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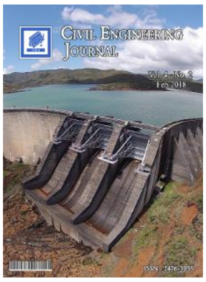

Mechanistic Approach for Reducing the Thickness of Asphalt Layer Incorporating Steel Slag Aggregate

Adham Alnadish [a*], Yusri Aman [a]

[a] *Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia- 86400 Parit Raja, Malaysia.*

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Abstract

This study aimed to evaluate the possibility of reducing the thickness of asphalt layer as a novel solution for the high density of asphalt layer incorporated with steel slag aggregate, which increase the cost of transportation. Mechanistic-Empirical Pavement Design (MEPDG) approach was employed to evaluate the benefits of introducing polyvinyl alcohol fiber in terms of reducing the thickness of asphalt layer as well as the extension service life of asphalt layer. On the other hand, the correlation between creep strain slope (CSS) and secant creep stiffness modulus (SCSM) were assessed to provide a better evaluation and understanding concerning of the outputs of the dynamic creep test. The findings of this study showed that introducing polyvinyl alcohol fiber into the mixtures at the optimum content (0.5 kg/ton) have reduced the thickness of asphalt layer by approximately 10%. Additionally, polyvinyl alcohol fiber has increased the performance of the asphalt mixtures concerning of resilient modulus and dynamic creep. Furthermore, the correlation between CSS and SCSM was strong, which indicates that evaluation of permanent deformation using CSS and SCSM parameters provides better actual assessment than accumulation strain.

Keywords: Shear Stress; Asphalt; Steel Slag; Polyvinyl Alcohol; Fiber; Reduce Thickness; Creep Strain Slope; Secant Creep Stiffness.

1. Introduction

Asphalt mixture is a composite material containing coarse and fine aggregate, filler, and bitumen [1]. However, consumption of the natural aggregate has been increased due to the increasing projects in pavement applications [2]. As a result, there have been considerable efforts by researchers over the last two decades to reduce the increasing demand for the natural resources in the civil applications by using plants wastes as an alternative [3]. In this regard, steel slag is considered as a well-known by-product of steelmaking, which is used in the civil applications. Steel slag is produced by two manufacturing processes, which are basic oxygen furnace (BOF) and electric arc furnace (EAF) [4, 5]. Moreover, steel slag aggregate has been used for many decades due to its ability to enhance the performances of asphalt layer. Above that, the production of asphalt mixtures from slag instead from natural aggregate would decrease the amount of raw material extraction and enable further environmental benefit since less industrial by-products would be disposed in landfills [6].

Several studies have evaluated the utilization of steel slag aggregate in the asphalt mixtures as a partial or total replacement to the natural aggregate. Based on their finding, replacing the natural coarse aggregate by steel slag (EAF) exhibited better performances in contrast to control asphalt mixtures that containing 100% of the natural aggregate in connection with resilient modulus, dynamic creep, cracking resistance, fatigue resistance and moisture susceptibility. These enhancements were attributed to the properties of the steel slag aggregate (EAF) with reference to roughness, angularity, hardness, as well as it provides better interlocking and durability [6-13]. On the other hand, steel slag

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* Corresponding author: adhmalnadish@gmail.com

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aggregate has disadvantages concerning of its high specific gravity, which is considered as a main concern due to the transportation cost [14]. Additionally, replacing the natural aggregate by 100% of steel slag requires higher amount of bitumen due to its high porosity thus leads to compatibility problems during paving [15]. Furthermore, steel slag consists of free lime (Cao) and free magnesia oxide (Mgo), which reacts with water, thus expansion volume may have occurred, the amount of those chemicals depends on the production process. Free lime content should be less than 4%, so that the asphalt layer is not exposed to cracking due to the expansion, if quantity of the free lime exceeds 4% the steel slag should be weathering in order to reduce free lime content [16, 17].

Conversely, rapid increase in traffic volume with heavy loading and environmental impact has cause early damages, which deeply affect the service life of pavement layer [18]. Therefore, engineers have provide evidence that the weak tensile strength of asphalt layer as major concern, which brings about adverse effect on the asphalt mixture performances, which reduces the service life of asphalt layer and requires a full depth maintenance, thus consumption of additional costs [19]. The major issue regarding the tensile properties includes the failures related to the fatigue cracking at moderate and low temperature; therefore, the asphalt layer required rehabilitation instead of regular maintenance. Additionally, increasing costs of material and rising consumption of natural resources have prompted engineers and researchers to find alternatives for road construction or rehabilitation [20].

Consequently, introducing fiber in the asphalt mixture is one of the distinctive alternatives for enhancing the efficiency of asphalt layer to resist loads inflicted upon it. Besides, adding fibers to asphalt mixtures may reduce asphalt layer thickness and increase the services life of pavement, thus minimizing transportation cost of the material, particularly for the materials that have a high density, as well as reducing the demand for the natural aggregate [21-23]. Hence, introducing fiber into asphalt mixtures that containing steel slag aggregate may reduce transportation costs as well as provide high performances of asphalt mixture, with regard to the resistance of cracking that developed at the bottom of the surface layer (wearing layer) due to the applied stress by vehicles. In other words, the higher asphalt mixture performance, the higher service life of asphalt layer [24].

2. Materials and Experimental

2.1. Materials

A 80/100 grade of bitumen produced by Petronas, Malaysia was used in the experimental. Conventional tests were conducted to identify the properties of the binder such as penetration, ductility, softening point and viscosity. The physical properties of the binder are summarized in Table 1. Two types of aggregate were used in this study; Electric Arc Furnace (EAF) steel slag aggregate obtained from NSL, Singapore and crushed granite aggregate supplied by Hanson quarry located in Batu Pahat, Johor, Malaysia. In addition, Polyvinyl Alcohol supplied from Mainland, China was used; Table 2 displays the physical properties of the Polyvinyl Alcohol, which is provided by the supplier and Figure 1. shows shape of the fibers, respectively. A dense fine graded with 12.5 nominal maximum size aggregate was selected. Table 3. presents the properties of the steel slag and granite aggregate. In addition, Figure 2 describes the selected gradation of the aggregate within Superpave specification.

Figure 1. Polyvinyl alcohol fibers

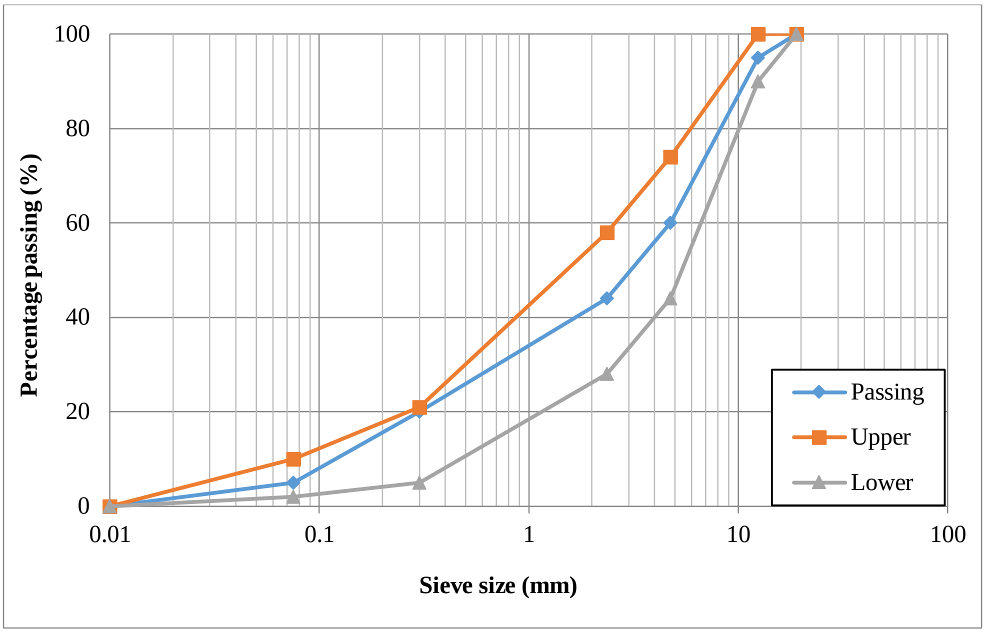

Figure 2. Gradation of designed aggregate

Table 1. Physical properties of the bitumen

Properties	Test value	Standard
Penetration at 25°C, 1/10 mm	87	ASTM D 36 - 06
Ductility at 25°C (cm)	> 100	ASTM D 113 - 07
Softening point	49	ASTM D 36 - 06
Specific gravity at (25°C) (g/cm3)	1.02	ASTM D 70 - 09
Viscosity @ 135 °C (cP) Viscosity @ 165 °C (cP)	487 144	ASTMD44
Mixing temperature Compaction temperature	160 °C 150 °C	ASTM D4402

Table 2. Polyvinyl Alcohol physical properties

Material Property	Measure
Material	Polyvinyl Alcohol (PVA)
Density	1.29 (g/cm3)
Tensile Strength	>1200 MPa
Modulus	>28 (GPa)
Melting Point	> 200 °C
Colour	Light yellow
Length	6 mm
Diameter	10-20um

Table 3. Physical properties of the aggregate

properties	EAF	Granite	Specification	Standard
Loss Angeles Abrasion	17.8	19.75	≤ 25%	ASTM C 131
Aggregate Crushing Value	22.6	25.4	≤ 25%	IS: 2386 (Part IV)
Bulk S.G	3.22	2.75	n/a	ASTM C127
Water absorption (%)	2.75	0.843	≤ 3%	ASTM C127
Free CaO content (%)	< 4%	n/a	4%	-

2.1. Mixtures Design

In this study, the asphalt mixtures containing coarse steel slag aggregate were incorporated with Polyvinyl Alcohol fibers at different proportions; i.e. 0.05, 0.15 and 0.3% by the total weight of the aggregate in order to produce reinforced asphalt mixtures. Mix0 and Mix1 represents the asphalt mixtures that containing 100% of granite and coarse steel slag aggregate, respectively. Meanwhile, Mix2, Mix3 and Mix4 corresponds to the asphalt mixtures containing coarse steel slag aggregate and incorporating of Polyvinyl Alcohol at different content; i.e. 0.05, 0.15 and 0.3% by total weight of the aggregate, respectively. The asphalt mixtures were prepared based on the Superpave specification [25]. Prior mixing, the aggregate was heated in the oven at the mixing temperature of 160 °C for four hours to ensure uniform temperature distribution within the aggregate. Then, the heated aggregate and bitumen were mixed in automatic mixer for one minute; then the fibers were introduced to the mixture and thoroughly mixed for another two minutes. This method called composite mixing. Thereafter, the mixtures were kept in the oven for two hours at the compaction temperature (150 °C) to simulate short-term aging, which represents producing, transportation and placing of the mixture in the field [1].

The Superpave gyratory compactor was used to produce the compacted asphalt mixtures by adopting 600 kPa pressure with 1.25° angle and speed of 30 rpm. 100 gyrations were employed, which based on the traffic load in the range of 3 to 30 million ESALs. Therefore, the volumetric properties of the mixtures were determined to meet the requirements of Superpave specifications. However, Figure 3 displays the Servopac Superpave Gyratory Compactor (SGC) and some of the produced samples. Table 4. shows the volumetric properties of the mixtures. As can be observed in Table 4, the asphalt mixtures comprising of polyvinyl alcohol fiber showed slightly lower bulk specific gravity as compared to the control mixtures. This was attributed to the slight increase in the thickness of the samples (0.5-1 mm). Thus, the samples weight in the water was increased in which the weight of the samples in water depends on the weight of the water displaced by the sample and the sample dimensions (volume).

Table 4. Volumetric properties of the asphalt mixtures

Mixtures properties	Mix0	Mix1	Mix2	Mix3	Mix4	Requirement
OBC	4.78	4.9	4.9	4.9	5.1	4-7
AV	4	4	4	4.2	4	3.5-5
VMA	15.91	14.7	14.65	15.44	15.2	Minimum 14
VFA	74.9	72.8	72.7	72.8	73.7	65-75
Bulk specific gravity	2.343	2.56	2.558	2.541	2.5٣9	N/A

Figure 3. Servopac Superpave Gyratory Compactor and the produced specimens

2.2. Resilient Modulus

Resilient modulus is defined as the strain energy that stored by material up to elastic limit. Resilient modulus is also used to estimate the elasticity modulus (E) of the material. However, this parameter is considered as main input in the Mechanistic Empirical Pavement Design approach, which is used to determine three different values, which are the horizontal strain (fatigue) at the bottom of the surface layer, vertical strain (rutting) on the top of the subgrade and the appropriate thickness of the pavement. These measurements are considered on the inputs such as loads, temperature, and resilient modulus of the material [26]. This test was conducted in accordance with ASTM D7369 [27], using servo hydraulic testing machine (UTM-5P). Prior to the test, the samples were conditioned in the climate chamber at the testing temperature of 25 °C for four hours to ensure that the equilibrium temperature is reached. The applied compressive load of 1000 N with haversine wave pulse was adopted, this load is non-destructive, and it was selected based on the 10% of indirect tensile strength. The frequency of the applied load was 1HZ, which represents the load width of 0.1 second and 0.9-second rest period to simulate the vehicle movement on the road. Moreover, every sample was tested at two angles (0 and 90°) and the average results per three specimens were calculated. UTM-5P machine's software computed the results by automatically calculating the resilient modulus of the mixture based on the applied load and the deformation that occurred. In addition, the deformation was measured using two set of Linear Variable Displacement Transducers (LVDTs).

2.3. Dynamic Creep

The accumulation of non-recoverable strain is generated due to the repeated load of the vehicle on the road, leading to the occurrence of permanent deformation. However, the permanent deformation is occurred at the top of 100mm due to the lateral movement of the layer [28]. Dynamic creep test was carry out in accordance with British standard BS DD 226 [29], in respect of assesses the resistance mixtures to the permanent deformation (rutting). Before testing, the specimens were conditioned in the climate chamber for four hours at 40 °C, to ensure that the temperature of the test has been equilibrated within the samples. The servo hydraulic machine (UTM-5P) was used to measure the permanent deformation of the specimens. The parameter of the test that include a stress of 12 kPa as a preload for 120 second to ensure the contact between the load and the specimen, thereafter the sample is subjected to repeated axial stress of 100 kPa. The wave pulse of the axial applied load is squared with a frequency of 0.5 HZ, the pulse loading comprising 1-second load width and 1-second rest period. The duration of the test is 3600 seconds, and the total numbers of the cycles are 1800, which is enough to compare the permanent deformation among the mixtures as well as to predict the permanent deformation. The result of the test consists of dynamic creep, accumulation strain and strain slope obtained from the machine's software and calculated based on the deformation that occurred due to the applied load. This deformation is measured using two sets of Linear Variable Displacement Transducers (LVDTs). Figure 4 shows the dynamic creep experimental setup.

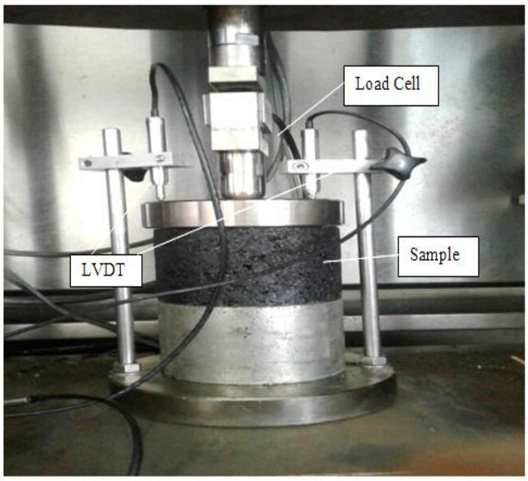

Figure 4. Dynamic creep experimental setup

2.4. Mechanistic–Empirical Design Approach

In this study, a new concept to minimize transportation cost and consumption of the natural aggregate was studied at which the mechanistic–empirical design approach was adopted to investigate the benefit of introducing polyvinyl alcohol fibre in increasing the service life of asphalt layer as well as to assess the possibility of reducing the thickness of asphalt layer. Bisar3 software was used to evaluate the benefit of reinforced asphalt mixture with regard to the possibility of reducing asphalt layer thickness as well as extension of the service layer. This software calculates the strains at the bottom of surface layer and at the top of subgrade layer based on the inputs data such as load and properties of the layers in terms of thickness and elastic modulus. In addition, the horizontal strain at the bottom of the surface layer is used to calculate the allowable repetition load until fatigue failure, while the vertical strain at the top of the subgrade layer is used to calculate the allowable repetition of axel until rutting failure. Furthermore, Equations 1 and 2 developed by Yang (1991) were employed to calculate the allowable repetition load until fatigue and rutting failure, respectively [30]. The proposed pavement section and its properties, which consist of four layers, are summarized in Table 5. However, the properties of the pavement section were selected based on the Malaysian standard specification for road works (JKR) [31]. Additionally, the load of standard dual wheel was selected in the analysis with a stress of 577 kPa and a radius of 105mm. However, the possibility of extending the service life of asphalt layer and reducing the thickness of asphalt layer are presented in the Equations 4 and 5, respectively.

$$\mathrm{Nd} = 1.365 \times 10^{-9}\ \varepsilon\mathrm{v}^{-4.477} \tag{1}$$

Where Nd is the number of repetition load to produce a rut of 12.7 mm with a reliability of 85%, while εv is the vertical compressive strain at the top subgrade layer.

Additionally, fatigue-cracking failure due to the repeated load of the axles is calculated as follow:

$$\mathrm{Nf} = 1.66 \times 10^{-10}\ \varepsilon\mathrm{t}^{-4.32} \tag{2}$$

Where Nf is the allowable number of axles load until fatigue failure, and εt is the horizontal tensile strain at the bottom asphalt layer. For the thin asphalt layers (less than 100 mm), Yang [30] suggested that the calculated allowable number of axles load until fatigue failure should be reduced by 20%.

Equations 3 and 4 are used to calculate the service life extension of pavement (TBR) and the possibility of reducing the thickness of asphalt layer (LTR), respectively.

$$\mathrm{TBR} = \mathrm{Nfm}/\mathrm{Nfu} \tag{3}$$

Where Nf is the number passes of axels until fatigue failure; while m and u the reinforced mixture and unreinforced mixtures, respectively.

$$\mathrm{LTR} = (\mathrm{Tu} - \mathrm{Tm})/\mathrm{Tu} \tag{4}$$

Where Tu and Tm = Thickness of the asphalt layer with and without fiber, respectively.

Table 5. The proposed pavement layers (conventional pavement)

Layer	Thickness (mm)	Resilient Modulus (MPa)	Poisson's ratio (ν)
HMA	100	Various	0.35
Base	250	350	0.4
Sub-base	300	200	0.4
Subgrade	-	100	0.45

3. Results and Analysis

3.1. Resilient Modulus

Results of the resilient modulus test for the mixtures are presented in Figure 5 The mixtures containing coarse steel slag aggregate and reinforced by Polyvinyl Alcohol fibre showed higher resilient modulus in comparison with the reference mixtures (Mix0 and Mix1) that containing 100% granite and coarse steel slag aggregate, respectively. In addition, the mixes that containing coarse steel slag aggregate (Mix1) showed higher resilient modulus than mixes that containing 100% granite aggregate. This is attributed to the mechanical properties of the steel slag aggregate concerning of its durability. On the other hand, Mix2 have the highest resilient modulus compared to Mix0 and Mix1 by approximately 16 and 9.4%, respectively. This is because Polyvinyl Alcohol fibres have enhanced the performance of the asphalt mixture by increasing the asphalt mixtures resistance to the indirect tensile strength. Conversely, Mix3 and Mix4 have higher resilient modulus than control asphalt mixtures (Mix0 and Mix1), while it showed less resilient modulus compared to Mix2. This was attributed to the high content of the fibre in the mixtures, which increased the samples thickness by approximately 0.5-1 mm, thus slightly higher deformation occurred.

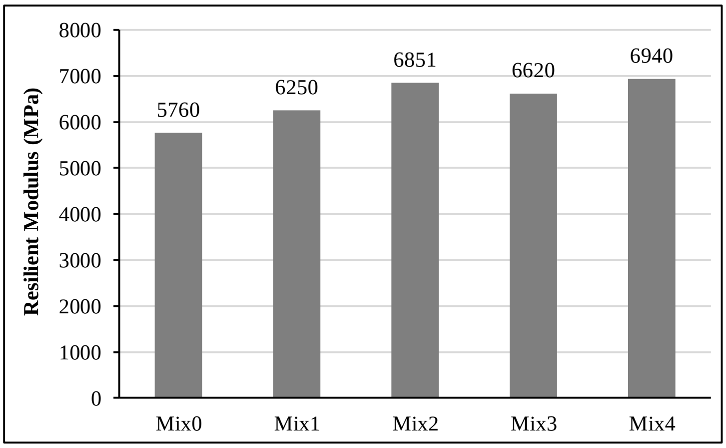

Figure 5. Results of the resilient modulus for the mixtures

3.2. Dynamic Creep

3.2.1. Accumulation Strain

The dynamic creep curve of the samples was obtained after 1800 cycles. This curve is shown in the Figure ٦, which represents accumulated strain of Mix0, Mix1, Mix2, Mix3 and Mix4, respectively. Furthermore, each accumulated axial strain curve consisting of two stages, the first stage called primary, while the second stage called secondary. In addition, the recoverable elastic strain occurs at the primary stage due to the compaction method and the gradation of the mixtures and not caused by the cumulative axial strain, while the viscoelastic strain occurs at the secondary stage because of the load cycles [32]. On the other hand, the terminated stage that represents failure of the specimen did not occur for all mixtures due to the limit of cycles. Moreover, the higher accumulated strained the lower permanent deformation resistance. As observed in Figure 6, Mix1 showed higher resistance to the permanent deformation as compared to the control mixtures (Mix0); this is attributed to the mechanical properties of the steel slag aggregate in terms of angularity and porosity. Moreover, Mix2 exhibited better permanent deformation resistance than Mix0 and Mix1 (control mixtures) by around 20 and 14%, respectively. This is because polyvinyl alcohol fibre has enhanced the mixture resistance to the permanent deformation. On the other hand, Mix3 and 4 showed slightly lower resistance to the permanent deformation as compared to the Mix2, due to high content of the fiber, which dramatically increased the permanent deformation at the primary stage, thus the permanent deformation is highly affected by the densification. Additionally, as shown in Figure 6. the correlation coefficient R^2 is approximately above 75% for the all curves, which indicates that the correlation between number of the cycles and the accumulated strain is good in terms of evaluating the permanent deformation.

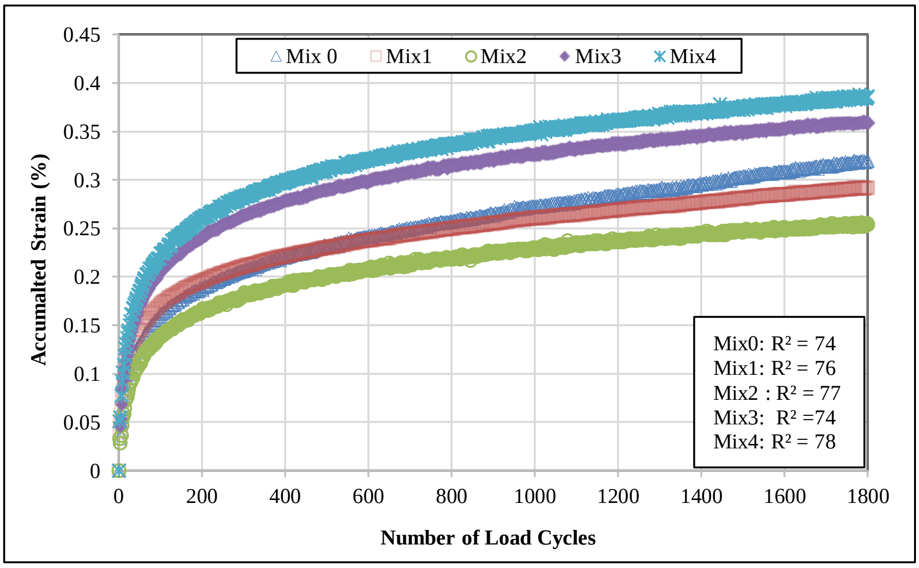

Figure 6. The accumulated strain against number of the cycles

3.2.2. Creep Strain Slope (CSS) and Secant Creep Stiffness Modulus (SCSM)

CSS is defined as the slope of the secondary stage, which caused by the accumulated strain. The cycles number is shown in Figure 7 at which the cycles start from the first stage to the transition point and this point is determined based on the slope of curve where the accumulated strain has same rate as well as linear with time, which is different from the primary stage. Moreover, the transition point deviated further from the initial axial strain, which negatively affect the results of stiffness dynamic creep due to the densification [33-36]. As can be observed in Figure 7, number cycles of the mixtures at the primary stage are approximately similar to each other with slight differences at the mixtures, which reinforced with fibers. This was attributed to the limitation of the test related to applied stress and temperature, which were fixed. In addition, Mixes 3 and 4 showed higher cycles number compared to the other mixtures, because of the high content of fibre, which required an increasing in the cycles number to avoid the primary stage that affected by the increment in the thickness of the samples due to the high content of polyvinyl alcohol fibre. CSS was employed to assess the susceptibility of the mixtures to the permanent deformation as it offers a better understanding of the dynamic creep behaviour. The higher CSS indicates that asphalt mixture is less resistant to the permanent deformation. In addition, CSS at the transition point was adopted to evaluate the resistance of the mixtures to the rutting (permanent deformation). It can be concluded from Figure 8, that Mix2 exhibited higher resistance to the permanent deformation compared to the other mixtures, while Mix3 and Mix4 exhibited slightly higher resistance than control mixtures. Additionally, Mix1 showed less CSS as compared to the control mixture without coarse steel slag aggregate (Mix0). The resistance of the mixtures to the rutting with respect to secant stiffens creep modulus is shown in Figure 9. The Secant stiffens creep modulus is defined as the ratio of the applied stress to the difference of axial strain at the transition point and the ultimate number of the cycles (1800). This is to ensure that stiffens creep modulus was determined based on the actual axial strain not by the initial axial strain that occurs by densification at the primary stage. Hence, the SCSM at the secondary stage describes the susceptibility of the mixtures to permanent deformation. Therefore, the secant stiffens creep modulus is calculated using. Equation 5:

$$\text{SCSM} = \frac{\sigma}{\varepsilon x - \varepsilon y} \tag{5}$$

Where σ is the applied stress, 100 kPa, while εx and εy are the accumulated strain at the transaction point and the ultimate cycle, respectively.

As clearly shown in Figure 9, the SCSM range from 270 to 285 MPa for the control mixtures (Mix0 and Mix1), which were relatively lower than Mix3 and Mix4, respectively. While, Mix2 achieved the highest value 420 MPa. Moreover, Figure 10. delineates the correlation between CSS and SCSM. It can be inferred that there is a strong correlation between CSS and SCSM. The relationship coefficient of the fitted curve, R^2, is 0.91 for the data of CSS and SCSM. In addition to that, when the CSS increases the SCSM decreases. Thus, the CSS and SCSM are considered helpful parameters to evaluate susceptibility of the mixtures to the permanent deformation, along with accumulated strain.

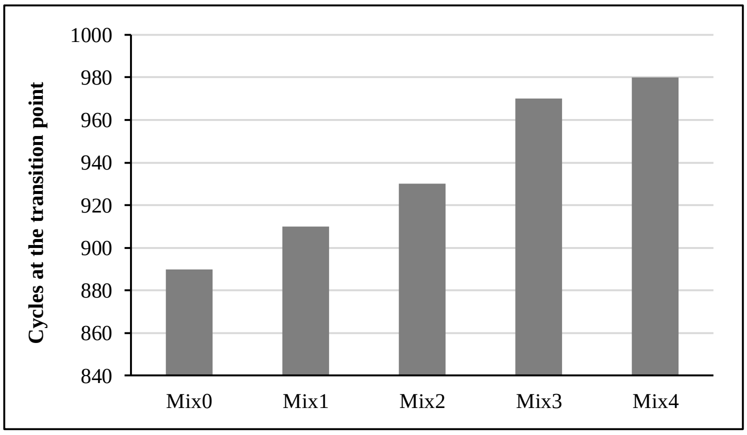

Figure 7. Number of the cycles until the transitions point

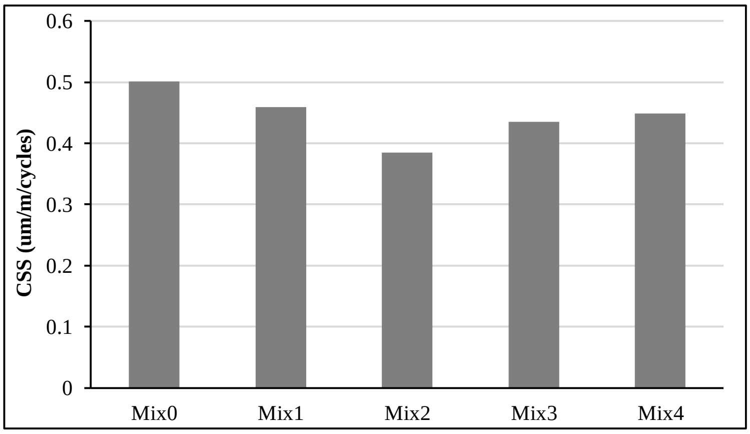

Figure 8. Creep strain slope of the mixtures

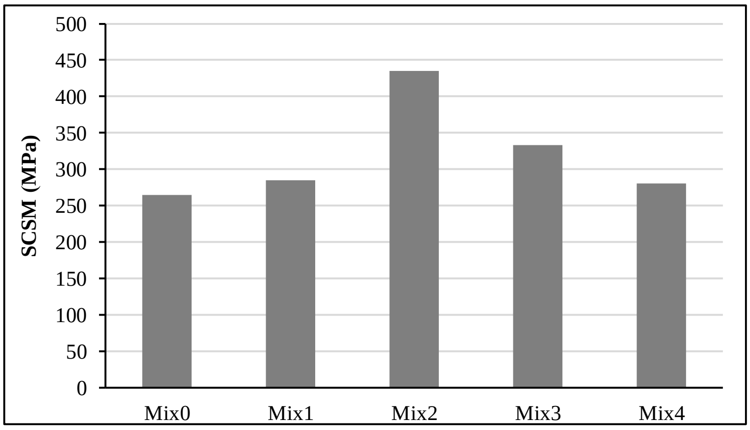

Figure 9. Secant stiffens creep modulus of the mixtures

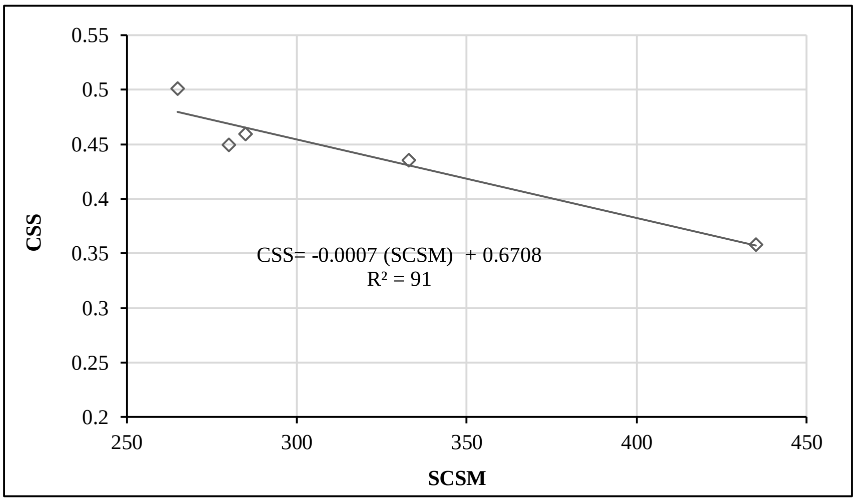

Figure 10. The correlation between SCSM and CSS

3.3. Benefit of Reinforced Asphalt Mixtures

Fatigue cracking and rutting (permanent deformation) are considered as the major failure in asphalt layer. Fatigue cracking occurs at the bottom of the surface layer due to the repetition load by vehicles, while rutting developed at the top of the subgrade layer [30]. The horizontal and vertical strain at the bottom of the surface layer (AC) and top of the subgrade layer are used to calculate the allowable repetition load. Mix0, Mix1, Mix2 are the mixtures that were assessed as a surface layer using mechanistic empirical design pavement approach. Mix0 and Mix1 represent the mixtures that containing 100% of granite aggregate and coarse steel slag aggregate, respectively. Mix2 was incorporated with coarse steel slag aggregate and the optimum content of the polyvinyl alcohol fibre (0.05% by total weight of the aggregate). Table 7. summarized the outputs of Bisar software, which it can be observed that the allowable number of repetition load until fatigue failure was the critical damage. However, Mix1 had extended the service life of asphalt layer by around 1.21 time compared to Mix0. While Mix2 improved the service life by 1.53 compared to the Mix0. In terms of the advantages of introducing fiber to reduce the asphalt layer thickness, it can be observed that Mix2 showed better service life than Mix0 by 1.3 and 1.1time longer after reducing the thickness by 5% and 10%, respectively. Furthermore, the thickness of asphalt layer that will be prepared by Mix2, which containing coarse steel slag aggregate and polyvinyl alcohol fibre at the optimum content (0.5kg/ton) can be reduced by around 10%. In addition, it will provide an extension in the service life by 1.1 times longer compared to the conventional asphalt layer, if prepared by Mix0 (granite aggregate).

Table 7. The outputs of the mechanistic empirical design pavement analysis

Mixture Type	LTR (%)	h(mm)	εh	εv	Nf (10^6)	Nd (10^6)	TBR
Mix0	0	100	102.3	196.6	28.7	53.5	1
Mix1	0	100	97.9	194.2	34.7	56.6	1.21
Mix1	5	95	102.2	199.5	28.8	50.1	1
Mix1	10	90	106.7	205	23.9	44.4	0.83
Mix2	0	100	92.6	191.2	44	60.7	1.53
Mix2	5	95	96.64	196.9	36.7	53.2	1.3
Mix2	10	90	101	202	30.3	47.4	1.1

4. Conclusions

This study aimed to evaluate the asphalt mixture containing coarse steel slag aggregate in regard to the resilient modulus and permanent deformation. In addition to that, the study focused on the investigating the possibility of reducing the asphalt layer thickness by introducing polyvinyl alcohol fiber at different percentages. The following outputs were made:

- Using steel slag as a coarse aggregate in the asphalt mixtures have improved the performance of the asphalt mixtures in terms of resilient modulus and permanent deformation.
- Utilization of steel slag as a coarse aggregate does not affect the bitumen content. In addition, selection of the gradation as finer-gradation has reduced the impact of steel slag porosity on the bitumen content.

- The compacted asphalt mixtures that incorporating coarse steel slag aggregate have higher specific gravity than conventional mixtures (granite aggregate) by around 8%, which may increase the transportation costs by 8%.

- Introducing polyvinyl alcohol into the asphalt mixtures containing coarse steel slag aggregate have increased the resilient modulus of the mixtures as well as exhibited higher resistance to the permanent deformation in contrast with the mixtures that containing 100% of granite aggregate and coarse steel slag aggregate, respectively. However, the optimum content of the polyvinyl alcohol was at 0.05% by total weight of the aggregate (0.5 kg/ton). In addition, the other proportion achieved better permanent deformation in comparison with the control mixtures in terms of CSS and SCSM.

- With respect to the permanent deformation, there is a strong correlation between CSS and SCSM at the transition point, which represents the number of cycles required to avoid the primary stage. However, these parameters provide a better evaluation than accumulation strain in terms of the mixtures resistance to the permanent deformation, due to the fact that the permanent deformation after the primary stage corresponds to the actual value, while the accumulation strain considered the total deformation.

- Based on the outputs of Bisar software, the asphalt mixtures containing coarse steel slag aggregate exhibited higher service life than conventional mixtures by 1.21 time longer, while the mixtures that incorporating coarse steel slag aggregate and the optimum content of polyvinyl alcohol fibre (0.5 kg/ton) showed the highest service life. On the other hand, the thickness of the asphalt layer containing coarse steel slag and the optimum content of polyvinyl alcohol can be reduced by around 10%, as well an extension of the life service by 1.1 as compared to the conventional layer with granite aggregate.

- The optimum content of the fibre in this study was 0.5 kg/ton, proving that introducing polyvinyl alcohol at the optimum content has the ability to reduce the cost by around 10% per ton in terms of the aggregate and the bitumen costs. Furthermore, adding polyvinyl alcohol fiber may also reduce the transportation cost by approximately 10% .However, the transportation costs depends on the distance between the quarry and site of the road construction.

5. Acknowledgements

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