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PRELIMINARY DEVELOPMENT OF A MASONRY UNIT COMPOSED ONLY OF SOIL AGGREGATE

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ABSTRACT

This paper describes a preliminary study to develop a bitumen bound soil aggregate masonry block initially targeted for use in developing countries. In many ways it is an extension of an adobe unit which uses bitumen as a water-proofer however the proposed new unit is expected to be significantly more durable. Bitumen (100pen grade) was used as the binder, encapsulating the material (soil) and hence binding by means of cohesion. The objective of this paper is to investigate and evaluate the engineering performances of the Soilblock and compare these with a coarse aggregate concrete block found in the UK. The overall performance of the unit in terms of compressive strength and creep was at least comparable with that of the coarse aggregate concrete block. It was found that the properties of the new unit could be improved by increasing the compaction level (effectively reducing porosity) and by increasing the curing temperature / duration. Further optimisation of the manufacturing process is required however currently a compaction level of 2 MPa and a curing regime of 200°C for 24 hours are recommended.

KEYWORDS: soilblock, bitumen, cohesion, strength, compaction.

INTRODUCTION

In general, cement or lime are used to bind naturally extracted aggregates for producing masonry building blocks. However, in an attempt to improve the sustainability of masonry units the investigators have been searching for alternative binders as well as more sustainable aggregates and in doing so have also considered individual economic, geographical and political locations. The masonry blocks investigated here are termed Soilblocks. Soil is still commonly used as a construction material in many countries. As an adobe block it can be stabilised using compaction and water-proofed using asphalt. However, to improve its performance it is possible to use bitumen as a binder [1]. This approach could be potentially suitable for regions where large quantities of naturally occurring bitumen exist or where there is close proximity to oil refinery plants. It is believed that Soilblock could become an attractive option for constructing low cost housings and for encouraging people empowerment programmes in developing / transitional countries.

The bitumen used for this investigation was the residual or by product from the fossil crude oil refinery industry. Bitumen of different grades (hardness) is used with aggregates for producing mixtures for road pavement layers. Harder bitumen is widely used for industrial purposes such as water proofing for roofs, impermeable coating for pipes and underground structures. Bitumen is solid at ambient temperature and softens and even can become very fluid at higher temperatures [2]. Bitumen acts as a binder by encapsulating the material (soil) and binds by means of cohesion. Different types of bitumen can be used, however, the utilization of softer grade bitumen was found most effective as the heating and mixing temperature can be lower compared with the use of harder grade bitumen. The softer bitumen also effectively stiffens during the heat curing regime [3].

The development of a masonry block using soil and bitumen has been introduced in this paper. Briefly, the soil was heated and pre-coated with molten bitumen, cooled down, screened with 2.36 mm sieve, and then compacted cold. The objective of this paper is to investigate and evaluate the engineering performance of Soilblocks (compressive strength and creep) and compare these with the properties of coarse aggregate concrete blocks found in the UK. This investigation is a part of an larger research program for developing mixes with bitumen (as a binder) for different construction components such as, blocks, bricks, tiles etc.

THE TYPE OF SOILS USED

The soil used in this investigation was from a construction site in Hunslet, Leeds, UK. The soil was sieved through a 2.36mm sieve size. Two types of soils were used (see Figure 1). The particle sizes of the soils were of a relatively continuous grading (see Figure 2), where Soil 2 was slightly finer than Soil 1. The soil fraction was very brittle and could easily be crushed by hand. The larger particles were porous by nature.

The plasticity properties of the soil were determined in accordance with BS 1377-2:1990 [4] and the particle density (specific gravity) were determined based on BS 812 Part 2:1995 [5] (see Table 1).

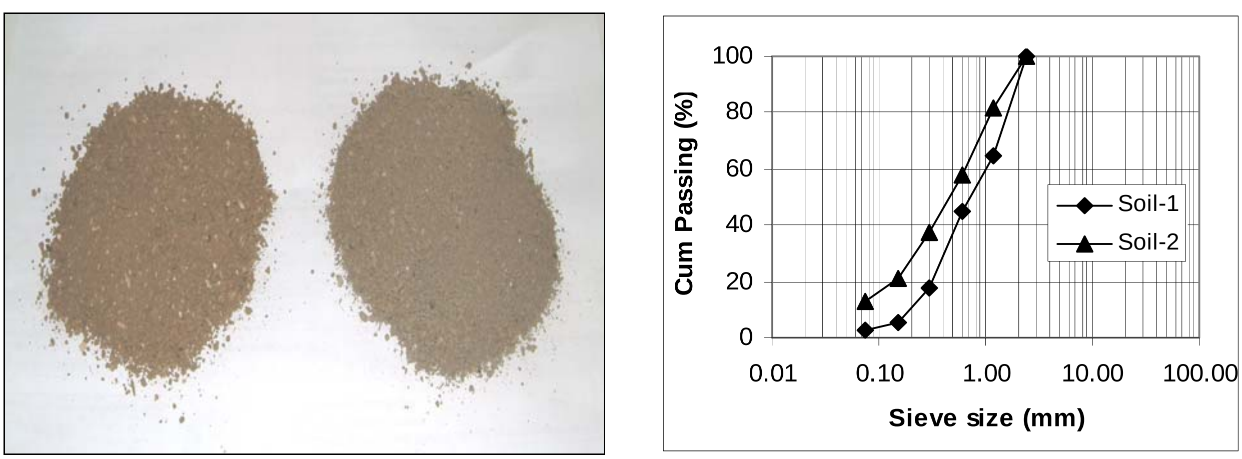

Figure 1: The soil used: a) (Soil-1 with brownish colour on the left, and Soil-2, with greyish colour on the right); b) Particle distribution of the soils.

Table 1: Properties of the soils.

Properties	Soil1	Soil 2
Liquid limit	29 %	27 %
Plastic limit	23 %	22 %
Plasticity index	6 %	5 %
Specific gravity	2.397	2.400
Water absorption	12.1 %	11.2 %

Referring to the particle size distribution chart of BS 1377-2:1990, Soil 1 and Soil 2 both lie within the category of a silty sand. The classification of soil based on plasticity was performed using Casagranda's plasticity chart as shown in Figure 2 [6].

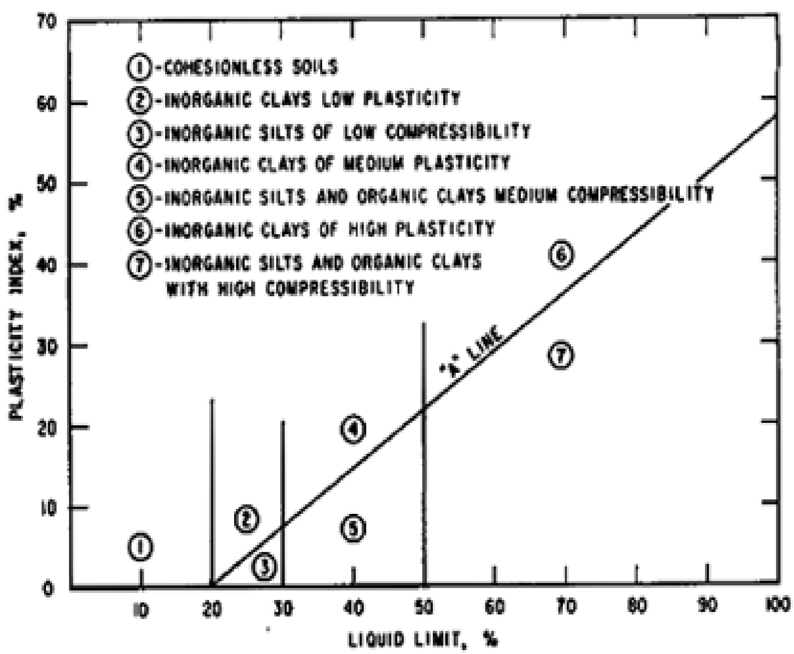

Figure 2: Casagranda's plasticity chart.

In Figure 2, an empirical boundary known as the "A" line separates inorganic clays from silty and organic soils. Soils of the same geological origin usually plot on the plasticity chart as straight lines parallel to the A line. The larger the plasticity index the greater will be the volume change characteristics. "Fat" or plastic clays plot above the line. Organic soils, silts and clays containing a large portion of "rock flour" (finely ground non-clay minerals) plot below it.

By referring to the data in Table 1 and Casagrande's chart, both Soil1 and Soil 2 have a liquid limit less than 50% (i.e., low plasticity). These are the preferred types of soils to be used for producing Soilblock. Utilization of soils with high plasticity or expansive soils for most works can affect the volume stability when subjected to moisture [6]. Soil 1 falls into category 3 (inorganic silt with low compressibility); Soil 2 can be grouped between category 2 and 3 (between inorganic silt with low compressibility and inorganic clays with low plasticity).

PRODUCTION OF THE SOILBLOCKS

The Bitumen used was 100 penetration grade and with specific gravity (SG) of 1.02. The bitumen content was determined based on the minimum content required for satisfactory coating. The Soilblocks were produced based on standard asphalt technology [7]; [8]; [9]. Trial tests showed that the minimum bitumen content was 17.7% by weight of soil or 15% by weight of total mixture. The soil (passing 2.36mm) and bitumen (pre heated at 160°C for 3 hours) were mixed to produce Soilblocks [1]. The compaction levels investigated were 1, 2, and 4 MPa. The samples were compacted at 100-110°C. Following compaction, the Soilblock samples were cured in an oven. The curing regime has previously been found to play a very significant role. When using a 50pen bitumen and cured at 160°C, the curing duration required to satisfy creep performance was 72 hours; softer grade bitumen was found to undergo more effective curing [2]. In order to reduce the curing duration in this investigation, the samples were cured at 200°C for 24 hours. The volumetric properties of the samples were calculated according to equations 1, 2 and 3. The properties of the samples are given in Table 2.

$$SG_{mix} = \frac{100}{\frac{\%a}{SGa} + \frac{\%b}{SG_b} + \frac{\%c}{SG_c} + ... + \frac{\%binder}{SGbinder}}$$, (% by weight of total mix)……………...... (1)

Note: a, b, c, …are aggregate fraction of mixtures (BS EN 12697-5:2002).

Sample Bulk Density = weight in air / volume

= weight in air / (weight SSD-weight in water), ...…….. (2)

Weight SSD is the weight of sample after weighing in water then towel dried (BS EN 12697-6, 2003)

$$\text{Porosity (P) \%} = \left(1 - \frac{\text{Density}}{SG_{mix}}\right) \times 100\%$$, (BS EN 12697-8, 2003)…………………..(3)

VOLUMETRIC AND MECHANICAL PROPERTIES

The volumetric and mechanical properties of the samples are shown in Table 2.

Table 2: Properties of the Soil Bitublock samples

Compaction level (MPa)	IRS* (kg/ m^2/min)	Density (gr/cm3)	SGmix	Porosity (Vol%)	Uncured comp. strength (MPa)	Cured ** comp. strength (MPa)	Water Abs. *** (Wt%)
Soilblock 1							
1 MPa	0.08	1.478	1.993	25.9	0.75	4.7	5.4
2 MPa	0.05	1.595	1.993	20.0	1.5	9.1	4.8
4 MPa	0.09	1.671	1.993	16.1	2.2	12.2	4.2
Soilblock 2							
1 MPa	0.09	1.474	1.995	26.10	0.62	3.6	5.8
2 MPa	0.07	1.566	1.995	21.5	1.3	7.6	5.1
4 MPa	0.10	1.648	1.995	17.4	2.0	10.8	4.45

* initial rate of suction (IRS) ** 200°C for 24 hours ***24 hours water immersion

Referring to Table 2 it can be seen that the porosity of the samples was relatively high compared to Bitublock samples previously made with waste aggregate materials, where the porosity was between 15-20% at 2 MPa compaction level [10]. This is thought to be because the granular particles of the soils were formed by agglomeration of fine soil components that were actually of a porous nature. The sample surface texture was smooth. The reasonably low water absorption values suggest that the soil agglomerations were encapsulated successfully by the bitumen.

The initial rate of suction (IRS) test was carried out by immersing samples in a 3mm depth of water for 60 seconds. The weight of water absorbed by the sample was then calculated and divided by the area in contact with water [11]. IRS is a parameter that can provide an indication of the effect of the unit on the mortar. Units with high IRS require very plastic mortar (high water/cement ratio), while units with lower IRS need stiffer mortar [12]. The IRS value of the Soilblock was found to be lower than the range of IRS values for clay bricks recommended in the United Kingdom (between 0.25-2.0 $kg/m^2/min$). It is thought that the low value of IRS recorded in this investigation is due to the surface of the samples which was smooth and mostly coated by a thin bitumen film that has hydrophobic character. This suggests that stiffer mortars are more suitable for producing Soilblock masonry. This is advantageous in a sense that in remote geographical areas where quality control may be low and the availability of water restricted, a poor quality, stiffer mortar could potentially be tolerated.

The compressive strengths of the uncured samples were considered borderline acceptable for the UK market however they are suitable for low-rise construction in developing / transitional countries. The strengths significantly increased when cured. The compressive strength of the cured samples complies with the British Standards for concrete masonry units, where the range of strength expected is between 2.8 - 10 MPa [13]. This indicates that the curing regime applied (200 °C for 24 hours) gave satisfactory results. The mode of failure of the samples was brittle (see Figure 3).

Figure 3: Brittle mode of failure of the samples.

EXPANSION CHARACTERISTICS OF SOILBLOCKS

Volume stability was carried out by monitoring expansion or shrinkage of the units. The samples were placed on a table at room temperature of 21±1°C and relative humidity (RH) of 60±5 %. Monitoring began immediately after manufacture (once the blocks had cooled down). It was found that initially the samples expanded with time however beyond two weeks they were stable (see Figure 4). The results suggested that the expansion was caused by moisture adsorption from the environment. Adsorption of water molecules onto the surface of the particles reduces the surface energy which decreases the balancing internal compressive stress leading to volume increase or swelling [14]. The ingress of water also decreases surface tensions which will result in swelling [15]. (It was thought that the expansion may also have happened because some hydrocarbons were adsorbed on to the clay sheets within the soil - the size of the hydrocarbon molecules can significantly contribute to volume expansion. However, further investigation using x-ray diffraction discounted this.) Lower expansion occurred on samples with higher compaction level (see Figure 4).

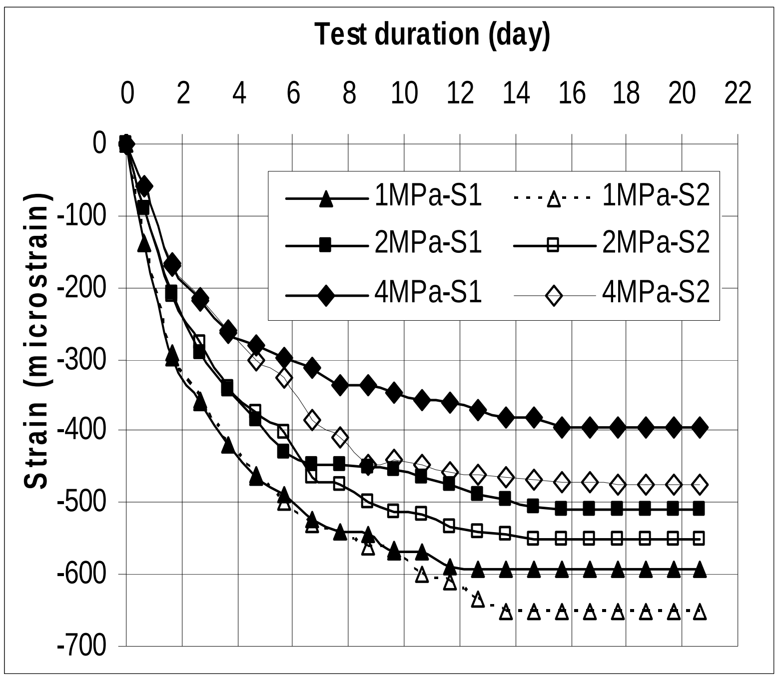

Figure 4: Expansion test results of the Soilblock1 and 2 (S1 and S2) at different compaction level (1, 2 and 4 MPa).

The expansion of Soilblock 2 was higher than Soilblock 1. This may be because Soilblock 2 consists of finer soil particles (Figure 1b) and hence possesses a higher particle surface area. As the bitumen content was kept constant, it is therefore expected that the degree of bitumen coating or the bitumen film thickness in Soilblock 2 was less or thinner than in Soilblock 1. This could have caused Soilblock 2 to absorb more moisture from the environment which would cause larger expansions. The magnitudes of the expansions at the end of the test are given in Table 3 in accordance with the results in Figure 4.

Table 3: The magnitude of the Soilblock expansion at the end of test.

Compaction level	Exp. of Soilblock1 (microstrain)	Exp. of Soilblock2 (microstrain)
1 MPa	594.0	650.9
2 MPa	509.85	551.9
4 MPa	396.0	475.8

It was observed that the expansion of the samples did not cause any visible cracks. The compressive strengths (Table 2) were obtained after the expansion tests were completed. This indicated that despite the expansion, the samples still gave acceptable strength. If the Soilblocks are used to construct a wall, the expansion of the unit may counteract some or all of the shrinkage that commonly occurs in cement mortar [12]. The expansion of the unit could also provide a pre-stressed condition to the wall structure that can improve the ability of the wall to bear horizontal loads. However, in general it is recommended from the results that units are not used in masonry at least until they are two weeks old.

CREEP PERFORMANCE

For the creep test, the samples were loaded using a static dead-weight lever arm machine with mechanical advantage of 4 as shown in Figure 5a. The stress applied was 1 MPa [16]. The strain was monitored on each of the four faces of each sample and measured by means of a 50mm Demec gauge (Figure 5b), and then averaged.

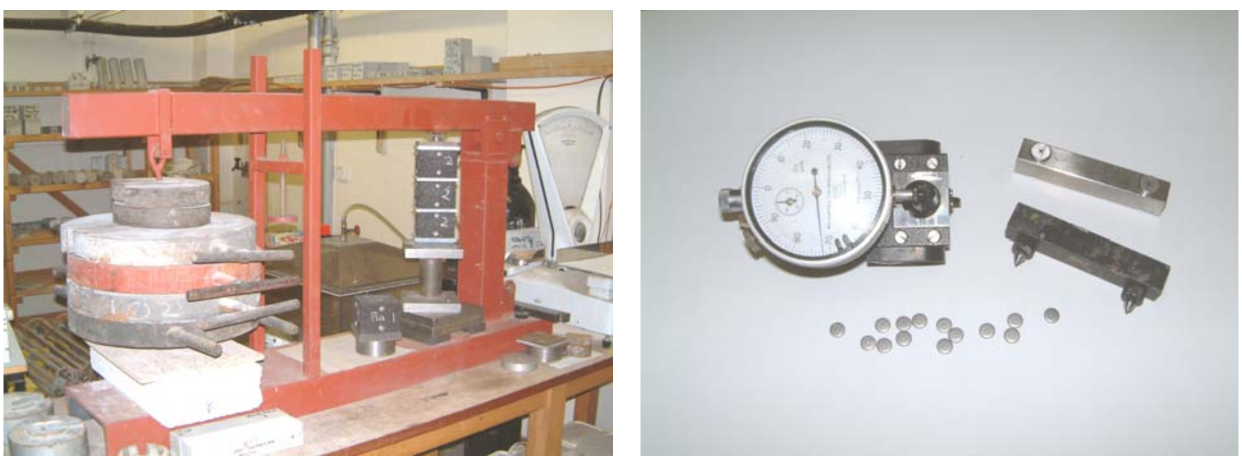

Figure 5: Creep test: a) Static deadweight load lever arm machine; b) A 50mm Demec gauge with its supporting equipment.

The samples were loaded at room temperature (21±1°C) and in a relative humidity (RH) of 60±5%. The creep performances of the samples under a 1 MPa stress are shown in Figures 6 and 7. A summary of the results is also given in Table 4.

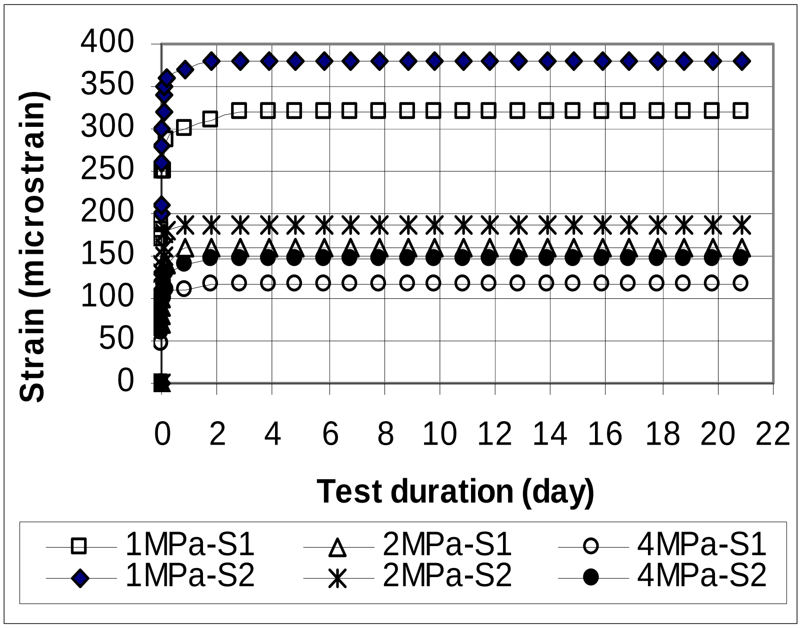

Figure 6: The total strain of the Soilblock1 and 2 (S1 and S2), at different compaction level (1, 2 and 4 MPa).

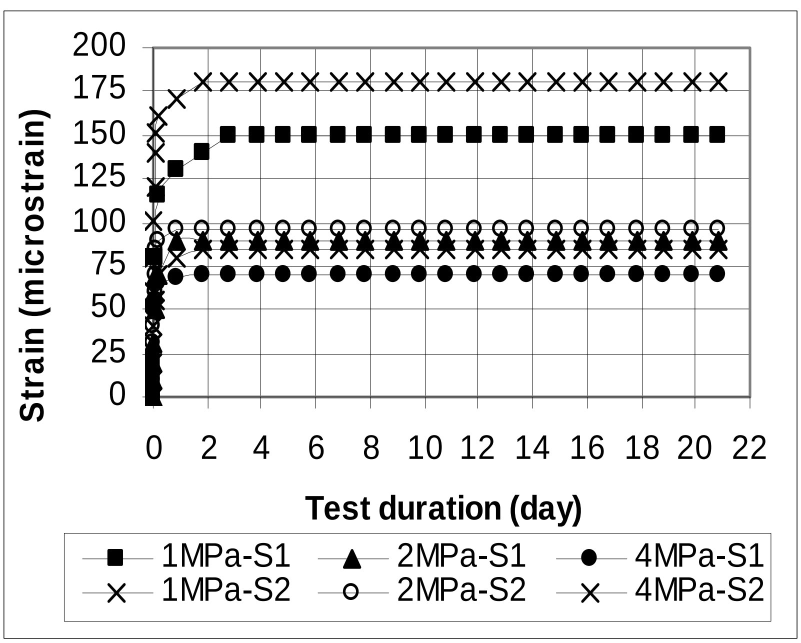

Figure 7: The creep strain of the Soilblock1 and 2 (S1 and S2), at different compaction level (1, 2 and 4 MPa).

Table 4: Creep performance of the Soil Bitublock samples.

Comp level (MPa)	Total Strain (με)	Elastic Strain (με)	Elastic modulus (MPa)	Creep Strain [1] (με)	Expansion at creep test * (με)
Soilblock1					
1	320.80	170.50	5865.10	150.3	*
2	160.40	70.55	28348.68	89.85	*
4	115.20	45.60	87719.29	69.60	*
Soilblock2					
1	380.60	200.21	4994.75	180.39	*
2	185.50	90.25	22160.66	95.25	*
4	145.20	60.32	66312.99	84.88	*

[1] creep strain = total strain – elastic strain – shrinkage or expansion.

* the samples were tested for creep after the expansion was stable (at zero expansion).

Figures 6 and 7 indicate that creep had finished after 2 days. The total creep of the samples compacted at 2 and 4 MPa were less than 100 microstrain and are at least compatible to creep recorded in concrete blocks. The level of creep and the cessation of creep after such a short time (as well as the compressive strength failure mode) confirm the manufacturing process has converted the bitumen bound unit from a viscous-plastic material to an elastic brittle material. Realistically, for low rise construction in developing countries, a higher level of creep may be acceptable. As such, the curing regime (temperature and duration) adopted for this investigation could therefore be reduced.

CONCLUSIONS

It can be concluded that:

a. Soil can be used as an aggregate for a masonry block, which can possess compressive strengths comparable to concrete blocks commonly used in the United Kingdom.
b. The Soilblock expands due to the moisture adsorption from the environment. The expansion can be reduced by increasing the compaction level.
c. A curing regime of 200°C for 24 hours was found sufficient to harden the bitumen and hence meet the required Soilblock performance. However, this regime could be relaxed for developing country construction
d. The creep of the Soilblock can be reduced by increasing compaction level. A minimum compaction level of 2 MPa is recommended.

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