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Investigating Physical Stability of a Novel Sustainable Building Block

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ABSTRACT

The UK government's strategy to reduce waste disposal via landfill has encouraged the use of waste materials in the construction industry. This investigation is part of an ongoing programme of laboratory based research to develop building block mixes with bituminous bound waste materials such as, steel slag, crushed glass, coal fly ash, rice husk ash (RHA), incinerator sewage sludge ash (ISSA), and municipal solid waste incinerator bottom ash (MSWIBA) also known as IBA. Compressive strength, creep and expansion tests were carried out on a number of mixes. The block samples were 100mm × 100mm × 60mm in size and compacted at 1, 2 and 4MPa stress. The curing regime of 200°C for 24 hours gave satisfactory compressive strengths and creep strains that are comparable with standard coarse aggregate concrete blocks. The optimum bitumen content of these blocks was found to be 6% at 2MPa compaction level. The expansion of Bitublocks was tested to check volume stability. The average expansion was 215 microstrain at a relative humidity (RH) of 62±1%; the samples were stable after 14 days.

INTRODUCTION

The laboratory scale masonry blocks described in this paper incorporated various combinations of waste aggregates, namely: steel slag, crushed glass, coal fly ash and rice husk ash (RHA), incinerator sewage sludge ash (ISSA), and municipal solid waste incinerator bottom ash (MSWIBA) also known as IBA. The binder used was a 50pen bitumen. The driver behind the development of these blocks was the desire to support and enhance the UK government's aims of reducing the quantity of waste materials being sent to landfill. One of the UK government's targets has been to reduce the amount of commercial and industrial wastes going to landfill to 85% of 1998 levels (Defra UK, 2007). The introduction of the landfill directive represents a step change in the way waste materials are disposed of in the UK and has helped to drive forward waste minimization and increased the levels of recycling and recovery (Defra UK, 2007).

This investigation is part of an ongoing programme of laboratory based research to develop more sustainable building blocks (i.e. the sustainability of the blocks is improved as they are composed entirely (100%) of waste aggregates). The objective of the paper is to compare the compressive strength of these new blocks with current coarse aggregate dense concrete blocks (previously, compressive strength has been shown to be a good indicator of overall performance of the blocks). The creep behaviour and expansion due to exposure to moisture and temperature will also be investigated.

EXPERIMENTAL INVESTIGATION

Performance Criteria

Referring to the currently available specifications for building blocks, the bitumen bound unit should achieve the following level of performance:

- Compressive strength ≥ 2.8 MPa at room temperature, this is in line with the compressive strength of concrete blocks commonly found in the UK (2.8 – 10 MPa), (BS6073-1, 1981).

- Initial rate of suction (IRS) values shall be equivalent to the IRS values of clay bricks found in the UK (0.25 – 2 kg/m2/min). The IRS is a parameter that can provide an indication of the effect of the unit on the cement mortar (quality of bond). Units of the high IRS require very plastic mortar (high water/cement ratio), while units with lower IRS need stiffer mortar (BS3921, 1985 and Vekey, 2001).

- Possess specific creep (static creep strain per unit stress in MPa) of ≤100 microstrain, tested at 20ºC. This target is in line with the specific creep level of concrete blocks currently used in the UK (approximately 100 microstrain). The level of stress of 1MPa shall be used for the creep test as this is considered representative in masonry experiments (Tapsir, 1985 and Forth et al, 2006).

Materials

Bitumen type and content

In principal, all types of bitumen (hard/penetration grade or bitumen emulsion) can be used as a binder. However, it is preferable to use a 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 bitumens would not provide a significant improvement to the end product. 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 47ºC. A range of bitumen contents between 5 and 6.5% was considered. (Note: the development of the new blocks has progressed so that now all traditional aggregates can be replaced with waste or secondary materials. Beyond this work, the intention is to replace the commercially available standard bitumen that is currently being used as the binder in these investigations with bitumens that are considered ‘waste bitumens’ by the petroleum industry so that a completely sustainable block made from 100% waste materials is achieved.)

Aggregate type and grading

In order to reduce the amount of bitumen required, (and hence enhance the economics of the mix) and yet still ensure satisfactory bitumen coating, the incorporation of a combination of waste aggregates with lower absorption properties have been considered for this investigation. From the initial investigation (optimization), Mix No. 1, as shown in Table 1 was selected. The proportion of the materials used for all mixtures are shown in Table 1. Changes in the quantities of materials incorporated were carried out by volume substitution, by referring to the volume of crushed glass.

Table 1: Type of mix and aggregate materials used.

Mix No.	Mix name	Course aggregates (40%)		Fine aggregates: 2.36-0.075mm (50%)	Filler Pass 0.075mm (10%)
		5%(14-10)mm 20% (10-5)mm	15% (5-2.36)mm		
1	B50p-fa	Steel slag	Crushed glass	Crushed glass	Fly ash
2	B50p-ISSA	Steel slag	Crushed glass	Crushed glass	ISSA
3	B50p-RHA	Steel slag	Crushed glass	Crushed glass	RHA
4	B50p-IBAc	IBA	IBA	Crushed glass	Fly ash
5	B50p-IBAf	Steel slag	Crushed glass	75% Crushed glass 25% IBA fines	Fly ash

Table 2: The properties of the aggregate materials

Materials	Density (gm/cm3)	Water Absorption (%)
Course aggregate (CA)	-	-
Steel slag	3.39	1.9
Crushed glass	2.51	0.5
IBA	2.42	2.91
Fine aggregates (FA)	-	-
Crushed glass	2.51	1
IBA	2.15	9.9
Filler	-	-
Fly ash Ferrybridge	2.16	-
Rice Husk Ash	2.04	-

Aggregate grading

The choice of aggregate grading is largely affected by the performance criteria specified above. Previously it has been found that a gap graded distribution of aggregate consisting of about 40% course aggregate (maximum normal size of 14mm; minimum retained 2.36mm) and 60% fine (50% fine aggregates (2.36-0.075mm) and 10% filler (passing 0.075mm) was preferable). The grading enabled the application of a low compaction level to satisfy the block performance. The properties of the materials used are shown in Table 2. Figure 1 shows further details of the aggregate particle distribution and compares this with that specified for aggregates used in the hot rolled asphalt by the British Standards (HRA-BS594).

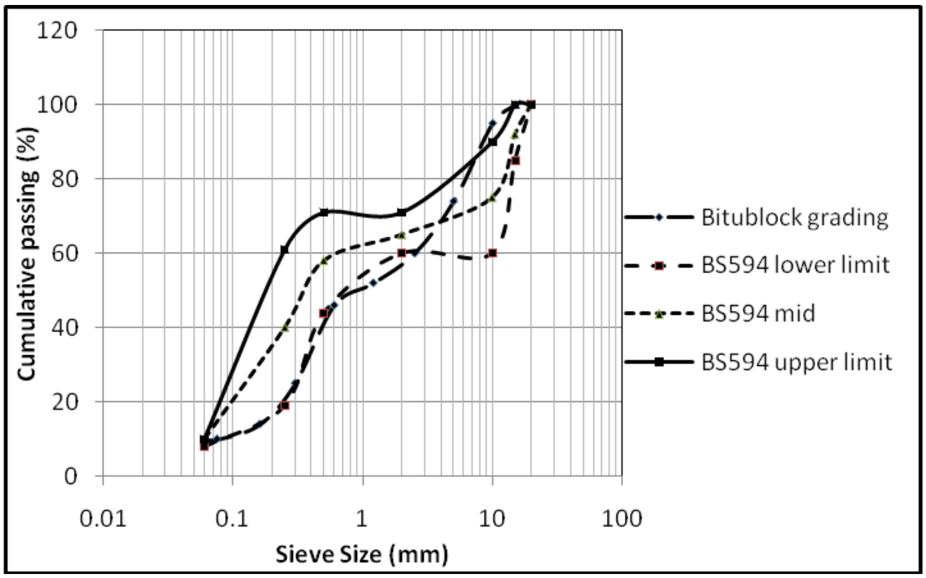

Figure 1: Aggregate grading used in comparison with hot rolled asphalt aggregates (HRA-BS594), an example case.

RESULTS AND DISCUSSIONS

Bitublock Unit Optimization

The manufacture of the blocks has been reported previously by Forth et al (2006), van Dao et al (2006) and Forth et al (2008). Briefly, to facilitate mixing the aggregate materials and the 50pen bitumen were preheated at 160-180ºC (Withoeak, 1991) for 3 hours. The loose mix was then placed in a mould and compacted.

Following compaction, the samples were cured in an oven. Curing has previously been found to play a significant role. When using a 50pen bitumen and curing at 160ºC, the curing duration required to satisfy creep performance was 72 hours (Thanaya et al., 2006). In order to reduce the curing duration, in this investigation the samples were cured at 200ºC for 24 hours.

The performance of the block is influenced by porosity and the heat curing regime. A lower porosity (higher compaction) gives improved aggregate interlock which increases the potential compressive strength. However, more efficient heat curing (lower porosity – greater depth of bitumen oxidation/hardening) improves the long-term stability of Bitublock (i.e. reduces the creep potential). In this investigation, the curing regime was fixed and the compaction level applied was 1, 2 and 4MPa; the bitumen content was varied from 5 to 6.5% in 0.5% increments. Figure 2 to 4 illustrate the optimization of Mix No. 1.

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

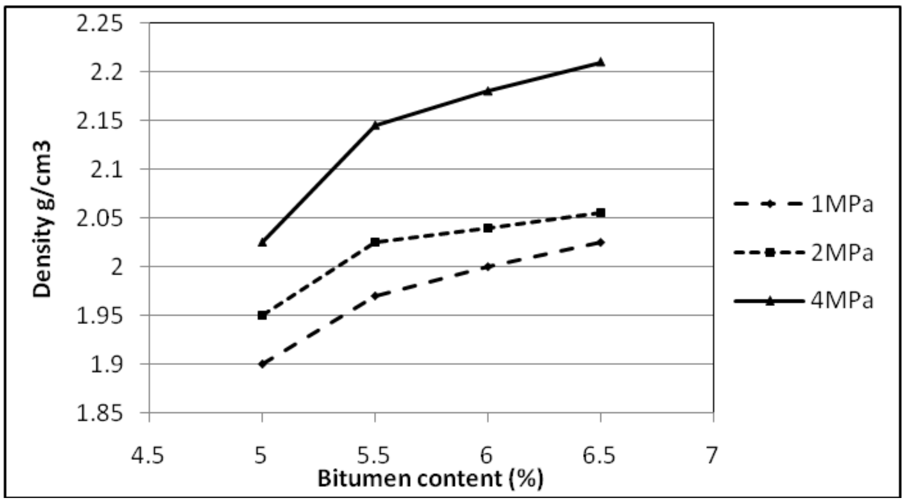

Figure 2: Bitumen content vs. density.

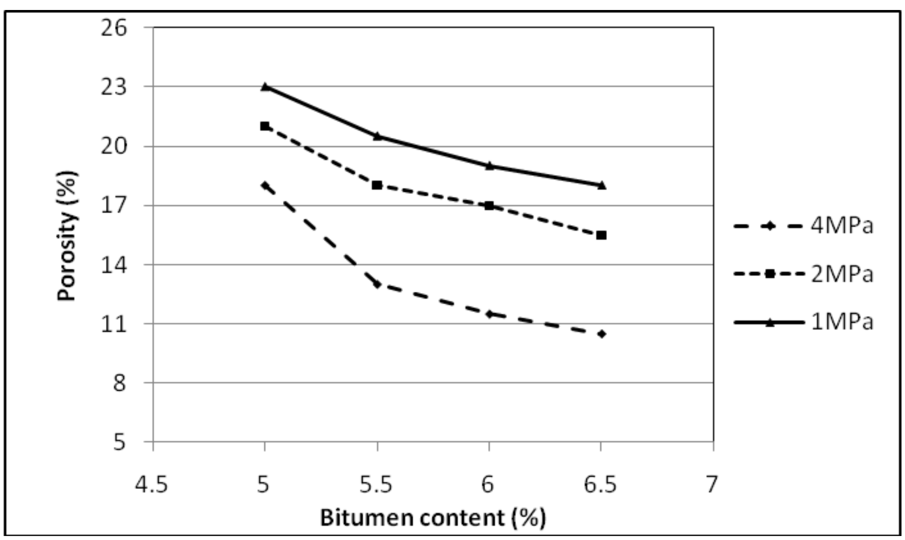

Figure 3: Bitumen content vs. porosity.

From Figure 2 and 3 it can be seen that a decrease in bitumen content from 6.5% to 5%, corresponds to a decrease in density and an increase in porosity. This is a common trend in bituminous mixtures as the mixture becomes less workable at lower bitumen contents. As expected, a reduction in compaction level also corresponds to a decrease in density and an increase in porosity. The compressive strength trends shown in Figure 4 are in line with the trend identified for density. However, for units compacted at 2MPa there is little improvement in compressive strength beyond 6% bitumen content. It has been shown previously that further increases in bitumen content (higher than 6.5%) can enhance the density and hence the compressive strength. However, by observing the satisfactory degree of coating of the aggregates; the surface texture of the units and the stability of the samples during handling, together with the insignificant improvement in compressive strength of samples with over 6% bitumen content compacted at 2MPa, it was decided not to optimize the bitumen content further on this occasion. For the remainder of the investigation it was therefore decided to fix the bitumen content at 6% and the compaction level at 2MPa. The compressive strength of these units still exceeded the compressive strength of concrete blocks commonly used in the UK (2.8 – 10MPa). Also, a 0.5% reduction in the bitumen content and a slightly higher porosity is expected to improve the long-term stability of the unit. Stability of the block units was monitored under ambient conditions: 21±0.5ºC and relative humidity (RH) of 42±1%.

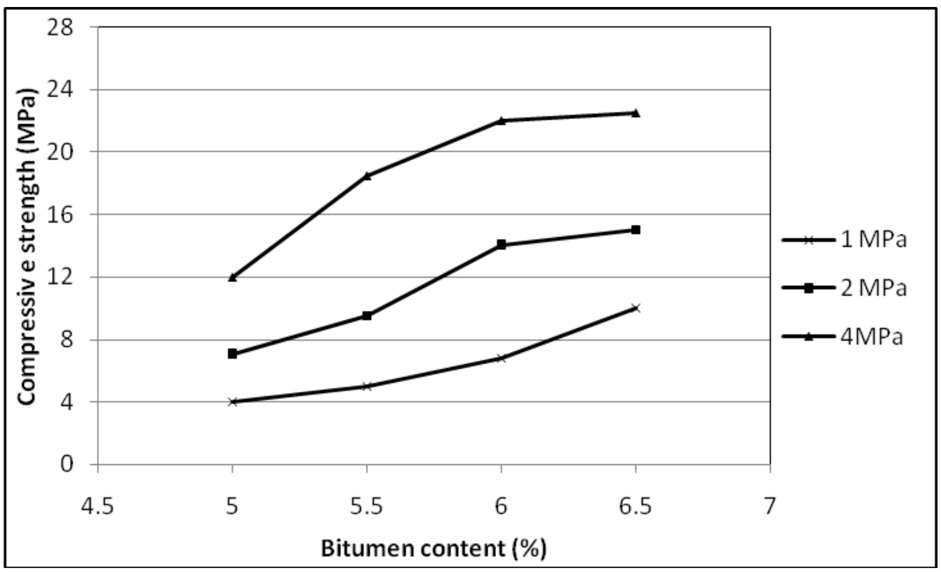

Figure 4: Bitumen content vs. compressive strength.

For the volume stability test, four samples of the blocks (Mix No. 1 as in Table 1: Mix 50p-fa) with a size of 100×100×65mm were tested. Expansion was recorded on four vertical sides of the samples by means of a 50mm Demec gauge. Average expansions of 215 microstrain were recorded, as shown in Figure 5. At a relative humidity (RH) of 62±1%, the samples were relatively stable after approximately 14 days.

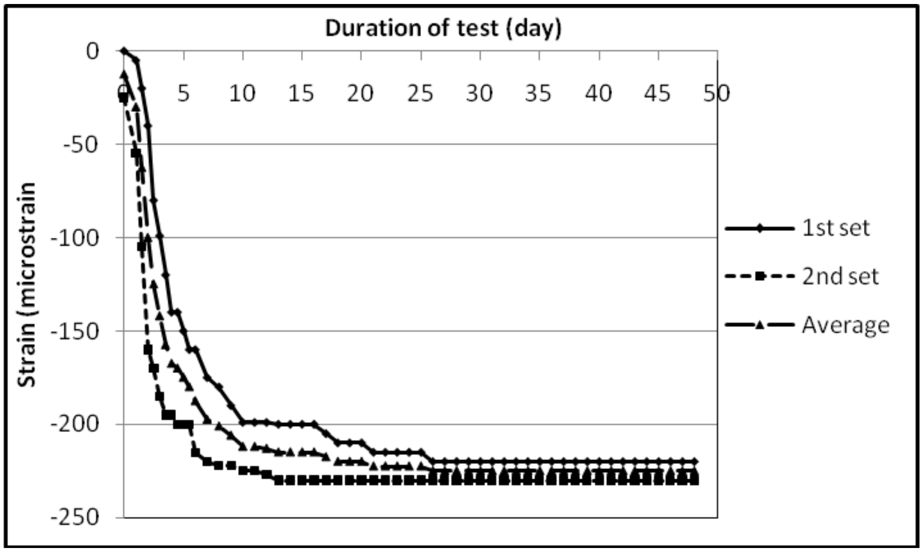

Figure 5: Expansion of block (Mix B50p-fa) at 21.0±0.5ºC and relative humidity (RH) of 62±1%.

Creep Test on Mix 50p-fa

Referring to the results in Figure 5, the samples were almost stable after 14 days. For this reason the age of the samples used for the creep tests were between 2-3 weeks.

The creep tests were initially carried out on Mix No. 1a and b (Table 3 - Mix 50p-fa) with two compaction levels (1MPa and 2MPa). The samples were loaded using a static dead-weight lever arm machine (Mechanical advantage of 4) as shown in Figure 6. The stress applied was 1MPa. The strain was monitored on the four vertical faces of each sample using a 50mm Demec gauge (Figure 7) and then averaged. The samples were loaded in a controlled environment (62±1% RH and 21±0.5ºC).

Figure 6 and 7: Static deadweight load lever arm machine and a 50mm Demec gauge with its supporting equipment.

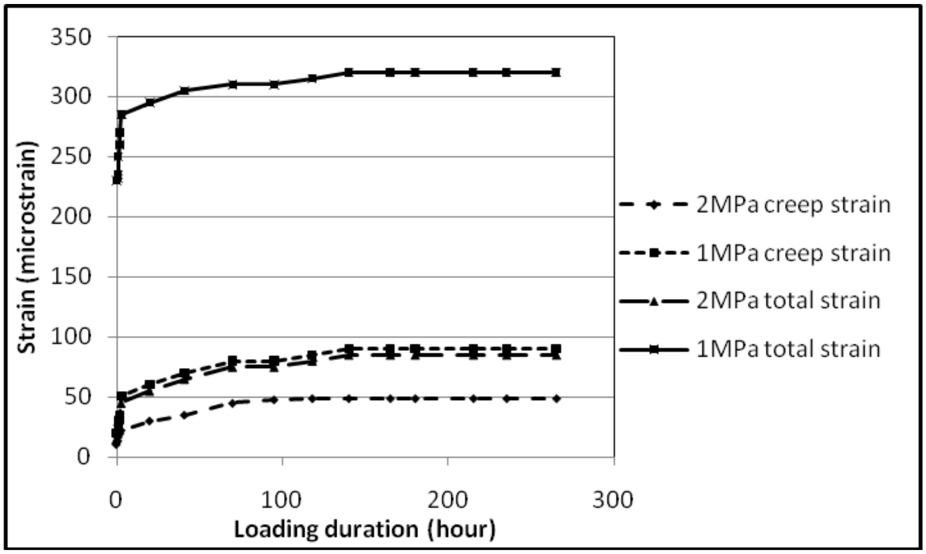

Figure 8: Creep test results of the block units (Mix B50p-fa) compacted at 1 and 2 MPa.

Figure 8 also shows the elastic strain (the strain soon after loading) of the samples. The creep of the units compacted at the both 1 and 2MPa were acceptable (in terms of their comparison with concrete blocks), however, the compaction level of 2MPa was chosen for producing other type of mixtures as mentioned in Table 1, to ensure satisfactory performance. The properties of mixtures are given in Table 3.

Table 3: Properties of the mixes with 6% bitumen content.

Mix No.	Mix name	Density (g/cm3)	Porosity (%)	IRS (kg/m2/min)	Water abs. (%)	Compressive strength (MPa)	
						uncured	Cured*
1MPa compaction level							
1a	B50p-fa	2.000	19.2	0.41	6.1	-	6.8
2MPa compaction level							
1b	B50p-fa	2.044	17.4	0.35	5.5	2.6	14.2
2	B50p-ISSA	2.057	18.2	0.44	6.1	-	8.6
3	B50p-RHA	2.013	17.8	0.37	5.4	-	12.7
4	B50p-IBAc	2.253	17.0	0.38	5.8	-	11.6
5	B50p-IBAf	2.071	17.6	0.46	6.0	-	12.0

*cured at 200ºC for 24 hours.

For the samples compacted at 2MPa, the recorded porosities were between 17.0% and 18.2%. The lower strength recorded for Mix No. 2 was thought be due to a slight reduction in the degree of coating of the aggregates of this mix. This reduced the workability of the mix which led to an increase in porosity and the subsequent reduction in compressive strength. The higher porosity of this mix is also due to the presence of ISSA, which is very porous. The overall variation in porosity of the mixes can also be explained by the nature of the materials used (i.e. their differences in surface texture, shape and particle porosity).

The creep results of the mixtures compacted at 2MPa are shown in Figure 9 and 10; all of the results (i.e. elastic and time-dependent movements) are summarized in Table 4.

Table 4: Elastic and creep performance of the samples.

Mix No.	Mix name	Total strain (με)	Elastic strain (με)	Creep strain1 (με)	Elastic Modulus2 (GPa)
1MPa compaction level					
1a	B50p-fa	321.75	232.65	89.1	4.3
2MPa compaction level					
1b	B50p-fa	79.2	34.65	44.55	28.9
2	B50p-ISSA	386.1	272.25	113.85	3.7
3	B50p-RHA	64.35	14.85	49.50	67.3
4	B50p-IBAc	79.2	24.1	55.1	41.5
5	B50p-IBAf	79.2	14.85	64.35	67.3
1 creep strain = total strain – elastic strain, 2 elastic modulus = (1MPa/elastic strain)					

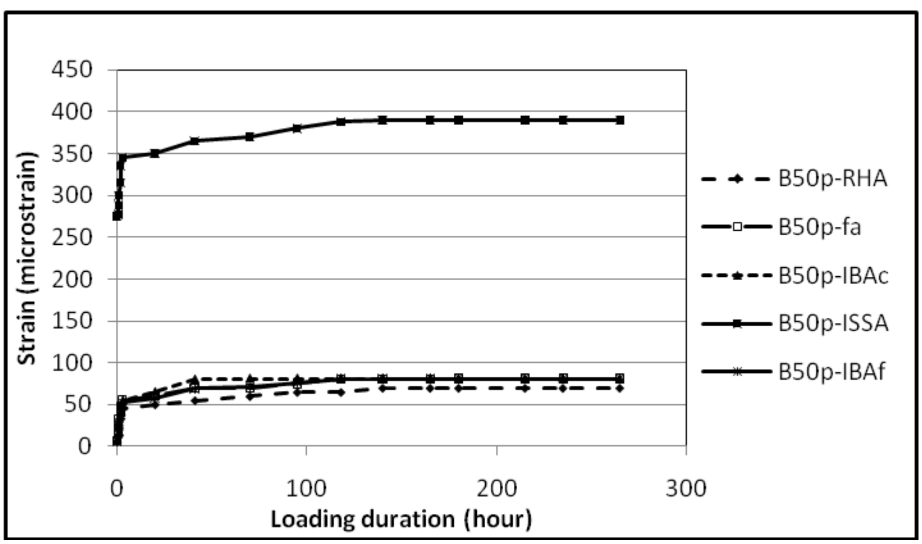

Figure 9: Total strains of Bitublock mixes using 50pen bitumen compacted at 2MPa, cured for 24 hours at 200ºC.

With reference to Figures 8, 9 and 10 and Table 4, the creep of the mixes (compacted at 1 and 2MPa) were generally satisfactory, i.e. they met the specific creep target of 100 microstrain; the exception was Mix No. 2, which gave a creep of 113.85 microstrain however this was only marginally higher than the target. Compared to other mixes, Mix No. 2 exhibited a significantly higher elastic strain. This can again potentially be explained by the higher porosity of the blocks made from this mix.

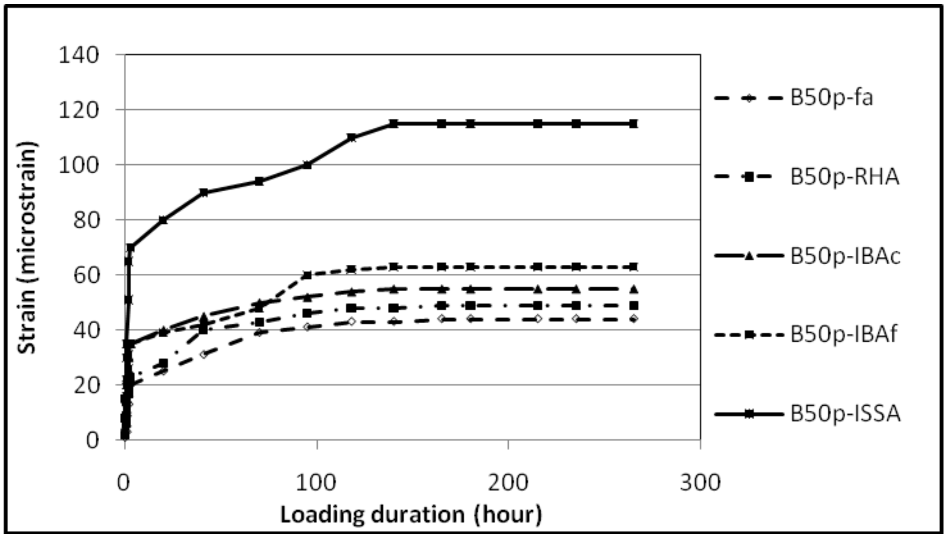

Figure 10: Creep strains of Bitublock mixes using 50pen bitumen compacted at 2MPa, cured for 24 hours at 200ºC.

From the creep results, it is clear that the curing regime adopted (200ºC at 24 hours) significantly hardens the thin bitumen film which binds the aggregates. However, it is also apparent how the hardening of the bitumen within the block is a combination of the curing regime and the porosity of the blocks.

CONCLUSIONS

- Bitumen bound blocks can be manufactured from 100% waste / secondary aggregates superseding any need for traditionally extracted aggregates.
- The performance of the new block can be improved by optimizing porosity and the curing regime.
- The performance of the new blocks in terms of compressive strength and creep are comparable to concrete blocks currently available in the UK.
- Bitumen bound blocks can be produced with lower compaction levels provided the aggregate grading is suitable.
- The expansion of these new blocks may be affected by the environment (relative humidity, RH). At an RH of 62±1%, the expansion of the Bitublock was 215 microstrain.

ACKNOWLEDGEMENTS

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