ASPHALT-BOUND MASONRY BLOCK INCORPORATING CONSTRUCTION DEMOLITION WASTE

by I Nyoman Arya Thanaya[1]

ABSTRACT

Utilization of waste aggregates for construction industry had been encouraged in line with increasing pressures to reduce exploration of natural aggregates. One alternative material that can be used as masonry block unit is the construction demolition waste (CDW) with asphalt as the binder (CDW block). The objective of this paper is to produce CDW block with a performance equal to the concrete block commonly used in the United Kingdom with a compressive strength between 3.5 MPa and 7 MPa and the specific creep strain less than 100 microstrain. The CDW block requires suitable particle size proportion, in order to obtain satisfactory results and to meet the demand of using minimum bitumen content and low compaction level. The CDW block requires sufficient heat curing to harden the asphalt. It was found that CDW materials were a very suitable material to be used for making CDW blocks. Compaction level of 2 MPa and curing regime of 200°C for 24 hours were sufficient and gave satisfactory results.

KEYWORDS: *asphalt, construction demolition waste, compressive strength, creep.*

INTRODUCTION

Demand on aggregates for construction industries world wide continues to increase. For example, aggregate demand of the United Kingdom (UK) raise from a level of 270 million tonnes in 1989, to a predicted demand of 420-490 million tonnes by 2011[1]. Meanwhile there has been increasing pressures to reduce exploration of natural aggregates. This situation encourages the utilization of waste and secondary aggregate materials for construction industry.

Currently, 160,000 new homes are built each year in the UK of which 90 percent are constructed from masonry. Each house on average, requires approximately 200m^2 of building block work resulting in approximately 350 million blocks being manufactured each year. Waste or by product materials such as steel slag, crushed glass, and coal fly had been incorporated into masonry building blocks[2].

Another alternative material that can be used is construction demolition waste (CDW) from buildings or road pavement[3]. Around 17 percent of the total UK waste arises from the construction and demolition industries[4]. Although large proportion of waste created is recycled in some way, most of it is used for low grade purposes such as access roads within landfill sites and only 4 percent is used to replace primary aggregates[5].

There are many potential uses for CDW materials, however they are deterred by the perceived risks involved due to its low strength[6]. There is a need to increase confidence in the use of CDW recycled materials, which can only be achieved by identifying, undertaking and monitoring appropriate demonstration projects, and disseminating the results through publications and seminars.

The coarse fraction of the aggregate for concrete mixtures can be replaced by up to approximately 20 percent with CDW aggregates without significantly affecting the compressive strength[6].

The objective of the investigation described within this paper was to produce CDWblock with compressive strength at least equal to concrete blocks commonly used in the United Kingdom (UK), i.e. between 3.5-7 MPa[7,8] and specific creep strain less than 100 microstrain[9].

Researches can always be carried out anywhere, where skill, information and facilities are available. The application of this research is possible when large amount CDW is available due to demolition of old buildings, and/or due to inevitable natural disasters, such as earth quake, flood, cyclone, etc. This works is more attractive in areas close to oil refinery, especially in oil producing countries, where a lot of asphalt (oil distillation residue) which can be used as an alternative binder, widely available. The people in unfortunate disaster areas can be trained to make CDWblocks for providing building materials for them selves.

EXPERIMENTAL INVESTIGATION

Materials

The aggregate used was aggregate from construction demolition waste (CDW). This material was of non homogeneous material as it may come from demolition of various types of buildings or constructions. The CDW used for this investigation consisted of a mixture of broken concrete, clay brick masonry, sand cement mortar, and reclaim asphalt pavement (RAP) in a random proportion as can be seen in Fig. 1. The CDW particle size distribution is shown in Fig. 2, with maximum particle size of 10mm.

The bitumen used as the binder was 100pen grade bitumen. This is relatively soft grade bitumen, and was found to give satisfactory results[10]. Referring to Fig. 2, the gradation of the CDW used was found relatively of a continuous grading. It contains filler component (particles sizes passing 0.075mm) of 2 percent by weight of total aggregates, or 3.5 percent of the fine aggregates (passing 2.36 mm). The properties of the CDW aggregates were tested in line with the BS 812[11], and are given in Table 1.

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Table 1. Properties of the CDW aggregates

Properties	Unit	Coarse CDW (> 2.36mm)	Fine CDW (< 2.36mm)
Density (bulk)	grm/cm3	2.415	2.341
Density (ssd)	grm/cm3	2.478	2.433
Density (app)	grm/cm3	2.569	2.578
Water absorption	%	2.5	3.9

Fig. 1. The construction demolition waste (CDW) aggregate material

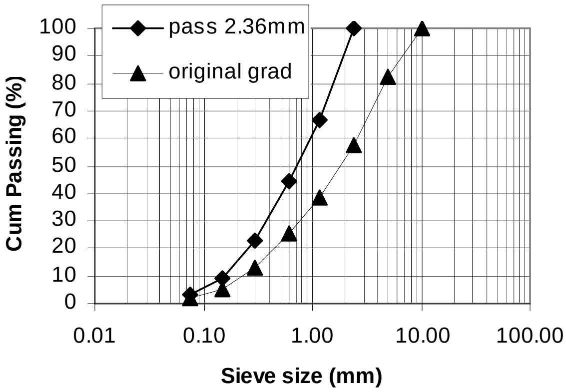

Fig. 2. The CDW original gradation (max 10mm), and the gradation of CDW passing 2.36 mm

Referring to Table 1, the properties the CDW aggregates were found very comparable with commonly aggregates available for building industries. However, as the CDW is processed from waste materials, therefore the homogeneity of the aggregate component may not be consistent.

Initial Trial

Building block units bound with asphalt can be produced with either using continuous or gap aggregate grading. When using continuous aggregate grading, higher compaction effort commonly needed[2]. Within this investigation gap aggregate gradation was selected in order to enable the use of lower compaction effort. As there is no standard specifically available for building block aggregate bound with asphalt, Hot Rolled Asphalt (HRA) gap aggregate gradation was referred to as an initial reference, then modified based on trials results.

During the initial trials, the CDW material particles sizes were graded (sieved) into: coarse fraction of 10-5mm and 5-2.36mm, and fine fraction of all passing 2.36 mm. Initially the aggregate grading used for the CDWblock was the same as the Bitublocks (similar block incorporating various waste aggregate materials) previously produced with a gap graded aggregate grading[12], but with maximum particle size of 10mm. The aggregate composition was: 40 percent coarse fraction, 50 percent fine fraction, and 10 percent coal fly ash filler as shown in Fig. 3, which is completed with a hot rolled asphalt (HRA) grading of the BS 594[13], for a general comparison, and for a better appreciation on the aggregate composition.

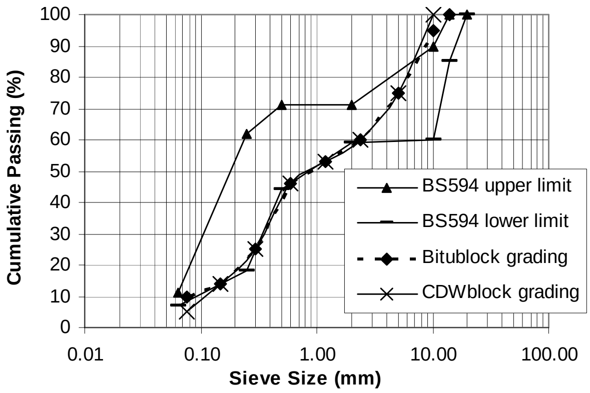

Fig. 3. The CDW block aggregate grading compared with the Bitublock grading and the BS594[13]

The bitumen used as the binder is a commercially valuable by product material from crude oil refinery industry, therefore the CDWblocks were produced with lowest bitumen content possible, that can give sufficient or adequate bitumen coating with satisfactory shape stability during handling and satisfactory performances when compacted at low compaction effort.

Minimum bitumen content of 5 percent by weight of total mixture was initially tried. The compaction was static compaction of 1 MPa for 1 minute. The degree of bitumen coating was not very satisfactory; and the shape of the blocks was not stable. The corner sides or edges were easily taken off as shown in Fig. 4. The surface texture was rather smooth, and some aggregate particles on the edge sides of the samples were taken off. This had caused some parts of the sample had open textures, therefore water absorption after 24 hour immersion was found high (6.9 percent), as shown in Table 2 (Mix A).

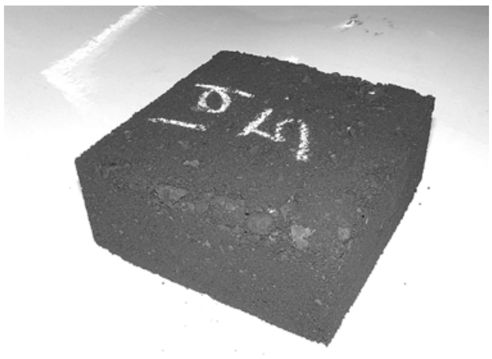

Fig. 4. The appearance of the CDWblock initially produced, with 5 percent bitumen content, with unsatisfactory coating (Mix A)

Table 2. The Properties of the CDWblocks

Mix	Comp. effort (MPa)	Density (g/cm^3)	Porosity (%)	IRS (kg/m2.min)	Water Abs * (%)	Comp. Strength (MPa)	
						uncured	cured
Mix A	1	1.925	15.1	0.105	6.9	2.0	8.1
Mix B	1	1.872	17.5	0.028	3.3	2.8	10.2
	2	1.950	14.0	0.021	2.7	3.8	17.5
	4	1.992	12.2	0.018	1.6	5.4	25.8

* 24 hours immersion in water

Gradation Modification and the Properties of the CDWblock

The specific gravity of the CDW materials were not the same with the Bitublock previously made[12], so it affects the volumetric composition of the materials. This was found to give effect of the sample's shape stability (compactness). In order to improve the CDWblock shape stability, the aggregate grading was slightly modified. The max particle size used was 10mm, instead of 14 mm as used for the Bitublock. The filler content was reduced from 10 to 5 percent, but increasing the fine fraction from 50 to 55 percent, where the coarse fraction remains at 40 percent (Fig. 3).

This gradation modification was found to give more compact samples with surface texture neither too smooth nor too rough. Overall, the aggregate gradation of the mix became coarser, hence theoretically it has lower total surface area. Even at asphalt content of 5 percent as initially tried the asphalt film thickness would increase.

Fig. 5. The CDWblock appearance, with modified grading and with 5.5 percent bitumen content, with satisfactory coating (Mix B)

In order to improve impermeability, asphalt film need to be made thicker. For this reason the bitumen content was increase from 5 to 5.5 percent, in addition to the reduction of aggregate surface area as mentioned above. The shape stability during handling was found satisfactory and the surface texture of the newly produced sample was found neither too smooth nor too rough as shown in Fig. 5. By visual observation, the asphalt coating was also satisfactory, and theoretically with thicker asphalt film than the one in Fig. 4. This was considered necessary in order obtain satisfactory overall performances.

The increase of the bitumen content was also done for anticipating the variation in quality of the CDW materials which are very likely of various water absorption properties, as they are indeed a waste material. CDWblock with modified gradation (Mix B in Table 2), were then produced with compaction effort of 1, 2, and 4 MPa, with bitumen content of 5.5 percent by weight of total mixture.

Heat Curing

Asphalt is a viscoelastic material. It has viscous and elastic component. The viscous component of the asphalt would cause creep when loaded. It had previously been found that curing regime played a very significant role for hardening the asphalt due to the evaporation of the volatile components and increasing the asphaltene potion of the asphalt[2,22], hence can reduce creep deformation due to static load[2]. It had been previously investigated that when using a 50 pen bitumen and cured in oven at 160 °C, the curing duration required to satisfy creep performance was 72 hours[10.]

In order to reduce curing duration, in this investigation the samples were cured at 200°C just for 24 hours, and the sample was found to gave satisfactory creep resistant.

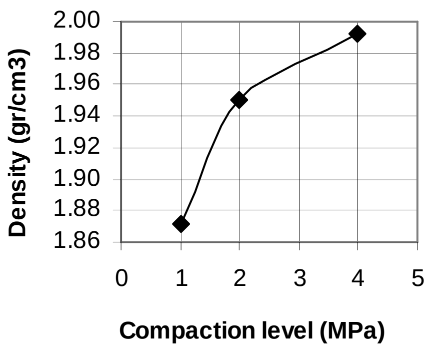

Fig. 6. Compaction level vs. density (Mix B)

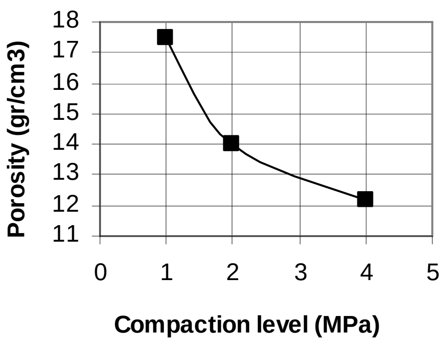

Fig. 7. Compaction level vs. porosity (Mix B)

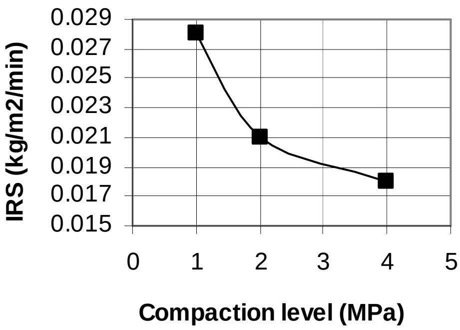

Fig. 8. Compaction level vs. IRS (Mix B)

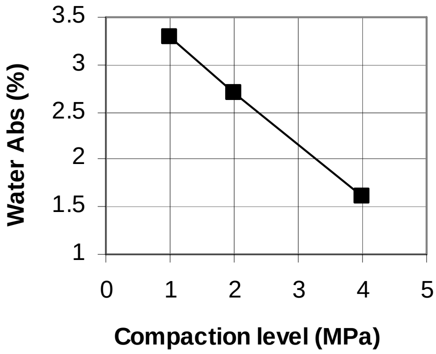

Fig. 9. Compaction level vs. water absorption

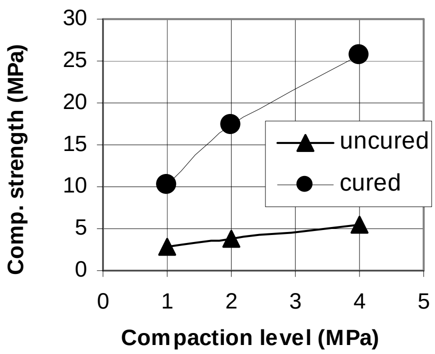

Fig. 10. Compaction level vs. compressive strength

Initial Rate of Suction (IRS)

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[14]. 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[15].

Volumetric Calculation

The volumetric parameters of the block were calculated using Equations 1, 2 and 3. The SG_{mix} (max theoretical density) of mix A and B was 2.269 and 2.255 respectively. The properties of the samples are given in Table 2.

$$SG_{mix} = \frac{100}{\frac{\%a}{SGa} + \frac{\%b}{SG_b} + \frac{\%c}{SG_c} + \ldots\ldots\ldots\ldots + \frac{\%\text{binder}}{SG\text{binder}}}$$

(percent by weight of total mix).....................................(1)

Note: a, b, c, …are aggregate fraction of mixtures[16].

$$\text{Sample Bulk Density} = \frac{\text{weight in air}}{\text{volume}} = \frac{\text{weight in air}}{(\text{weight SSD - weight in water})} \quad \ldots\ldots\ldots\ldots (2)$$

Weight SSD is the weight of sample after weighing in water then towel dried[17].

$$\text{Porosity}(P)\% = \left(1 - \frac{Density}{SG_{mix}}\right) \times 100\% \qquad (3)$$ [18]

In addition to the data presented in Table 2, the data for Mix B are also plotted in graphs as shown in Figs. 6 to 10.

Referring to Table 2, the performance of Mix A was affected by its aggregate grading which contained 10 percent filler compared with Mix B with 5 percent filler content, and also affected by its lower bitumen content. As Mix A finer than Mix B, at 1 MPa compaction level Mix A was of lower porosity than Mix B. However the water absorption was higher as the bitumen film was thinner. The compressive strength of Mix B was better than Mix A, as Mix B was slightly coarser and of thicker asphalt film. It is logical, that the performance of Mix B was improved at higher compaction level. Curing regime had been experienced to significantly improve the compressive strength of the samples.

The water absorption of Mix B was in reasonable level, which indicated that at 5.5 percent bitumen content, the samples became more impermeable. The IRS values were found relatively lower than the typical IRS values of clay brick found in the UK (0.25 – 2.0 kg/m2/min). This indicates that the CDWblocks require sand cement mortar with lower water cement ratio[15].

Expansion/Shrinkage Test

This test was carried out by measuring the expansion and shrinkage of the samples at different environment condition. The equipment used was a 50 mm Demec gauge with its supporting parts, i.e. demec points. Two Demec points were pasted on each of the four sides of the samples as shown in Figs. 11 and 12.

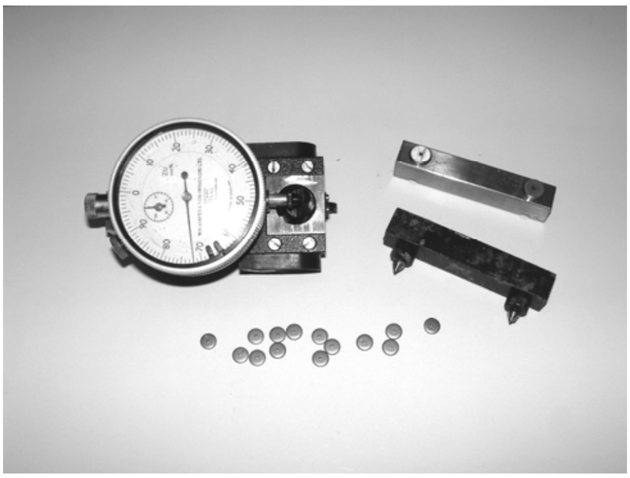

Fig. 11. A 50mm Demec gauge with its supporting equipment

Creep Test

This test was done in order to evaluate the resistance of the samples to deformation due to static load. The samples were loaded by means of a simple arm load machine (Fig.13), with 1 MPa stress. This stress (specific creep stress) is commonly applied in masonry creep test[9].

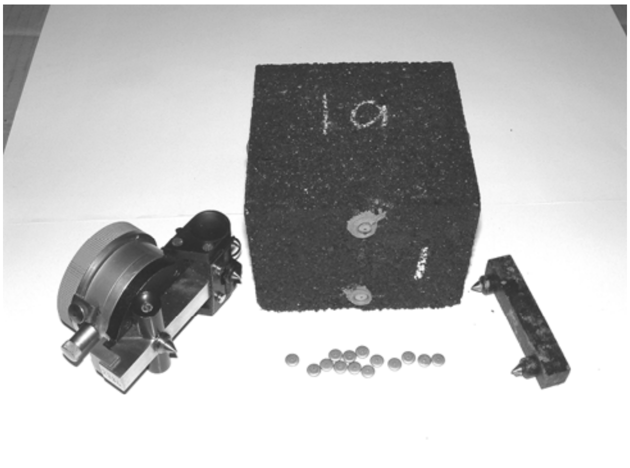

Fig. 12. The CDWblock sample and strain measuring equipment

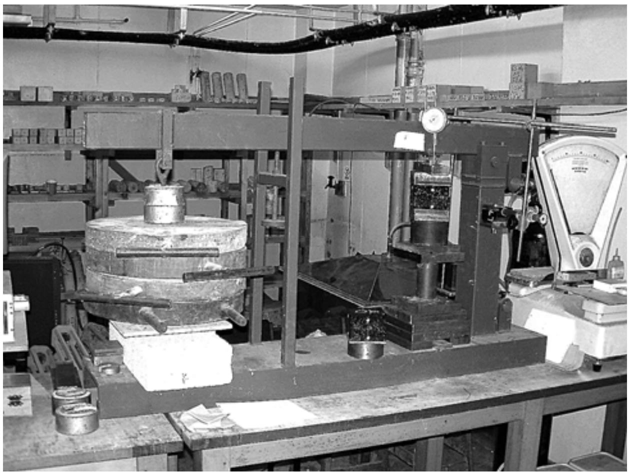

Fig. 13. Arm load machine used for creep test loading

EXPERIMENTAL RESULTS AND DISCUSSION

Compressive Strength and IRS

Referring to Figure 10, it is revealed that the cured compressive strength of the samples were satisfactory, i.e. well exceeded 7 MPa, where common compressive strength value for concrete blocks found the UK is between 3.5-7 MPa[7,8]. The IRS values of the CDWblock were found somewhat lower than the range of 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 asphalt which has hydrophobic character. This suggest that the CDWblock tested in this experiment would require or more suitable to use stiffer mortar.

Expansion Due to Moisture Absorption

Before doing creep test, the cured samples were tested for their expansion at room environment condition (21±0.5 °C and 46 percent relative humidity (RH)). It was found that the samples expanded then stabilized after about 7 days. The samples with higher compaction level gave lower expansion as shown in Fig. 14.

In order to evaluate the performance of the samples at different relative humidity, a further volume stability test was done. Expansion and shrinkage was tested in vertical and horizontal direction (Fig. 15). Two samples were initially conditioned at room environment (at a different room from previous experiment). The temperature was relatively constant at 21.0 ± 0.5 C°, but the humidity fluctuated (62±2% RH). The samples were also conditioned at 12 percent RH and 85 percent RH which were carried out by using desiccators filled with lithium chloride and potassium chloride hygrostatic solution respectively, as shown in Fig. 16, where two samples were tested for each conditioning.

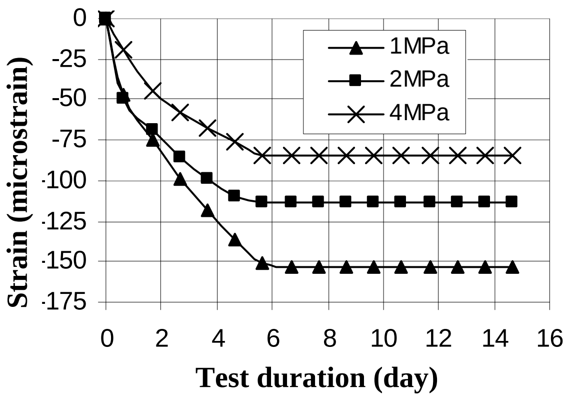

Fig. 14. The vertical expansion test results

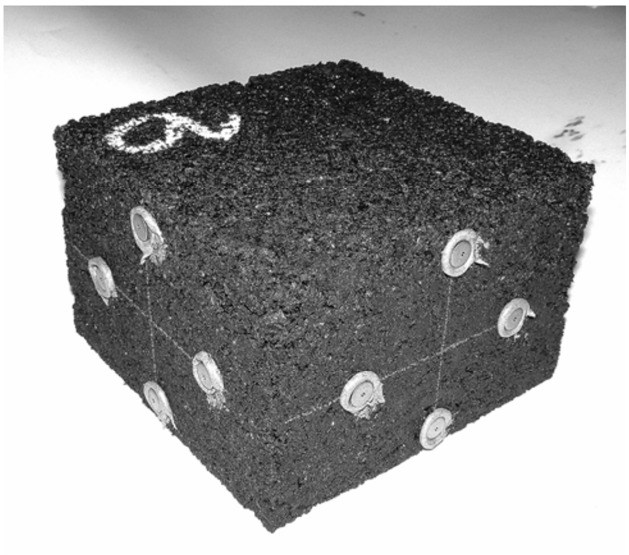

Fig. 15. The samples pasted with Demec points in vertical and horizontal direction

Fig. 16. Conditioning of samples in a desiccators

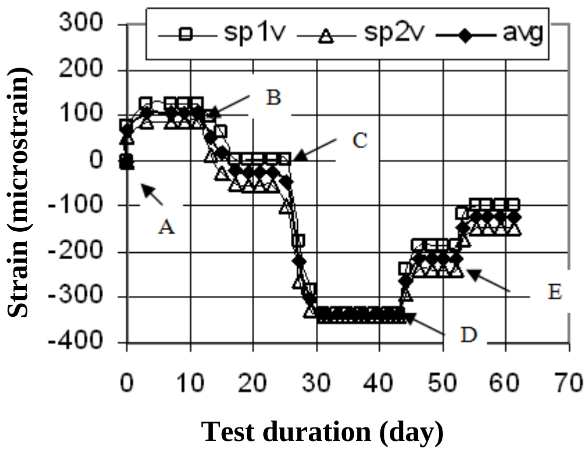

Fig. 17. Average movement of the samples (sp) in vertical (v) direction

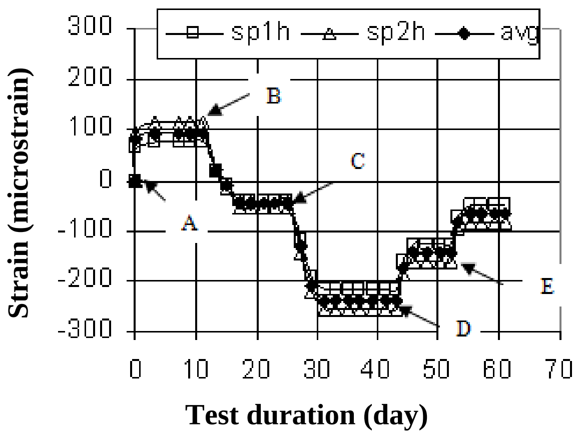

Fig. 18. Average movement of the samples (sp) in horizontal (h) direction

The expansion reading was taken in vertical and horizontal direction at certain time interval until the expansion stabilized. Then the conditioning was changed. The results are shown in Fig. 17 (movement in vertical direction) where the start of conditioning changes, were coded from A to E. Similar results are given on Fig. 18 (movement in horizontal direction). It is shown in Figs. 17 and 18, that the vertical and horizontal movement of the samples was found not exactly isotropic. This matter could be affected by the nature of the CDW materials which was not homogeneous.

The samples were initially left overnight at room environment with 62±2 percent RH before the first strain reading was noted. After conditioning at room environment, the samples were then conditioned in a desiccator with 12 percent RH, using lithium chloride hygrostatic solution (start of conditioning A). 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 with 62±2 percent RH (start of conditioning B). The samples slowly expanded then stabilized at -20 microstrain. Starting from day 24^{th} the samples were put back into a different desiccator with 85 percent RH utilizing potassium chloride hygrostatic solution (start of conditioning C).

The samples expanded (towards negative strain values) then stable at -340 microstrain. Starting for day 44^{th} and then the following days, the samples were consecutively conditioned until stabilized at room environment (start of conditioning D), then at again at 12 percent RH (start of conditioning E).

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. Quiet a large portion of the movement was irreversible. This situation is similar to clay brick[15].

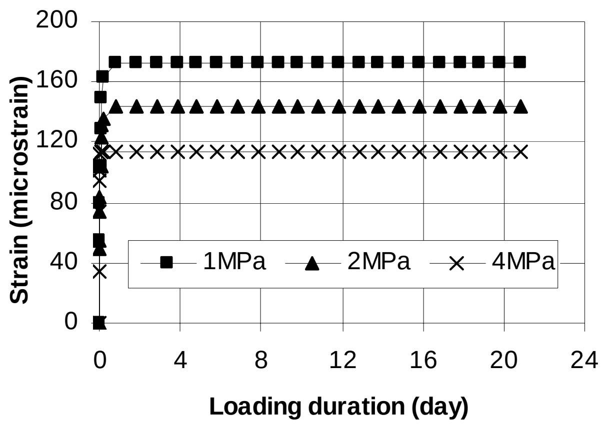

Fig. 19. The total strain of the samples compacted at different compaction level

The results suggest that the expansion of the samples were of similar mechanism with cement paste or concrete, i.e. due to moisture adsorption. Due to adsorption of water molecules onto the surface of the particles reduces the surface energy on the capillary system, hence reducing the balancing internal compressive stress leading to volume increase or swelling[19]. This is also described by Neville[20] 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 surface tension, and results in swelling.

The expansion reading was taken in vertical and horizontal direction at certain time interval until the expansion stabilized. Then the conditioning was changed. The results are shown in Fig. 17 (movement in vertical direction) where the start of conditioning changes, were coded from A to E. Similar results are given on Fig. 18 (movement in horizontal direction). It is shown in Figs. 17 and 18, that the vertical and horizontal movement of the samples was found not exactly isotropic. This matter could be affected by the nature of the CDW materials which was not homogeneous.

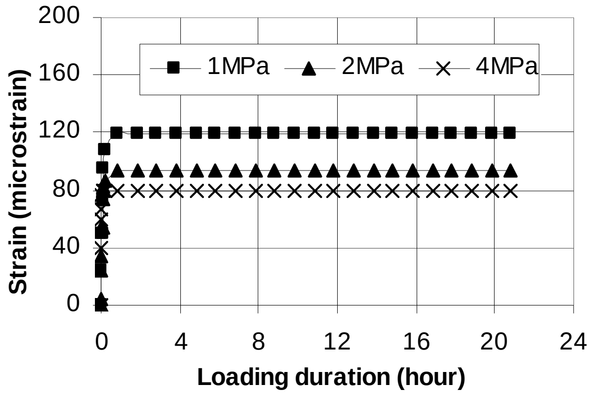

Fig. 20. The creep strain of the samples compacted at different compaction level

It was also observed that the samples did not crack which indicated 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 pre-stressed condition to the wall structure which can improve the ability of the wall to receive horizontal load.

Table 3. Creep performance of the CDWblock samples

Comp level (MPa)	Total Strain (με)	Elastic Strain (με)	Creep Strain[1] (με)	Expansion at creep test* (με)
1	173.25	54.45	118.8	*
2	143.55	49.5	94.05	*
4	113.85	34.65	79.20	*

[1]creep strain = total strain – elastic strain – shrinkage or expansion.
*the samples were tested for creep after the expansion stabled (at zero expansion).

Creep Performance

After the expansion test with results as in Fig.14 (after the volume of the samples stable), the samples were then tested for creep at the same environment. The stress applied was 1 MPa. This stress is commonly applied in masonry experiments in order to evaluate specific creep, i.e. creep strain per MPa unit stress. The creep test results are shown in Figs.19 and 20, and summarized in Table 3.

The creep test results indicated that the all of the samples gave creep strain at least equal of concrete block commonly used in the UK[7,8]. In order to ensure better deformation resistant, creep strain of less than 100 microstrain was recommended[9], therefore compaction level of at least 2 MPa was suggested.

Table 4. Data comparison between the CDWblock and the Bitublock

Description	CDWblock (Mix B)	Bitublock
Max aggregate size	10mm	14mm
Coarse agg.	CDW	steel slag
Fine agg.	CDW	crushed glass
Filler	coal fly ash	coal fly ash
Filler content	5%	10%
Asphalt grade	100pen	50pen
Asphalt content	5.5 %	6 %
Compaction level	2 MPa	2 MPa
SG of bitumen	1.02	1.03
Curing regime	200°C for 24 hr	200°C for 24 hr
Porosity	14%	17.4
Compressive strength (cured)	25.9 MPa	14.2 MPa
Specific creep	94.1 microstrain	44.6 microstrain

Comparison to Bitublock

This section is intended to compare the CDWblock with a similar type of asphalt bound block named as Bitublock.[10] The Bitubolck aggregate grading was as shown in Fig. 3.[12] Further data of the two blocks are shown in Table 4. The samples were produced with minimum possible asphalt content.

Referring to Table 4, a general comparison between the CDWblock and Bitublock was made. All of the samples were of a good degree of coating, where some particles of the CDW materials were of reclaimed asphalt pavement (RAP) as shown in Fig.1. The porosity of the CDWblock was about 3 percent lower than the Bitublock. This was attributed by the use of softer bitumen grade for the CDWblock, where at the same compaction level and correct temperature the CDWblock would be more workable during compaction. The effect of this lower porosity was revealed on the higher compressive strength of the CDWblock due to better aggregate interlock condition. In addition to lower porosity, the materials used for the CDWblock would have given better aggregate friction compared to the large portion of crushed glass used for the Bitublock.

The specific creep results were principally satisfactory (less than 100 microstrain). The Bitublock performed better than the CDWblock. This situation suggests that the harder binder (50 pen) at the heat curing regime applied (200 ºC for 24 hours) gave better resistant to static load.

CONCLUSIONS

Some conclusion can be withdrawn from the investigation, i.e.:

a. The CDW materials were found very suitable for producing asphalt bound construction demolition waste masonry block (CDWblock).
b. Compaction level minimum of 2 MPa and the curing regime applied (200 °C for 24 hours) were found to give satisfactory compressive strength and creep strain. The compressive strength of the CDWblocks were found at least equal to the concrete blocks commonly used in the United Kingdom (UK).

c. The volume stability of the CDWblock is affected by relative humidity (RH). Higher RH environment tends to cause higher expansion, and vice versa.
d. The volumetric movement of the CDWblocks due to environment moisture was not fully reversible, but only partly reversible.

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