EVALUATING THE PROPERTIES OF MASONRYBLOCKS BOUND WITH BITUMEN

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Abstract: This paper covers investigation which was carried out in the United Kingdom (UK), where utilization of waste materials in building industry had been encouraged in line with the UK government strategy to reduce waste disposal to landfill. The investigation was about building block named as Masonryblock, a masonry building block material that incorporates waste materials, namely steel slag, crushed glass, and coal fly ash, bound with bitumen (asphalt). The binder used was 50 pen bitumen. The materials were hot mixed, statically compacted then cured at 200°C for 24 hours. The main properties of the blocks evaluated were compressive strength, creep and volume stability due to moisture and thermal exposure. It was found that the Masonryblock compressive strength was comparable or even can exceed the compressive strength of concrete block commonly used in the UK (2.8-10 MPa), and can satisfy creep strain < 100 microstrain. The volume stability of the Masonryblock was found affected by moisture exposure. The samples expanded due to higher relative humidity and vice versa. On thermal exposure the samples expanded and the expansion was found highly reversible. The Masonryblocks gave coefficient of thermal expansion comparable to clay bricks.

Keywords: masonry, properties, bitumen, waste material.

EVALUASI SIFAT MASONRYBLOCK YANG DIREKAT DENGAN ASPAL

Abstrak: Paper ini mencakup penelitian yang dilaksanakan di Inggris (United Kingdom), dimana penggunaan bahan bekas untuk industri bangunan sudah terus digalakkan sejalan dengan strategi Pemerintah Inggris untuk mengurangi pembuangan bahan bekas sebagai urugan. Penelitian yang dilaksanakan adalah tentang blok bahan bangunan yang disebut *Masonryblock*, suatu blok bahan pasangan dinding yang terdiri atas bahan bekas, yaitu *steel slag*, pecahan kaca/botol, dan abu terbang batu bara, yang direkat dengan aspal. Aspal yang dipergunakan aspal penetrasi 50. Material dicampur secara panas, dipadatkan dengan pemadatan statis, dan dipanaskan pada temperatur 200°C selama 24 jam. Sifat-sifat utama yang dievaluasi adalah kuat tekan, rangkak (*creep*), dan stabilitas volume akibat ekspos teradap kelembaban dan panas. Ditemukan bahwa kuat tekan sampel sebanding bahkan bisa lebih tinggi dari kuat tekan blok beton yang biasa dipakai di Inggris (2.8-10 MPa), dan memenuhi regangan rangkak (*creep strain)* < 100 *microstrain*. Stabilitas volume dari *Masonryblock* dipengaruhi oleh kelembaban. Sampel mengembang pada kelembaban relatif yang lebih tingi demikian pula sebaliknya. Pada ekspos panas, sampel mengembang dan dapat kembali lagi ke kondisi semula. *Masonryblock* memberikan koefisien pengembangan termal sebanding dengan batu bata tanah liat.

Kata-kata kunci: pasangan dinding, sifat-sifat, aspal, bahan bekas.

INTRODUCTION

The United Kingdom (UK) government target to reduce the amount of commercial and industrial waste going to landfill to 85% of 1998 levels by 2005 (Defra UK, 2007). The Landfill Directive represents a step change in the way waste materials are disposed in the UK and will help to drive waste up the hierarchy through waste minimization and increased levels of recycling and recovery (Defra UK, 2007).

The production of masonry building block described in this paper, i.e. Masonryblock, certainly supports the UK government efforts in reducing wastes material to landfill. The materials incorporated namely: steel slag, crushed glass, and coal fly ash. The binder used was a 50 pen bitumen. This paper relates to the previous publication by the author (Thanaya et al, 2006; Thanaya, 2010).

Issues on movement of masonry had been widely documented. Problem can arise when materials with different movement characteristics are jointed together. Differences on materials volume stability (movement) should be accommodated on the construction of masonry walls by providing sufficient movement joints in order to minimize risk of damage (Vekey, 2001).

The objective of this paper is to evaluate the compressive strength and volume stability of the Masonryblocks as a sustainable masonry building material, due to exposure to moisture and temperature.

THE TYPE OF MASONRYBLOCK INVESTIGATED

The authors had previously published their work on similar Masonryblocks incorporating various waste materials, namely steel slag, crushed glass, coal fly ash, coal bottom ash, municipal solid waste incinerator bottom ash, and incinerator sewage sludge ash (Thanaya et al, 2006; and Forth et al, 2006).

Within this paper the type of Masonryblocks investigated were the one that incorporated steel slag, crushed glass and coal fly ash. After series of trials, it was found that a gap graded distribution with aggregate grading as shown in Figure 1 was preferred. The aggregate grading was derived from the British Standard (BS594-1, 2003). This grading contains high fine fraction, hence enables the application of low compaction level to satisfy the Masonryblock performances. The percenttage proportion of the materials used is given in Table 1.

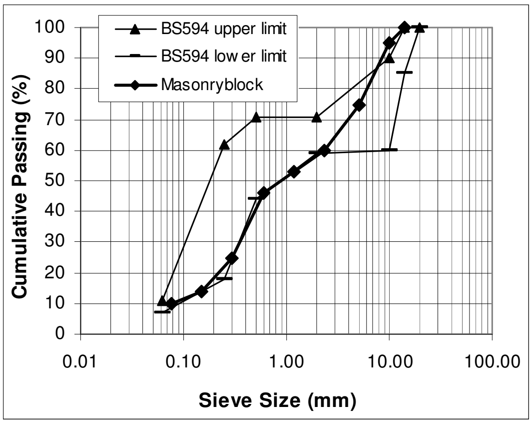

Figure 1. The Masonryblock aggregate grading used in comparison to hot rolled asphalt (HRA), (BS594-1, 2003)

Table 1. Proportion of aggregate used

Aggregates	%	Materials Used
Coarse aggregates: - (14-10)mm - (10-5)mm - (5-2.36)mm	 5 20 15	 steel slag crushed glass crushed glass
Fine aggregates: (2.36-0.075) mm	50	crushed glass
Filler: - passing 0.075 mm	10	coal fly ash

In order to enable the use of less bitumen needed, hence enhance the economics of the mix and yet still ensure satisfactory bitumen coating, the incorporation of combination of waste aggregates with lower absorption properties have been considered for this investigation. The properties of the materials selected are shown in Table 2.

In term of the type of bitumen used**,** in principal all types of bitumen (hard/penetration grade or bitumen emulsion) can be used as the binder. However, it is preferable to use softer grade bitumen as this requires a lower handling temperature. Moreover, as the samples will be heat cured in order to improve their resistance to long-term deformation, the use of harder grade bitumen would not provide a very significant improvement to the end product (Thanaya et al, 2006). The type of bitumen used for this investigation was 50 penetration grade (50 pen or 40/60 bitumen) with specific gravity of 1.03 and softening point of 47°C.

Table 2. The properties of the aggregate

Materials	Density (gr/cm3)	Water Abs. (%)
Coarse agg. (CA):		
Steel slag	3.39	1.9
Crushed glass	2.51	< 0.5
Fine Agg. (FA):		
Crushed glass	2.51	< 1
Filler:		
Fly ash Ferrybridge	2.16	-

DETERMINATION OF BITUMEN CONTENT AND COMPACTION LEVEL

The manufacture of Masonryblock has been reported previously (Forth et al, 2006). Briefly, to facilitate mixing the aggregate materials and the 50 pen bitumen were pre-heated at 160-180 °C (Whiteoak, 1991) for 3 hours. The loose mix was then placed in a mould and compacted.

Following compaction, the Masonryblock samples were cured in an oven. Curing regime had previously been found to play a very significant role. When using a 50 pen bitumen and cured at 160 °C, the curing duration required to satisfy creep performance was 72 hours. In order to reduce curing duration, in this investigation the samples were cured at 200°C for 24 hours. After some trials this was found to give satisfactory results (Thanaya et al, 2006).

The performance of Masonryblock is influenced by porosity and the heat curing regime. A lower porosity (higher compacttion) gives improved aggregate interlock which increases the potential compressive strength. However, more efficient heat curing (higher porosity – greater depth of bitumen oxidation / hardening) improves the long-term stability of Masonryblock (i.e. reduces the creep potential). In this investigation, the curing regime was fixed and the compaction level applied was 1, 2, and 4 MPa, and bitumen contents were varied from 5 to 6.5%. with 0.5 % increment.

The main property considered within this stage of the investigation was the compressive strength, which is given in Figure 2.

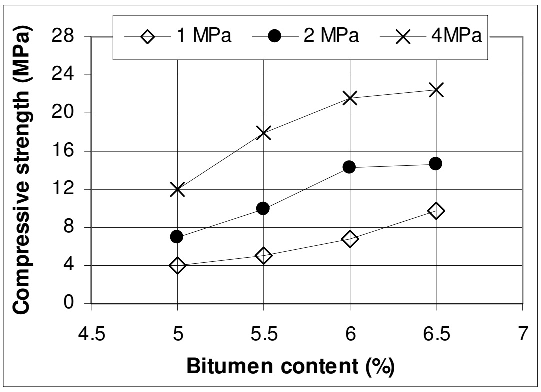

Figure 2. Bitumen content vs. Compressive strength (the samples were compacted at different compaction level and cured at 200 °C for 24 hours)

Referring to the aggregate grading shown in Figure 1, the minimum bitumen content for road bituminous mixtures recommended by BS594 (2003) is 6.5% by weight of total mixture; this is to ensure adequate coating and durability. With this in mind, the bitumen content was optimased taking the figure of 6.5% as a maximum.

The compressive strength trends are shown in Figure 2. At all compaction level (1, 2, and 4 MPa) the compressive strength of the sample was satisfactory, i.e. well above 2.8 – 10 MPa (BS 6073-1, 1981). It was intended to choose lower compaction level, but should give satisfactory results, i.e. to ensure the sample's shape stability during handling. As had been experienced during the investigation, compaction level of 2 MPa gave satisfactory samples performance therefore 2 MPa compaction level was chosen.

For the samples compacted at 2 MPa there is little improvement in compressive strength above 6% bitumen content. Observing the satisfactory degree of coating of the aggregates; the surface texture of the samples and the stability of the samples during handling, together with the insignificant improvement in compressive strength of samples with higher than 6% bitumen content compacted at 2 MPa, it was then decided not to increase the bitumen content higher than 6.5%. For efficiency of bitumen content, it was decided to fix the bitumen content at 6% and the compaction level at 2 MPa.

PROPERTIES OF THE MASONRY-BLOCKS

General Properties

The properties tested were volumetric properties (density and porosity), initial rate of suction (IRS), water absorption, compressive strength. A summary of test results at the chosen 6% bitumen content and 2 MPa compaction efforts is given in Table 3.

The IRS test was carried out by immersing the sample in 3mm depth of water for 60 second. The weight of water absorbed by the sample was then calculated and divided by the area in contact with water (BS 3921, 1985). IRS is a parameter that can provide an indication of the effect of the unit on the sand cement mortar. Units with high IRS require very plastic mortar (high water/cement ratio), while units with lower IRS need stiffer mortar (Vekey, 2001). The IRS values of the Masonry-block were found at lower range compared to IRS values for clay brick found in the United Kingdom (between 0.25-2.0 kg/m^2/min). Low IRS values were obtained because the aggregates were evenly coated by bitumen which has hydrophobic character. This suggest that the Masonryblocks tested in this experiment would require or more suitable to use stiffer mortar.

Table 3. The properties of the mixtures at the chosen 6% bitumen content, compacted at 2 MPa

Properties	Unit	Value
Density	g/cm^3	2.044
Porosity	(%)	17.4
IRS	kg/m2. min	0.35
Water abs. by 24 hr immersion	(%)	5.5
Comp. Strength - Uncured - Cured *	MPa	 2.6 14.2

* cured at 200° C for 24 hours

Creep Performance

Creep tests were carried out by loading the samples using a simple equipment, i.e. an ‘arm load equipment’ (Thanaya, 2010). The stress applied was 1 MPa which is the level of stress commonly applied on masonry material (Forth et al., 2006). The samples creep strains were measured by means of a 50 mm Demec gauge, which is completed with its supporting parts (Figure 4) which measure the strains occurred between a pair of Demec points that is attached vertically in the middle of each side of the samples (Figure 2). The testing temperature was room temperature 21 ± 0.5 °C

The creep properties (specific creep) under 1 MPa stress are given in Figure 3 and Table 4. The creep strain met the expected value, i.e. < 100 microstrain (Forth et. al., 2008; Tapsir, 1985).

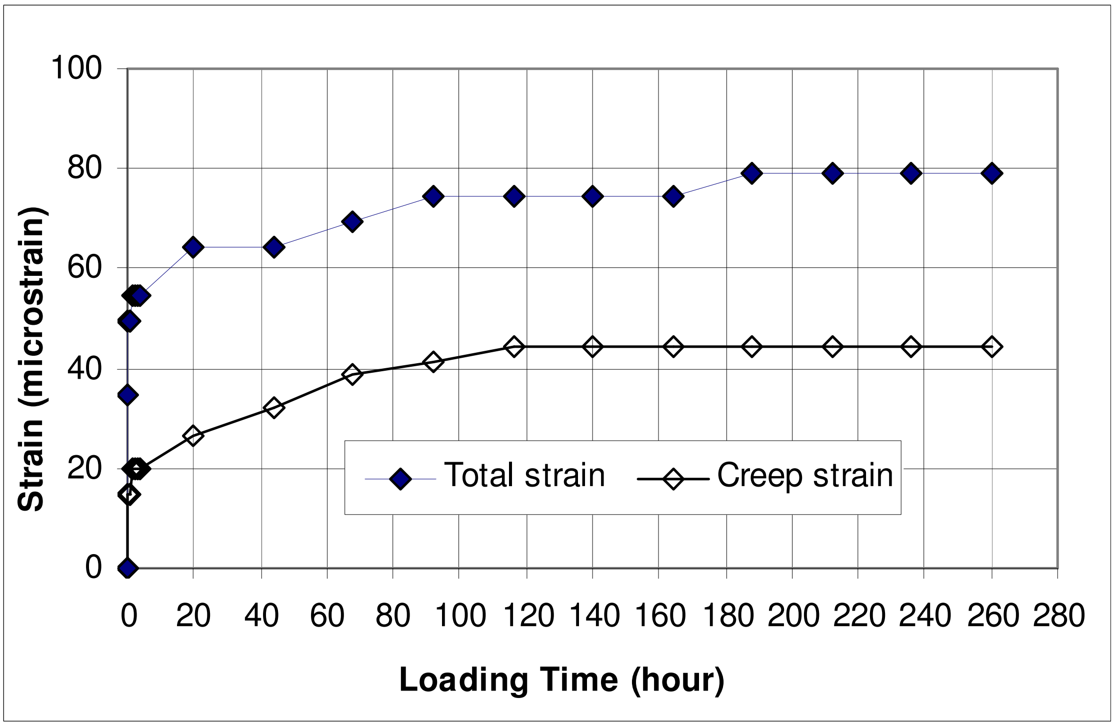

Figure 3. The creep test results of the Masonryblock wall samples

Table 4. Creep performance of the Masonryblock samples, at 2 MPa compaction level

Mix No	Mix Name	Total Strain (με)	Elastic Strain (με)	Creep Strain [1] (με)	Elastic Modulus [2] GPa)
1	Bwall sample	79.2	34.65	44.55	28.9
[1] creep strain = total strain – elastic strain			[2] elastic modulus = (1 MPa / elastic strain)		

VOLUME STABILITY OF THE MASONRYBLOCK UNITS AT CONTROLLED ENVIRONMENT

Expansion Test at Two Different Relative Humidity

For volume stability test, the samples were conditioned in a relatively controlled environment, i.e. at the same temperature of 21±0.5°C, but at two different relative humidity (RH) condition, i.e. at 42±2% RH and at 62±1% RH (at two different curing room). Four samples with size of 100x100x65mm were tested at each conditioning. A pair of demec points which had been designed to have a small notch (holes), were pasted on the four sides of the samples by means of super glue. The expansion of the samples was monitored by means of a 50mm Demec gauge (Figure 4), by inserting the pointed part of the Demec gauge (on the other side of the dial gauge), then the reading on the dial gauge noted. The typical room conditioning of the samples is shown in Figure 5. The results are shown in Figures 6 and 7.

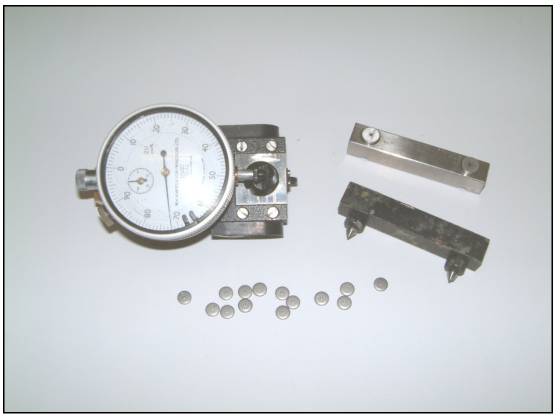

Figure 4. A 50mm Demec gauge with its supporting equipment

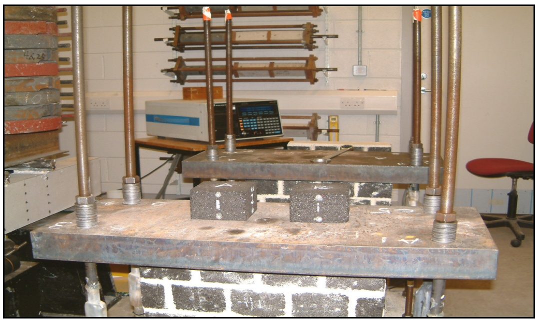

Figure 5. Conditioning of the samples in a controlled environment

Referring to the expansion results in Figure 6, at 42±2% RH the sample gradually expanded to about 68 microstrain and stabilized after 15 days. At 62±1% RH, the averaged expansion was 215 microstrain as shown in Figure 7, and stabilized 20 days. The results show that the samples undergo larger expansion at higher relative humidity.

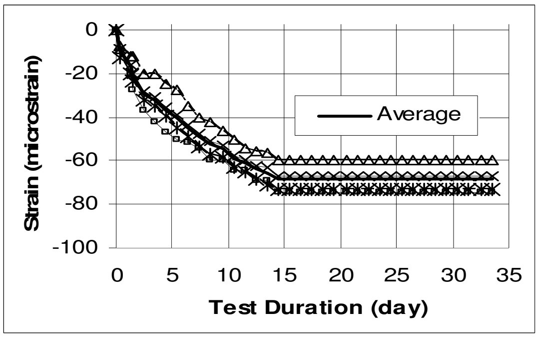

Figure 6. Expansion of the Masonryblock at 21.0 ± 0.5 °C, and 42±2% RH

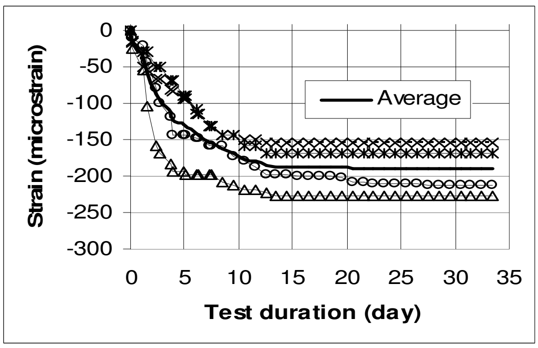

Figure 7. Expansion of the Masonryblock at 21.0 ± 0.5 ° C, and 62±1% RH

Expansion Test on The Effect of Relative Humidity (RH) Changes

In order to create testing environment with constant RH, two type of testing environment were prepared using desiccators added with two hygrostatic solutions, i.e. solution for lithium chloride (12%RH) and potassium chloride (85%RH), (Figure 8).

Figure 8. Sample conditioning in desiccators, with hygrostatic solution at the base.

Referring to Section 1, the prepared sample was initially conditioned overnight at room environment. The initial reading was taken before placing the samples into the desiccators, then expansion/shrinkage was measured after 5 hours, and then 3, 6, 9, 14, and 21 days. These reading periods were taken in an effort to minimize disturbance to the RH conditioning of the sample in the desiccators.

It is necessary to mention that during overnight conditioning at room environment, there was water leak from pipe water installation at a corner of the room. This situation caused the environment RH on the initial reading was unusually high: 72%. The room temperature was relatively constant at 21±0.5 °C. The results are presented in Figure 9.

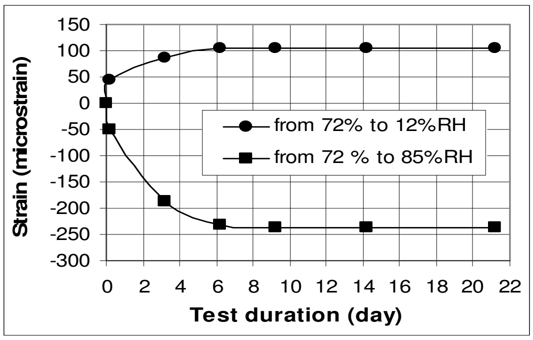

Figure 9. Volume stability of the samples due to changes in relative humidity (RH)

Considering the environment RH on the initial reading was unusually high: 72%, but with relatively constant room temperature 21±0.5 °C, Figure 9 shows that the sample gradually shrunk to around 102 microstrain (positive value) when it was conditioned from 72%RH to12%RH. When the other sample was conditioned from 72%RH to85%RH, it expanded to about 235 microstrain (negative value). Figure 9 clearly demonstrates that the sample shrinks at lower RH, and expands at higher RH. Stable volume was achieved after about 6 days of conditioning. This later results confirmed the results obtained earlier.

Thermal expansion at 70 °C

Within this test the sample was prepared by sticking a pair of Demec point in vertical direction at each of the four vertical faces/sides (f1 to f4) of the samples (Figure 5). Two cycles of thermal expansion were monitored by manual measurement using a 50mm Demec gauge. The sample was heated in oven. Target temperature of 70 °C was achieved within two hours then expansion measurement was carried out. Cooling of the to room temperature 21 °C sample requires 4 hours when the oven door opened. The expansion of the sample is shown in Figure 10.

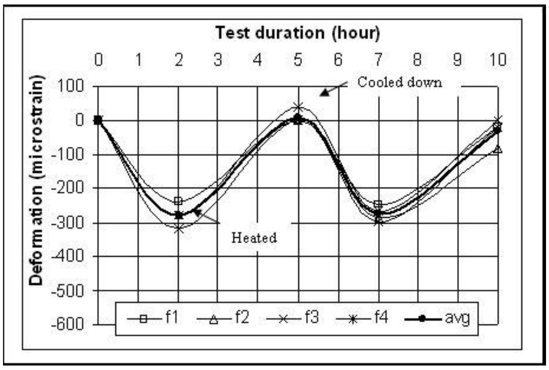

Figure 10. The expansion of the sample at 70 °C

Figure 10 shows the sample expanded to about 280 microstrain when heated from room temperature 21 °C to 70 °C (49 °C elevated temperature). This gives coefficient of thermal expansion about 5.7 microstrain per 1 °C elevated temperature, which is within similar range of coefficient of thermal expansion of clay bricks: 4.5 to 7.2 x 10^{-6} /°C, and slightly lower than concrete masonry unit: 7.2 to 9.0 x 10^{-6} /°C (Drysdale, 1994). In general the results indicated that the volume expansion the sample due to heat exposure of 70 °C was highly reversible to its original condition.

CONCLUSION

Considering the results and the analysis, the following conclusions were withdrawn:

- The performance of the Masonryblocks in term of compressive strength is comparable or even well above compressive strength of concrete blocks currently used in the UK.
- The creep performance of the Masonryblocks was found satisfactory, i.e. < 100 microstrain.
- The volume stability of the Masonryblocks was found affected by environment relative humidity (RH). Higher RH causes higher expansion and vice versa. When the sample was conditioned to lower RH, it shrunk.
- The expansion of the Masonryblock was found larger at higher relative humidity.
- Thermal expansion of the Masonryblocks was found highly reversible.

ACKNOWLEDGMENT

The author would like to express his gratitude and appreciation to the Engineering and Physical Sciences Research Council (EPSRC) - United Kingdom for providing funds, and his research supervisors Dr. S.E. Zoorob and Dr. J.P. Forth who had given guidance during the author's post doctoral research at The School of Civil Engineering Leeds, University-United Kingdom, in the year of 2004-2007.

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