TITLE: Bituminous Surfacing for Heavily Trafficked Roads in Tropical Climates

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ITU MININOUS SURFACINGS FOR HEAVILY TRAFFICKED ROADS IN TROPICAL CLIMATES

1 INTRODUCTION

The standard of road networks in developing countries is increasing and new roads have been built with thick asphalt concrete (AC) surfacings to accommodate increasing traffic volumes. There are situations when the use of AC designed by the Marshall method is very difficult, if not inappropriate, such situations include;

- areas of high traffic stresses such as climbing lanes and junctions;
- where high pavement temperatures occur; and
- where design traffic loading significantly exceeds 1 million esa, which is the minimum value of the Asphalt Institute definition of heavy traffic (MS2-1994).

A fundamental assumption in the Marshall procedure is that the density obtained during the test represents the ultimate density of the AC in the road pavement after years of secondary compaction under traffic. This is very difficult to predict and, where loading conditions are severe, it is most likely that the commonly used 75 blow Marshall compaction will underestimate the effect of secondary compaction.
When secondary compaction of the AC surfacing is underestimated there is a high risk that structural instability may develop and result in plastic deformation. Such failures are an expensive waste of non-renewable resources because, in the majority of cases, the deformed asphalt must be removed and replaced with new material.

Plastic deformation of thick bituminous surfacings is by no means a new phenomenon. A review in 1975 (OECD, 1975) referred to widespread problems in Europe, North America and Japan and noted that, although the problems were more severe in countries with hot climates, hilly terrain and heavy traffic, there were also problems in temperate climates in more sensitive areas such as bends, junctions etc. The report proposed bituminous mixes that were less susceptible to secondary compaction by traffic and suggested methods of designing these mixes that included, lowering the binder content, using a stiffer or a polymer modified binder and improving aggregate angularity and grading.

The importance of maintaining sufficient voids in the mix (VIM) after trafficking was emphasised in the Desert Roads Manual (Halcrow, 1980) which required that heavy duty dense bitumen macadams for use in hot arid areas should retain a VIM of not less than 3% at refusal density. Further work (Cooper et al, 1985) showed that the resistance to deformation of continuously graded mixes increased as the voids in the mineral aggregate (VMA) decreased until refusal density was approached at very low values of VMA, when resistance to deformation began to decrease rapidly. The initial increase in resistance to deformation was
thought to be caused by the increase in aggregate contact as the coarser particles were forced together. However, as compaction was increased further the fines/filler mortar gradually filled more of the void space between the coarse particles, eventually reducing aggregate contact and making the mix less resistant to deformation. These results again infer that a minimum level of VIM at refusal density would prevent the majority of failures through plastic deformation.

Despite these and other published design modifications for continuously graded mixes in hot climates there are still far too many occasions in the developing world when limited maintenance resources are being used to resurface roads that have failed through premature plastic deformation.

2 FULL-SCALE TRIALS AND FAILURE INVESTIGATIONS

The Transport Research Laboratory (TRL), in cooperation with both the Public Works Institute in Malaysia (IKRAM) and the Institute of Road Engineering (IRE) in Indonesia, have undertaken research to investigate the nature of premature plastic deformation and also developed low cost mix design procedures that will prevent its occurrence.

The research in Malaysia centred around two sets of experimental surfacing trials on a particularly severe climbing lane on the Kuala Lumpur - Karak highway, which carried more than 1000 commercial vehicles per day (Hizam and Jones, 1992)(Hizam and Morosiuk, 1995). The climbing lane had a grade of 6% and the average speed of the commercial vehicles was 15 kph. The studies have shown that the AC wearing course materials
designed by the Marshall procedure were compacted by the slow moving and heavy vehicles. Figure 1 illustrates this effect and shows that a rapid decrease in void content in the surfacings, of typically 2%, occurred over the first few months. After this, the rate of secondary compaction decreased as the materials approached their refusal densities. In this case the refusal density is the maximum density to which each particular material will be compacted by the traffic using the climbing lane.

Further monitoring of these trials has shown that if the level of air voids in the surfacings can be maintained above 3% at its refusal density, then there is a high probability that plastic deformation of the material will not occur.

In addition to the research in Malaysia the results of further investigations on heavily trafficked roads and climbing lanes in the Middle East and East Africa has confirmed these findings. In these studies the material properties of deformed AC surfacings were compared to the properties of materials which had performed satisfactorily. The results, shown in Figure 2, confirm those found in Malaysia namely that if mixes can be designed in such a way that there is a residual void content of 3% after compaction by traffic, the surfacing is unlikely to fail through premature plastic deformation.

3 RECENT DESIGN DEVELOPMENTS

The occurrence of plastic deformation as a result of increased heavy traffic has lead to corresponding changes in existing design procedures and also
to the development of other design techniques. Most notable of these is the recent change in the Marshall design procedure (Asphalt Institute, 1994) and the development of the SUPERPAVE method of design as part of the Strategic Highway Research Program (Cominsky, 1994). Both these methods emphasise the importance of maintaining a minimum level of voids after secondary compaction by traffic.

The Marshall method of determining the desired bitumen content is by far the most common procedure used to design continuously graded mixes in developing countries. It has proved to be robust and inexpensive and is enshrined in most of the general specifications found in the developing world. The method requires test specimens having increasing bitumen contents to be moulded at a specified compactive effort under standard conditions. The compactive effort varies according to the traffic level with a maximum of 75 blows of the Marshall hammer on both sides of the specimen usually being assumed as appropriate for traffic levels of more than one million equivalent standard axles. In the past (Asphalt Institute, 1988) the optimum bitumen content of the mix was then determined by taking an average of the bitumen contents which gave:

(a) maximum unit weight;
(b) maximum stability; and
(c) air voids of 4%.

To be acceptable the mix also had to comply with a number of empirically derived criteria namely, minimum values of stability and values of flow, air voids and voids in the mineral aggregate which were within defined ranges.
One disadvantage of this method was that the optimum bitumen content was often higher than that bitumen content which corresponded to 4% air voids and therefore the design mix could possess air voids somewhat less than 4% and often close to 3%. When this occurs the mix becomes more susceptible to plastic deformation, particularly if the compaction under traffic is greater than the equivalent of 75 blows of the Marshall hammer. This is often the case on most climbing lanes.

In the latest versions of the design manual (Asphalt Institute, 1992 and 1994) there are two major changes. Firstly the introduction of a criterion to limit the voids filled with bitumen, particularly at high traffic levels, and secondly a recommendation to select the design bitumen content as that which will result in 4% void content. Both these changes tend to increase the air voids in the design mix and therefore reduce the possibility of the surfacing reaching an unacceptably low level of air voids after secondary compaction by traffic.

The 1994 version of the manual also states "mixtures that ultimately consolidate to less than 3% air voids can be expected to rut and shove" and emphasises that the design range of air voids (3-5%) is the level desired after several years of compaction by traffic. However, it is not explicit on how this level of compaction can be simulated in the test procedure stating that "the design range (3-5% air voids) will normally be achieved if the mix is designed at the correct compactive effort and the air voids after construction is about 8%". The result from the study in Malaysia tends to confirm this fact with the voids in the wheelpath decreasing by
approximately 3 to 4% over a period of two years (see Figure 1). However, the surfacing material outside the wheel paths is unlikely to receive appreciable secondary compaction and the binder may be prone to ageing and subsequent cracking (Rolt et al, 1986)(Smith et al, 1990).

4 LABORATORY TRIALS

4.1 The effect of compaction level chosen for mix design

It is clear that the level of compaction used for designing a mix, which is to be subjected to severe loading conditions, is fundamental to the long term performance of the material. Laboratory tests have shown that the selection of a fixed number of blows in the Marshall test is an arbitrary one if there is no prior knowledge of the degree of secondary compaction that will occur under traffic.

In the laboratory, samples of an AC wearing course were subjected to 75, 120, 300 and 600 blow Marshall compaction and also to refusal compaction using an electric vibrating hammer. The vibrating hammer test is based on an extended form of the compaction procedure used in the Percentage Refusal Density (PRD) test (BSI, 1989) and is discussed more fully in Section 5 of this paper.

Figure 3 shows the relationship between VIM and bitumen content for the selected levels of compaction. The results demonstrate that the use of 75 blow compaction for design, when secondary compaction in the road is better represented by 300 blow compaction, will probably result in plastic
deformation. This is because at 75 blow compaction, 3% air voids is obtained at a bitumen content of approximately 4.7%. If secondary compaction is indeed equivalent to 300 blows in the Marshall test then the resulting air voids at a bitumen content of 4.7% will be reduced to approximately 1.8%, i.e. considerably less than the 3% criterion.

The refusal density obtained in the vibrating hammer test could be adopted as a 'reference density'. This is because a mix which is capable of retaining 3% air voids at this reference density cannot undergo a further reduction of air voids to below 3% under secondary compaction since it is unlikely that the vibrating hammer produces a density which is significantly less than the absolute maximum that can be achieved.

4.2 Bituminous surfacings for severely loaded sites

The capacity of a given graded aggregate to carry bitumen is controlled by the VMA after compaction. The effect of VMA on the relationship between VIM and bitumen content when subjected to compaction to refusal is shown in Figure 4 for six mixes with different aggregate gradings.

The mix which had VMA of only 9.9%, can only carry 3% bitumen if it is to retain 3% air voids at refusal density. This mix was typical of a wearing course material and would be too stiff to be workable during construction. As the VMA at refusal density increases so the bitumen content, which can be carried without reducing VIM to less than 3%, also increases. With information such as that shown in Figure 4 it is possible to choose an aggregate grading which simultaneously meets the requirements of
sufficient bitumen for good workability during construction and sufficient voids to maintain a value of VIM of 3% at refusal density.

For severe sites, the basecourse specifications given in Overseas Road Note 31, (Transport Research Laboratory, 1993) are likely to produce the most appropriate mix. The aggregate grading of these materials are summarised in Table 1.

Ensuring that the composition of a mix is correct and that the VIM value will not fall below 3% is a vital part of the design process. However, the degree of aggregate interlock and friction between particles also has an important bearing on the resistance to shear failure of a bituminous mix. Uncrushed rounded gravel could meet the minimum VIM requirement when compacted to refusal in a mould, but aggregate interlock is unlikely to be sufficient to prevent shear failure under heavy traffic. Additional tests are therefore required to determine the likely performance of asphalt surfacings under heavy traffic. Such tests can include:

(a) determinations of mix stiffness moduli; and

(b) wheel tracking rates at temperatures of 45°C and 60°C.

Many developing countries do not have the facilities for such performance testing but do have considerable experience of the performance of materials designed by the Marshall method. It is therefore recommended that in these cases the normal Marshall design procedure (Asphalt Institute, 1994), using 75 blows on each face, should be completed first to ensure the normal Marshall design parameters can be met. This, together
with past experience is likely to ensure that the aggregate being used will be satisfactory in terms of having good particle interlock.

Table 1 Basecourse grading

<table>
<thead>
<tr>
<th>BS test Sieve (mm)</th>
<th>Asphalt Concrete</th>
<th>Dense Bitumen Macadam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent by mass passing sieve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>80-100</td>
<td>95-100</td>
</tr>
<tr>
<td>14</td>
<td>60-80</td>
<td>65-85</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>52-72</td>
</tr>
<tr>
<td>6.3</td>
<td>-</td>
<td>39-55</td>
</tr>
<tr>
<td>5</td>
<td>36-56</td>
<td>-</td>
</tr>
<tr>
<td>3.35</td>
<td>-</td>
<td>32-46</td>
</tr>
<tr>
<td>2.36</td>
<td>28-44</td>
<td>-</td>
</tr>
<tr>
<td>1.18</td>
<td>20-34</td>
<td>-</td>
</tr>
<tr>
<td>0.6</td>
<td>15-27</td>
<td>-</td>
</tr>
<tr>
<td>0.3</td>
<td>10-20</td>
<td>7-21</td>
</tr>
<tr>
<td>0.15</td>
<td>5-13</td>
<td>-</td>
</tr>
<tr>
<td>0.075</td>
<td>2-6</td>
<td>2-8</td>
</tr>
<tr>
<td>Bitumen grade (pen)</td>
<td>80/100 or 60/70</td>
<td>80/100 or 60/70&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Bitumen content (%)</td>
<td>4.8 - 6.1&lt;sup&gt;2&lt;/sup&gt;</td>
<td>5.0 ± 0.5&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Notes 1. 60/70 is preferred
2. Determined by Marshall design method

5 REFUSAL DENSITY DESIGN FOR SEVERELY LOADED SITES

Some authorities have adopted a procedure using increased numbers of blows of the Marshall hammer to design surfacings which will retain a required minimum level of VIM after compaction by traffic. An alternative is to use the vibrating hammer as described above. Neither of these methods
exactly reproduces the mode of compaction which occurs under heavy traffic. However, the latter procedure is preferred because it allows a degree of kneading of the mix which is more representative of field compaction and it is a much quicker.

After the Marshall design binder content, for 75 blow compaction, has been determined samples are made with bitumen contents decreasing in 0.5% increments from the design value. These samples are then subject to vibratory compaction to establish the bitumen content at which 3% VIM is retained at refusal density.

5.1 Vibrating hammer compaction

The equipment and the method of compaction used in the vibrating hammer test procedure are in accordance with the PRD test (BSI, 1989). The sample is compacted in a 152-153mm diameter mould to approximately the same thickness as will be laid on the road. Two tamping feet are used, having diameters of 102mm and 146mm.

The small tamping foot is used for most of the compaction sequence, which involves moving the foot from position to position to cover the whole of the surface of the sample. At each position compaction should continue for between 2 and 10 seconds, the limiting factor being that the material should not be allowed to 'push up' around the compaction foot. The compaction sequence is continued for a total of 2 minutes ± 5 seconds. The large tamping foot is then used to smooth the surface of the sample.
Irrespective of layer thickness, a spare base-plate should be used to so that the mould can be inverted. The sample is forced to the new base plate with the large tamping foot and the compaction sequence repeated to ensure that refusal density is achieved.

To ensure that the reference refusal density is obtained in thick layers, it may be necessary to repeat this procedure a second time. It is suggested that trial mixes with a bitumen content which corresponds to approximately 6% VIM in the Marshall test are used to:

(a) determine the mass of material required to give a compacted thickness of approximately the same thickness as for the layer on the road; and

(b) determine the number of compaction cycles which will ensure that the reference refusal density is achieved.

5.2 Transfer of laboratory design to compaction trials

After the standard PRD cycle, samples of basecourse which have been compacted from the loose state can be expected to have densities between 1.5% and 3% lower than for the same material compacted in the road and then cored out and subjected to the PRD test. This is an indication of the effect of the different compaction regime and is caused by a different resultant orientation of the particles. The differences between the densities for laboratory compaction and field samples after refusal compaction should be measured to confirm whether this difference occurs.
A minimum of three trial lengths should be constructed with bitumen contents at the laboratory optimum for refusal density (3% VIM) and at 0.5% above and below the optimum. The trials should be used to:

(a) determine the rolling pattern required to obtain a satisfactory density;

(b) establish that the mix has satisfactory workability to allow a minimum of 93% of PRD (standard compaction (BSI, 1989)) to be achieved after rolling; and

(c) obtain cores so that the maximum binder content which allows 3% VIM to be retained at refusal density can be confirmed.

For a given level of compaction in the Marshall test, VMA reduces to a minimum and then increases as bitumen content is increased. However, samples compacted to refusal density will have sensibly constant values of VMA over a range of bitumen contents before the aggregate structure begins to become 'over filled' and VMA increases. This means that during the trials it will be a relatively simple matter to determine the sensitivity of the mix to variations in bitumen content and to confirm the bitumen content required to give a minimum of 3% VIM at refusal density. If necessary the aggregate grading can be adjusted to increase VMA which will reduce the sensitivity of the mix to changes in bitumen content.

A minimum of 93% and a mean value of 95% of the standard PRD density is recommended as the specification for field compaction of the layer. From these trials and the results of the laboratory tests, it is then possible to establish a job mix formula. After this initial work, subsequent compliance
testing based on analysis of mix composition and refusal density should be quick, especially if field compaction is monitored with a nuclear density gauge. This initial procedure is time consuming, but is justified by the long term savings that can be made by extending pavement service life and minimising eventual rehabilitation costs.

*It is essential* to seal mixes designed by this method with a surface dressing. This greatly reduces the risk of premature 'top down' cracking associated with bitumen age hardening (Rolt et al, 1986)(Smith et al, 1990). This is important not only during the period when secondary compaction occurs in the wheelpaths but also for long term protection of those areas which will not be trafficked and which are likely to retain air voids above 5%.

### 6 SUMMARY

Research has shown that the risk of plastic deformation in asphalt concrete surfacings on severely loaded sites can be minimised if VfM of at least 3% can be retained after secondary compaction by traffic.

A methodology which combines two standard test procedures has been proposed for the design of bituminous surfacings for such sites in developing countries with tropical environments and where, as is commonly the case, equipment for mix design is limited. Whilst the procedure described will bring immediate benefit to many road projects, improvements in the methodology can be expected with the further introduction of suitable laboratory mix performance tests.
7 REFERENCES


OECD (1975). Resistance of flexible pavements to plastic deformation.


Figure 1 Reduction in VIM in the wheelpath ACWC designed by Marshall Procedure (75 blows)

Figure 2 Occurrence of plastic deformation in the wheelpath
Figure 3 Relationship between bitumen content and VIM for different levels of compaction of wearing course mix

Figure 4 Relationships between mix properties at refusal density