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Dynamic Creep Performance of Hot Mix Asphalt Mixture Incorporating Fibre

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Abstract: Permanent deformation is one of the distress that develops gradually as the number of load applications increases and appears as longitudinal depressions in the wheel paths and small upheavals to the sides. For this reason, numerous studies conducted on modification asphalt binder or mixture by various fibre. This paper presents the evaluation of creep modulus and permanent deformation of modified asphalt mixture with fibres. In order to envisage the modified asphalt mixture, Forta-fi, Kenaf and PET was blended to estimate the creep properties and rut depth value at different loading pattern. Superpave mix design method was employed with NMAS 12.5mm to obtain the optimum bitumen content established at 4% air void. In the respect, bitumen 60/70 penetration grade with 0.5% of Forta-Fi, 0.1% Kenaf fibre and 0.5% PET by weight of asphalt mixture were prepared. Dynamic Creep Test was performed in accordance with the EN 12697-25:2005 guidelines using the Universal Testing Machine (UTM). As the result, the minimum value of permanent deformation was found at 0.5% of PET. Based on these studies, adding a minimum percent of PET in the asphalt mixture shows a better resistance to rutting deformation and enable a better understanding of the properties in modified asphalt mixtures.

Keywords: Permanent deformation, creep modulus, forta-fi, PET, kenaf fibre

1. Introduction

Hot mix asphalt (HMA) is a mixture of course mineral material, mineral filler, and a relatively small amount of asphalt binder. A pavement is designed to last, but it often does not perform as expected and, after a relatively short period of time, needs to be rehabilitated. In designing asphalt concrete, understanding the effects of repeated creep was very important. A heavy vehicle with full load traveling on a loaded climbing lane causes considerable distress to the pavement structure during a hot summer day. The repetition of heavy axle loads becomes more pronounced with the increases in traffic loads.

Heavy traffic causes the most important failures in a pavement producing permanent deformation that require pavement rehabilitation. Similar problems can be encountered even on straight road sections due to the slow speed and heavy loads of trucks and trailers. There were also similar problems with the pavement around traffic lights and bus stops. Hence, visible defects associated with rutting Constructions of asphaltic concrete in Malaysia has brought with the problem of the extensive quality control even though these materials are produced complied with the specification The asphalt binder was often significantly modified by various fibre [1]. Bitumen and filler together form the so-called mastic that act as an effective binder for the lithic skeleton when mixed with the aggregates. As a result, mastics play a crucial role in the performance of the HMAs during their service life, as they must bear both traffic loads and climate change [2].

The permanent deformation or rutting is one of failure modes in flexible pavement, which referred to the accumulation of small deformations densification and repeated shear deformations under wheel loads application. Several

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factors such as lateral movement and consolidation of the bituminous under traffic found as the causes of this deformation [3], [4]. There are various causes of crack formation and enlargement in asphalt overlays, but it is possible to categorize the mechanisms involved as traffic induced, thermally induced and surface initiated [5]. It was quite clear that roads did not crack immediately after the start of traffic, it usually takes many years and many millions of vehicle tire load application. Road pavement, whether asphalt or concrete, suffers from the well-known phenomenon fatigue, which is the slow development and propagation of a crack under repeated loading [6]. Following a certain number of years of service, pavement cracking appears on the surface due to repeated traffic loading, local environmental distress, and ageing [7].

The dynamic creep test has been utilized to assess the distortion obstruction (rutting susceptibility of asphalt mixture [8]. The most common dynamic creep test is the unconfined dynamic creep test, known as the axial repeat-load test (RLAT). The term creep test was utilized to demonstrate tests for evaluating the permanent deformation resistance of asphalt mixture [9]. The RLAT is used more and more in preference to the uniaxial creep (UC) test because the pulsed load is a more accurate traffic load simulation [10]. Other than to determine the deformation of resistance, creep test can also estimate the rutting depth towards permanent deformation of bituminous layer. The rut depth can be computed using formula in Eq. (1) [11].

$$\text{Ruth Depth} = C_m h_1 \left(\frac{\sigma_{av}}{S_{mix}} \right) \quad (1)$$

where C_m is a correction factor (assume to be 1), h_1 is a thickness of asphalt layer (mm), σ_{av} is an average vertical stress in asphalt layer (kPa) and S_{mix} is a stiffness modulus (MPa). The dynamic creep modulus can be determined using Eq. (2).

$$\text{Dynamic Creep Modulus} = \frac{\text{Applied axial strees}}{\varepsilon_{3600} - \varepsilon_{1200}} \quad (2)$$

where ε_{3600} is an accumulated strain at 3600 cycles and ε_{1200} is an accumulated strain at 1200 cycles.

Many types and forms of fibres have been used in asphalt mixtures. Cellulose, mineral, and polymers fibre are the most common fibres. Based on the findings, the use of fibre in pavement construction deserves serious consideration as it significantly enhances deformation resistance compared to unmodified mixtures [12]. The effect of fibre is more significant at high stress and temperature. This is in line with the conditions in Malaysia which experience tropical weather and high volume of traffic [13]. Moreover, addition of fibre will increase the resistance to deformation of mixtures. Fibre can therefore improve performance in several ways compared to a traditional mixture against expected significant pavement pain, including permanent deformation, fatigue cracking, and thermal cracking [14]. Also, fibre is economically beneficial due to the low cost of it.

2. Materials and Methods

In the present study, the rounded specimen was prepared of size 100 mm in diameter with 65 mm height. Superpave method was employed with NMAS 12.5 mm. The following subsections describe the materials and methodology used in this study.

2.1 Asphalt Binder

The asphalt binder used in this study is the common type of bitumen that was used in the road construction in Malaysia. Asphalt binder bonds all materials and provides the characteristics of hardening. The asphalt binder PEN 60/70 was supplied by Kemaman Bitumen Company Sdn Bhd. Table 1 shows physical properties test of the asphalt binder.

2.2 Aggregates

The crushed granite aggregate that was used to perform the laboratory test was supplied by Hanson Quarry Sdn Bhd, Batu Pahat. The aggregates used must be angular, hard, rough and also free from any dust, clay or vegetative materials. To construct a quality pavement and comfort the road user throughout its service life, it is important to aggregate must be strong and durable. An approximately 1200 g of granite aggregate were used to prepare the sample and the job mix formula for NMAS 12.5 mm is tabulated in the Table 2.

2.3 Forta-Fi Fibres

Forta-fi fibre is a blend of synthetic fibres de-signed for use in HMA applications. The proprietary blend consisted of polyolefin and aramid fibres as shown in Fig. 1. Forta-fi fibres is acquired from AHN Vertex Sdn Bhd was utilized as a fibre in this study. Aramid fibres with a high temperature of decomposition are a class of heat-resistant and solid synthetic fibres with excellent abrasion resistance and organic solvents. The size of this aramid is 19 mm, monofilament form with specific gravity value 1.44. Polyolefin consists of serrated form in size of 19 mm with specific gravity value 0.19. Aramids share a high degree of orientation with polyolefin fibres and strong fabric integrity. Due to the low cost of polyolefin fibres, the use of aramids and polyolefin fibres is also economically beneficial. The fibres were designed to reinforce the HMA in three-dimensional orientations.

Table 1 - Physical properties test of 60/70 asphalt binder

Physical Test	Standard	Results
Penetration at 25ºC (0.1 mm)	ASTM D5	68
Softening Point (ºC)	ASTM D36	48
Rotational Viscosity (Pa.s)	ASTM D4402	0.2
Flash and Fire Point (ºC)	AASHTO T48	260
Ductility at 25ºC (cm)	ASTM D113	140

Table 2 - Job Mix Formula for NMAS 12.5mm

Sieve size (mm)	Specification Grading Zone	Job Mix Formula (%)	Retained (%)	Weight Used (g)
19	100	100	0	72
12.5	90-100	94	6	84
9.5	80-90	87	7	324
4.75	50-75	60	27	300
2.36	28-58	35	25	144
1.18	18-40	23	12	84
0.6	12-30	16	7	60
0.3	7-20	11	5	48
0.15	4-15	7	4	36
0.075	2-10	4	3	48
Pan		0		1200

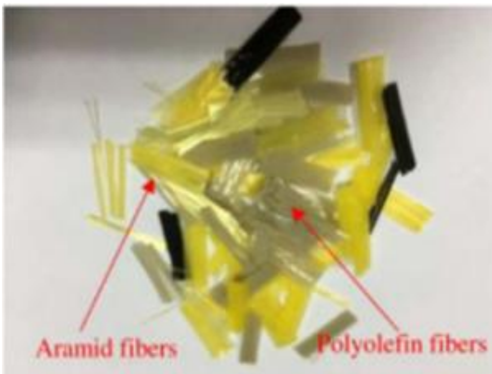

Fig. 1 - Forta-fi fibers

2.4 Polyethylene Terephthalate (PET)

The rutting properties of asphalt mixture modified by PET standard particles were assessed in another investigation. PET chips with the maximum size of 2.36 mm as shown in Fig. 2 were utilized and fatigue properties of PET modified asphalt mixture were evaluated. The outcomes demonstrated that the exhaustion life expanded significantly under dynamic loading and the mixture containing higher measure of PET substance indicated higher opposition against fatigue cracking. In other examination, permanent deformation qualities of PET modified asphalt mixture under dynamic loading was explored at different temperatures and stress, and it was appeared perpetual strain diminished significantly by use of PET modification.

(a) (b)

Fig. 2 - (a) Polyethylene terephthalate (PET); (b) 2.36 mm PET chips

2.5 Kenaf Fiber

The twisting of Kenaf strands has been contemplated where the Young's modulus from estimation of the power required to avoid the free finished of an edge of filaments organized cantilever-design. Extrapolations of the information to littler distances across demonstrates that the pliable incentive for the modulus of 4000 g/Tex at 100% expansion would be come to at a mean width of around 40 mm. The impact of delignification on the bending modulus of Kenaf was additionally analysed, utilizing the fringe technique, and this demonstrated progressive extractions of lignin from similar strands brought about an expanding adaptability and a diminishing Young's modulus. Fig. 3 shows the kenaf fibre used in this study with 2.3 mm in sizes.

Fig. 3 - Kenaf fiber

2.6 Sample Preparation and Modification Process

An approximately 1200 g granite aggregate were batched and pre heated in an oven for at least 4 hours at mixing temperature as determined by rotational viscosity test. The PEN 60/70 penetration grade was heated at mixing temperature for 2 hours prior to mixing. Once the asphalt binder reaches the mixing temperature, the heated aggregate was placed in the mixing bucket and the fibre were added (0.5% of Forta-Fi, 0.1% Kenaf fibre and 0.5% PET) by weight of asphalt mixture onto hot aggregate. Subsequently, the mixing bucket containing hot aggregate and fibre were place on the weighing scale and fluid binder was poured onto the hot aggregate at the desired amount. Then, the mixing bucket were placed in the heavy-duty mixer and run for two (2) minutes to come up with a homogenous fibre modified asphalt mixtures. After mixing, the loose fibre mixtures were conditioned in an oven for two (2) hours at the compaction temperature to allow asphalt binder absorption as recommended by the Asphalt Institute [15]. The fibre mixtures were compacted using superpave gyratory compactor at 100 gyrations. The specimens are allowed to be cool at ambient temperature for further laboratory testing.

2.7 Dynamic Creep Test

The dynamic creep test was performed as outlined in EN 12697-25:2005 using UTM-5P [16] to evaluate the creep modulus, permanent deformation, and rut depth of fibre reinforced asphalt mixture. The specimens have been compacted to 100 mm in diameter and 65mm in height at 4% air voids. The conditioning stress 10 kPa was applied for120 seconds to the asphalt mixture specimens. Then, the fabricated specimens conditioned in the chamber for 2 hours to achieve uniform temperature before tested.

The UTM-5P machine was set up by placing the sample between two metal steel that works to distribute load uniformly over the top surface of a sample. When it reached 3600 cycle, the test was stopped for each sample and the result for permanent deformation with creep modulus was recorded. This test technically was stimulated from a real field where stress level indicates to vehicles pressure tire that made contact toward road surface which is wearing course. Loading and rest time, represent the repeated load of moving traffic. Table 3 shows the test parameters used for dynamic creep test.

Table 3 - Dynamic creep test parameter

Parameter	Information
Temperature (^{0} C)	60
Pulse width (ms)	100
Rest period (ms)	900
Contact stress (kPa)	9
Deviator stress (kPa)	207 and 500
Stop test cycle	3600

3. Results and Discussion

The dynamic creep test is an important test conducted to determine the creep modulus and permanent deformation behaviour of a specimen. In this study, the test was conducted on the specimens under different deviator stress. The following subsections describe the further analysis of modified mixtures.

3.1 Dynamic Creep Analysis

The variations in the creep stiffness of asphaltic samples incorporating different percentages of fibre at 60°C test temperature using Universal Testing Machine are shown in Fig. 4. A comparison between control and three fibre asphalt mixtures were conducted strictly followed by EN 12697-25 standard. The result indicated that the specimens containing recycled Polyethylene Terephthalates (PET) fibre tested at 207 deviator stress indicates a higher creep stiffness compared to tested at 500 deviator stress.

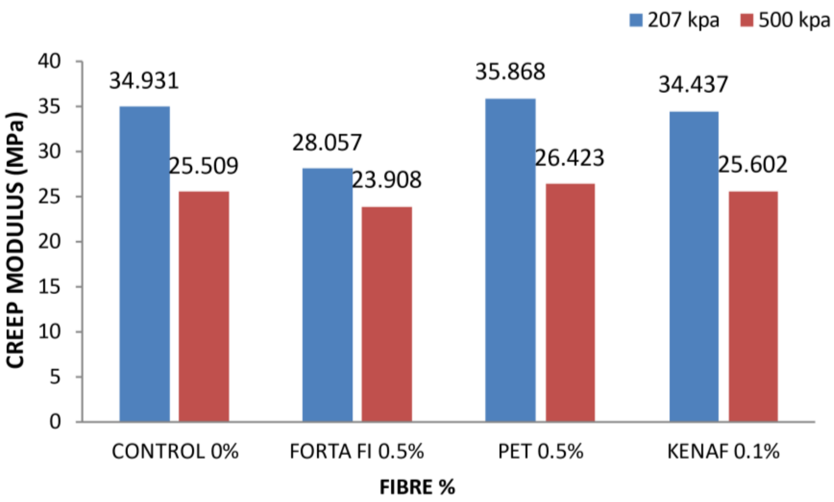

Fig. 4 - Effect of different fibre on creep modulus

Generally, it shows that additional Forta fi and Kenaf lowered the value of the creep stiffness except for PET fibre compared to the control specimens. This may be due to inadequate natural fibre content in the mix has decreased the interaction between the aggregate and bitumen binder, resulting low tensile strength mixes. The creep stiffness value was recorded in the range between 28.057 to 35.868 MPa and 23.908 to 26.423 MPa at 207kPa and 500 kPa deviator stress, respectively. As can be seen in this Fig. 4, creep stiffness of PET modified mixture improved approximately 2.7% and 3.6% for 207kPa and 500 kPa deviator stress as compared to the control mixture, respectively. According to Moghaddam et al. [17], the used of PET fibre in an asphalt mixture gives a better result in elastic properties where the mix specimens become more flexible to reduce the mix deformation.

There was also small variance for the creep stiffness value of the modified mixture as compared to the control mixture. The dynamic creep results are summarized and arranged in the sequence shown in Fig. 4. Overall, the creep stiffness results for specimen containing 0.5% of PET fibre are constantly highest when tested using 207 and 500 kPa deviator stress regardless of test temperature compared to other specimens.

3.2 Analysis of Permanent Deformation

The permanent deformation test results for specimens incorporating various percentage of the fibres tested at 60^0 C was shown in Fig. 5. From this graph, the value of control sample was recorded 0.375 mm at 207 kPa and 1.075 mm at 500 kPa, respectively. As the deviator stress increase increases, the permanent deformation increases. Specimens prepared with 0.5% Forta-fi, 0.5% PET and 0.1% kenaf fibre tested for 207 and 500 kPa deviator stress load, resulted the permanent deformations in ranges of 0.370 mm to 0.983 mm, 0.359 mm to 0.817 mm and 0.363 mm to 0.935 mm, respectively. This shows that 0.5% PET had the lowest permanent deformation at 207 kPa deviator stress compared to the control sample and other fibres.

Another outcome result was from 500 kPa for 0.5% Forta-fi, 0.5% PET and 0.1% kenaf was 0.983 mm, 0.817 mm, and 0.935 mm. This shows that 0.5% PET had the lowest permanent deformation at 500 kPa deviator stress compared to another fibre. A minimum value of permanent deformation was found at 0.5% PET compared to another fibre. This clearly noted that the increment of deviator stress to the specimen affected the permanent deformation values. As agreed by Modarres et al. [18], the use of PET in asphalt mixture can improve in elastic properties where the sample becomes more flexible. However, by incorporating 0.5% of PET fibre, the creep stiffness exhibits higher values as shown in Fig. 4 which indicate better resistance to plastic deformation of asphalt mixtures.

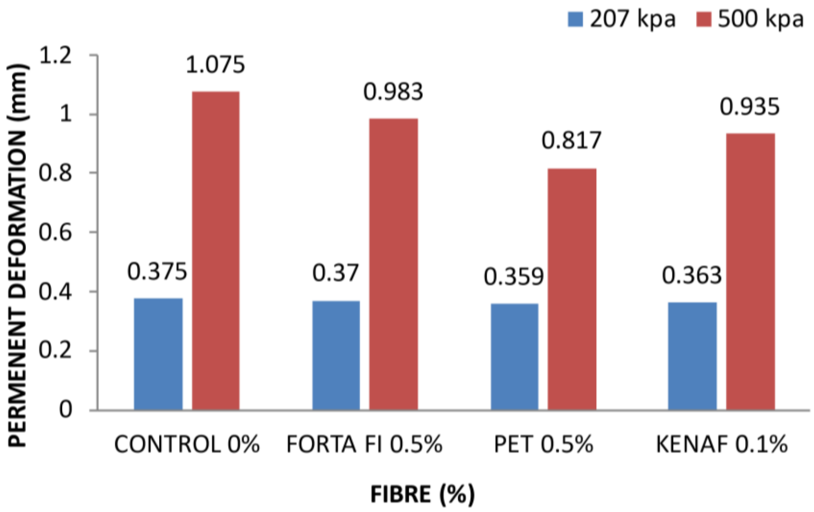

Fig. 5 - Effect of different fibre on permanent deformation

3.3 Analysis of Ruth Depth

Fig. 6 displays the rut depth results for specimen prepared with 0.5% Forta-fi, 0.5 PET% and 0.1% kenaf fibre tested at 60^0C. To obtain a consistent result, an average reading from three specimens were recorded. Overall trends show that the presence of fibre decreases the rut depth values for both deviator stress. The rut depth value of mixes incorporating fibre tested at 207 kPa and 500 kPa deviator stress were recorded in ranges of 0.028 to 0.030 mm and 0.060 mm to 0.073 mm, respectively.

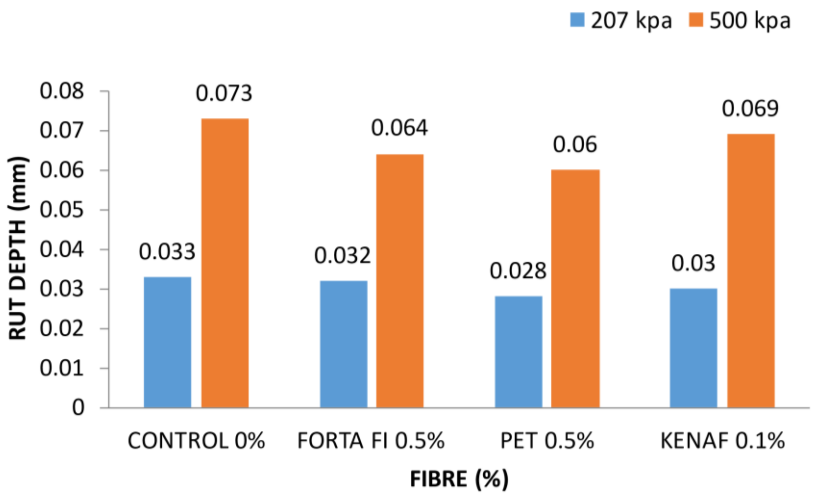

Fig. 6 - Effect of different fibre on rut depth

It can be clearly seen, 0.5% PET exhibits the lowest rut depth at207 kPa and 500 kPa deviator stress and resistance to permanent deformation. The percentage decrease in rut depth is remarkably pronounced with PET mixes. The decrease in rut depth may be due to the superior interaction of aggregates to binder adhesion exhibited by the PET. For instance, the rut depth of control mix at 207 kPa is 0.033 mm but the rut depth of the asphaltic concrete with 0.5% PET in mix is 0.028 mm, which represents a 15% decrease. Accumulation of these small deformation occurred shows that bituminous mixture with fibre contribute to permanent deformation under repeated loading. Thus, the 0.5% PET is considered the optimal limit. The permanent deformation values were obtained directly from the Universal Testing machine and rut depth values was computed. The results were accepted since all the modified mixtures improved in permanent deformation remarkably compared to the control.

4. Conclusion

This study evaluated the effects of three difference types of fibre on the creep stiffness asphalt mixtures at different deviator stress. The results indicate that asphalt mixture containing 0.5% of PET fibre shows higher creep stiffness has improved the rutting resistance and lower permanent deformation. The result of rut depth can be concluded that 0.5% PET has the lowest value that is 0.028mm for both deviator stress compared to other fibre which indicates that adding the fibre have enhanced the resistance of the mixture to permanent deformation. All in all, it can be concluded that the optimization results showed that 0.5% of PET fibre can be recommended for modification of the asphalt mixtures as optimum contents for modified asphalt mixtures. For a further study that related to this research, it is recommended to use different percentage of Forta-fi, PET % and kenaf, dimension length and size. The air void of performance test should be considered according to EN 12697-25:2005 specification. Thus, the air void gives an impact result for these studies.

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