112kg/m^2.min Class B – 0.0008 kg/m^2.min
Compressive strength	9.8MPa (dry)	6.9MPa (wet)	
Freeze-thaw	F1		
Durability	-0.6% weight change after exposure	-2.9% compressive strength change after exposure	Comparison: London Stock brick – disintegrated Class B – no weight change, no change in compressive strength
Fixings	341N mean pull out strength of screw fixing		Comparison: London stock brick – 180N Class B – 292N
Composite/plastering	0.41MPa mean adhesive bond strength		Comparison: London stock brick – 0.28MPa Class B – 0.54MPa

DISCUSSION

The density of the bricks is less than traditional clay bricks due to the use of a lightweight aggregate, furnace bottom ash. This has the advantage of allowing a brick to be produced which has a lower weight then either a clay brick or concrete coursing brick and would reduce the transport costs associated with its delivery to a site. In terms of Manual Handling, these properties are also beneficial. The compressive strength of the bricks is relatively low compared to clay bricks (>15MPa) but is comparable to concrete coursing bricks, which are above 3.6MPa.

The water absorption of the bricks was between the London Stock brick and an engineering brick. Furnace bottom ash is a porous aggregate and although when initially mixed with the vegetable oil it would result in the oil coating the aggregate, in the case of aggregate particles with larger pores, it is more likely the oil would coat the inside of those pores instead of completely enveloping the aggregate particle. Thus, some of the furnace bottom ash particles would still retain a certain degree of porosity. The initial rate of water absorption was between the two comparators. At 0.0038kg/m^2.min, it is well below the maximum of 1.5kg/m^2.min stated in BS5628: Part 3 [6] and the bricks will not therefore require 'docking' prior to laying. These water absorption properties indicate that there should be no problems with combining the units with a standard mortar when building with this product.

Two different freeze-thaw tests were performed on the vegetable oil bound FBA/PFA brick. The first was a standardized test carried out on all bricks within the UK (DD CEN/TS EN 772-22:2006). After 100 freeze-thaw cycles were completed the bricks achieved an F1 classification, indicating that their use was suitable in conditions with moderate exposure. The second test was a freeze-thaw test usually carried out on natural stone, whereby, the stone is frozen in air and thawed in water. This test was carried out to give an indication of how the polymerized vegetable oil binder would perform when subjected to severe adverse conditions. The weight loss and any changes in compressive strength were determined on oven dried samples after the test was completed. The Stock bricks disintegrated during this test and it was not possible to record the weight loss or test the compressive strength. In comparison, only a small change in weight and compressive strength was recorded for the vegetable oil bound FBA/ PFA bricks, indicating a greater durability than Stock bricks.

In addition to these durability tests, a masonry panel was constructed outside in an exposed position and monitored at Poundbury, Dorset (Poundbury is an urban development created and overseen by HRH Prince Charles). Figures 3 and 4 illustrate the panel in situ. The panel has so far been monitored for 3 years, which included two very harsh winters, and no deterioration in performance was observed. Figure 3 illustrates the panel in its entirety and Figure 4 illustrates the joint between the panel and the plinth on which it was constructed, as well as providing a closer detail of the brick. The units are 65mm high; with this scale information it is possible to see that the mortar joints are less than the standard minimum 10mm thick used in traditional clay masonry. This is possible with Encobrick because the manufacturing process (forming and curing) results in more uniform bricks being produced. The joint shown in Figure 4 is important as if there were to be any sign of deterioration it would likely be in evidence here. From the figure it can be seen that there is no evidence of deterioration in this joint.

Figure 3: Masonry test panel constructed at Poundbury

Figure 4: Detail of bedding joint between panel and base plinth

As internal walls are often coated with plaster and have fixings drilled into the bricks, it was necessary to test how well plaster would bond to the bricks and how much force was necessary to pull a screw from a wall. The composite/plastering test showed that the vegetable oil bound FBA/PFA brick performed well, with values falling between those of the Class B and the Stock brick. In addition, the fixings test showed how it performed better than either of the comparator products. This indicates that the use of the FBA/PFA brick would be suitable for the construction of internal walls.

Fire tests have also been performed at Bodycote, 'Warrington Fire' (see Figures 5 to 7). These tests were performed in-line with the heating conditions given in BS476: Part 20: 1987 [7]. The panels were 1 m^2 single-leaf panels with 50% of the surface covered with 12.5mm plasterboard 'dot and dabbed' to the exposed face. The tests ran for between 1 and 2 hours. The ambient temperature in the vicinity of the unexposed face was 16°C at the start of the test; the maximum variation during the test was 2°C. The temperature on the unexposed face of the wall never at any stage or location increased sufficiently to suggest that any transfer of risk through the wall would occur. At 30 minutes, the plasterboard exhibited numerous cracks and at 55 minutes the plasterboard became completely detached from the exposed face. Beyond 60 minutes there was no further significant change observed.

Figure 5: Unexposed face of masonry panel before start of fire test

Figure 6: Exposed face – with and without plasterboard (note cracks in plasterboard)

Figure 7: Exposed face at end of fire test

Although other tests still need to be completed on a vegetable oil bound FBA/PFA brick such as, moisture movement, shear strength, flexural strength, thermal expansion and thermal resistance, early indications are that it could be possible to manufacture a brick which has the physical properties and durability characteristics that are comparable or slightly better than a London Stock brick. The natural grey colour of the brick, from the addition of PFA, leads itself to the possibility of producing bricks with added pigments, to create a range of bricks with different colours using iron oxide pigments commonly used with concrete. This will then allow the production of bricks with a more aesthetic look to them.

Further testing is continuing, as is development using alternative aggregates. The use of alternative aggregates could improve the physical properties and durability characteristics of the vegetable oil bound bricks.

CONCLUSION

It is possible to manufacture bricks using only vegetable oil and aggregate. The low temperature curing process reduces the amount of carbon dioxide emitted during their production, compared to traditional brick manufacturing. The physical performance and durability suggest their use as a replacement to common and facing bricks is possible, after further testing.

REFERENCES

1. Moedinger, F., (2012) “Sustainable clay brick production – a case study” http://www.tbe-euro.com/downloads/SustainableBuildingConference-Italy.pdf, (accessed 13/11/12)
2. Sanford, J., (2012) “Manufacturing headlines for the Wienerberger Ltd. UK Brick sites based on performance in 2011” http://www.wienerberger.co.uk/sustainability/environmental-sustainabililty-management/operational-data, (accessed 13/11/12)
3. “Reducing CO2 with ‘green’ concrete”, (2012) http://www.ice.org.uk/topics/environment/Journal-abstracts/Reducing-CO2-with-green-concrete, (accessed 13/11/12)
4. Forth, J. P., Zoorob, S. E. and Thanaya, I. N., (2006) “Development of bitumen-bound waste aggregate building blocks”, Proceedings of the Institution of Civil Engineers, Construction Materials, vol. 159, pp.23-32.
5. “Laboratory testing of Encobrick”, (2012) Building Research Establishment, Test report 270872/R1, 29 February 2012
6. British Standards Institution, (2005) “Code of Practice for the use of Masonry, Materials and Components, Design and Workmanship”, BS 5628: Part 3: 2005 (status – withdrawn)
7. British Standards Institution, (1987) “Methods for the determination of fire resistance of non-load bearing elements of construction”, BS 476: Part 20: 1987,