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Creep Behavior of Polyethylene Modified Bituminous Mixture

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Abstract

This paper present a part of research conducted to investigate the deformation behaviour of the well graded bituminous concrete mixture using dynamic creep test for the unmodified control mix and Polyethylene modified bituminous mix. Control mix was prepared with 80/100 Pen bitumen while polyethylene modified mix was prepared using low density polyethylene (LLDPE) as modifier, blended with 80/100 Pen bitumen. The concentration of polymer in the blend was kept at 1%, 2% and 3% by weight of bitumen content. Marshall Specimens prepared at optimum bitumen content were used to investigate the creep stiffness of both modified and control mixes. It was found that 3% LLDPE modified bituminous mixes offer better results in comparison to control and 1% & 2% LLDPE modified mixed samples when they were investigated in terms of mixture stiffness obtained at 40°C by dynamic creep test. The rut depth estimation as observed by wheel tracking test results also follows the same trend as observed by dynamic creep results.

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Keywords: Linear low density Polyethylene modified bitumen, Rutting, Dynamic creep test, Wheel tracking test

1. Introduction

One of the distresses that commonly occurred in flexible pavement at high pavement temperature is rutting due to accumulation of permanent deformation of each layer of the pavement structure under repetitive traffic loading action. Permanent deformation usually do occur due to consolidation of either underlying base course due to repeated traffic load along the wheel path or due to plastic flow near the pavement surface [1], which significantly reduces both structural and functional performance of the pavement. In order to have bituminous

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mix which can perform adequately under a wide range of temperature, offering resistance against degradation because of stresses and load, its properties must be compatible to offer thermal stability, load spreading and chemical stability to prevent the pavement from rutting, fatigue and thermal cracking [2].

Polyethylene is widely used in order to achieve the desired properties of elasticity, strength and adhesion to increase pavement life[1]. Modification of bitumen with synthetic polymer binder provides a new approach to overcome new technical demands [2].The use of synthetic polymer either by chemical or physical blending improves the properties of elasticity, strength and adhesion to increase the pavement life [3].

In this study, it is aimed to investigate the mechanical property of bituminous mixture in terms of mixture stiffness and estimated rut depths.

2. Methodology

2.1. Material

Material used in this study includes 80/100 penetration grade base bitumen obtained from PETRONAS refinery at Malacca, Malaysia. The polymer linear low density Polyethylene (LLDPE) used for modification was supplied by Polyethylene Malaysia in pellet form. Crushed aggregates were obtained from quarry located at outskirt of Ipoh Malaysia, while river sand was used as fine aggregate. Ordinary Portland cement was used as filler. Physical properties of material used are shown in Table 1.

2.2. Sample preparation

2.2.1. Polymer Modified Bituminous Blend (PMB)

PMB blend was prepared by mixing about 400g of bitumen with polymer in shear mixer at 120rpm, while the temperature was kept at 160°C. The concentration of LLDPE was kept as 1- 3% by weight of the bitumen. Mixing was continued for 1 hr. Virgin bitumen was subjected to same shearing action in order to have uniformity in testing conditions. Empirical test such as penetration ASTM D-5, softening point ASTM D-36 and viscosity ASTM D-4402 were then conducted on the prepared samples. Test results are presented in Table 2.

Table 1. Physical Properties of Material Used

Material	C.A.	F.A.	Polymer LLDPE	Bitumen	Filler
Specific gravity	2.63	2.64	0.895	1.01	3.26

Table 2. Properties of Virgin and Polymer Modified Bitumen

Bitumen	Pen. at 25°C (dmm)	Softening Point °C	Viscosity, Pa.s	P.I.
80/100 Pen. Bitumen gravity	84	53	0.44	0.5
1% LLDPE	35	53	0.63	-1.5
2% LLDPE	30	53	0.76	-1.85
3% LLDPE	25	60	1.43	-0.7

2.2.2. Marshall samples

All Marshall Samples were prepared according to ASTM D1559 using Gyratory compactor adjusted at an angle of gyration of 1.25°, normal pressure of 600 kPa and number of gyration of 200. Two different types of mix were prepared namely control mix prepared with virgin bitumen and LLDPE polymer modified mix using polymer modified bitumen with polymer concentration varying between 1-3% by weight of bitumen. The optimum bitumen content obtained for control mix was found to be 5% while for 1%, 2% and 3% LLDPE mix was 5.2%, 5.4% and 4.7%, respectively. All creep samples were prepared at these OBC values.

2.2.3. Experimental set up for dynamic creep test

The dynamic creep test was performed according to British Standard DD 226. The creep deformation of standard Marshall Specimens prepared at OBC for virgin and LLDPE modified mix was measured as a function of pulse counts. The load used represents the repeated application of axle loads on the pavement structure. The specimen was preloaded with 12 kPa stress for two minutes before being subjected to 100 kPa stress for 1 hr.

2.2.4. Wheel tracking test

Wheel tracking test was performed according to BS 598 -110. Standard wheel runs back and forth across a prepared bituminous sample at a frequency of 42 wheel passes/minute. The test was conducted at 40°C where the Wessex software records the total rut depth for number of wheel passes for 45 minute loading period.

3. Results & Discussion

3.1. Empirical test results

A sharp decrease in the penetration value of 84dmm for base bitumen to 35dmm at 1.0% concentration of polymer reflects increase in the hardness of the PMB. The use of the high molecular weight polymer LLDPE having melt flow index of 0.9g/10min, increases the viscosity of the PMB. Although LLDPE has melting temperature around 122°C but doesn't get completely dissolved into bitumen due to lower shear rate and mixing time. The increase in viscosity and thus hardness of PMB was considered due to absorption of some oily component of bitumen and release of low molecular weight fraction into the bitumen which increases the viscosity of the PMB [4]. Thus the release of lower molecular weight fraction sufficiently increase the viscosity till the end of mixing process, and by the time it cools harden mixture was formed. The hardening of the bitumen can be beneficial as it increases the stiffness of the material, thus the load spreading capabilities of the structure but also can lead to cracking [5].

The softening test results doesn't show any change in softening temperature for PMBs up to 2% concentration of polymer in bitumen as compared to base bitumen, but as the concentration was increased to 3% an increase in softening temperature was observed. This phenomenon might have occurred as increase in hardness as observed by lower penetration value, indicates that modified binder would require higher temperature to soften the PMB. The test result of softening point till 2% polymer remains same as for unmodified binder, indicating that modified binder was least affected by temperature variation. The softening test results for 3% LLDPE PMB concentration indicates higher softening temperature thus making the binder more creep resistant.

3.2. Viscosity of PMB blends and base bitumen

Fig. 1 shows an increase in viscosity with the increase in polymer concentration. The non-Newtonian characteristic as seen by a decrease in viscosity with the increase in shear rate was observed for all concentrations of polymer in bitumen. Viscosity test results show that as the shear rate is increased the viscosity of the blend reduces with all the values well below 3 Pa s, as mentioned by ASSHTO specification

ASSHTO MP1[4] for a workable mix. This behavior of bitumen from the viscosity stand point shows that it is neither Newtonian nor non-Newtonian. Shear thinning phenomenon was observed for all LLDPE concentration up to 3%.However it is very difficult to say that polymer modified bitumen purely exhibits shear thinning phenomenon with the increase in shear rate as shear thickening phenomenon was also observed for 1% and 3% polymer concentration in the blend between 2000-4000sec^{-1} shear rate. Although viscosity results shows increment by the addition of polymer in the blend but still all the values are well below 3 Pa s, as mentioned by ASSHTO MP1 for workable bituminous mix.

Thus improved viscous property of modified binder is considered as one of additional factor increasing the cohesion and internal friction angle of mixture offering higher shear strength reducing the chances of rutting in the pavement.

3.3. Dynamic creep results

Dynamic creep test was conducted on triplicate samples prepared at OBC. The average mix stiffness modulus (S_{mix}) obtained from the creep modulus of three prepared mix specimen at OBC for particular bituminous mix is plotted in double logarithmic scale against stiffness modulus of bituminous binder (S_{bit}), evaluated by using Van der Poel's nomograph as shown in Fig. 2.The resistances to permanent deformation from the creep tests can be observed from the slope of the line of the log-log relationship of mixture stiffness versus binder stiffness. The slope of the line for each particular mix indicates sensitivity of the mix to loading time and hence bitumen stiffness [6].

Among LLDPE modified bituminous mixes it was observed from Fig. 2, that only 3% LLDPE bituminous mix offered increased mixture stiffness in comparison to other mixes. At higher concentration of polymer (3%) the increase in viscosity makes the binder rather incompressible while the partially immiscible polymer induces the stiffening affect. The behavior of the LLDPE at lower polymer concentration could be attributed by the failure of formation of proper polymer bitumen network as observed by the change in viscosity of the binder

The pattern of estimated rut depth can be explained in context with the viscosity function, that although enhanced viscosity of binder increases stiffness in bituminous mix but doesn't necessarily reduces the rut depth as it also depend on aggregate cohesion in mix, binder content, degree of compaction and porosity in mix. The LLDPE PMB mix unable to show better performance as branched polymer usually shows high degree of shear thinning, where irreversible bulk deformation of polymer which is associated with irreversible slippage of molecular chains doesn't exists sufficiently to overcome the strains induced due to repeated load action.

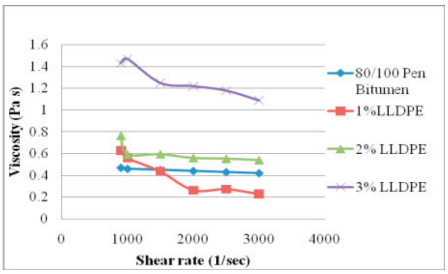

Fig. 1. Viscosity of Bitumen and LLDPE PMB at 135oC

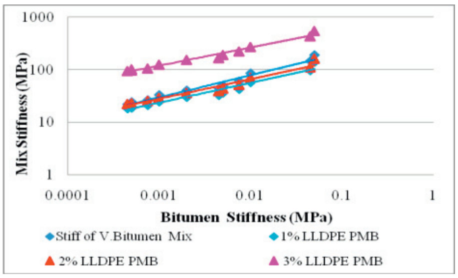

Fig. 2. Mix Stiffness Vs Bitumen Stiffness

3.4. Estimation of rut depth using dynamic creep test results

Results of the rut depth calculated shown in Fig. 3. From the figure it was observed that for the rut depth corresponding to one million axle wheel loads, 3% LLDPE modified bituminous mixture shows lowest rut depth in comparison to unmodified, 1% and 2% LLDPE mix. The rut depth for the unmodified 80/100 pen bituminous mixture was found to be 10.57mm. After modification with 3% LLDPE rut depth has been reduced to 1.14mm. Such a drastic reduction in rut depth was considered due to the stiffening effect induced by the polymer as observed by the decrease in penetration value and increase in softening temperature.

1% and 2% LLDPE PMB shows shear thinning behavior where irreversible slippage of molecular chain does not exist sufficiently to overcome the strain induced by the repeated load actions. As the compatibility of polymer and bitumen also plays significant role in overcoming the stress induced by the repeated load action it can be safely concluded that polymer bitumen networks start to form at concentration above 3% LLDPE polymer concentration as observed by the increase in bitumen stiffness and decrease in rut depth compared to unmodified, 1% and 2% LLDPE PMB.

3.5. Estimation of rut depth using wheel tracking results

The results obtained from wheel tracking test are presented in Fig. 4. The rut depths obtained shows the same trend as was being observed by the dynamic creep results. 3% LLDPE modified bituminous mixture shows better performance in comparison to other. Beside binder viscosity which contributes to adhesion ability to resist deformation, aggregate packing also considered as influential factor affecting the deformation behavior of the mix.

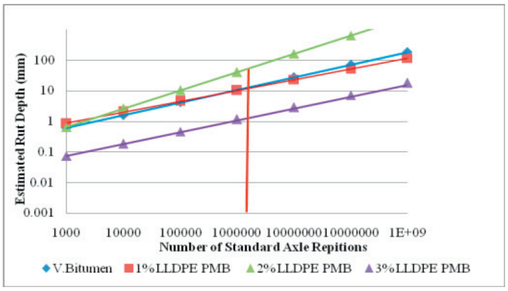

Fig. 3 Estimated rut depth at 40°C corresponding to one million standard axle repetitions

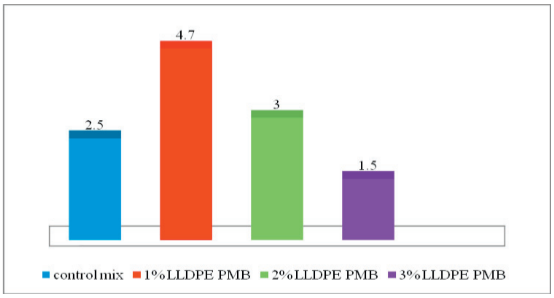

Fig. 4 Estimated rut depth (mm) obtained from Wheel Tracking Test

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