DOUBLE LAYERS APPLICATION AND REINFORCEMENT OF COLD BITUMINOUS EMULSION MIXTURES (CBEMs)

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Abstract
The natures of cold bituminous emulsion mixtures (CBEMs) are weak at their early life time. Increase of strength of CBEMs largely affected by the evaporation of the volatile components of the compacted mixtures. CBEMs can be applied in double layers. The first layer was compacted then left for a period of time before laying and compacting the second layer. The results indicated that the strength of the double layers were only marginally different from a single layer application. CBEMs resistance to deformation can be improved by giving plastic cell/grid reinforcement positioned close to the surface. Combination of double layers and reinforcement of CBEMs is practicable and suitable for pavement maintenance.

Keywords: Double layers, emulsion mixture, early life failure, reinforcement.

INTRODUCTION
Unlike hot asphalt mixtures, cold bituminous emulsion mixtures (CBEMs) are weak at their early life time. This is the nature and as the down side of CBEMs. However CBEMs when properly design and applied, had been known of their energy efficiency and simplicity (Thanaya and Zoorob, 2002).

Low strength of CBEMs at their early life time is due to the presence of water within the compacted mixtures. The strength of the CBEMs will improve as the water content evaporates with time. The time required for CBEMs to gain their maximum strength largely depends on climatic condition. CBEMs are more suitable at warmer environment, for small scale works such as for road maintenance and works in remote areas (Thanaya, 2003).

In order to accelerate the evaporation of the volatile components of the compacted mixtures, application of double layers (two thin layers) was investigated. The first layer was given simulated curing in oven before the application of the next layer. Additionally, deformation of CBEMs can be prevented by giving plastic cell reinforcement.

Reinforcement of hot asphalt mixtures by means of high tensile polymer grid reinforcement had been investigated in the early 1980’s (Brown et al, 2001). The 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. Brown et al, 2001, found that the correct placement of grid is at bottom of the hot asphalt layer.

Meanwhile, early life failure prevention by application of ‘plastic cells’ reinforcement on CBEMs described within this paper, was an investigation of a different nature, where the weak early life strength of the CBEMs is the main concern (Thanaya, 2003).

The objectives of the investigation were to evaluate the performance of CBEMs double layers application and to find out the suitable location of the reinforcement of CBEMs for preventing excessive deformation.

METHOD
The type of materials used for manufacturing the CBEMs were: limestone coarse aggregates with max aggregate size of 12 mm, asphalt sand and red porphyry sand (RPS) fine aggregates, cationic bitumen emulsion binder produced by Nynas-UK, with 100 pen base bitumen, with 60 % bitumen content.

The aggregates gradation was determined by means of Modified Fuller’s Curves or Cooper’s Curve/Formula (Cooper et.al., 1985). The CBEMs designed method was based on modification of the Marshall design method (Thanaya and Zoorob, 2002).

Double Layers Application
Since curing of emulsion bound bituminous mixtures is such a critical parameter that influences performance, in particular moisture loss, it was hy-
pothesized that a thinner layer would be capable of achieving a higher level of curing faster than a thicker layer. It was therefore decided in this part of the investigation to assess the mechanical properties of multi layered thin CBEMs.

The first thin layer (approx. 25 to 30mm) was allowed to achieve a high level of curing at 40°C in an oven for 24 hours and then cooled down to room temperature for at least 3 hours. Before constructing the second layer, a tack coat (50% emulsion : 50% water) was evenly applied onto the first layer in order to enhance the bond to the second layer. The key question was whether the two compacted thin layers (requiring a relatively short combined curing period) would behave at least as well as a fully cured (long curing period) single thick layer of equivalent thickness.

The two layers compaction was not practicable using a gyratory compactor, therefore the samples were compacted using a Static Compression Machine as shown in Figure 1, where the supporting equipments can also be seen.

The first compacted layer was kept in the mould and cured in an oven at 40°C for 24 hours to simulate a high degree of curing prior to the application and compaction of the second layer. The combined specimens (2 layers each) were then cured again at 40°C until they achieved ‘full curing’ (indicated by constant weight) prior to testing.

The samples were compacted at 180 kN for 3.5 minutes in order to gain the targeted porosity of 8%. The results of Porosity and ITSM values of all the specimens manufactured with and without cement addition are shown below in Table 1, where comparison with a single layer sample compacted using a gyratory compactor are also presented.

It was noted that the porosity of the samples compacted using static compaction were almost equal to those compacted using a gyratory compactor, however the ITSM values were slightly lower, but within repeatable range of values. This is because there is a slightly less interlock between the interfaces of the two layers in the double layers application, and due to the effective compaction of the gyratory compactor. This should nevertheless not distract from the fact that multi layered CBEMs are a very viable solution to the problem of curing.

Figure 1. Static compression machine and supporting equipments for CBEMs double layers compaction.
Table 1. Properties of the double layers CBEMs at full curing.

<table>
<thead>
<tr>
<th>Type of Mixture</th>
<th>Double layer *</th>
<th>Single layer **</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Porosity (%)</td>
<td>ITSM (MPa)</td>
</tr>
<tr>
<td>CBEMs without cement</td>
<td>8.1</td>
<td>1564</td>
</tr>
<tr>
<td>CBEMs + 2% cement (OPC)</td>
<td>8.2</td>
<td>2326 *</td>
</tr>
</tbody>
</table>

* Static compaction ** Compacted using a gyratory compactor in the conventional manner.

Plastic Cells Reinforcement

The materials used for reinforcement were 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. The Plastic Strip was ‘slotted’ or ‘cut’ with cut size of 1 mm 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 6 mm diameter in order to provide better bonding of materials within the plastic cells blocks as shown in Figure 2.

![Figure 2. Plastic Cell with two holes on its wall side](image)

The CBEMs samples were of 150 mm diameter, and were tamped and then compacted using a gyratory compactor with 240 revolutions, at 540 kPa vertical pressure (equals to 2 times Marshall heavy compaction level) for obtaining 8% porosity value to meet most specifications (MPW-RI, 1990 and Nikolaides, 1994).

The dynamic loading was done using materials 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: 100 kPa (standard loading for dynamic creep test), conditioning time: 2 minutes, pre-load rest time: 1 minute, recovery time: 60 minutes, testing temperature: 40°C.

Un-reinforced sample and Initial Reinforcement Trial

An un-reinforced sample (no plastic cell: NPC sample) was first made. The samples were tested at earliest age practicable, 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 the samples were practically can be handled (although they were weak). Then the samples were then left (cured) for 24 hours at room temperature 24 °C. The sample was capped with sand cement mortar to obtain parallel flat surfaces, and left for two more days to allow the mortar sufficiently hard. The overall age of the samples by the time it was subjected to dynamic loading was 3 days of age.

The un-reinforced sample totally failed (Figure 3) after 68,000 pulse of dynamic loading (Figure 7). The ITSM at 20 °C of this sample: without (No) plastic cells (NPC) was 469.62 MPa.

![Figure 3. Total failure of the sample without or no plastic cell (NPC)](image)

Then the plastic cells were initially positioned at mid height the samples. To obtained this, a half amount of loose mixture was poured into the mould, then tamped with a metal tamping rod 20 times around the edge and 15 times in the middle (in line with the size of the sample). Next, the arranged plastic cells were placed and followed by the next tamped loose mixture. The sample was then compacted.
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 5.

Further Reinforcement Trial

Based on result from the initial reinforcement trial, then a sample was prepared with plastic cells positioned close to the surface (about 5 mm from the surface). This was achieved by managing the amount of loose materials poured into the mould for the first layer (more loose mixture) and a lot less loose mixture for second layer. This sample was also tested at 3 days of age, with ITSM value at 20 °C of 355.61 MPa. The sample remained intact (Figure 6). The results of the dynamic loadings is given in Figure 7.

![Figure 4. Significant cracks occurred on sample plastic cells at mid depth](image1)

![Figure 5. The plastic cells prevent the total failure of the sample](image2)

![Figure 6. WPC (with plastic cells) position close to the surface of the sample at the end of dynamic creep test remained intact](image3)

![Figure 7. Permanent axial strains vs. Loading Cycles, of CBEMs at 3 days of age.](image4)

Note: WPC = with plastic cell position close to the surface; NPC = without or no plastic cell
RESULTS AND DISCUSSION

Double Layers Application
This application for CBEMs is attractive for accelerating the curing time of CBEMs. The first layer can be left for a period of time until undergoes sufficient curing. Then the second layer to be applied. The strength of the double layer was only marginally different with the single layer (Table 1).

CBEMs Reinforcement
The result from the initial reinforcement trial showed that the sample was heavily cracked. This is because the upper side of the sample was still weak, and could not withstand the stress applied.

On the further trial, the ITSM of samples with plastic strip (WPC) positioned close to the surface was 355.61 MPa, which was slightly lower than the samples without plastic cell (NPC): 469.62 MPa. This is because the WPC sample does not behave as a composite mass, although effort had been made to provide two holes on the wall side of the plastic cell blocks for giving additional interlock-ing. There is no continuous bonding of the mix due to the presence of the plastic cell blocks. Addition-ally, bonding between the mix and the plastic cell is weak as the surface of the plastic is very smooth and absorbs no liquid. Therefore, the WPC test resulted in greater deformation during ITSM test, hence gave lower stiffness values. Although the plastic strip did cause 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 were primarily evaluated on the permanent axial strains vs. loading cycles as presented in Figure 7. The NPC sample gives higher permanent axial strains and totally collapse at 68,000 loading cycles.

On the other hand the WPC did not fail 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 6).

Figure 6 indicates that the plastic cells (positioned close to the surface) give significant prevention to deformation under dynamic loading. This is because the plastic cell is able to hold the mixture and prevent the propagation of cracks, hence significantly reduces vertical deformation. Application of plastic cell on CBEMs appears to be encouraging for preventing deformation of CBEMs during their early life time.

Combination of Double Layers and Reinforcement
Referring to the above results, it is very practicable to combined double layers application with reinforcement on the construction of CBEMs pavement. The reinforcement grid to be placed on top of the first layer that had been compacted, then lays the second layer. The thickness of the first and the second layer can be arranged, so the reinforcement grid will take position close to the surface of the finish double layer. This practice can be suitable for doing pavement maintenance for repairing large potholes.

CONCLUSIONS
There are some points can be concluded from this investigation, namely:
- CBEMs double layers application gave reasonable strength with marginal difference with a single layer.
- 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).
- The plastic cell used can resist the stress applied hence prevent the sample from failure.
- Combination of double layers and reinforcement of CBEMs is practicable and suitable for road maintenance (e.g. for patching potholes).

REFERENCES
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