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Laboratories Investigation on Creep Stiffness of Aphalt Mixture Incorporating Steel Fibre

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Abstract: Flexible pavement is the most common type of pavement found on Malaysian roads. The three most common types of pavement failure are rutting, fatigue cracking, and thermal cracking. The focus of this research was to develop asphalt mixture for flexible pavement based on the JKR/SPJ/2008 standard specification and it is regarding asphalt mixture incorporating with steel fibre. The objectives of this study were to investigate the properties of asphalt binder, aggregates, and steel fibre in HMA mixture and to evaluate the creep stiffness of fibre reinforce asphalt mixtures. The properties of steel fibre, aggregate and asphalt binder were characterised according to the standard and specification AASHTO, ASTM and JKR and the performance of the steel fibre asphalt mixture was tested using dynamic creep test. The expected outcome of the study was to determine the deformation of the asphalt mixture when it is mix with the steel fibre according to the percentage of the mixture, reduce rutting and improve the strength of pavements using steel fibre (SF) as a reinforcement. and expected to benefit the future of flexible pavement in Malaysia, as well as aid in the development of the use of asphalt mixtures with steel fibre in road construction in Malaysia, as per the JKR standard.

Keywords: Steel Fibre, Asphalt Mixture, Dynamic Creep, Permanent Deformation

1. Introduction

Highway, sometimes known as an expressway, is a major road network that connects all of a country's roads and is one of the most vital communication linkages for citizens. A modern highway or public transportation system improves the ability of community to travel to other places. In general, all roads in Malaysia are made of flexible pavement with an asphaltic concrete mixture as the wearing course. Flexible and rigid pavements are the two types of pavements in Malaysia. Malaysia is one of the countries that uses flexible pavement design the most. The Malaysian flexible pavement, which includes bituminous surfacing, granular road base, sub-base, and subgrade formation, was designed using the Jabatan Kerja Raya (JKR) and Spesifikasi Pembinaan Jalan (SPJ) 2008 standards. The axle

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load limits and climate conditions are used to develop flexible pavement. It is reported that Malaysia's road network covers 218,987.800 km in 2016 and this record is an increase from the previous number of 197,014.900 km for 2015. The Japanese Expressway System and the Chinese Expressway System are also closed toll expressway systems. All toll expressways in Malaysia are controlled-access highways that are operated under the Build-Operate-Transfer (BOT) scheme [1]. During its service life, flexible pavement should also provide a durable, skid-resistant surface. Flexible pavements can be built and restored rapidly and efficiently. Every 10 to 15 years, it would need to be maintained or rehabilitated [2]. Rutting, fatigue cracking, and thermal cracking are the three most common types of pavement failure. Since our country experiences a wide range of environmental patterns, the temperature has an effect on the state of the pavement. Furthermore, overcrowding by heavy vehicles will cause the pavement's structure to deteriorate, resulting in road pavement damage [3]. Excessive traffic has caused significant damage to many highways in the last five years. Excessive traffic loads are the primary cause. This resulted in destruction and suffering on Malaysia's flexible pavement.

In this research, I did an experimental study on creep stiffness of asphalt mixture incorporating steel fibre. The expected outcome of the study is to determine the deformation of the asphalt mixture when it is mix with the steel fibre according to the percentage of the mixture, reduce rutting and improve the strength of pavements using steel fibre (SF) as a reinforcement. Through proper selection and optimization by preparing three specimens for each of a series of different fibre rates, the best result in the stability can be determined and the performances of asphalt mixtures can be improved. The advantages of including steel fibre were expected to contribute to the improvement of the physical and mechanical properties of asphalt binders and mixtures.

2. Materials and Methods

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Materials

The materials chosen for this study are important in achieving defined outcomes. According to JKR/SPJ/2008, the materials used must meet all of the standards. The materials chosen can have an impact on the outcomes of the laboratory tests as well as the accuracy of the data obtained. The materials being tested include steel fibre, aggregates, as well as bitumen.:

- Steel fibre
- Aggregates
- Bitumen

2.2 Methods

The procedure of laboratory tests that were performed to meet all of the objectives of this study is described in the Figure 1.

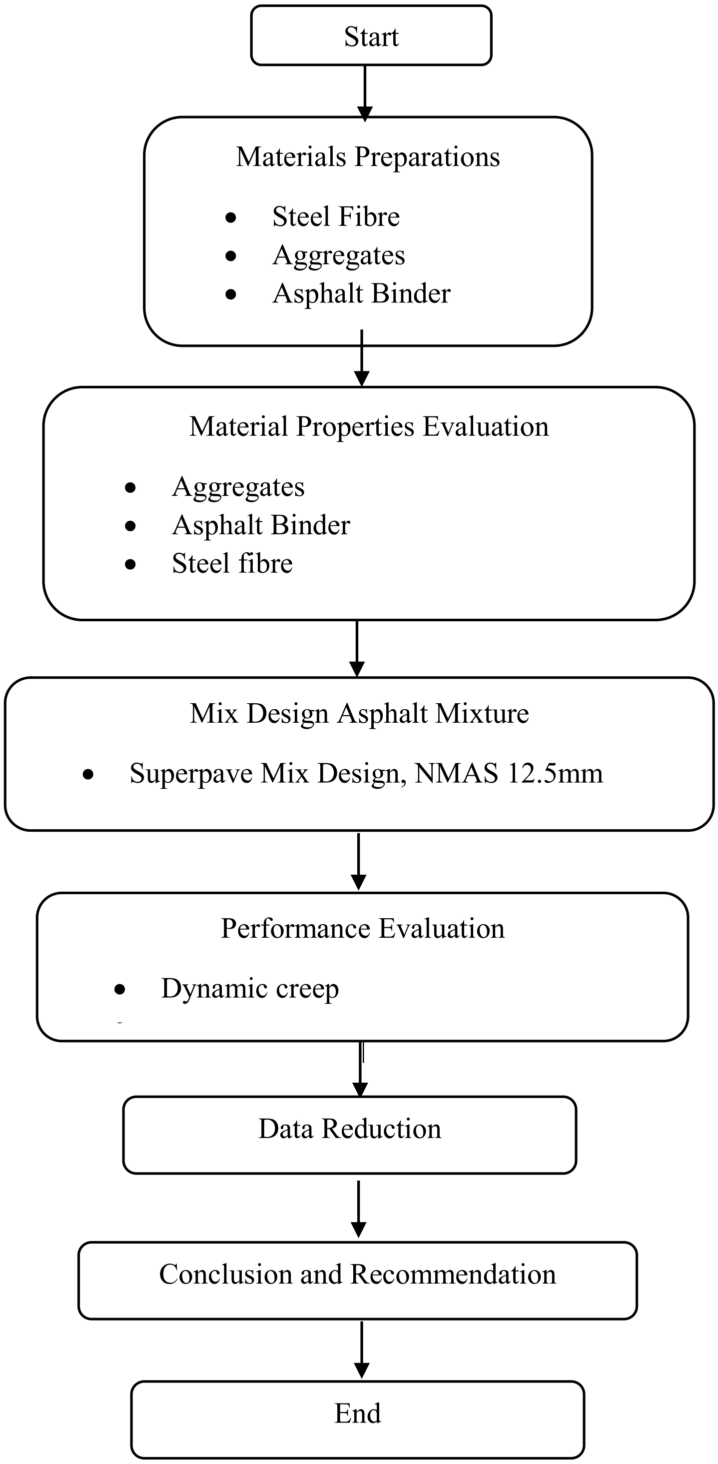

Figure 1: Flowchart of methodology

2.3 Equations

In general, the dynamic creep test is based on the equation:

$$Creep\ Steady\ Slope\ (CSS) = \left(\frac{Log\varepsilon 3600 - Log\varepsilon 2000}{Log\ 3600 - \log 2000}\right) Eq.1$$

$$Dynamic\ Creep = \left(\frac{Applied\ load\ stress}{Accumulated\ \varepsilon 3600 - Accumulated\ \varepsilon 2000}\right) Eq.2$$

3. Results and Discussion

The results of the tests were shown in this topic, with the summarising elements such as material properties of aggregates, asphalt binder and preparation of asphalt mixture with steel fibre according to superpave mix design standard. Finally, the performance of the steel fibred hot mix asphalt mixture is shown and analysed. The test was performed using Universal Testing Machine (UTM) accordance to EN 12697-25. In this test, ultimate strain is the maximum result after the specific cyles of loading that can be used to control the overall deformation of the mixture.

3.1 Results

3.1.1 Aggregate Properties

Table 1: Result of the aggregate properties

Properties	Standard	Specification	Result
Flat and elongated particles in coarse aggregate (%)	ASTM D4791	Max 10	3.75
Aggregate impact value (%)	BS812-112	Max 30	11.56

Table 2: Specific gravity and water absorption sizes for coarse aggregate

Aggregate size (mm)	Specific Gravity		Water absorption (%)
	Bulk	Apparent	
12.5	2.555	2.571	0.630
9.5	2.546	2.563	0.690
4.75	2.522	2.532	0.370

Table 3 Specific gravity and water absorption of fine aggregate

Aggregate size (mm)	Specific Gravity		Water absorption (%)
	Bulk	Apparent	
2.36	2.626	2.648	0.321
1.18	2.597	2.689	1.276
0.6	2.692	2.774	1.092
0.3	2.688	2.725	0.503
0.15	2.614	2.703	1.256
0.075	2.577	2.630	0.786
Pan	2.610	2.676	0.949

Table 4: Gradation used for 1200g asphalt mixture sample

Sieve size (mm)	Percentage passing (%)	Percentage retained (%)	Weight of sample (gm)
19	100	0	0
12.5	93.1	6.9	82.8
9.5	79.9	13.2	158.4
4.75	57.9	22	264
2.36	41.9	16	200
1.18	24.9	17	210
0.600	16	8.9	106.8
0.300	4	7	84
0.150	9	5	65
0.075	4	1	12
Pan	4	1	12
Total	-	100	1200

3.1.2 Binder Properties

Table 5: Result for penetration grade 60/70

Number of Penetration	**Penetration(mm)**
1	69.7
2	64.9
3	68.6
4	73.0
5	72.6

Table 6: Softening point result

Number of test	**Softening Point(˚C)**
1	55.1
2	55.8
Average	55.45

Table 7: Rotational viscosity test result for binder 60/70 penetration grade

Binder 60/70 (mPa.S)			
°C	**Sample 1**	**Sample 2**	**Average**
125	1080	1080	1080
145	380	380	380
155	300	300	300
165	280	280	280

3.1.3 Dynamic Creep

Table 8: Summary of Dynamic Creep test results

Steel fibre content (%)	Creep Steady Slope (CSS)	Dynamic Creep (MPa)	Permanent Deformation (mm)
0%	0.372	173.36	0.434158
0%	0.399	512.99	0.13768
0%	0.281	388.06	0.249048
Mean	**0.351**	**358.13**	**0.27363**
1%	0.451	226.75	0.291801
1%	0.465	259.81	0.249872
1%	0.246	218.19	0.255726
Mean	**0.387**	**234.97**	**0.26579**
1.5%	0.371	80.037	0.980855
1.5%	0.434	172.19	0.38464
1.5%	0.461	119.921	0.542485
Mean	**0.422**	**124.05**	**0.63599**
2%	0.363	200.22	0.393694
2%	0.259	180.99	0.606557
2%	0.391	176.89	0.422369
Mean	**0.337**	**186.03**	**0.474**
2.5%	0.360	109.29	0.775189
2.5%	0.386	135.55	0.7005269
2.5%	0.334	202.07	0.447082
Mean	**0.360**	**148.97**	**0.54173**
3%	0.421	126.381	0.551691
3%	0.284	210.854	0.496978
3%	0.131	161.77	1.319219
Mean	**0.277**	**166.34**	**0.78929**

3.2 Discussions

From Figure 2, the Creep Strain Slope (CSS) was plotted based on axial strains against load cycles. These CSS values were analysed on the mean of three replicate specimens for each rate of steel fibre asphalt mixture. It can be found from the test that there is a linear relationship between strains and number of load cycles after 1000 cycles. Issues on rutting behaviour at carly stage, characteristic of specimen under load repetition and resistance to permanent deformation of the compacted specimen can be examined through this CSS curve. In addition, the mixture susceptibility of pavement rutting corresponds to CSS revealed the lowest CSS found in the mixture with 1% steel fibre content. This situation clearly explained that the mixture with lowest CSS able to resist more rutting.

Moreover, as can be seen in the Figure 3, rutting resistance of steel fibre asphalt mixture decreased remarkably compare to the asphalt mixture without steel fibre. Increasing of the steel fibre content in the samples at 40°C temperature have significant effects on creep stiffness. This is evident from the creep stiffness of 1% steel fibre sample for 40’c temperature, where the creep stiffness is approximately 20% lower than the sample without steel fibre content. Moreover, 1% steel fibre content asphalt mixture is having highest creep stiffness value which is 234.97MPa compare to other rate steel fibre content samples. As the percentage of steel fibre increase, the stiffness modulus of modified asphalt decreases. As for the creep stiffness, the 1% steel fibre content mixture value was recorded as 234.97 MPa, while other mixtures with different rate of steel fibre, the value range between 124.05 Mpa and 186.03 MPa. However, the creep stiffness for the mixtures with 0% steel fibre content were recorded the highest which is average of 358.13 MPa. The CSS value of some mixtures also exhibit lower than 0.250 (refer Table 1). Therefore, it can be concluded that these asphalt mixtures complied with Standard Specification of Road works [4].

The result of the axial strain was taken directly from universal machine by average of three samples for each steel fibre rate tested at 40°C as shown in Figure 4. It is apparent that specimens prepared with steel fibre mixture asphalt show an higher cumulative permanent strain compared to mixtures without steel fibre. Addition of 3% steel fibre into the mixture (0.277) has the lowest accumulated micro strain which is less than 11% compared to the asphalt mixture without steel fibre (0.351). In all cases, permanent strain decreases at steel fibre contents. It also demonstrates that changes in the measure of steel fibre content create sizable differences in the stiffness modulus of asphaltic samples.

Other than that, the observation from the Figure 5 reveals that asphalt mixture incorporating steel fibre performs better than the asphalt mixture without steel fibre. It can clearly seen, 1% steel fibre asphalt mixture has lowest resistance to permanent deformation. The increase in permanent deformation may be due to the air voids caused by excessive content of steel fibre. For instance, the permanent deformation of 1% steel fibre is 0.26579 mm but the value of 3% asphalt mixture is 0.7893 mm, which represents a 49% increase. The previous study conducted presents the test results of resilient modules to identify the permanent deformation of both normal mixture and steel fibre specimens [5]. The author stated that the asphalt mixture with fibre specimens had relatively better deformation value than the laboratory mixed specimens. The more the steel fibre content increase, the more the permanent deformation value increases too.

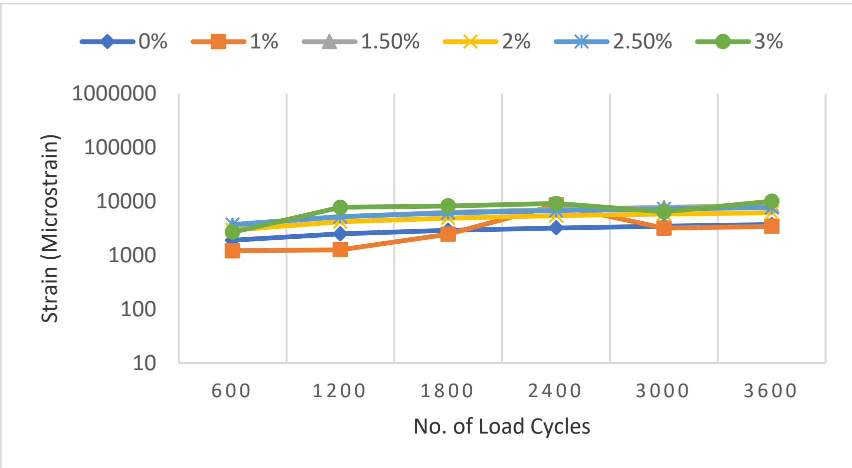

Figure 2: Relationship between cumulative strain and number of cycles

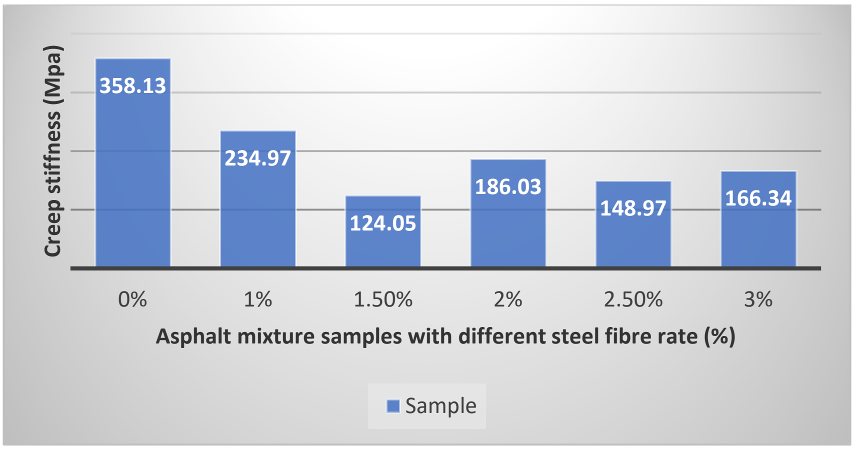

Figure 3: Effect of steel fibre asphalt mixture on Creep Stiffness at 40'c

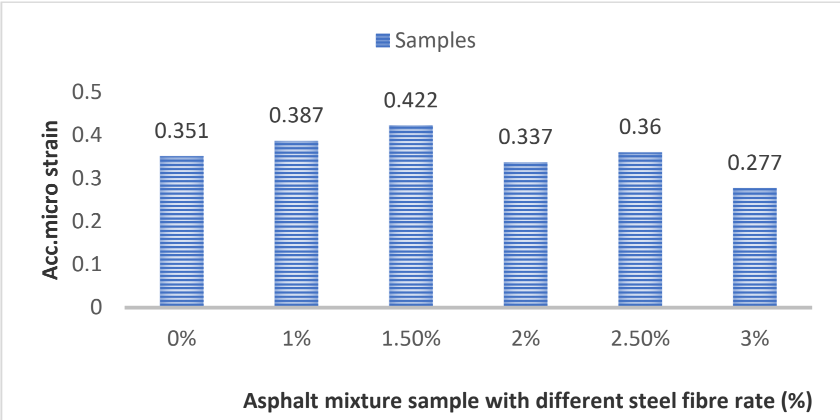

Figure 4: Effect of steel fibre on Accumulated Micro strain

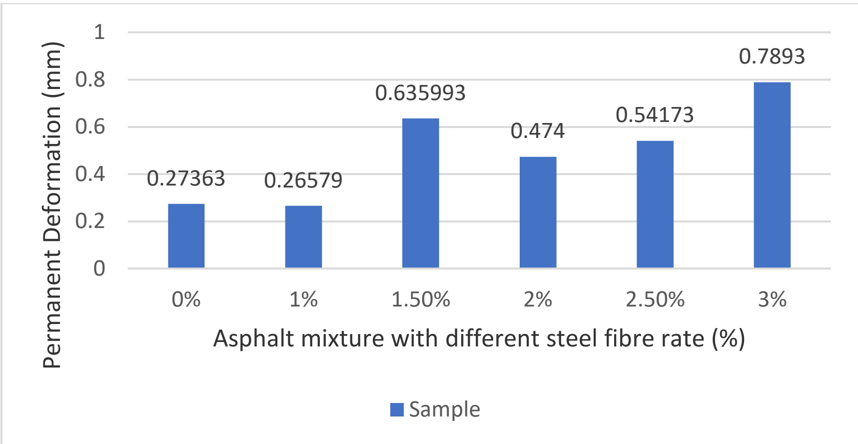

Figure 5: Effect of steel fibre asphalt mixture on permanent deformation

4. Conclusion

In summary, the objective of this research was to improve the characteristics of asphalt binders by incorporating steel fibre. There are some key points to consider. Firstly, there are many factors could lead to pavement deformation such as environment, truck speed and repeatedly heavy wheel loading. Traffic is as essential factor of pavement performance and majorly affected by the loading magnitude, configuration and the number of heavy vehicle load repetitions [6]. Therefore, the addition of a substantial amount of steel fibre can help to enhance the physical properties of asphalt mixture. Focusing on the performance of asphalt mixture, the combination of steel fibre and asphalt mixture was found to significantly affect the performance of asphalt mixture. Besides that, this particular combination produced the same outcomes to that of the standard asphalt mixture which is asphalt mixture without steel fibre. Based on the result, a certain quantity of steel fibre in asphalt mixture can cause dramatic improvements in the asphalt mixture's physical properties and performances. Meanwhile, the outcomes of the dynamic creep test revealed improved workability of creep stiffness and permanent deformation of asphalt mixture with the addition of certain amount of steel fibre.

As recommendations for future research, it is recommended to reduce the size of the steel fibre as the longer the steel fibre, the larger it caused voids. Secondly, future research should look at the fatigue effect of steel fibre asphalt mixtures. Thirdly, it is suggested to add any type chemical substances like Cecabase and Rediset as asphalt additive in steel fibre asphalt mixture to the increase the pavement ability and improve overall performance and properties of asphalt mixture [7]. Lastly, it is mainly recommended to identify the mechanical properties of steel fibre such as melting point, elasticity and density.

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