ABSTRACT

Laboratory investigations of Civil Engineering Material Unit (CEMU) the University of Leeds, UK have shown that recycled plastics composed predominantly of Polyethylene can be incorporated in conventional Asphaltic Concrete (AC), referred to as AC-Plastiphalt, road surfacing mixtures. The durability behaviour, in terms of water susceptibility, behaviour of the mixture results indicated that the AC-Plastiphalt mixes have excellent resistance to water damage. Age hardening of the bitumen in the bituminous mixture is another factor affecting the durability behaviour of the mixture. Ageing of bituminous mixtures is of increasing concern in the maintenance of flexible pavements. This process is due to factors such as volatilisation, oxidation and hardening of the bitumen in the mixture.

Age hardening of the bitumen in the bituminous mixture is another factor affecting the durability behaviour of the mixture. Ageing of bituminous mixtures is of increasing concern in the maintenance of flexible pavements. This process is due to factors such as volatilisation, oxidation and hardening of the bitumen in the mixture. This paper presents the durability behaviour of the AC-Plastiphalt mixes, especially on the ageing behaviour. Due to the fact that ageing test methods for bituminous mixtures have not yet been standardised, the Strategic Highway Research Program (SHRP) methodology, as set in project A-005A (conducted at Oregon State University) for oven ageing was adopted in this investigation. Two over-ageing methods were introduced in SHRP, i.e. short-term oven ageing (STOA) and long-term oven ageing (LTOA).

The laboratory experimental results on short and long-term oven ageing of AC-Plastiphalt mixtures indicated improvement in all strength and stiffness parameters investigated (indicated by >100% retained values) compared to the original mixture. The AC-Plastiphalt mixture is highly capable of dealing with the mixture ageing process not only during construction but also after 10 years services.

INTRODUCTION

Ageing of bituminous mixtures is of increasing concern in the maintenance of flexible pavements. This process is due to factors such as volatilisation, oxidation and hardening of the bitumen in the mixture. Ageing results in an increase in the elastic modulus and brittleness of the bituminous mixture. Although the increase in elastic modulus can improve the load distribution system of the pavement structure, the increase in brittleness as a result of excessive hardening often leads to pavement cracking and loss of durability in terms of water resistance and moisture susceptibility [Li et al., 1995].

Due to the fact that ageing test methods for bituminous mixtures have not yet been standardised, the Strategic Highway Research Program (SHRP) methodology, as set in project A-005A (conducted at Oregon State University) for oven ageing was adopted in this investigation. Two over-ageing methods were introduced in SHRP, i.e. short-term oven ageing (STOA) and long-term oven ageing (LTOA).

The STOA method is designed to simulate the ageing of the mixture during the construction process: mixing, transporting, spreading and compaction. The LTOA method is conducted to simulate the ageing of the mixture in service. Several durations of LTOA were introduced depending on the service time expected for the bituminous mixture. A 2-day oven ageing regime appears representative of young project of up to 5 years old in service and an ageing period of 4 or 5 days is to simulate the ageing process for 10 years old projects.

Several tests were conducted in this investigation to evaluate the effect of ageing on the Plastiphalt mixture. The ideal test procedure would be non-destructive, such as the indirect tensile stiffness modulus test, so that before and after tests can be performed on the same specimen. However, in this study additional tests were also performed, including Marshall stability and flow, and indirect tensile strength tests.

This paper presents a laboratory design methodology and durability results especially in ageing of plastic modified bituminous mixtures. The mix was a continuously graded bituminous composite (Asphaltic Concrete) contained recycled plastics aggregate replacement (referred to as AC-Plastiphalt). The test results of plastic modified mix was compared with a control mix having a very similar gradation manufactured with conventional mineral aggregates.

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DURABILITY OF PAVING MIXTURES

In terms of its application to bituminous paving materials, durability can be defined as the ability of the materials in the asphalt pavement structure to withstand the effects of environmental conditions, such as water, aging and temperature variations without any significant deterioration for an extended period for a given amount of traffic loading (Scholtz and Brown, 1996). Durability of bituminous mixtures must be taken into account, as the costs of maintenance and rehabilitation of pavement structures that do not endure their design life can be substantial.

a. Factors affecting durability of pavement mixtures

Many factors affect the durability of bituminous mixtures for instance the composition of the bitumen, the type and grading of the aggregate, the interaction between aggregate and bitumen, bitumen content, mixture permeability, construction practices and climate. By assuming that bituminous pavement layer is constructed perfectly according to specifications, then based on the above definition, three major factors will affect the durability of bituminous paving mixtures, i.e. water, aging and temperature variations. However, it is generally agreed that damage due to water (moisture damage) and age hardening are the major factors affecting the embrittlement of bitumen.

Age hardening of the bitumen also affects the durability of the bitumen-aggregate matrix. This behaviour is presented in this paper.

b. Age hardening of bituminous paving mixtures

Kliewer et al. [1995] studied the relationship between field performance and laboratory aging properties of asphalt mixtures. Short-term and long-term aging methods developed by the Strategic Highway Research Program (SHRP) Project A-003A were applied in their investigation. The recommended laboratory procedure for short-term aging is to heat the loose mixture in an oven for 4 hours at a temperature of 135°C. The short-term oven aging (STOA) procedure simulates the aging of the asphalt mixture during the construction process. The recommended laboratory procedure for long-term aging (LTOA) is to heat the compacted specimen in an oven at 85°C. This LTOA procedure is designed to simulate the aging of the bituminous mixtures during service. A 2-day aging period represents the aging of 5 years old pavement layers. An aging period of 4 or 5 days is recommended to simulate a 10 years old pavement. Other long term aging methods were also performed i.e. low-pressure oxidation (LPO) which was carried out by passing oxygen through the compacted specimens at a pre-selected temperature while confined in a triaxial cell.

The laboratory work investigated 32 mixture combinations resulting from eight different bitumen types and four different aggregate types. The compacted specimens were manufactured with a target air voids content of 8±1 percent. All mixtures were first short-term aged using the STOA procedure. Four different long-term ageing procedures were then examined on these specimens, LTOA at 85°C for five days, LTOA at 135°C for five days and LTOA at 100°C for two days.

The field validation programme was conducted on selected road projects that represented ‘new’, ‘young’ and ‘old’ pavement sites and a range of climatic regions. The specimens taken from the new site were used to validate STOA and these laboratory specimens were subjected to 0, 4 and 8 hours STOA. The specimens taken from young and old site were used to validate LTOA and all laboratory specimens were subjected to four hours of STOA at 135°C and the long term aging was then conducted at either 85°C for 0, 2, 4 or 8 days or at 100°C for 0, 1, 2 and 4 days.

Aged specimens were subsequently tested for indirect tensile resilient modulus. Some results found that the aging of bitumen-aggregate mixture (as measured by the change in resilient modulus) is influenced by both the bitumen and aggregate components. Aged bitumen alone does not appear to be an adequate means of predicting mixture performance especially on ageing. The influence of the aggregate on mixture ageing appears to be related to the chemical interaction of the aggregate and bitumen. This interaction may be related to adhesion; greater adhesion resulting in reduced aging. For the new and young field sites, 4 hours of oven aging at 135°C was representative of the short term aging which occurs in the field during the construction process. 100°C oven aging for 1, 2 and 4 days achieved similar stiffness to 85°C oven aging for 2, 4 and 8 days respectively but the samples were found to be damage in the process. Long term aging at 135°C was considered to be more reliable to express the long-term aging in the field.

The effect of bitumen modifiers on the long-term ageing characteristics of bituminous mixtures has been investigated by Huang et al. [1995]. Six types of bitumen modifiers including pumicite, carbon black, fine ground tyre rubber, styrene-butylene-rubber (SBR), ethylene vinyl acetate (EVA), and styrene-ethylene-butylene-styrene (SEBS) were used in this investigation. These modifiers were blended with three different types of bitumen (AC-30, AC-20 and
AC-5) to produce ten modified bitumens. The ageing method applied in this study was to store the compacted modified and unmodified asphaltic concrete mixtures in a forced-draft oven at 60°C for 90 days and under natural sunlight for six months. These specimens were then evaluated by resilient modulus tests (ASTM D-4123) and indirect tensile tests at 5°C and 25°C.

The results indicated that the modified bituminous mixtures have more pronounced delayed elastic behavior compared to the unmodified mixtures. The rate of age-hardening (characterized by the mean of the ratio of the resilient modulus after and before ageing process) of open graded mixtures was lower than that of the dense graded mixtures. This indicates that the aggregategradation along with proper mix design play an important role on the pavement age-hardening.

On the basis of the ratio of the resilient modulus values at 25°C, all the modified open graded bituminous mixtures, with the exception of mixtures containing EVA and SEBS, demonstrated slower rate of age-hardening compared to the unmodified mixtures.

In terms of cracking potential, with the exception of the mixtures containing EVA and SEBS modified AC-5 bitumens, the modified bitumen mixtures showed higher failure strains than the conventional AC-30 bitumen mixtures. This indicates that, the combination between proper modified binders and proper aggregate type and gradation could retard the hardening process of bituminous mixtures.

The rate of age-hardening as evaluated by means of the ratios of indirect tensile strength values at temperature of 25°C of open-graded asphalt mixtures was slightly slower compared to the dense graded mixtures. All the modifiers mentioned earlier have the potential to slow down the rate of age-hardening of conventional bituminous mixtures.

**RESEARCH METHODS**

**Materials Used and Specimen Manufacturing**

Figure 1 shows the aggregate gradation of the control and Plastiphalt dense graded Asphaltic Concrete (A.C.) mixtures. The A.C. gradation was developed at Leeds (Zoorob et al., 1999) using maximum aggregate packing principles and is specifically designed to withstand combinations of heavy traffic stresses at elevated temperatures.

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**Figure 1** - Aggregate gradations used in this investigation
The plastic pellets, used in the AC-Plastiphalt mix were predominantly composed of low density polyethylene (LDPE) of single size (5.0-2.36 mm). Table 1 shows the characteristics of the bitumens and waste LDPE plastic pellets used in this investigation.

<table>
<thead>
<tr>
<th>Test description</th>
<th>Bitumen types</th>
<th>Waste LDPE plastic pellets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50-pen</td>
<td>100-pen</td>
</tr>
<tr>
<td>1. Penetration at 25 °C (mm)</td>
<td>54</td>
<td>98</td>
</tr>
<tr>
<td>2. Specific gravity</td>
<td>1.03</td>
<td>1.02</td>
</tr>
<tr>
<td>3. Softening point (°C)</td>
<td>48.5</td>
<td>47</td>
</tr>
<tr>
<td>4. Melting point (°C)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

It was decided in this investigation to replace by volume the mineral aggregate fraction having the same size as the plastic granules in the original AC mixes with LDPE pellets. The aggregate gradation of the resultant Plastiphalt mixes was therefore very similar in terms of volumetric proportions to the original control mixes. Based on the selected gradings and the size of the waste plastic granules; a maximum of 29.7% by volume of the total AC-control mix was replaced with waste LDPE plastics to create the AC-Plastiphalt mixes.

The Leeds Design Method (Cabrera, 1996) was then used to obtain the optimum bitumen content (o.b.c.) of the design mixture. At o.b.c., further investigations and tests were carried out to fully characterise the properties of the design mixture. The mixing and compaction temperatures need to be carefully controlled to cater for the differing softening points of the two plastic types.

The o.b.c for the AC-Control mix was calculated at 5.0% which agrees with previous investigations (Zoorob et al., 1999), whilst the o.b.c for AC-Plastiphalt mix was determined at 6.0% (Zoorob and Suparwa, 2000).

Laboratory test procedures for ageing

In this paper presents two types of laboratory test for ageing bituminous mixture. These two methods referred to as:

a. SHRP short-term oven ageing (STOA) method

The procedure for this method is as follows:

1) A predetermined quantity of mineral aggregates, bitumen and waste plastics materials are combined and mixed following the same procedure as that adopted for manufacturing compacted specimens. The loose bitumen coated mixture is spread evenly in a pan at a rate of approximately 21-22 kg/m².

2) In the short-term oven ageing procedure, the loose bituminous mixture is subjected to a four-hour curing period in a force draft oven at 135°C prior to compaction.

3) The loose bituminous mixture is stirred and turned once an hour to ensure uniform ageing throughout the mixture.

4) After the short-term oven ageing process, the loose bituminous mixtures are brought to the compaction temperature and compacted using a Gyratory at the correct compactive effort.

In this investigation, the compacted specimens, with the exception of the specimens which would be further subjected to long-term oven ageing, were subsequently tested for Marshall stability and flow, indirect tensile stiffness modulus, and indirect tensile strength tests.

b. SHRP long term oven ageing (LT OA) method

1) This procedure is carried out on compacted specimens that have already undergone the short-term oven ageing procedure.

2) Compacted specimens are placed in a force draft oven at 85°C for 240 hours (5 days).

3) At the end of the ageing period, the oven is switched off and left to cool to room temperature before removing the specimens. The specimens are not tested until at least 24 hours after removal from the oven.

4) In this investigation the specimens were subsequently tested for Marshall stability and flow, indirect tensile stiffness modulus, and indirect tensile strength tests.

RESULTS AND DISCUSSIONS

The laboratory results of the mixture characteristics of short and long-term oven ageing of AC-Plastiphalt mixtures are presented in Table 2.

Table 2 presents the properties of the AC-Plastiphalt mixture after being subjected to short and long-term oven ageing compared to the properties of the original mixture. The results presented in this table indicate that in almost every parameter investigated the retained values were found to be better (indicated by >100% retained values) than the control mix. The bitumen ageing during construction process, indicated by the results from the STOA process, of the AC-Plastiphalt mixes influenced on the flow values. This result indicated that the permanent deformation of the mixture has already occurred since the construction process. This phenomenon
The presence of plastic material in the mixture affected on the maintaining the mixture strength not only during construction but also until the end of service life. These behaviours are indicated by higher retained values in Marshall stability, ITSM and tensile strength ratio.

The ageing process in this investigation results in an increase in the elastic modulus of the AC-Plasticphalt mixture; however, the brittleness of this mixture, can be indicated by tensile strength values, is maintained by the presence of plastic material incorporated in the mixture. The increase of elastic modulus can improve the load distribution system of the pavement structure and the decrease of brittleness prevents the AC-Plasticphalt mixture from pavement cracking and loss of durability in terms of water resistance and moisture susceptibility. This result shows contrary with the argument before that the ageing can increase the brittleness of the pavement mixture [Li et al., 1995] due to the incorporation of the plastic material as an aggregate replacement.

Table 2 - STOA and LTOA characteristic values of AC-Plasticphalt mixtures

<table>
<thead>
<tr>
<th>Properties</th>
<th>Unconditioned (original)</th>
<th>STOA</th>
<th>LTOA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value</td>
<td>% retained</td>
<td>Value</td>
</tr>
<tr>
<td>1. Marshall Stability (KN)</td>
<td>37.3</td>
<td>37.49</td>
<td>100 (100.4)%</td>
</tr>
<tr>
<td>2. Marshall flow (mm)</td>
<td>7.3</td>
<td>8.00</td>
<td>higher</td>
</tr>
<tr>
<td>3. Marshall Quotient (KN/mm)</td>
<td>5.1</td>
<td>4.7</td>
<td>lower</td>
</tr>
<tr>
<td>3. ITSM (MPa) at:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. 20°C</td>
<td>2815</td>
<td>410</td>
<td>&gt;100 (1.46)%</td>
</tr>
<tr>
<td>b. 40°C</td>
<td>770</td>
<td>1727</td>
<td>&gt;100 (2.24)%</td>
</tr>
<tr>
<td>c. 60°C</td>
<td>235</td>
<td>424</td>
<td>&gt;100 (1.81)%</td>
</tr>
<tr>
<td>4. Static ITS (kPa) at:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. 20°C</td>
<td>1508</td>
<td>1486</td>
<td>99</td>
</tr>
<tr>
<td>b. 40°C</td>
<td>796</td>
<td>699</td>
<td>99</td>
</tr>
<tr>
<td>c. 60°C</td>
<td>318</td>
<td>548</td>
<td>&gt;100</td>
</tr>
</tbody>
</table>

* the value in the bracket indicates the actual value of percentage retained Marshall stability of the mixture
* the value in the bracket indicates the ITSM ratio value of the mixture

Overall, according to the results presented in Table 2, it can be summarised that the AC-Plasticphalt mixture is highly capable of dealing with the mixture ageing process not only during construction but also after 10 years servicing.

CONCLUSIONS
1. Short and long-term oven ageing of AC-Plasticphalt mixture indicated improvement in all strength and stiffness parameters investigated (indicated by >100% retained values) compared to the original mixture.
2. Due to the incorporation of plastic material in the mixture, the ageing processes affected in an increase of the mixture stiffness and decrease the brittleness of the mixture.
3. AC-Plasticphalt mixture is highly capable of dealing with the mixture ageing process not only during construction but also after 16 years of serving.

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