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Moisture Absorption and Thermal Expansion of Building Blocks Bound with Bitumen

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Abstract

This paper described about masonry wall building blocks that incorporate waste aggregate materials, namely steel slag, crushed glass, and coal fly ash. The binder used was 50 pen bitumen. The investigation was carried out at the University of Leeds United Kingdom (UK). The samples were produced by hot mixing the waste aggregates, compacting by static compaction, then applying heat curing to the compacted samples to harden the bitumen binder. The objective of the investigation was mainly to evaluate the building blocks compressive strength and volume stability (expansion and shrinkage) due to moisture and thermal exposure. It was found that the sample's compressive strength was comparable to concrete block commonly used in the UK. The volume stability of the sample was found largely irreversible due to moisture exposure, but highly reversible due to heat conditioning. The samples gave coefficient of thermal expansion comparable to clay bricks and concrete masonry blocks, and coefficient of moisture expansion similar to clay bricks. The blocks are suggested to be used for internal walls and are not exposed to outdoor weather, and should be protected with sand cement mix plaster.

Keywords: M*asonry, bitumen, moisture, thermal, expansion.*

Abstrak

Paper ini menguraikan tentang blok pasangan dinding yang menggunakan agregat dari bahan bekas yaitu: steel slag, *pecahan kaca, dan abu terbang batu bara. Bahan perekat yang dipergunakan adalah aspal penetrasi 50. Penelitian dilaksanakan di* Leeds University United Kingdom (UK). *Penggunaan bahan bekas dalam industri bangunan sudah digalakkan sejalan dengan strategi. Sampel diproduksi dengan dicampur secara panas, dipadatkan dengan pemadatan statis, dan dipanaskan untuk mengeraskan perekat aspal. Tujuan dari penelitian ini utamanya adalah untuk mengevaluasi kuat tekan dan stabilitas volume (pengembangan dan penyusutan) dari blok bahan dinding akibat terekspos air dan panas. Ditemukan bahwa kuat tekan sampel sebanding dengan jenis bata beton yang umum dipergunakan di Inggris. Stabilitas volume sampel dalam porsi besar tidak kembali ke kondisi semula akibat terekspos air, namun dapat kembali ke volume semula akibat terekspos panas. Sampel memberikan koefisien ekspansi termal yang sebanding dengan bata tanah liat dan bata beton, dan memberikan koefisien pengembangan lembab mirip seperti bata tanah liat. Blok pasangan yang diteliti ini, disarankan untuk digunakan sebagai dinding di dalam ruangan yang tidak terpapar cuaca luar dan diberi pelindung plesteran pasir-semen.*

Kata-kata Kunci: *Pasangan, aspal, lembab, panas, pengembangan.*

1. Introduction

The production of masonry Building Blocks described in this paper incorporated waste aggregate namely: steel slag, crushed glass, and coal fly ash. The binder used was a 50pen bitumen. This paper relates to the previous publication by the authors (Thanaya et al, 2006; Forth et al, 2008).

Works on this blocks, certainly supports the UK government efforts in reducing wastes material to landfill. The United Kingdom (UK) government has the 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).

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

Thin single leaf masonry wall is more sensitive to movement which can be cause by various aspects, among other: load, temperature and moisture changes, and chemical interaction. Movement can be permanent or temporary that depends on the materials and cause of movement. Movement due to temperature and moisture is affected by of geographic location and regional climate. The resultant of varying movement shall be accommodated by providing sufficient vertical and horizontal joints. This matter need to be taken into consideration on masonry wall design. Material for the movement joint shall be able to withstand compression (such as fiber boards) and expansion (such as bitumen impregnated foamed) that compressible up to 50% of its thickness. The joint should be protected by about 10 mm mastic sealant (BS5628-3, 2005; Hanson, 2007).

This work is more attractive in areas close to oil refinery, especially in oil producing countries, where a lot of bitumen (oil distillation residue) which can be used as an alternative binder and waste aggregate materials are available.

The objective of this paper is to mainly evaluate of the compressive strength and volume stability (expansion and shrinkage) of the building blocks due to exposure to moisture and temperature.

2. The Type of Building Block Investigated

Within this paper the building blocks investigated incorporated steel slag, crushed glass and coal fly ash. For a balance among porosity and heat curing efficiency, the building block can be produced with low compaction level and posses enough shape stability during handling. The building blocks aggregate grading as shown in **Figure 1**, was determined based on trials by modifying the grading of hot rolled asphalt (BS594-1, 2003), that contains sufficient fines. The aggregate grading gave a texture which was neither too smooth nor too rough. The material proportion and properties are given **Table 1**. Changes of material incorporated were carried out by volume substitution, by referring to the volume of crushed glass.

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 (crushed glass) have been considered for this investigation. The properties of the materials selected are shown in **Table 1**.

In term of the type of bitumen used**,** in principal all types of bitumen (hard/penetration grade) can be used as the binder. However, it is preferable to use softer grade bitumen as this requires a lower handling temperature. Also, 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 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 a specific gravity of 1.03 and a softening point of 47 °C, which was softer than hard bitumen H 80/90 previously tried (Thanaya et al, 2006). The 50 pen bitumen is widely available in the United Kingdom (UK).

3. Building Blocks Production and Optimization

The blocks were produced in hot mix method. The aggregate materials that had been proportioned and the 50pen bitumen were pre-heated at 160-180 °C (Withoeak, 1991) for 3 hours. The loose mix was then placed in a mould and compacted by static compaction of 1, 2 and 4 MPa. The sizes of the samples were 100x100x65mm.

Following compaction, the 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 (Thanaya et al, 2006). 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.

The performance of the blocks is influenced by porosity and the heat curing regime. Sample with lower porosity (higher compaction level) improved aggregate interlock which increases the compressive strength. However, more efficient heat curing would occur when the porosity is sufficient, as this will improves the long-term stability of the blocks (i.e. reduces the creep potential). In this investigation, the curing regime was fixed at 200°C for 24 hours, and bitumen content were varied from 5 to 6.5%, with 0.5 % increment.

For efficiency, the samples were produced by utilizing less bitumen content and low compaction level. With this principle, and considering the compressive strength results shown in **Figure 2**, compaction level of 2 MPa and bitumen content of 6 % were chosen, as these had given satisfactory results, i.e. adequate degree of coating, stable during handling and sufficient cured compressive strength. Additional bitumen content was not found to give significant improvement.

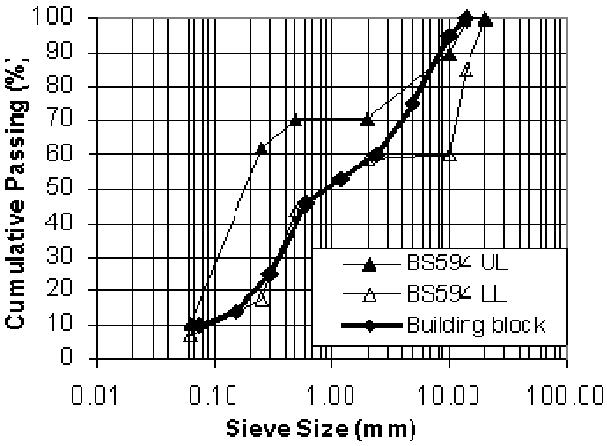

Figure 1. The building block aggregate grading used in comparison to hot rolled asphalt (BS594) Note: UL= upper limit; LL= lower limit

Table 1. The properties of the aggregate materials

Materials	Density (gr/cm3)	Water Abs (%)
Coarse agg (CA); > 2.36mm (40 %)		
Steel slag	3.39	1.9
Crushed glass	2.51	< 0.5
Fine agg. (FA); (2.36-0.075mm), (50%)		
Crushed glass	2.51	< 1
Filler; passing 0.075mm (10%)		
Fly ash Ferrybridge	2.16	-

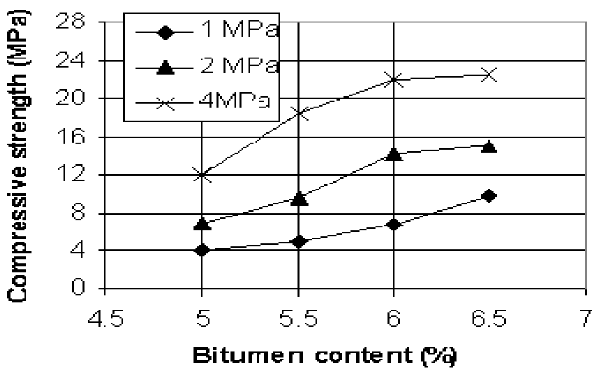

Figure 2. Bitumen content vs. compressive strength (cured samples)

The compressive strength of the units at this option was 14.2 MPa which exceeded the compressive strength of concrete blocks commonly used in the UK: 2.8 to 10 MPa (BS 6073-1, 1981). Static creep test had been carried out, and gave satisfactory creep strain per MPa stress (specific creep) as given in **Table 3**, i.e. less than 100 microstrain (Tapsir, 1985).

4. General Properties of the Building Blocks

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

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 blocks 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 suggests that the Building Blocks tested in this experiment would require or more suitable to use stiffer mortar.

5. Expansion due to Moisture Adsorption (MA)

Two samples with size of 100x100x65mm were tested. Two pairs 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, as shown in **Figure 3**. The expansion of the samples was monitored by means of a 50mm Demec gauge as shown **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.

Table 2. The properties of the Building Blocks at 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	MPa	2.6
- Cured *		14.2
Specific creep	microstrain	44.6

***** cured at 200˚ C for 24 hours

Figure 3. The samples pasted with Demec points

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

On the first test two samples were conditioned at room environment, i.e. at temperature of 21. 0 ± 0.5 C° and 62±2% relative humidity (RH). The strain measured was on the vertical direction only. It was found that the samples expanded with average value of about 215 microstrain (10-6) as shown in **Figure 5**.

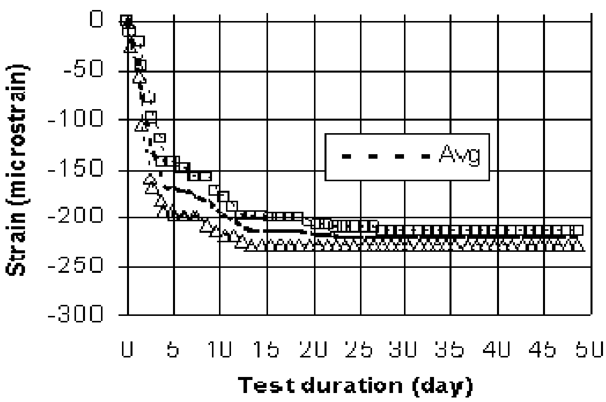

Figure 5. Expansion of the blocks at 21.0 ± 0.5 C°, and 62±2% RH

In order to evaluate the performance of the samples at different relative humidity, a second test was done by initially conditioning two samples at room environment. The temperature at the testing room was the same as in the first test, i.e. relatively constant at 21.0 ± 0.5 C° with relative humidity of 62±2% RH. The samples were also conditioned at 12%RH and 85%RH which were carried out by using desiccators filled with lithium chloride and potassium chloride hygrostatic solution respectively, as shown in **Figure 6**, where two samples were tested for each sample conditioning.

The expansion reading was taken in vertical and horizontal direction at certain time interval until the expansion stabilized. Then the conditioning was changed to a different relative humidity condition. The results are shown in **Figures 7** and **8**. The expansion reading was taken in vertical and horizontal direction at certain time interval until the expansion stabilized. Then the conditioning was changed to a different relative humidity condition. The results are shown in **Figure 7** (movement in vertical direction) where the starting of conditioning changes is coded from 1 to 5. Similar results are given on **Figure 8** (movement in horizontal direction). It is shown in **Figures 7** and **8**, that the vertical and horizontal movement of the samples were found not exactly isotropic. This matter could be affected by the nature of the materials used which were not homogeneous.

Figure 6. Conditioning of samples in a desiccator

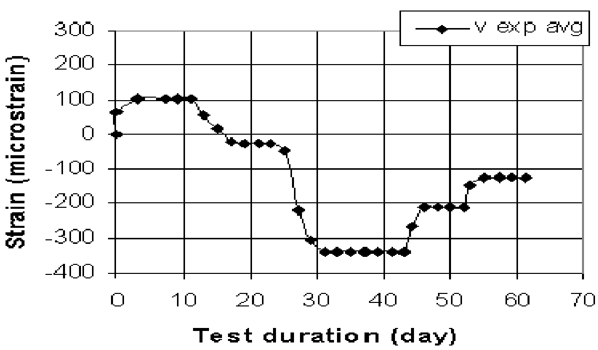

Figure 7. Average movement of the samples in vertical (v) direction

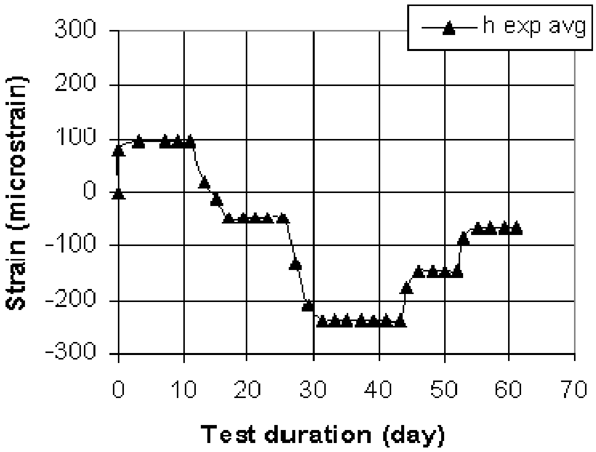

Figure 8. Average movement of the samples in horizontal (h) direction

The description of the samples movement in vertical direction (**Figure 7**) is as follows: the samples were initially left overnight at room environment with 62±2% RH before the first strain reading was noted. After conditioning at room environment, the samples were then conditioned in a desiccator with 12%RH, using lithium chloride hygrostatic solution (start of conditioning 1). The samples gradually shrunk then stabilized at +100 microstrain. Starting on day 11th, the samples were taken out from the desiccator and left at room environment (62±2% RH), (start of conditioning 2). The samples slowly expanded then stabilized at -20 microstrain. Starting from day 24th the samples were put back into a different desiccator with 85%RH, using potassium chloride hygrostatic solution (start of conditioning 3). The samples expanded (towards negative strain values) then stable at -340 microstrain. Starting for day 44th and then the following days, the samples were consecutively condition until stabilized at room environment (start of conditioning 4), then at again at 12%RH (start of conditioning 5). Similar description applies to the horizontal movement (**Figure 8**). The vertical and horizontal movement were found rather an-isotropic. This is predicted to be caused by the non homogeneous nature of materials used.

This further test confirmed that the volume stability of the samples was affected by changes in relative humidity. Conditioning to lower relative humidity caused the samples to shrink and vice versa. However, the magnitude of expansion and/or shrinkage was found not proportional to the changes in RH. The results indicated that the samples movement were partly reversible and partly irreversible. Almost all of the movement was irreversible. This situation is similar to clay brick (Vekey, 2001).

The results suggest that the expansion of the samples had similar mechanism with cement paste or concrete, i.e. due to moisture adsorption. Due to absorption of water molecules onto the surface of the particles, it reduces the surface energy on the capillary system, hence reducing the balancing internal compressive stress leading to volume increasing or swelling (Domone, 1994). This is also described by Neville (1991) that during water adsorption, the water molecules act against cohesive forces and tend to force the cement gel particles further apart. The ingress of water also decreases the surface tension, and results in swelling.

It was also observed that the samples did not crack which indicates that the expansion was not excessive. The expansion of the unit would be neutralized by the shrinkage of the sand cement mortar joints in wall construction. The expansion can also give a prestressed condition to the wall structure which can improve the ability of the wall to receive horizontal load.

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6. Stability of the Building Blocks During Vacuum Saturation and Air Drying

Moisture exposure to samples can be done in various method, namely by water immersion, by immersion in boiling water, and by vacuum saturation. The effectiveness of any method is largely affected by the porous nature of the samples. Vacuum saturation had been found to give effective and fast moisture conditioning. However, there is no standard currently available for vacuum saturation test (Wilson et al, 1999).

Within this experiment, an innovative vacuum saturation test was carried out by using a set of equipment as shown in **Figure 9**. The lowest vacuum strength can be done in line with the equipment used was 70-80 kPa. This pressure is far larger 5 kPa (50 mbar) recommended in the BS 812, for evacuating trapped air bubbles in testing the density of filler (BS 812, 1995). It had been experienced by the author that in line with the nature of the samples (with 15-20% porosity), the effectiveness of the vacuum saturation test method mentioned above was found equal to the water absorption value obtained by water immersion for 24 hours as shown in **Table 2**. So this method gave a significant time saving.

The test was carried out in three cycles. Each cycle consisted of the following procedure: the samples were initially vacuumed without water for 30 minutes, then water was supplied until the sample was fully immersed. The immersed samples were then vacuumed for a further 30 minutes, after that they were left soaked for 30 more minutes. Then the samples were weighed and air dried at room environment until the weight of the sample stabilized as shown in **Figure 10**. It shows that the vacuum saturation test applied gave the 6 % water absorption

Measurement of the volume stability (expansion or shrinkage) and weighing of the samples was done every 24 hours. The results are shown in **Figures 11** and **12**.

Figure 9. Vacuum saturation test equipment

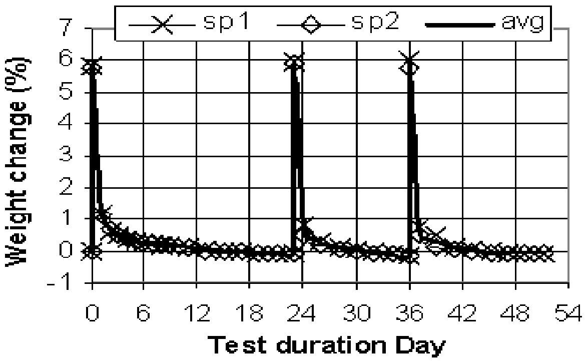

Figure 10. The Weight change of the samples (sp) during vacuum saturation test and air drying cycles

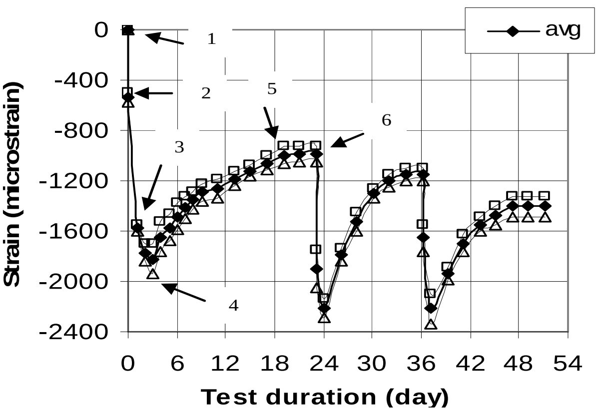

Figure 11. The strain profile of the samples (sp), during vacuum saturation and air drying, in vertical (v) direction

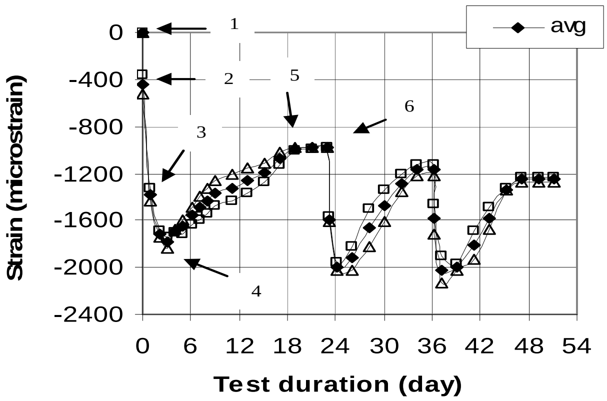

Figure 12. The strain profile of the samples (sp), during vacuum saturation and air drying, in horizontal (h) direction

Figure 11 and **12** revealed an interesting behaviour. The vertical movement of the sample is shown in **Figure 11**. The samples movement during the vacuum and saturation cycle was coded by code 1 to 6. The first vacuum saturation caused the samples to expand to about 500 microstrain (from 1 to 2), then samples were air dried at room environment. After 1 day of air drying the samples continued to expand to about 1600 microstrain (from 2 to 3). Expansion still occurred on the following two days to a maximum of 1850 microstrain (from 3 to 4), regardless of continuous moisture loss as shown in **Figure 10**. The samples were then very gradually shrunk before becoming stable at 1000 microstrain (from 4 to 5). It took more than three weeks for the samples to stabilize on the first cycle.

After that two more vacuum saturation and air drying cycles were carried out. The room temperature during air drying process was relatively constant at 21.0 ± 0.5 C°, but the relative humidity (RH) was fluctuated. During the first cycle of air drying the RH was 62±2 %, then 50±2 % on the next two cycles. This cycle should affect the rate of expansion and shrinkage of the samples. The second cycles was started from code 6 where the measurement of the sample's movement was done in similar pattern with the first vacuum saturation cycle.

Referring to **Figure 12**, it was revealed that similar pattern of result was obtained in horizontal direction, but of smaller magnitude than in vertical direction (**Figure 11**). The results indicated that samples movements were anisotropic, where the horizontal movements were about 14 % less than the vertical movements. This may also be associated with the vertical direction of compaction.

Figure 11 and **12** show that the expansion due to vacuum saturation on the first cycle was totally irreversible. Then the partial reversible movement occurred during air drying, i.e. the samples expanded then shrunk, but it did not return to their position at the start of air drying conditioning. The results indicated that due to moisture exposure the volume stability of the Building Blocks were largely (or partly) irreversible from its original condition. This properties is similar to concrete masonry (CST, 2007), as well as to clay brick (Vekey, 2001). The moisture expansion of the Building Bcocks was found comparable to the expansion of fired clay brick which can vary between 500-2500 microstrain (ADS, 2007).

The results also suggest that the volume stabilities of the Building Bcocks were in line with the mechanism of shrinkage and swelling in concrete technology. Free water surfaces in the capillary will be in surface tension. When water evaporates due to a lowering of ambient vapour pressure, the surface tension increases and causes increases of tensile stress. This will be balanced by compressive stresses in the surrounding solid which results in its shrinkage (Domone, 1994). Neville, 1991, suggests that the cause of shrinkage shall be sought in the physical structure of the gel rather than in its chemical and mineralogical character.

Meanwhile, due to absorption of water molecules onto the particle surfaces within the Building Blocks, it reduces the surface energy, hence reducing the balancing internal compressive stress leading to volume increase or swelling (Domone, 1994). It is also described (Neville, 1991) that during water absorption, the water molecules act against cohesive forces and tend to force the cement gel particles to further apart. The ingress of water also decreases surface tension, and results in swelling.

Considering the effect of moisture or water to the volume stability of the samples, the blocks are suggested to be used for internal free standing walls, and protected with sand cement mix plaster. The blocks are not suitable for external use that directly exposed to weather.

7. Thermal Expansion of the Building Blocks

Thermal expansion test was carried out by conditioning the samples in oven at 70 °C for 3 hours. This time was sufficient to generate the targeted heat on the core of the samples (tested using a wire thermocouple, where the wire was inserted into a hole drilled at one of the samples). After heating, the samples were left at room environment (21.0 ± 0.5 °C, with 50±2% RH) until stable. The results are presented in **Figures 13** and **14**.

Referring to **Figure 13** (strain in vertical direction), within the first heating cycle the samples expanded to 750 microstrain (10-6). Then the samples were taken out from the oven and conditioned at room environment for 2 days. Within the first day at room environment the samples shrunk almost to its original position and then slightly expanded on the next day due to the moisture absorption from the environment (as had been experienced). Similar procedures were carried out on the next two cycles. Strain in horizontal direction was of similar pattern, but with lower strain magnitude as shown in **Figure 14**. There was element of anisotropic movement between the vertical and horizontal movement, i.e. similar to the movement due to vacuum saturation and air drying described in Section 6). The horizontal movement was about 13 % less than the vertical one. This may be associated to the compaction from vertical direction.

Thermal expansion of the blocks was found highly reversible, similar to concrete masonry (CST, 2007). The coefficient of thermal expansion on the Building Blocks was around 600-700 microstrain or (1×10-6) per 70 °C, or about 8.6-10x10-6 /°C. This coefficient should have affected by the size of the samples (100x100x65mm) and the level of curing regime applied. The coefficient is comparable to the coefficients of expansion of concrete masonry units, i.e. 7.2 to 9.0 x 10-6 /°C (Drysdale et al., 1994).

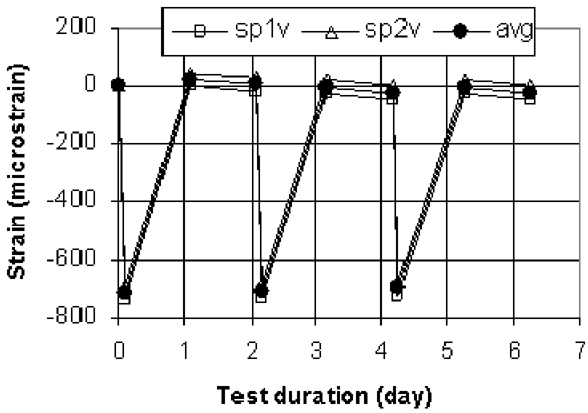

Figure 13. The strain profile of the samples (sp), during heating at 70 °C for 3 hours, in vertical (v) direction

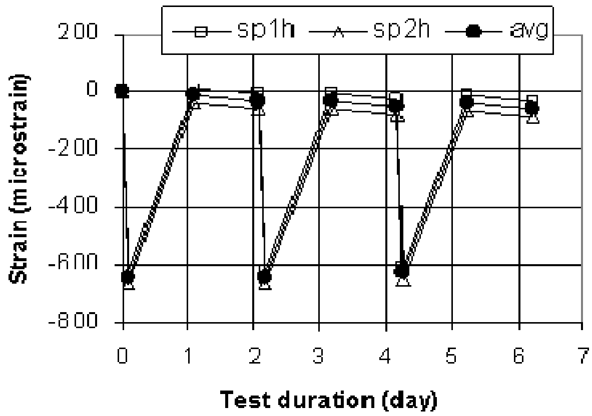

Figure 14. The strain profile of the samples (sp), during heating at 70 °C for 3 hours, in horizontal (h) direction

8. Conclusions

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

1. The performance of the Building Blocks in term of compressive strength were comparable to the concrete blocks currently used in the UK.

2. The expansion of the Building Blocks was affected by environment relative humidity (RH). Conditioning at lower relative humidity caused the samples to shrink and vice versa.

3. The magnitude of expansion and/or shrinkage was found not proportional to the changes in RH.

4. Due to the moisture exposure the Building Blocks were generally expanded, and the volume stability of the Building Blocks was found largely irreversible from its original condition. The moisture expansion of the Building Blocks was comparable to clay bricks.

5. Thermal expansion of the Building Blocks was found highly reversible, with coefficient of thermal expansion comparable to the concrete masonry block.

6. The Blocks are suitable for internal walls, protected with sand cement mix plaster, and could not directly be exposed to weather (this is subject to further investigation).

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