Evaluation on The Performance of Asphalt Block, A Building Block Unit Using Asphalt As The Binder

Evaluasi Kinerja Asphaltblock, Sebuah Unit Blok Bangunan Menggunakan Aspal Sebagai Bahan Pengikat

I Nyoman Arya Thanaya
Senior Lecturer in Department of Civil Engineering, Udayana University.
Kampus Bukit Jimbaran Denpasar 80364. Bali-Indonesia.
E-mail: aryathanaya@ymail.com

ABSTRACT

The investigation described within this paper is results of initial stage of a research project carried out at Leeds University, United Kingdom. It covers the development of a new range of building masonry units composed entirely of recycled and waste aggregates bound with asphalt (Asphaltblock). It is driven by the issue of sustainability where complete replacement of natural aggregates is possible because Asphaltblock uses asphalt as the binder which adhesively binds the waste materials without chemical interaction. Three types of waste materials were used: crushed glass, coal fly ash, and steel slag. The type of asphalt used was hard H 80/90 asphalt. The Asphaltblocks were mainly evaluated based on compressive strength and creep performance. It was found that all these properties are dependent on the types of aggregates, the binder used, porosity and the heat curing regime. It was concluded that Asphaltblock can be produced by incorporating waste materials with properties that are at least equivalent to current concrete block masonry units found in the UK. The performance of the Asphaltblock can be improved by optimizing the porosity and heat curing regime.
Keywords: asphaltblock, waste materials, compressive strength, creep.

ABSTRAK

Penjelasan investigasi pada tulisan ini adalah hasil-hasil dari tahap awal program riset yang dilakukan di Leeds University, UK. Penjelasan ini mencakup pengembangan baru dari unit-unit tembok bangunan yang terdiri atas agregat limbah dan daur ulang yang diikat dengan aspal (*asphaltblock*). Gagasan ini didorong oleh isu sustainabilitas dimana penggantian seluruh agregat alam dimungkinkan karena *asphaltblock* menggunakan aspal sebagai bahan pengikat yang merekat bahan-bahan limbah tanpa bahan kimia. Tiga jenis bahan limbah digunakan: pecahan kaca, abu terbang batubara, dan terak baja. Jenis aspal yang digunakan adalah aspal keras H 80/90. *Asphaltblock* dievaluasi terutama berdasarkan kekuatan tekan, dan kinerja creep. Semua propertis diketahui tergantung dari jenis agregat,bahan pengikat yang digunakan, porositas, dan faktor perawatan panas. Berdasarkan hasil pengujian dapat disimpulkan bahwa *asphaltblock* dapat diproduksi menggunakan bahan limbah dengan propertis minimum sepadan dengan unit blok beton yang saat ini digunakan di UK. Kinerja *asphaltblock* dapat ditingkatkan melalui optimasi porositas dan faktor perawatan panas.
Kata-kata kunci: *asphaltblock*, bahan limbah, kekuatan tekan, creep.

INTRODUCTION

The development Asphaltblocks as a new type of building units is driven by the issue of sustainability both nationally and globally, where the units can be produced using waste materials. In the UK, Europe and the USA, masonry is already considered a sustainable material (Robert, 1988), however, further improvements can still be made.

Currently, 160,000 new homes are built each year in the UK of which 90% are constructed from masonry. Each house on average requires approximately 200m^2 of blockwork resulting in approximately 350 million blocks being manufactured each year.

One possible replacement material is coal fly ash or pulverised fuel ash (PFA). At present, approximately 6 million tonnes of PFA are produced each year in the UK and only 40 - 50% is utilised. The remainder is landfilled or used for quarry / land restoration projects adjacent to power stations. Incorporation of PFA in concrete masonry units is already standard practice for the majority of block manufacturers in the UK (Sear, 2005).

As well as PFA as filler replacement, aggregate replacement is also to be considered, further saving natural resources. The new material would be extremely suited to the incorporation of crushed glass, in particular green / mixed glass. The glass manufacturing sector (closed loop recycling) has a limited capacity to accept green and mixed colour glass. As glass collection increases (to meet the 2006 packaging targets of 60% an 'excess' (300,000 to 400,000 tonnes) of green glass is likely, for which alternative high value, high volume markets are required (Forth et al., 2006).

Steel slag are secondary products of the refining of metals from the steel industry. In the UK in 1996, there were approximately 1.5 million tonnes of this industrial by-product produced each year and only 200,000 tonnes were recycled. In 2002, the volume of production had reduced to approximately 1 million tonnes. This material is particularly suitable as a coarse aggregate and is commonly used in road construction materials. Steel slag contains free calcium oxide (CaO) and free magnesium oxide (MgO). In moist condition reaction occurred which had been known to cause volume expansion, therefore steel slag need to be weathered until stable volume obtained before use (Dunster, 2002).

Asphalt can be considered as a by-product of the petroleum industry. However, asphalt has a high commercial value. This situation is believed to be offset by the benefits of utilising recycled and waste materials. Due to this reason the intention is to use the least possible asphalt content. Aggregate grading that gives lower surface areas is suitable, therefore within the initial stage of the investigation a continuously graded aggregate with higher maximum aggregate size (e.g. 14 mm is suitable), and low percentage of filler content was tried.

As asphalt is a viscoelastic material, even when using hard type asphalt (in this case Hard H80/90 asphalt), creep deformations are inevitable. Therefore, a heat curing regime is necessary to increase the hardness of the asphalt in the compacted Asphaltblocks. This is achieved by (oven) heat curing the compacted Asphaltblocks. Due to the severity of the curing regime, it causes the asphalt to become progressively harder and more brittle as a result of oxidation. As asphalt would coat and bind the aggregates, there very low risk due to chemical interaction that can affect the stability of the product.

Based on trials, for optimum heat curing effectiveness, compacted Asphaltblock specimens were designed to have sufficient porosity. Within this experiment a porosity range of 10 - 15 % were found to give a balance between strength and curing effectiveness. Within this porosity range, the interconnectivity of the air void network ensures that every part of the specimen is accessible to heat curing and that oxidation is not restricted to the external surfaces of the Asphaltblocks. The level of compaction is dependent on the types of materials used (in particular the type of asphalt) and the compaction temperature used. The compaction levels required to satisfy the desired range of compacted density and hence porosity therefore had to be determined experimentally.

The main objective of these investigations was to develop and evaluate the performance of a building block with asphalt as the binder. In order to achieve the objective, the approach adopted by the author was to compare the properties of the Asphaltblocks with those of traditional concrete block units found in the UK. The comparisons were made primarily on the basis of compressive strength, where compressive strengths of 3.5 – 7.0 MPa were targeted (Sear, 2005). However, due to the susceptibility of the asphalt mixtures to deformation, an assessment has also been made on the creep performance of the unit.

PROPERTIES OF THE MATERIALS USED

The materials used for the investigation were crushed glass from waste bottles, fly ash, and steel slag, with properties as given in Table 1.

Table 1. Materials used for the Asphaltblock mixtures

Materials	Density (gr/cm^3)	Water Abs. (%)
Crushed glass	2.51	< 1
Fly ash (Ferrybridge PS)	2.16	-
Steel Slag	3.39	1.9

Note: PS = power station

It had been known that asphalt is a thermoplastic material in which its performance is affected by temperature and can deform under loading. During application, Asphaltblock will be subjected to static load, therefore creep performance of the Asphaltblock is of an important parameter. In order to reduce susceptibility to temperature and loading, the type of asphalt used was hard asphalt. For the experiments Hard 80/90 asphalt type was used.

Hard asphalt is a type of asphalt that usually used for industrial application, e.g. for coating, roofing, and impermeable layers. Hard asphalt is manufactured by air blowing asphalt in which the hydrocarbon chain is dehydrogenated resulting in oxidation and polycondensation, increasing the molecular size of the existing asphaltenes and forming addition asphaltenes from the malthenes phase. This process causes the asphalt becomes harder, therefore it is more resistance to deformation and less susceptible to temperature. The properties of the asphalt used are given in Table 2 (BS3690, 1982).

Table 2. The properties of Hard 80/90 asphalt

Property	Value
Penetration grade at 25° C	6 – 12 dmm
Softening point	80 – 90 °C
Specific gravity	1.05

AGGREGATE GRADATION

Selection of the continuous aggregate gradation of the mixtures was based on a Modified Fuller's Curve (MFC) or Cooper's Formula (Cooper et al, 1985) as shown below:

$$P = \frac{(100 - F)(d^n - 0.075^n)}{D^n - 0.075^n} + F \qquad (1)$$

Where P = % material passing sieve size d (mm), D = maximum aggregate size (mm), F = % filler, n = an exponential value that dictates the concavity of the gradation line. The n value used was 0.45 which is the exponential factor that can be used to produce the best aggregate packing in continuously graded asphalt mixtures. The value for D was taken as equal to 14 mm, and F was taken as equal to 4 % based on the lower range of filler content recommended for Dense Asphalt Macadam grading (BS4987, 2003). The aggregates were separated into the following coarse fractions: (14-10)mm, (10-5)mm, and (5-2.36)mm. The fine fraction was designated as (2.36-0.075)mm, and the filler fraction was that passing 0.075 mm.

The aggregate gradation based on Coopers' formula for the Asphaltblock is shown in Figure 1 where the gradation is within the range of a typical Dense Asphalt Macadam mixture.

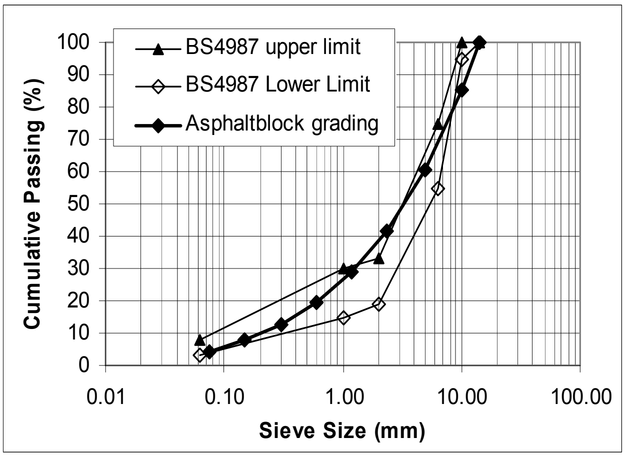

Figure 1. Aggregate gradation of the Asphaltblocks, compared with Dense Asphalt Macadam (BS 4987, 2003)

SAMPLE PRODUCTION

Two types of mixture were produced as shown in Table 3. As the particle density of the steel slag significantly higher than the crushed glass (Table 1), the incorporation of steel slag into Mix 2 was carried out by volume substitution based on Mix 1. The incorporation of steel slag was expected to improve the performance of the Asphaltblock as it has been known that due to its angular shape and high surface friction, it can help to improve the compressive strength and reduce the creep deformation (Thanaya, 2006).

Table 3. Mixture Designation

Mix	Coarse agg. (58.5 %)	Fine Agg. (37.5 %)	Filler (4 %)
Mix 1	Crushed glass	Crushed glass	Fly ash
Mix 2	Steel slag	Crushed glass	Fly ash

For manufacturing samples, the proportioned aggregate materials were dry mixed, and together with the hard asphalt H 80/90 were heated to 200 °C for 3-4 hours. All materials were then mixed until satisfactory coating achieved. The coated loose mixes were put back in an oven set at 200 °C for 15-20 minutes to regain heat. The loose mixtures were poured into a mould, then compacted using a static compaction pressure of 8 MPa stress for 1 minute. This level of compaction had previously been found to give a porosity of between 10 - 15 %, which is considered effective in optimising the curing effect (Thanaya et al, 2006). Owing to the time taken to prepare the loose mix and to transport the samples to the static compression machine and the time taken to compact the sample, the temperature dropped to 100-110 °C during compaction. The compacted samples were cooled down and then de-moulded.

DETERMINATION OF OPTIMUM ASPHALT CONTENT (OAC)

The OAC was determined based on the performance of the uncured Mix 1 which is shown in Figures 2. The asphalt content was varied from 5.5 % (min. recommended asphalt content in BS 4987) down to 3 % by mass of total mixture with decrement of 0.5 %. It was found that at up to 3 % bitumen content the mixture was still gives satisfactory coating as it only used crushed glass which has very low absorption property.

It can be seen in Figure 2 that the compressive strength peaks at 5% asphalt content by mass of the total mix. Mix 2 in the later stage was produced with the same 5 % optimum asphalt content.

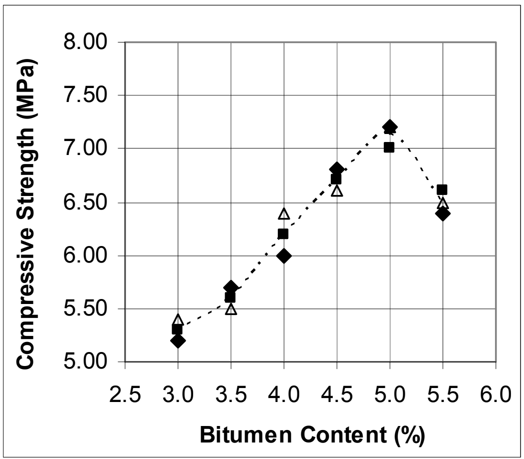

Figure 2. Asphalt Content vs Compressive Strength (uncured condition)

CURING OF THE SAMPLES

Two types of sample conditioning were prepared, i.e. uncured and cured. The heat curing regime applied was 160 °C for 12, 24, 48, and 72 hours. This was aimed at hardening the samples, so the samples would be more resistant to creep deformation.

CREEP TEST METHOD

Creep was obtained from samples which were loaded using a static dead-weight lever arm machine (mechanical advantage of 4) as shown in Figure 3. The total strain measurements were taken using a 50mm Demec gauge (Figure 4) on four faces of the sample (Figure 5).

The applied stress was 1 MPa. This level of stress is representative in masonry construction and provides the creep values in terms of specific creep strain (creep strain per unit stress). The experimental rig allows up to 4 samples to be tested at the same time. Creep measurements were obtained from the total strain measured on the loaded samples (Forth et al., 2006).

Figure 3. Creep test using a static dead-weight lever arm machine

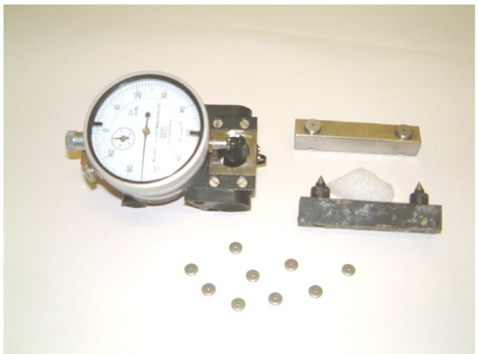

Figure 4. A Demec gauge, and its supporting equipment

Figure 5. A sample with a pair of Demec points (dp) glued to its side

The initial elastic strain was recorded soon after the samples loaded, then total strain was measured initially at regular intervals of 15 minutes. Following the first hour of monitoring, strains were then measured every 30 minutes, and then every 60 minutes. After the first day of loading, strains were recorded 3 times a day. Relatively constant strain for this initial investigation was achieved after one week. The room temperature during testing was maintained at 20 °C.

RESULTS AND DISCUSSION

Volumetric Properties and Compressive Strength

The properties of the Asphaltblocks at 5 % asphalt content are given in Table 4. Data in Table 4 indicate that the Asphaltblock has a comparable density to concrete blocks available in the UK. The density of Mix 2 is higher than Mix 1, as it contains steel slag which has high density (Table 1). The water absorption was relatively low as the aggregate were evenly coated with bitumen. When using hard H 80/90 asphalt, even in uncured condition the samples had met the compressive strength targeted (3.5 – 7 MPa) as shown in Table 5.

Table 4. The property of the uncured Asphaltblocks mixtures at 5 % Optimum Asphalt Content

Description	Mix 1	Mix 2
Density (gr/cm^3)	2.068	2.452
Porosity (%)	12.3	12.8
Water Abs. *(%)	2.1	2.7
Compressive Strength (MPa)	7.1	8.2

* after 24 hour immersion

The influence of the coarse steel slag aggregate on the compressive strength of the two mixes can also be seen in Table 5. Mixes incorporating steel slag possess (Mix 2) comparatively higher compressive strengths, indicating the significance of the angular nature, rough surface texture and high surface friction of this type of aggregate. Furthermore, accelerated hardening of asphalt may in part be caused by the presence of ferric and ferrous oxide in the steel slag. Ferric and ferrous components are typically used as catalysts to accelerate oxidation of asphalt in the production of air blown (oxidised) asphalts (Dunster, 2002). Oxidised asphalts have higher viscosity and softening point, lower penetration, lower ductility and adhesiveness than regular straightrun distillation asphalts. However it has higher resistant to temperature.

Table 5. Compressive Strength of the cured samples

Mixture	Curing (°C/hours)	Compressive Strength (MPa)
Mix 1	uncured	7.2
	160 °C /12 h	7.8
	160 °C /24 h	8.4
	160 °C /48 h	9.1
	160 °C /72 h	10.1
Mix 2	uncured	8.2
	160 °C /12 h	9.1
	160 °C /24 h	9.8
	160 °C /48 h	13.0
	160 °C /72 h	16.6

Elastic Modulus

The elastic moduli of the two mix types for the various curing times can be found in Table 6. All elastic strains were measured within 10 minutes of the application of load which is below the critical value 15 minutes. After this time the elastic modulus (i.e. stress/elastic strain) will be significantly influenced by creep (Neville, 1983).

Table 6. Creep Strains data of the Mix 1 (from Figure 6)

Curing at 160°C	Total Strain (με)	Elastic Strains (με)	Creep Strain [1)] (με)	Elastic Mod [2)] (GPa)
Mix 1				
12 hrs	5370.75	539.55	4831.2	1.85
24 hrs	1571.625	259.875	1311.76	3.85
48 hrs	534.4	89.1	435.6	11.24
72 hrs	403.425	64.35	339.075	15.6
Mix 2				
12 hrs	856.35	336.6	519.75	2.97
24 hrs	556.875	133.65	423.225	7.46
48 hrs	128.7	34.65	94.05	28.57
72 hrs	64.35	20.79	43.56	47.62

[1)] creep strain = total strain – elastic strain [2)] elastic modulus = (1 MPa / elastic strain)

The effect of curing can clearly be seen on the elastic modulus of the Asphaltblock. The elastic modulus Mix 2 is significantly higher than those of Mix 1. This further highlights the influence of the nature of the steel slag aggregate, .i.e. cubical and rough surface texture, and can accelerate the oxidation of the asphalt (Section 1).

Creep

Initially, an uncured sample of Mix 2 was tested. After less then 48 hours the sample failed. This indicated that the samples required heat curing to harden the asphalt binder. Figures 6 and 7 illustrate the creep of the cured mixes by oven curing at 160°C ranged from 12 to 72 hours.

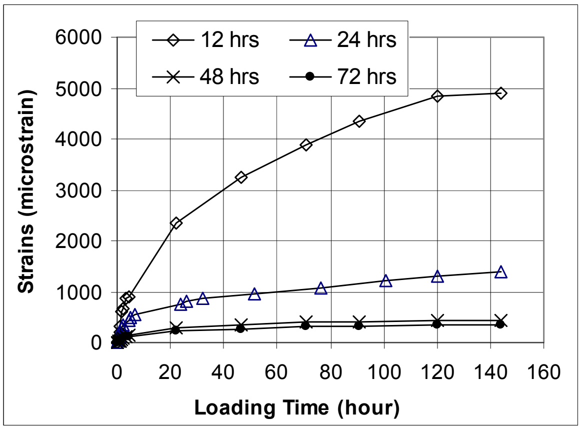

Figure 6. Creep strain of Mix 1 cured for various times at 160 °C

Samples were only loaded for just under a week as this duration was considered sufficient to provide an idea of creep behaviour of the Asphaltblock. The lower creep of Mix 2 when compared to Mix 1 is as expected from a consideration of the relative values of the elastic modulus of the two mixes (Table 6).

The influence of the aggregate material is also evident in the comparison of the levels of creep of the two mixes. In addition to the potential for ferric and ferrous components to cause accelerated ageing, the surface roughness & water absorption values (voids) of the slag compared to the crushed glass means that the asphalt is spread over a larger surface area and hence it exists on the aggregate surfaces in thinner film thicknesses.

Therefore, during oven curing the thinner asphalt films are more prone to oxidation (oxygen attacks & penetrates the depth of the asphalt film by diffusion and hence a thinner film is oxidised faster).

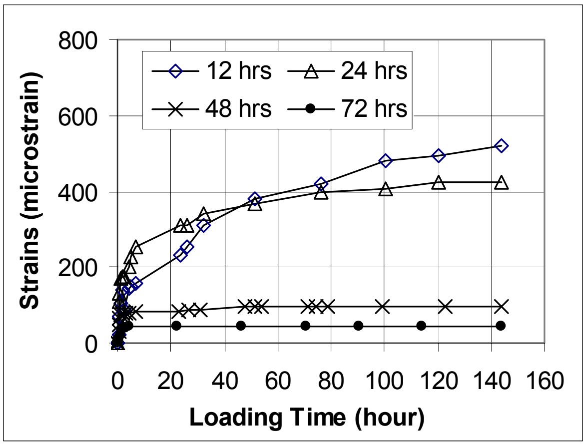

Figure 7. Creep strain of Mix 2 cured for various times at 160 °C

From Figure 7, it can be seen that creep of Mix 2 can almost be eliminated if the units are cured for 48 hours. Curing for 24 hours at 160°C will produce a unit which still has creep properties equivalent to concrete blocks currently used in the UK (Tapsir, 1985). As can be seen earlier with the elastic modulus results for this mix, curing the samples for longer than 24 hours will provide a unit with significantly improved elastic and long-term properties which easily exceed those of current concrete blocks found in the UK.

CONCLUSIONS AND SUGGESTION

Conclusions

From the results and analysis of this initial investigation it can be concluded that:

- Asphaltblock can be produced with a compressive strength at least equal to the current normal aggregate block produced in the UK :3.5-7.0 MPa (Sear, 2005),
- Asphaltblock provides an ideal opportunity to make use of many waste materials.
- The performance of the Asphaltblock can be further improved by optimising the porosity of the unit and also concomitantly the heat curing regime.

Suggestion

For further works, it is suggested that Asphaltblock can be produced at lower compaction level for ease of production. This likely can be done by adjusting the aggregate grading that contains higher fine fraction.

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