IMPROVING THE EARLY LIFE STRENGTH OF COLD BITUMINOUS EMULSION MIXTURES BY PLASTIC CELLS REINFORCEMENT

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ABSTRACT

Cold Bituminous Emulsion Mixtures (CBEMs) for road pavement are weak at their early life time because they still contain some amount of water. When it is necessary reinforcement on CBEMs is possible to improve the early life strength of the mixtures. The objective of the investigation was to find out the suitable position of the reinforcement on CBEMs in order to improve the early life strength of the mixture that can prevent early life failure. The reinforcement materials used was 'plastic cells' which were made from standard extruded polyvinyl chloride (PVC) sheet. The plastic cells were positioned at the middle height and at the upper side close to the surface of the CBEMs samples. The samples were subjected to dynamic cylindrical loading, where the number of dynamic load applied and the deformation were electronically recorded. Stress and strain distribution was analyzed using BISAR 3.0 software from Shell company. It was found that the suitable position of the reinforcement on CBEMs is on the upper side (close to the surface), which gives significant prevention on deformation and crack during early age of CBEMs.

Keywords: cold asphalt mixtures, early failure, reinforcement

1. INTRODUCTION

Strengthening of asphaltic hot mixtures by means of high tensile polymer grid reinforcement had been investigated in the early 1980's (Brown et. al, 2001). When properly applied, grid reinforcement can enhance the cracking and rutting resistance of asphalt concrete layer in pavements. It was found to be essential to locate the grid at the correct level within the asphalt layer.

Research carried out at Nottingham University investigated the performance of hot mix macadam 14 mm asphalt concrete layer without and with grid reinforcement, constructed over a low stiffness of granular base and subgrade. The asphalt concrete layer was subjected to a simulated traffic loading. It was found that grid positioned at bottom of the asphaltic concrete mixture gave minor evident of cracking with no significant deformation, as shown in Figure 1. This confirms that placement of grid at bottom is the correct position to encounter the tensile strains which cause cracking (Brown et. al, 2001). The loading was carried out when the hot asphalt concrete mixture at optimum strength, i.e. soon after the hot mixture cooled down.

Meanwhile, improvement of the early life strength on CBEMs by giving 'plastic cells' reinforcement on CBEMs (a mixture of properly graded coarse and fine aggregates, pre-wetted water and bitumen emulsion) described within this paper, was an investigation of a different nature.

The weak early life strength of the CBEMs is the main concern (Thanaya, 2003). The objective of the investigation was to find out the suitable location of the reinforcement on CBEMs at earliest age when the CBEMs are generally still weak (Asphalt Institute, 1989) in order to improve the early life strength that can prevent early life failure due to excessive deformation.

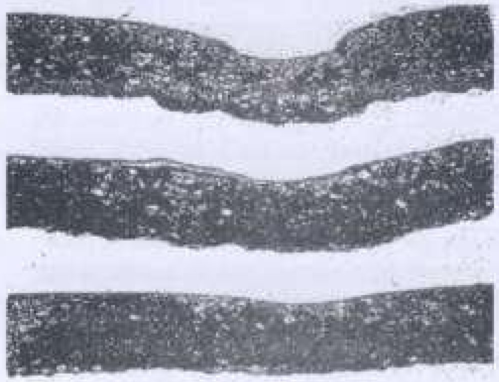

Figure 1. Cross section of hot mix macadam 14 mm asphalt pavement reinforced with geosynthetic grid following trafficking. Top Figure - without grid, Middle Figure - grid at mid depth of asphalt layer, Bottom Figure - grid at underside of asphalt layer.

2. MATERIALS AND EXPERIMENTAL METHOD

The type of materials used for manufacturing the CBEMs were: limestone coarse aggregates with max aggregate size of 12.7 mm, natural sand, fly ash filler, and cationic bitumen emulsion binder produced by Nynas-UK with 100 pen base bitumen. The aggregates gradation was determined by means of Modified Fuller's Curves or Cooper's Curve/Formula (Cooper et.al., 1985), with 4 % filler content. The CBEMs designed method was based on modification of the Marshall design method (Thanaya and Zoorob, 2002).

The 'plastic cells' or 'blocks of plastic strip' (supplied as a courtesy of 'Phi Design Ltd'., Northampton, UK) was made from standard extruded polyvinyl chloride (PVC) sheet that had been cut into strips. The plastic strip was of 20 mm width, 0.40 mm thick (measured using an electrical vernier caliper 'Micro 2000'). It was supplied with 600 mm long. The length can be supplied to meet demand. The Plastic Strip was slotted or cut with cut size of 1mm width and 10 mm length (half of its 20 mm total width) to enable the formation of plastic strip blocks or 'plastic cells' with block size of 35 x 35 mm. The wall side of the plastic cells was given two holes of 6mm diameter in order to provide better bonding of materials within the plastic cells blocks (this was based on trials results that were carried out beforehand) as shown in Figure 2.

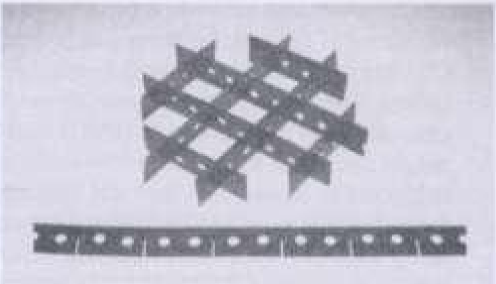

Figure 2. Plastic Cell with two holes on it's wall side.

The CBEMs samples were of 150 mm diameter, and were tamped and then compacted using a Gyropac compactor with 240 revolutions, at 540 kPa vertical pressure (equals to 2 times Marshall heavy compaction level) for obtaining about 8 % porosity value to meet most specifications (MPW-RI, 1990 and Nikolaides, 1994). Two types of sample were manufactured, i.e. With Plastic Cells and Without Plastic Cells.

Regarding the positioning of the plastic cells, it was thought that it would not be the same as in hot mixture where the correct positioned was found at the base of the pavement. As cold mixtures are weak at their early life time, therefore it would be more suitable if the reinforcement is positioned closer the surface which is the area of highest stress (the load contact area). Based on this consideration, then the plastic cells were initially positioned at mid height, then close to the surface of the samples.

As the samples were compacted using a gyratory compactor, the base and the surface of the samples were not in a parallel flat condition, therefore the sample was capped with sand cement mortar (Figure 3) for obtaining even surface (parallel flat) and cured for a further 48 hours to allow the mortar to harden.

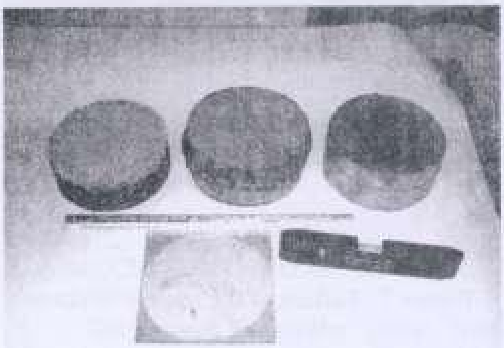

Figure 3. Capping of samples to obtain two parallel flat surfaces, where the capped surface was positioned as the base side during testing , as shown in (Figure 4).

Initially, a trial on sample of 4 weeks of age (since production plus 48 hours after capping) with plastic cells positioned at mid height was carried. Even at this age (the samples normally stronger in line with age) and with reinforcement at the mid height of the sample, under dynamic loading, large cracks occurred as shown in Figure 4. This indicated that the position of the reinforcement was not suitable.

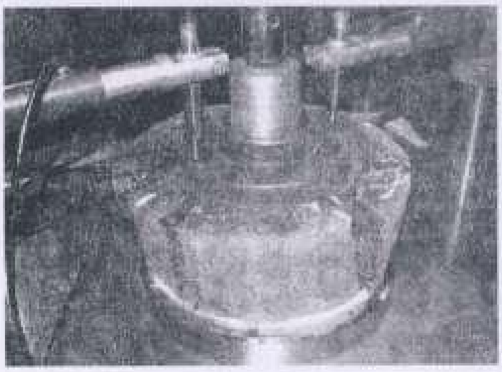

Figure 4. Significant cracks occurred on sample with plastic cells at mid depth.

Then a further trial was done on sample without and with plastic cells positioned close to the surface of the sample. At this trial, the samples were tested at earliest age practicable (at 3days) where the samples are still weaker, in order to evaluate the effectiveness of the utilization of the plastic cells. The samples were extruded from the mold soon after compaction. It was found that the samples were practically can be handled (although they were weak). Then the samples were left (cured) for 24 hours at room temperature 24 °C, and then tested for indirect tensile stiffness modulus (ITSM) at 20 °C. Then the samples were capped with sand cement mortar and left for a futher 48 hours. The overall age of the samples by the time it was subjected to dynamic loading was 3 days of age. The dynamic loading was done using a universal material testing apparatus (MATTA) machine.

After carrying out several trials, for convenience, the dynamic loading was set at: terminal pulse count: 100,000 pulses, conditioning stress: 10 kPa, loading stress: 100kPa (standard loading for dynamic creep test), conditioning time: 2 minutes, pre-load rest time: 1 minute, recovery time: 60 minutes, testing temperature: 40°C. Stress and strain distribution were analyzed using BISAR 3.0 software from Shell company, with a schematic loading for stress distribution analysis as shown in Figure 5.

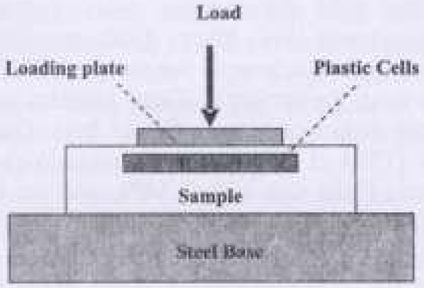

Figure 5. Schematic loading for stress distribution analysis.

3. RESULTS

Results from the initial trial

Test result on the sample With Plastic Cells positioned at mid of its height (4 weeks of age) gave indirect tensile stiffness modulus (ITSM) of 1427.5 MPa (tested 20°C). At this age the CBEMs sample should have stronger as some water content of the sample had evaporated. However, under creep dynamic loading it was observed that significant cracks and deformation occurred, as shown in Figure 4. However the sample did not totally collapse. This was because the total failure was prevented by the plastic cell as shown in Figure 6.

Figure 6. The plastic cells prevent the total failure of the sample.

Results from the further trials

Based on result from the initial trial, at this trial the samples were prepared Without and With Plastic Cells positioned close to the surface of the sample (about 5 mm from the surface). These samples were tested at earliest age possible (3 days of age). The ITSM at 20 °C of the sample Without Plastic Cells was 469.62 MPa, and the one With Plastic Cells was 355.61 MPa.

The sample Without Plastic Cells totally collapsed as shown in Figure 7, whereas the sample With Plastic Cells remained intact (Figure 8). The dynamic loading test result is presented in Figure 9.

Figure 7. Failure of the sample Without Plastic Cells

Figure 8. The sample With Plastic Cells (close to the surface) at the end of dynamic creep test, remained intact.

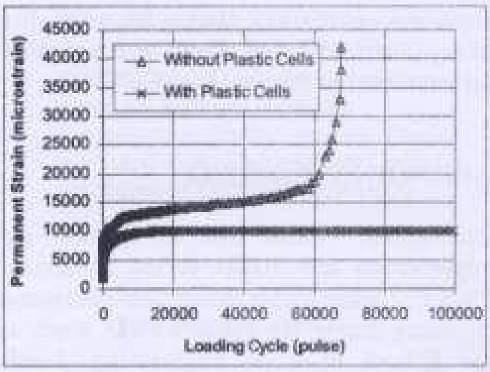

Figure 9. Sample's permanent axial strain vs. loading cycle, at 3 days of age.

4. DISCUSSION AND ANALYSIS

The result from the initial trial showed that the sample was heavily cracked (Figure 4). This is because the upper side of the sample was still weak, and cannot withstand the stress applied.

On the further trials, the ITSM of the sample With Plastic Cells were slightly lower than the sample Without Plastic Cells, although effort had been made to provide two holes on the wall side of the plastic blocks for giving additional interlocking. This is because the sample With Plastic Cells did not behave as a composite mass. There is no continuous bonding of the mix due to the presence of the plastic cells. Additionally, bonding between the mix and the plastic cells is weak as the surface of the plastic cells is very smooth and absorbs no liquid. Therefore, test on the sample With Plastic Cells resulted in greater deformation during ITSM test, hence gave lower stiffness values. This trend met with laboratory evidences which indicated that there is a potential bond reduction between the asphalt mixture above and below any geosynthetic reinforcement (Brown et. al, 2001). Although the plastic strip does causes less stiffness of the sample, the reduction of stiffness was minor and within a repeatable stiffness values under ITSM testing mode.

Test results of the dynamic loading on the further trial was primarily evaluated on the permanent axial strains vs. loading cycles as presented in Figure 9. The sample Without Plastic Cells gives higher permanent axial strains and totally collapse at 68,000 loading cycles (see also Figure 7). On the other hand the sample With Plastic Cells was not failed even at the end of 100,000 preset number cycles of loading, and showing very small deformation but with some minor cracks of about 0.5 mm width and 6 mm length at some parts of the upper side of the sample (Figure 8). Figure 9 also indicates that at early age of 3 days, samples with plastic cells reinforcement positioned close to the surface, give significant prevention to deformation under dynamic loading. This is because the plastic cells are able to hold the mixture and prevent the propagation of cracks, hence significantly reduces vertical deformation. This result suggests that application of plastic cell reinforcement on CBEMs during their early life time appears to be encouraging for preventing deformation of CBEMs.

Analysis of stress distribution was carried out using BISAR 3.0 software of the Shell company. The test was analysed as a single asphaltic layer which rest on a semi infinite base.

The objective of this analysis was to estimate the stresses act on the sample Without Plastic Cells which totally failed/collapse during testing (Figure 7), and to interpret that these stresses were resisted by the plastic cell as in the case of the sample With Plastic Cells , hence prevented the sample from failure. The strength of the plastic cell was stronger than the stresses occurred due to the loading.

Based on the dynamic load setting as previously described with loading stress set at 100 kPa stress, it was found to give 2.5 kN actual vertical force. This actual load was calibrated using a calibrated proving ring.

The 2.5 kN force was dynamically loaded on to the sample Without Plastic Cells through a cylindrical plate of 16 mm thick and 100 mm diameter or 50 mm radius (Figure 5). This loading condition was use as the input load into the BISAR 3.0 software.

With dynamic load application as shown in Figures 4 and 5, the pavement structure for the analysis was considered consisted of one CBEM (asphaltic) layer with 74 mm thick, to rest on a very rigid base, which was a steel base. The modulus elasticity for the CBEMs and the steel base was 355.61 MPa and 190 GPa respectively. The Poisson's ratio of the CBEM and the steel base was 0.35 (commonly use value), and 0.28 respectively. The properties of the steel base were taken as a typical of stainless steel property (UMIST, 2003). Base on the BISAR 3.0 out put, the stresses occurred due to loading was compressive stress of 145 kPa, which failed the sample Without Plastic Cells , but can be resisted by the plastic cells reinforcement on the sample With Plastic Cells .

5. CONCLUSIONS

There are three conclusions can de withdrawn from this investigation, namely:

- The plastic cells (or any type of geosynthetic) reinforcement of CBEMs does reduce stiffness, however the reduction of stiffness was not significant.
- The suitable reinforcement position of CBEMs is on the upper side (close to the surface), which can give very significant prevention to deformation and cracks at early age due to dynamic loading which simulate loading from passing traffics.
- The plastic cell used can resist the stress applied hence prevent the sample from failure.

6. SUGGESTION

Further works are needed in order to ensure efficiency, i.e. the type, the strength capacity, and the dimensions of the geosynthetic cells and aspect of practicality on installing reinforcement on CBEMs.

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