Investigation of the Permanent Deformation Characteristics of Overlaid Pavement Incorporating Stress Absorbing Membrane Interlayers

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Abstract: This study was carried out to evaluate the resistance of overlaid pavement incorporating stress absorbing membrane interlayers to permanent deformation. In this study, the permanent deformation of the interlayer mixtures was determined using the RLAT (repeated load axial test) carried out in the Nottingham Asphalt Tester. Also, a test pavement was constructed in the laboratory to assess the resistance to permanent deformation of overlaid pavement incorporating SAMIs (stress absorbing membrane interlayers). The test pavement was divided into two along the centre line. Each of the divisions has three sections—two having SAMIs and one without SAMIs. The pavement was instrumented and trafficked. Trafficking was stopped when the pavement was deemed to have failed. The results showed that the measured permanent deformation values of the control sections were less than the sections having SAMIs. The increased permanent deformation values indicate that the introduction of SAMIs causes more vertical/horizontal deformation of the pavement. It was also found that the permanent deformation values varied depending on the composition and thickness of the SAMIs.

Key words: Permanent deformation, pavement, cracks, trafficking, SAMIs, overlaid pavement.

1. Introduction

Pavements are rehabilitated by overlaying with new surfacing material because of distresses in the existing pavement. Distress may occur in the pavement during construction and while in service. It may be due to the materials used for pavement construction, poor workmanship, environmental factors or the loading to which they are subjected. The two principal modes of failure in pavements are fatigue cracking and permanent deformation. Engineers seek to hold these forms of failure to acceptable limits within a pavement design life. Another mode of failure, which has not been given much attention and is not considered in most pavement design approaches, is reflective cracking. This form of failure occurs when

pavements with critical level of serviceability are rehabilitated by overlaying. Reflective cracking is now a major concern to pavement engineers and attempts are being made to solve the problem. Mallick and El-Korchi [1] described reflective cracking as cracks in asphalt overlays caused by discontinuities in the pavement structure underneath. Cleveland et al. [2] defined it as the propagation of cracks from the movement of the underlying pavement or base course into and through the new overlay as a result of load-induced and/or temperature induced stresses. Penman and Hook [3] put it as the process by which an existing crack, joint or discontinuity propagates towards the surface through an overlying layer of asphalt concrete, with the rate of propagation varying significantly based on various environmental and trafficking factors. In summary, reflective cracking can simply be defined

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2 Investigation of the Permanent Deformation Characteristics of Overlaid Pavement Incorporating Stress Absorbing Membrane Interlayers

as the propagation of existing cracks in an old pavement through the underside of the overlay to the surface.

Various measures are used to reduce or retard reflective cracking in rehabilitated pavements. One of these involves the use of soft interlayer between the old and the new surfacing. These interlayers are called SAMIs (stress absorbing membrane interlayers). A typical example of the SAMIs is the sand asphalt. They are designed to dissipate energy by deforming horizontally or vertically, therefore allowing the movement (vertical/horizontal) of the underlying pavement layers without causing large tensile stresses in the asphalt overlay. Barksdale [4] defined a stress-relieving interlayer as a soft layer that is usually thin and is placed at or near the bottom of the overlay. He stated further that the purpose of the soft layer is to reduce the tensile stress in the overlay in the vicinity of the crack in the underlying old layer and hence “absorb” stress. The major concern in the use of stress absorbing membrane interlayers is permanent deformation. Permanent deformation or rutting is the depression along the wheel path. This is caused by gradual build up of irrecoverable strains under repeated loading which develop into a measurable rut. These strains are due to the visco-elastic response of bituminous materials to dynamic loading. Also, rutting may occur because of base, subbase or subgrade failure. It is usually measured with a profiler or straight edge. The introduction of the soft interlayers between the overlay and the existing pavement reduces the bending stiffness of the pavement. This increases the susceptibility of the pavement to permanent deformation.

This study looks at the resistance of rehabilitated pavements incorporating stress absorbing membrane interlayers to permanent deformation. This was achieved using the RLAT (repeated load axial test) and accelerated pavement testing.

2. Materials and Methods

2.1 Materials

The materials used for the study are grouped into two: materials for stress absorbing membrane interlayers and those for the pavement constructed in the PTF (pavement test facility) for accelerated pavement testing.

2.1.1 Stress Absorbing Membrane Interlayers

The SAMIs considered in the study are Sand Asphalts 1, 2 and 3 and SAMIs 1 and 2. The mix compositions of Sand Asphalt 1, Sand Asphalt 2 and Sand Asphalt 3 are shown in Table 1. The particle size distribution curves of the aggregates blend for each of the sand asphalts determined in accordance with BS (British Standard) 1377-2, 1990 [5] are shown in Fig. 1. The other two SAMIs used in the study are chopped-glass fibres impregnated with bitumen emulsion called SAMIs 1 and 2. The materials for SAMIs 1 and 2 are glass fibres, ordinary bitumen emulsion, polymer modified bitumen emulsion and 6 mm single-sized aggregates.

The ITSM (indirect tensile stiffness modulus) test was performed on Sand Asphalts 1, 2 and 3 in accordance with DD (draft for development) 213, 1993 [6]. The test could not be performed on SAMIs 1 and 2 because of non-compatibility of their compositions and the ITSM procedure. In the ITSM, a load pulse is applied to the vertical diameter of the specimen positioned centrally between the upper and the lower platens and the resultant peak transient deformation along the horizontal diameter is measured. The method uses cylindrical specimens cored from the field or slabs in the laboratory. The cores are 100 mm in diameter, have thickness of 40 mm. The target rise time and the mean horizontal deformation were 124 ± 4 ms and 5 ± 2 μ m, respectively. The stiffness of the mixtures at 20 °C is shown in Table 2. The viscosity test was carried out on the bitumen emulsion and polymer modified bitumen emulsion used in SAMIs 1 and 2, respectively. The results are shown in Table 3.

Table 1 Mix composition for Sand Asphalts 1, 2 and 3.

Sample type	% by composition of aggregate		
	Sand Asphalt 1	Sand Asphalt 2	Sand Asphalt 3
0/4 crushed rock fill	95%	74.50%	-
Fine sand	-	20%	84%
Filler	5%	5.50%	16%
Binder type	Polymer modified binder	Polymer modified binder	160/220 bitumen
Binder content	9% by mass of total mix	9.1% by mass of total mix	10.3% by mass of total mix
Target air void	2%	2%	5%

Fig. 1 Particle size distribution for the blends of aggregates for the sand asphalts.**Table 2** Stiffness of mixtures at 20 °C.

Mixture type	Stiffness (MPa) at 20 °C												Average
Sand Asphalt 1	2,588	2,746	2,843	2,951	2,747	2,723	2,724	2,697	2,889	2,381	2,675	2,739	2,725
Sand Asphalt 2	2,773	2,479	2,298	2,364	2,280	2,335	2,497	2,447	2,332	2,521	2,508	2,490	2,444
Sand Asphalt 3	220	198	222	236	191	185	195	213	203	235	183	225	209

Table 3 Viscosity test results.

Bitumen emulsion	Viscosity (Pa·s) @ 25 °C	Viscosity (Pa·s) @ 30 °C	Viscosity (Pa·s) @ 40 °C
Ordinary bitumen emulsion	0.7	0.58	0.39
Polymer modified bitumen emulsions	0.184	0.194	0.18

Also, ITFT (indirect tensile fatigue test) was carried out on the sand asphalts but the test could not be performed on both SAMIs 1 and 2. The test involves applying a repeated diametrical line loading along the vertical diameter of the cylindrical specimen. This produces an indirect tensile stress on the horizontal diameter. The magnitudes of the stresses vary along the diameter but are at the maximum at the centre of the specimen. For this study, the test conditions were as follows: target rise time of 124 ± 4 ms; stress level from 225-600 kPa and temperature of 20 °C. The result is expressed as a relationship between tensile microstrain and the number of cycles to failure. The

test was carried out in accordance with DD ABF, 1993 [7].

Fig. 2 shows the fatigue lines of Sand Asphalts 1, 2 and 3. The empirical relationship used for regression analysis is as shown in Eq. (1) [8]. Table 4 shows the material constants, the *R*-square and fatigue lives at 200 microstrain of the fatigue lines. Read [9] stated that fatigue failure normally occurs at 30-200 microstrain. The fatigue lives of the mixtures were compared at 200 microstrain (Table 4). It can be seen that Sand Asphalt 2 has fatigue life more than twice that of Sand Asphalt 1, while Sand Asphalt 3 has the least fatigue life. This was due to the 20 % of sand in

4 Investigation of the Permanent Deformation Characteristics of Overlaid Pavement Incorporating Stress Absorbing Membrane Interlayers

Fig. 2 Fatigue lines of the sand asphalts.

Table 4 The material constants and the *R*-square and fatigue life at 200 microstrain.

Mixture	k_1	k_2	<i>R</i> -square	Fatigue life at 200 microstrain
Sand Asphalt 1	8.00E+06	-1.498	0.7898	13,593
Sand Asphalt 2	2.00E+11	-3.115	0.8937	33,920
Sand Asphalt 3	2.00E+12	-3.377	0.9589	2,859

Table 5 CBR and stiffness of subgrade and subbase.

Sections	Subgrade		Subbase	
	CBR (%)	Stiffness (MPa)	CBR (%)	Stiffness (MPa)
1	1	17.6	14	96.29
2	2	27.4	16	103.79
3	2	27.4	15	99.59
4	1	17.6	21	123.52
5	2	27.4	17	107.89
6	1	17.6	17	107.89
Average	1.5	22.5	17	106.00

the Sand Asphalt 2. As observed by Dukatz [10], the aggregate shape, morphology, gradation and strength have a major effect on fatigue. Generally, the results show that unlike the Sand Asphalt 3, Sand Asphalts 1 and 2 have good fatigue properties.

$$N_f = k_1 (\varepsilon_i)^{k_2} \quad (1)$$

where, N_f is the number of load applications to failure; ε_i is the initial strain and k_1 and k_2 are the material coefficients.

2.1.2 Accelerated Pavement Testing

The materials used for the construction of the pavement were clay subgrade, crushed rock subbase material, Sand Asphalt 1, SAMIs 1 and 2 and 10 mm asphalt concrete with 40/60 penetration grade bitumen for the base and surface layers (overlay). The strength

of the subgrade and subbase layers was determined using the DCP (dynamic cone penetrometer). The CBR (California bearing ratio) was determined from the DCP data using the software UK DCP version 3.1 described by Done and Piouslin [11]. Also, the approximate stiffness of the sections was calculated from Eq. (2) reported by Powell et al. [12]. The CBR and the stiffness values are shown in Table 5. The subgrade has average CBR and stiffness of 1.5% and 22.5 MPa, respectively, while the subbase has average CBR and stiffness of 17% and 106 MPa, respectively.

$$E = 17.6 \text{ CBR}^{0.64} \quad (2)$$

The base and the surface layers as earlier stated were made of 10 mm asphalt concrete with 40/60 penetration grade bitumen. Specimens for testing were

prepared by reheating some of the asphalt and compacting at 130 °C into a 305 mm × 305 mm × 130 mm mould to a thickness of 60 mm using a roller compactor. Five cores of diameter 100 mm and trimmed thickness 40 mm were cored from each slab. The ITSM test and ITFT were carried out as earlier described. The ITSM results at 20 °C are shown in Table 6. The fatigue line of the mixture is shown in Fig. 3. The results show clearly that the stiffness and resistance to fatigue of the asphalt concrete to be used in the pavement testing facility are adequate, thus eliminating the concern that may arise from poor asphalt properties, making it difficult to measure the permanent deformation performance of the SAMIs in the accelerated pavement testing.

2.2 Methods

The objectives of this study were achieved by carrying out repeated load axial test on Sand Asphalts 1, 2 and 3 and accelerated pavement testing on pavement incorporating two different thicknesses of Sand Asphalt 1 and SAMIs 1 and 2. This was used to investigate their performance against permanent deformation. The RLAT test could not be performed on both SAMIs 1 and 2 because of the non compatibility of the SAMIs composition and the RLAT test procedure. Also, only Sand Asphalt 1 and SAMIs 1 and 2 were considered in the accelerated pavement testing due to limited resources.

2.2.1 Repeated Load Axial Test

The test was developed at the University of

Nottingham to measure the permanent deformation of bituminous mixtures. The test configuration is shown in Fig. 4. The test samples were cores of 40 mm thickness and 100 mm diameter. The specimens were conditioned to ensure that the loading plates are properly seated before testing commenced. The conditioning was achieved by applying a static stress of 10 kPa on the specimen for 10 min. Then, a 100 kPa axial stress was applied in 1 s square wave pulses with 1 s rest periods. The test was repeated for 1,800 load cycles at 40 °C lasting a period of 1,800 s. The deformation was monitored by a pair of LVDTs (linear variable differential transformers) mounted on the upper loading plate. The permanent axial deformation is recorded after every 10th load application until the test is completed or stopped. The permanent axial strain is calculated as shown in Eq. (3). The test method is described in DD226, 1996 [13].

$$\varepsilon_p(n, T) = \Delta h / h_o \quad (3)$$

where, $\varepsilon_p(n, T)$ is the permanent axial strain after n load applications at temperature T ; h_o is the original distance between loading surfaces (specimen thickness); Δh is the change in distance between specimen loading surfaces (measures axial permanent deformation).

2.2.2 Accelerated Pavement Testing

The accelerated pavement testing was carried out in the University of Nottingham PTF. The wheel movement

Table 6 Indirect stiffness modulus test results.

Specimens	1	2	3	4	5	Average
ITSM at 20 °C	4,711	4,313	3,574	4,261	4,261	4,224

Fig. 3 Fatigue line of the asphalts.

Fig. 4 Test configuration of RLAT.

is controlled by the hydraulic motor which pulls the cable (steel ropes) in both directions (forward and backward). The PTF pavement has length, width and depth of 5.0 m, 2.4 m and 1.5m, respectively. The stress applied at the surface of the pavement by the tyre is about 600 kPa at 9.6 kN. This is similar to that applied by a tyre of a normal heavy goods vehicle. However, as the total load to be applied during the test is expected to be less than that applied by a real vehicle wheel/axle before failure, the thickness of each layer was scaled down, in order to obtain measurable results within a reasonable number of load applications (accelerated pavement testing).

The existing granular materials in the PTF were removed to the clay subgrade. Crushed rock subbase material was spread and compacted with a vibrating plate in three layers to a thickness of 400 mm. The first and second layers of the subbase were compacted to a thickness of 130 mm, while the third layer was compacted to a thickness of 140 mm. The strength of the prepared granular layer and the subgrade was determined using a dynamic cone penetrometer. 10 mm asphalt concrete with 40/60 penetration grade bitumen supplied was laid and compacted using a pedestrian roller at a thickness of 60 mm. To create the crack, the pavement was divided into six sections, so that there are two wheel paths with three sections each. Transverse cracks were created at the centre of

each section by cutting the full depth of the asphalt concrete (simulating existing pavement). The cut thickness was about 5 mm (thickness of the blade). Also, cracks were created at 200 mm from the end and at the end of each section as shown in Fig. 5.

The SAMI for Sections 1 and 3 was Sand Asphalt 1 compacted to thicknesses of 10 mm and 5 mm, respectively (Fig. 6). The aggregates and binders for Sand Asphalt 1 were batched and heated at a temperature of 180 °C, and compacted at a temperature of 150 °C using a vibrating hammer. The SAMIs for Sections 4 and 6 were bitumen-impregnated glass fibres called SAMIs 1 and 2 (Fig. 6). SAMIs 1 and 2 were prepared by sandwiching 60 mm glass fibre strands between layers of bitumen emulsion, and 6 mm aggregates were compacted on top using a vibrating plate. Ordinary bitumen emulsion and polymer-modified bitumen emulsion were used in SAMIs 1 and 2, respectively. Sections 2 and 5 were given no treatment (control).

The surface layer was made of 10 mm asphalt concrete with 40/60 penetration grade bitumen. The asphalt was compacted using a pedestrian roller. The full opening of cracks (cracks opening and closing as the wheel passes) was chosen as the failure criterion. The wheel path was painted white to monitor the appearance of cracks on the surface layer. The pavement was trafficked using a 9.6 kN wheel load at

Fig. 5 Section showing the sections and cracks (bold lines) created in the base layer.

Fig. 6 Pavement with 10 mm and 5 mm Sand Asphalt 1 and SAMIs 1 and 2.

an average speed of 3 km/h. Initial readings of the transverse profile were recorded. The number of wheel repetitions as the wheel load moves forward and backward was logged with the use of an electronic counter. A digital thermocouple was used to monitor the room temperature during the test. The permanent deformation values for the sections were recorded.

3. Results and Discussions

The average room temperatures in the morning, noon and evening when Wheel Path 1 was trafficked were 24 °C, 27.1 °C and 28.2 °C, respectively, while

for Wheel Path 2 the average morning, noon and evening room temperatures were 22.7 °C, 25.9 °C and 26.9 °C, respectively.

3.1 Repeated Load Axial Test Results

The results of the permanent strain measured from the RLAT are shown in Fig. 7. The results show that the accumulated strain increased rapidly at the start (primary stage) and with an almost linear relationship in log-log space towards the end defining the secondary stage of deformation. The permanent strains at 1,800 cycles are shown in Table 7. It shows

Table 7 Permanent strain at 1,800 load applications.

Materials	Permanent strain (%)
Sand Asphalt 1	1.1274
Sand Asphalt 2	1.5204
Sand Asphalt 3	7.4828

that Sand Asphalt 3 has the highest axial strain which implies poor resistance to permanent deformation. This is because of the bitumen (160/220) and fine sand used in its preparation. Also, it can be seen that Sand Asphalt 1 has a better resistance to permanent deformation than Sand Asphalt 2. This is thought to be because the Sand Asphalt 1 mix does not have fine sand and contains more crushed rock fill than Sand Asphalt 2. Generally, this indicates that, unlike Sand Asphalt 3, Sand Asphalts 1 and 2 might not be susceptible to permanent deformation when used with

overlay to retard reflective cracking. Again, it shows that the materials used in preparing the SAMIs influence their resistance to permanent deformation.

3.2 Permanent Deformation in Accelerated Pavement Testing

The permanent deformation of the pavement was measured after trafficking. That of Wheel Path 1 which consists of Sections 1, 2 and 3 having 10 mm Sand Asphalt 1, no SAMI and 5 mm Sand Asphalt 1 as the SAMI layers was measured after 64,495 wheel load applications, while Wheel Path 2 consisting of Sections 4, 5 and 6 having SAMI 1, no SAMI and SAMI 2 was measured after 61,662 wheel load applications. The rut depths measured at seven points along Wheel Paths 1 and 2 are shown in Figs. 8 and 9,

Fig. 7 Permanent deformation results.

Fig. 8 Permanent deformation for Wheel Path 1.

Fig. 9 Permanent deformation for Wheel Path 2.

respectively. The figures show that the permanent deformation of the control Sections 2 and 5 of both Wheel Paths 1 and 2 is less than their respective test sections with SAMIs (Sections 1, 3, 4 and 6). This agrees with the findings of Elseifi [14] that when a soft interlayer is used, more vertical and horizontal deformations are expected. However, the lives of the test sections (with SAMIs) before the appearance of cracks and to failure were more than the control sections [15, 16]. This shows that despite the section with SAMIs having more permanent deformation, they are able to retard reflective cracking.

It is not reasonable to compare the permanent deformation of the two wheel paths because the room temperatures during trafficking and the number of wheel loads applied to the wheel paths were different. Knowing that deformation of bituminous mixtures is greatly affected by temperature, obviously more deformation is expected in the sections in Wheel Path 1. This proved to be the case as the average deformation of the control (no SAMI) section for Wheel Path 1 was 5.36 mm while that of Wheel Path 2 was 3.36 mm. It can be seen from Fig. 8 that the permanent deformation of Section 3 having 5 mm Sand Asphalt 1 is less than that of Section 1 having 10 mm Sand Asphalt 1. This is because increasing the thickness of the SAMI results in the reduction of the flexural stiffness of the pavement. Also, as shown in Fig. 9, the lower viscosity of the emulsion used in SAMI 2 reflected in the results as Section 4 with

SAMI 1 has significant less permanent deformation than SAMI 2.

The permanent deformation recorded indicates that great importance must be attached to the properties of the SAMIs and the asphalt mix to be used in retarding reflective cracking. The asphalt concrete must have adequate stiffness and good resistance to fatigue and permanent deformation.

4. Conclusions

The RLAT test shows that Sand Asphalt 1 has a better resistance to permanent deformation than Sand Asphalt 2, while Sand Asphalt 3 has poor resistance to deformation. This indicates that Sand Asphalts 1 and 2 might not be susceptible to permanent deformation when used with overlay to retard reflective cracking. This was confirmed by the accelerated pavement testing, which shows that the section having Sand Asphalt 1, although has more permanent deformation than the sections without SAMIs (control), the value recorded will not be of great concern in the field. Also, it shows that the materials used in preparing the SAMIs influence their resistance to permanent deformation. This explains why in the RLAT test, Sand Asphalt 3 with 160/220 penetration grade bitumen has poor resistance to permanent deformation and in the accelerated pavement test, the resistance to permanent deformation of the SAMIs varies with the material used. The study reveals that the permanent deformations of the SAMIs vary with the thickness of

the SAMIs. Greater rut depths (permanent deformations) were recorded when greater thickness was used for the Sand Asphalt 1. A situation attributed to the lower stiffness of the SAMI layer compared to the overlay and consequently, reduction in the bending stiffness of the pavement.

Generally, the study shows that when SAMIs are introduced into a pavement to retard reflective cracking, more permanent deformation of the pavement is expected. Therefore, it is important that the mixtures that are used in the overlay have good resistance to fatigue and permanent deformation. For further studies, more tests with rigorous control of temperature should be carried out in order to define quantitatively the influence on mixtures.

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