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Engineering properties of unfired clay masonry bricks

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A B S T R A C T

The shortage of low cost and affordable housing in the UK has led to many investigations into new building masonry materials. Fired clay masonry bricks are conventionally used for mainstream masonry wall construction but suffer from the rising price of energy plus other related environmental problems such as high energy usage and carbon dioxide emission. The use of stabilised unfired clay bricks for masonry construction may solve these problems.

This paper reports on the engineering properties of unfired clay bricks produced during the first industrial trial of unfired clay material development carried out at Hanson Brick Company, in Stewartby, Bedfordshire, under the Knowledge Exploitation Fund (KEF) Collaborative Industrial Research Project (CIRP) programme. The mixes were formulated using a locally available industrial by-product (Ground Granulated Blastfurnace Slag — GGBS) which is activated with an alkaline (lime or Portland cement) combined with clay soil. Portland cement was not used in the formulation of the unfired stabilised masonry bricks, except as a control, which is a significant scientific breakthrough for the building industry. Another breakthrough is the fact that only about 1.5% lime was used for GGBS activation. This level of lime is not sufficient for most road construction applications where less strength values are needed and where 3–8% lime is required for effective soil stabilisation. Hence, the final pricing of the unfired clay bricks is expected to be relatively low.

The laboratory results demonstrate that the compressive strength, moisture content, rate of water absorption, percentage of void, density and durability assessment (repeated 24-hour freezing/thawing cycles) were all within the acceptable engineering standards for clay masonry units. The paper also discusses on the environmental performance of the unfired clay in comparison to the bricks, used in mainstream construction of today. The bricks produced using this technology can be used for low-medium cost housing and energy efficient masonry wall construction.

1. Introduction

During the brick manufacturing process several gases (CO_2 etc.) are typically released from the brick kilns (US EPA, 2003); these emissions are becoming a major environmental concern for many countries including the UK. Recent increases in gas prices, low economical activity and new government legislations (for example the Climate Change Levy — CCL and European Union Emissions Trading Scheme — EUETS) (Grubb, 2000; Defra, 2008; Netregs, 2008) will further exacerbate this cost element for fired clay bricks. Thus, this new technology focusing on unfired clay brick development is vital for the future of construction here in Wales and in the UK in general.

The unfired clay brick technology relies on the use of an activated industrial by-product (Ground Granulated Blastfurnace Slag — GGBS) and natural clay. It is anticipated that the final pricing of the unfired clay masonry building brick will therefore be reduced. The added environmental advantages of utilising industrial by-products in the region will further improve the Welsh profile on sustainability. The proximity of slag in the South Wales region of the UK (where the research work on unfired clay brick technology was carried out) will create an added impetus towards the emergent sustainability agenda in the region.

In the past, unfired clay soil has been a traditional construction material especially in rural regions. These materials were in various forms as sun-baked bricks, mortars and plasters. Because of its simplicity and low cost, good thermal and acoustic properties, and at the end of a building's life, the clay material can easily be reused by grinding and wetting or returned to the ground without any interference with the environment aided this material's flexibility. However, the main deficiency of unstabilised clay soil is its susceptibility to water damage. This problem is now overcome by stabilising the clay soil with the addition of a small amount of lime, thereby enhancing many of the engineering properties of the soil and producing an improved construction material (Kinuthia and Wild, 2001; Mckinley et al., 2001; Rao and Shivananda, 2005).

The drawback in using lime alone results in durability problems, as reported by other investigators (Wild et al., 1996, 1998). Works on how to correct the durability of lime-stabilised soil has been

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conducted by numerous researchers (Wild et al., 1999; Okagbue and Yakubu, 2000; Sivapullaiah and Lakshmikantha, 2005). The outcome of this research reveals that the addition of GGBS to a lime-stabilised system is able to improve many engineering properties of soil including durability (Tasong et al., 1999; Rajasekaran, 2005; Oti et al., 2008a). Regardless of the test methods and specimens used, the investigators seem to conclude that the reaction between amorphous silicon bodies of the hydration of activated GGBS and clay soil (towards the formation of additional pozzalanic C–S–H gel), is mainly responsible for the beneficial action of the system.

In highways and other foundation layers, around 3–8% lime is needed for effective activation of GGBS for soil stabilisation. However, the use of only about 1.5% lime for GGBS activation in building components is relatively new in construction and its use is rare in the UK. Thus, this work on unfired clay masonry material development and the viable building brick emerging from it is innovative and has great future potential.

This paper will report on compressive strength, moisture content, rate of water absorption, percentage of void, density and durability assessment (repeated 24-hour freezing/thawing cycles) of unfired clay bricks. The paper will also discuss on the environmental performance of the unfired clay bricks. The characterisation of the microstructure that is responsible for the changes in behaviour of the various unfired bricks is reported in the second part of the paper.

This work is aimed at contributing towards the application of this unfired technology in the building industry. Providing knowledge on the engineering performance of the unfired bricks, ensuring this is widely available to the fired clay sector and other building material manufacturers, especially in today's climate were energy prices and environmental awareness of the general public are on the increase. This paper is relevant to all those involved in the use of industrial by-products to improve soil and geometrical properties, including civil and construction engineers, and engineering geologists. Furthermore, this paper could also be of interest to people working in developing countries. They will learn the art of using industrial by-products (GGBS) for new soil-based materials development, to enable more giant steps towards similar product processes.

2. Methodology

2.1. Material

The materials used for the industrial trial consisted of Lower Oxford Clay (LOC), two different types of lime (L1, and L2), Ground Granulated Blastfurnace Slag (GGBS) and Portland cement (PC).

2.1.1. Lower Oxford Clay (LOC)

The LOC used in this study was supplied by Hanson Brick Company Ltd., from their Stewartby brick plant in Bedfordshire UK. The mineralogical composition is shown in Table 1. Its chemical and physical properties are shown in Table 2. This clay material is currently used by Hanson Brick Company Ltd. to make fired "London" bricks.

Table 1
The mineralogical composition of Lower Oxford Clay.

Composition (%)	Compound	Chemical formula
23	Illite	$(K,H_30)Al_2Si_3AlO_{10}(OH)_2$
10	Kaolinite	$Al_2Si_20_5(0H)_4$
7	Chlorite	$(OH)_4(SiAL)_8(Mg.Fe)_6O_{20}$
10	Calcite	$CaCO_3$
29	Quartz	SiO_2
2	Gypsum	$CaSO_4.2H_2O$
4	Pyrite	FeS_2
8	Feldspar	$CaAlSi_3O_8$
7	Organic materials	–

Table 2
Chemical composition and physical properties of Lower Oxford Clay, quicklime, hydraulic lime, GGBS and PC.

Oxide	LOC	L1	L2	GGBS	PC
CaO	6.15	89.2	66.6	41.99	63
SiO_2	46.73	3.25	4.77	35.35	20
Al_2O_3	18.51	0.19	1.49	11.59	6
MgO	1.13	0.45	0.56	8.04	4.21
Fe_2O_3	6.21	0.16	0.71	0.35	3
MnO	0.07	0.05	0.08	0.45	0.03–1.11
S^{2-}	–	<0.01	<0.01	1.18	–
SO_3	–	2.05	<0.01	0.23	2.3
SO_4	–	2.46	<0.01	–	–
$CaCO_3$	–			–	–
TiO_2	1.13			–	–
K_2O	4.06	0.01	0.25	–	–
N_2O	–	0.02	0.04	–	–
FeO	0.8			–	–
P_2O_5	0.17			–	–
Na_2O	0.52			–	–
CO_3	–	4	3	–	–
Soluble silica	–	1.1	4.77	–	–
Free lime	–	51.1	39.4	–	–
Physical properties					
Insoluble residue	–	4.1	2	0.3	0.5
Bulk density (kg/m^3)	–			1200	1400
Liquid Limit (LL) (%)	67			–	–
Plastic Limit (PL) (%)	35			–	–
Plasticity Index (%)	32			–	–
Colour	Grey			Off-white	Grey
Glass content	–			≈90	–

Notes
LOC Lower Oxford Clay from Hanson Brick Company Ltd., Stewartby, Bedfordshire, UK.
L1 Quicklime from Tŷ-Mawr Lime Ltd., Llangasty, Brecon, UK.
L2 Hydraulic lime from Tŷ-Mawr Lime Ltd., Llangasty, Brecon, UK.
GGBS Ground Granulated Blastfurnace Slag from Civil and Marine Ltd., Llanwern Works, Newport, UK.
PC Portland cement from Lafarge Cement, UK.

It is a challenging choice of clay material but a practical endeavour for the unfired clay material development, because:

1) It is generally hard to stabilise especially with lime because of its high organic and sulphate content.
2) It is currently being used for fired brick manufacture and therefore easier to compare the fired and unfired products.

It is anticipated that in future product development, not covered in this paper, the clay content used in this research may be partially replaced by colliery waste or dust from slate waste which are in abundance within the South Wales region of the UK. The aim is to improve on the sustainability profile of the end product.

2.1.2. Lime (L)

Two different types of lime (L1 and L2) were used in this study. L1 is a quicklime (CaO) while L2 is a hydraulic lime. Both L1 and L2 were supplied by Tŷ-Mawr Lime Ltd., Llangasty Brecon, UK. The chemical and physical properties of both limes are also shown in Table 2. The use of lime for clay soil stabilisation has been extensively applied in practice of civil engineering such as foundations, roadbeds, embankments and piles (Balasubramaniam et al., 1989; Bell, 1996; Du et al., 1999; Al-Rawas et al., 2005). In practice between 1 and 3wt.% lime is needed for modifying soil properties and between 2 and 8 wt.% lime for stabilisation. Previous research work by Kinuthia and Wild (2001) used 6 wt.% for stabilisation of kaolinite clay for road construction. In the current work a maximum value of 1.5 wt.% lime was chosen for the activation of GGBS after several trials.

The reason for using quicklime and hydraulic lime as the choice of binder was because quicklime for example has been used successfully for stabilisation of clays in the low temperature regions for road construction and for columns for the improvement of slope stability.