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Effects of filler type and particle size on permanent deformation of Stone Mastic Asphalt (SMA) mixtures

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ABSTRACT

Stone Mastic Asphalt (SMA) is a gap graded special mix consists of up to 80% by weight of coarse aggregate and 8 - 12% by weight of filler. The high proportion of coarse aggregate provides an interlocking stone-on-stone skeleton that resists permanent deformation. Since SMA contains large amount of filler, this paper presents an evaluation of the effects of filler type and particle size on the permanent deformation properties of SMA mixtures incorporating granite aggregates, 80/100 penetration grade asphalt, and four different fillers (limestone as control, ceramic waste, coal fly ash, and steel slag). The selected fraction of filler (10% by the total weight of aggregate) was blended in three different proportions 100/0, 50/50, and 0/100 passing the 75 and 20 micron. To determine permanent deformation characteristics of bituminous mixtures by repeated cyclic axial load indirect tensile testing using the Universal Testing Machine (UTM) in accordance with procedures outlined in BS-EN 12697-25:2005. The Repeated Load Axial Test (RLAT) and Resilient Modulus test were carried out on twelve different SMA mixtures using Marshall cylindrical samples to evaluate the effects of filler types and filler particle size on the SMA mixture deformation properties. The results and the analysis of the fundamental parameters of permanent deformation and resilient modulus have indicated the improved stiffness and the potential benefits in terms of high temperature rutting (increased stiffness and elastic response) of laboratory blended and proprietary of SMA mixtures incorporating ceramic waste and steel slag fillers with medium size particles (50/50 proportion) compared to the control mix. The coal fly ash mixtures are the least susceptible to permanent deformation.

Introduction

The main cause of premature failure of pavements in Malaysia is rutting due to uncontrolled large and heavy axle loads, increased traffic levels, and increased tire pressures have added to the already severe demands of load and environment on the pavement system. As the viscoelastic properties of asphalt cement is very much temperature-dependant, asphalt binder becomes viscous and displays plastic flow when subjected to loads higher than its viscosity at a higher temperature. The plastic flow occurs due to lack of internal friction between aggregate particles and use of excess asphalt binder. This has facilitated the need to enhance and improving the characteristics and the properties of existing asphalt material. The one known form of binder improvement is by means of fillers, traditionally used to improve the temperature susceptibility of asphalt by increasing asphalt binder stiffness at high service temperatures, enhances the service properties over wide range of temperature, when asphalt binders are combined with fillers, mastic is formed this mastic can be viewed as the component which glues the aggregate together and which undergoes deformation when the pavement is stressed during service.

Kandhal and Parker (1998) and Kandhal (1999) reported that various studies have shown that the properties of mineral filler, especially the material passing through a 0.075-mm (No. 200) sieve have a significant effect on the performance of asphalt paving mixtures in terms of permanent deformation, fatigue cracking, and moisture susceptibility [26, 27]. They summarized the influences mineral filler can have on the performance of HMA mixtures as follows: (a) Depending on the particle size, fines can act as filler or an extender of asphalt cement binder. In the later case, an over-rich Hot Mix Asphalt (HMA) mix can lead to flushing and rutting. (b) Some fines have a considerable effect on the asphalt cement, making it act as a much stiffer grade of asphalt cement compared with the neat asphalt cement grade and, thus, affecting the HMA pavement performance including its fracture behavior.

In another study, Kandhal PS (1998) reported that as different filler possess different properties, they can alter the physical or chemical properties of the binder in different ways. This alteration process largely depends on the following factors; (a) Type of filler, (b) Physico-chemical activity of filler, and (c) Concentration of filler in the mix [25]. Mohammad et al. (2000) stated that structurally, fillers consist of different sized particles. The larger ones fill up the voids between coarse aggregates and increase the stiffness of the bituminous mixtures while the smaller sized fraction increases binder film thickness enhancing viscosity of the binder and improving the binder cohesion. This, in turn leads the asphalt cement to coat the aggregate particles with a thicker film. As a matter of fact, adhesion between aggregate and binder increases, which results in a declination of mixture segregation [30].

Kavussi and Hicks (1997) reported that fillers contribute to workability, compaction characteristics, voids in the mix, and

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expected to significantly improve rutting resistance as a result of increasing moduli (viscous component) [28].

Anderson and Geotz (1973) evaluated the stiffening effect of a series of one-sized fillers ranging from 0.6 to 75 mm (passing No. 200 sieves). They concluded that both the size of the filler and bitumen binder composition had a significant influence on stiffening effect and that a proportion of the bitumen could be replaced by fine filler (<10 µm) but the mixtures produced were very sensitive to changes in the filler type [3]. However, Mogawer and Stuart (1996) investigated eight different filler materials which were known in Europe and they found that good quality fillers and poor quality fillers did not affect the performance of mixtures [29].

Hicks et al. (1997) in a study of four types of filler - limestone, quartz, fly ash and kaolin - attributed the higher stiffening potential of kaolin to the fineness and the surface affinity to bitumen [28].

Superior Performing Asphalt Pavements (Superpave), Superpave Mix Design (1996) reported that, previous research showed that the addition of mineral fillers (such as limestone powder) to asphalt could improve the rutting resistance performance. The mineral powder improved the high-temperature thermal properties, presumably because its small particle size which resulted in a large area of the interface between mineral powder and asphalt [33].

Ward (1979) study baghouse fillers from 16 different sources with a wide variety of particle size distribution, mineralogy and other physical properties, he indicated that fine dust, primarily 20 µm and finer, tended to combine with the bituminous binder and act as an asphalt extender [34].

Since the effect of mineral fillers is more prominent in gap graded asphalt mixtures, such as the stone matrix asphalt that contains large amounts of fines, it is important to understand the changes that occur in the properties of the mixture due to the fines. The primary objective of this study was to determine the impact of different types and particle size of fillers on the stiffness and deformation properties of stone mastic asphalt mixture. In this study four different mineral fillers namely, limestone (LS) as control filler, ceramic waste (CW), coal fly ash (CFA), and steel slag (SS) with three different particle size proportions. The selected fraction of mineral filler (10% of the total weight of aggregate) was blended in three different particle size proportions 100 % passing the 75, 50/50 % passing 75/20, and 100 % passing 20 micron to determine the effects of these fillers and particle size on the SMA mixture stiffness and deformation properties.

Materials and Methods

To satisfy the objective of this study, the SMA specimens were prepared at optimum asphalt content (OAC). Granite aggregate, asphalt with 80/100 penetration, cellulose oil palm fiber (COPF), one gradation, and four types of fillers with three different particle size proportions were used in preparing SMA specimens. Each SMA mixture was evaluated for resilient modulus and permanent deformation performance. The Resilient Modulus test was carried out in accordance with ASTM D 4123 [19] and the RLAT test was done using the Universal Testing Machine (UTM) in accordance with procedures outlined in BS-EN 12697-25:2005 to evaluate the effect of filler type and particle size on the deformation properties of SMA mixtures[24].

Asphalt:

Since the performance of the fillers were of concern in this study, the commonly used 80/100 penetration grade soft binder was selected. This is to make sure there are no additional properties derived from additives if modified binders such as 60/70 and PG 76 were used. The traditional rheological tests performed to evaluate the asphalt properties included the penetration test at 25°C [13], ring and ball (R&B) softening point test [12], viscosity test at 135°C and 165°C using Brookfield viscometer [10], ductility [20], and specific gravity [15] tests. The physical properties of the bitumen, the standard used, and the results are presented in Table 1.

Aggregate:

Crushed granite aggregate was selected because siliceous gravel is very hard materials while limestone is very soft. Granite aggregate is somewhere between these two extremes and provides excellent qualities. The cubical shape of granite aggregate provides unique properties to contribute to an SMA mixture and it is the most widely used aggregate on the Malaysian roads. Table 2 presents the properties of the coarse and fine aggregate and the test results. One aggregate gradation was chosen such that it was within the master gradation band for a 12.5 mm Nominal Maximum Aggregate Size (NMAS) SMA. The crushed granite aggregate was blended to meet the gradation recommended by the National Asphalt Pavement Association (NAPA) [32]. The aggregates were blended and the fillers were then added to the blend. The gradation, together with the corresponding mix designations are given in Table 3 and the resultant particle size distribution for SMA Mixture together with NAPA specification limits are shown in Figure1.

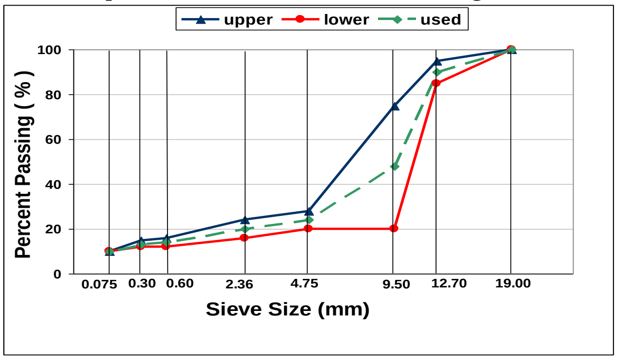

Fig 1. Aggregate gradation curve of SMA mixture by the NMAS 12.5 mm

Filler:

In this study four fillers namely Limestone, Ceramic Waste, Coal Fly Ash, and Steel Slag with particle size proportion (passing 75µm / passing 20 µm) with three combination of filler 100/0, 50/50, and 0/100 were evaluated for direct comparison. Fillers were crushed and ground to pass the standard sieve size 0.075 mm and 0.02 mm [14]. The particle size distributions of the fillers are shown in Figure 2.

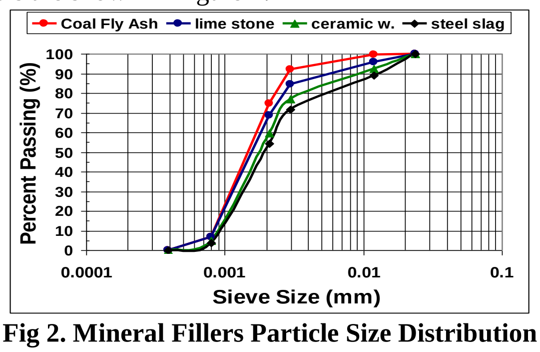

Fig 2. Mineral Fillers Particle Size Distribution

Fiber:

The fiber selected for inclusion in the testing matrix was Cellulose Oil Palm Fiber (COPF). This COPE is a University Putra Malaysia (UPM) initiated technology product and have had extensive use in SMA on Malaysian roads. Muniandy, (2006) reported that the COPF has been tried during full-scale and placement on an experimental basis and has proven very effective [31]. The (COPF) is introduced to the mix at a dosage of 0.3% of the total weight of mix.

Mix design and test method:

The method of Optimum Asphalt Content (OAC) determination based on the Marshall Method of mix design is available in another literature. The mixtures were designed in accordance to the design procedure outlined by the AASHTO PP 41-02 (2004), "Standard Practice for Designing Stone Mastic Asphalt (SMA)" [1]. These standards ensure that sufficient Voids in Mineral Aggregate (VMA), Voids in the Coarse Aggregate (VCA), and air voids exist in the mixture. It also ensures that an aggregate skeleton with stone-on-stone contact is produced. The design was accomplished for a 12.5 mm nominal maximum aggregate size (NMAS) SMA.

Samples preparation

The filler particle size combinations (passing 75/20 micron) were mixed at three different ratios, 100/0, 50/50, and 0/100, twelve mix designs were made with the same blend of coarse and fine aggregates to keep aggregate angularities and mineralogical characteristics constant. The only variable in the mixtures was the filler type and the filler proportion. The twelve mix designs were labeled as shown in Table 4 represent four types of filler and three combinations of particle size to produce SMA mixtures at established mixing and compacting temperatures using Marshall Mix Design procedure to sustain medium traffic using 50 blows per side. In this study triplicate specimens were prepared at each optimum asphalt content, a total of 36 specimens were prepared to evaluate the effects of the added filler type and particle size on the stiffness and deformation properties of SMA mixtures.

Resilient modulus:

The Indirect Tensile Stiffness Modulus (ITSM) test which is defined by BS DD 213 is a nondestructive test and has been identified as a potential means of measuring the stiffness properties and study effects of temperature and load rate [23]. Under uniaxial loading the stiffness modulus is generally defined as the ratio between the maximum stress and the maximum strain (ASTM D 4123 and BS DD 213) [14, 23]. The ITSM (Sm) in Mega Pascal (MPa) is calculated by the following equation:

$$Sm = [L\ (\nu + 0.27)] / D\ t \qquad (1)$$

Where L is the peak value of the applied vertical load (N), D is the mean amplitude of the horizontal deformation obtained from 5 applications of the load pulse (mm), t is the mean thickness of the test specimen (mm), and v is the Poisson's ratio (a value of 0.35 is normally used). The magnitude of the applied force conditioning pulses such that the specified target transient diametral deformation was achieved. The test is performed at 25 °C.

Repeated load axial test (RLAT):

One method for the assessment to determine permanent deformation characteristics of bituminous mixtures by repeated cyclic, or optionally, static axial load indirect tensile testing using the Universal Testing System (UTS) developed by Industrial Process Controls (IPC Global). Brown et al., (1994) reported that the repeated load tests (dynamic creep) correlate better with actual in-service pavement rutting than static creep tests [21]. The test equipment consists of a load frame capable of applying up to 4.5 kN loads for 0.5 seconds followed by a rest period of 1.5 seconds. The standard compressive stress is 200 kPa and the test is conducted at a temperature of 50ºC on cylindrical specimens. The main parameter derived from the RLAT test is the loading cycles versus permanent deformation (accumulated strain).

In this study Universal Testing Machine (UTM) was employed in accordance with procedures outlined in ASTM D 4123. Each test was conducted with three replicates to increase reliability of results. The RLAT test in accordance with BS-EN 12697-25:2005 is undertaken to establish the resistance of a mixture to permanent deformation. Marshall Cores (100x50mm) were used as specimen. Prior to testing, the specimens were conditioned in an environmental chamber for 3-4 hours. During the test, the specimen was pre-loaded by applying a load of 20 kPa (10% of peak stress) for one minute, to compensate for sample variations and ensures that samples surface and loading platen are completely in contact with each other and the loose parts in samples surface have done their deformation moves, so that the deformation measured during the test are related to the samples resilient and creep modulus. Thereafter, it was subjected to repeated axial loading; the loading parameters consisted of a haversine wave shape with 200 kPa peak stress and 1Hz frequency. The load was applied for 0.1 second followed by a rest period of 0.9 second as shown in Figure 4.

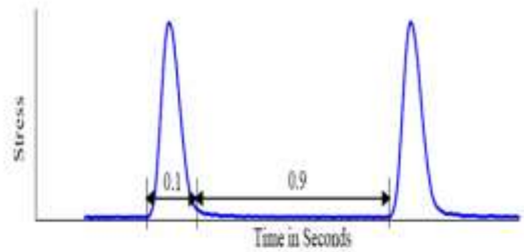

Fig 4. Haversine waveform

Pulse time was chosen 1second for high trafficked volume roads. Also vehicle speeds were observed at 0.1second rise time for low speed was used. The specimen was subjected up to a 3600 load cycles, at which point the accumulated strain was evaluated. The axial strain obtained at the end of the test is a valuable measure of the specimen's resistance to permanent deformation. During the test, axial deformation (strain) is measured as a function of time throughout the test. Table 5 presents the set up parameters for the RLAT test.

Results and discussion

Material testing:

The aggregates, mineral fillers, asphalt binder, and cellulose fiber were tested for compliance with the applicable specifications in the "Standard Specification for Designing Stone Mastic Asphalt". All materials were found suitable for use in SMA.

Resilient modulus:

The Resilient Modulus (RM) results for the twelve mixtures at 25°C are presented in Table 6 and Figure 5 respectively.

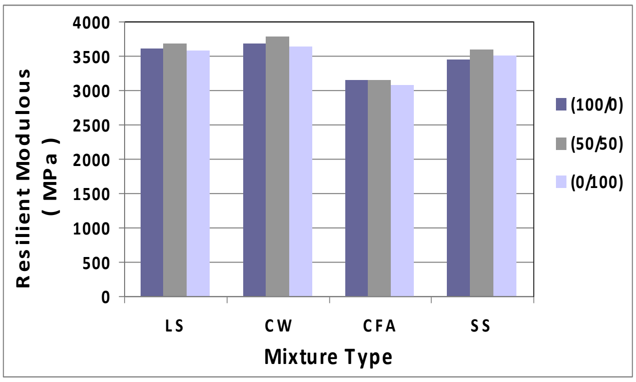

Fig 5. Resilient Modulus Test Results

A general trend was observed regardless the filler type that the Resilient Modulus values of paving mixtures increased when decreasing the particle size up to 50/50 ratio then Resilient Modulus started to decrease. It was observed also that the mixtures containing ceramic waste (C5) with 50/50 filler ratio are higher while the Resilient (Stiffness) modulus values of paving mixtures containing coal fly ash (F5) and steel slag (S5) with 50/50 filler ratio are slightly lower as compared to paving mixtures comprising of limestone filler (the control mix). The Filler proportion of 50/50 (medium size particle) regardless the filler type showed better response than the other proportions and among the four types of filler, ceramic waste mixture exhibited superior Resilient Modulus values compared to the other types as depicted in Figure 5. It is also observed that the results of the four types with the three filler ratios specimens are consistent with a very small variation; this small variation could be due to the small variation in the percentage of air voids. Based on the Resilient Modulus test results the ceramic waste (C5) with a proportion of 50/50 exhibited the best performance.

Permanent deformation (rutting):

The permanent deformation performance of the asphalt mixtures was quantified by the percentage strain after 3600 cycles, number of cycles to failure, and by the minimum rate of strain (micro-strain per cycle (με/cycle)) over the linear phase of the deformation response calculated by linear regression through the 3600 load cycles. The RLAT results for the twelve mixtures are presented in Figure 6 through Figure 9.

The plots showed the accumulation of permanent strain for the twelve SMA mixtures and clearly indicated a superior resistance to permanent deformation (% strain) for limestone mixture (L5) of the SMA asphalt mixture followed by ceramic waste mixture (C5), steel slag mixture (S5) ranked third and coal fly ash (F0) ranked forth.

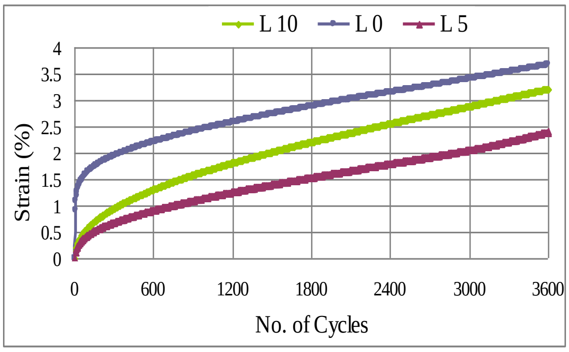

Fig 6. Axial strain versus number of load cycles for SMA Mix with limestone filler

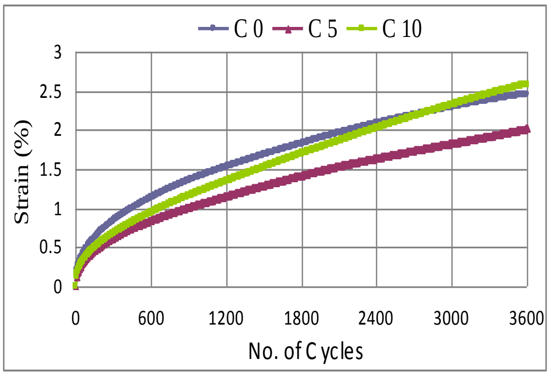

Fig 7. Axial strain versus number of load cycles for SMA Mix with ceramic waste filler

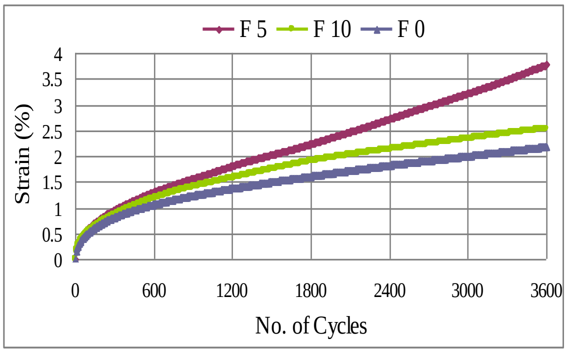

Fig 8. Axial strain versus number of load cycles for SMA Mix with coal fly ash filler

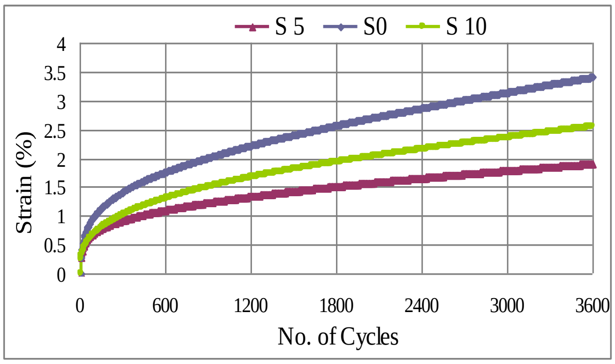

Fig 9. Axial strain versus number of load cycles for SMA Mix with steel slag filler

In order to compare the permanent deformation performance of all the SMA asphalt mixtures, the RLAT parameters, in terms of percentage strain, minimum strain rate (micro-strain per cycle), and number of cycles to failure are presented in Table 7 and depicted in Figure 10. Also included in Table 7 are the rutting performance rankings for each of the parameters for all the SMA mixtures.

The rankings as a function of the RLAT parameters and filler types and particle size have also been presented in the form of a bar chart in Figure 10. Triplicate specimens were experimented for each mixture type, and each vertical bar in Figure 10 is a representation of the average number of cycle's value of the three specimens per mixture. If a specimen never showed any tertiary flow during the whole loading cycle (i.e. 3600 cycles), the number of cycles (flow number value) of that specimen was reported as 3600 cycles.

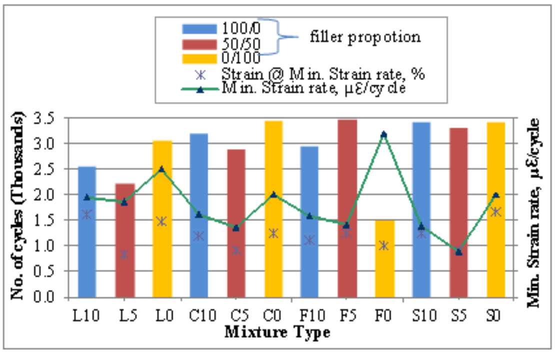

Fig 10.Permanent deformation performance results for All SMA Mixtures

Of the three parameters mentioned earlier, the minimum strain rate (µε/cycle) can be considered to be a more reliable measure of the rutting performance of the asphalt mixtures as this parameter, unlike the percentage strain, is independent of the initial strain experienced during the RLAT test. The plots of the strain rate versus number of cycles (number of repetitive load applications) are shown in Figure 11 through Figure 14.

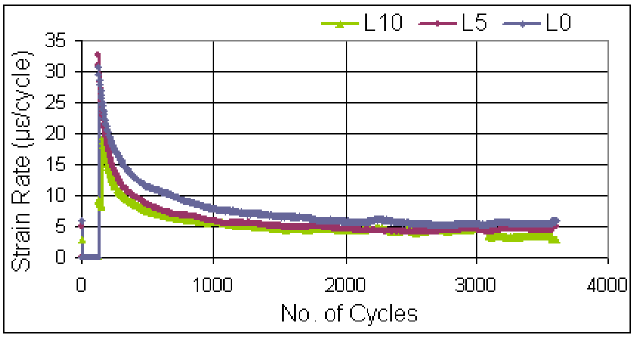

Fig 11. RLAT Strain Rate versus number of load cycles for SMA Mix with limestone filler

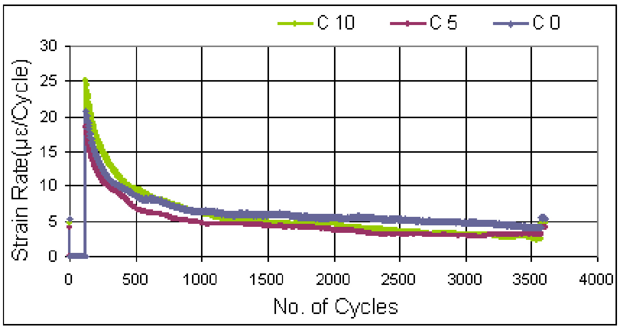

Fig 12. RLAT Strain Rate versus number of load cycles for SMA Mix with ceramic filler

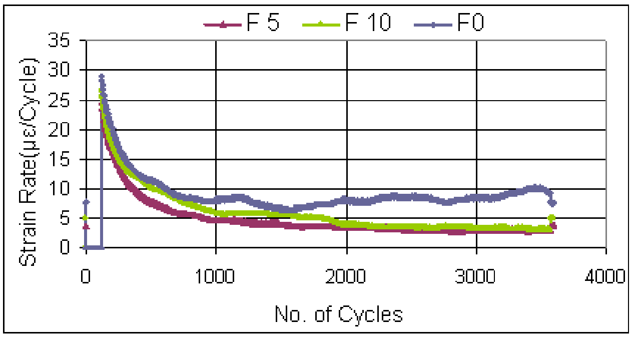

Fig 13. RLAT Strain Rate versus number of load cycles for SMA Mix with coal fly ash filler

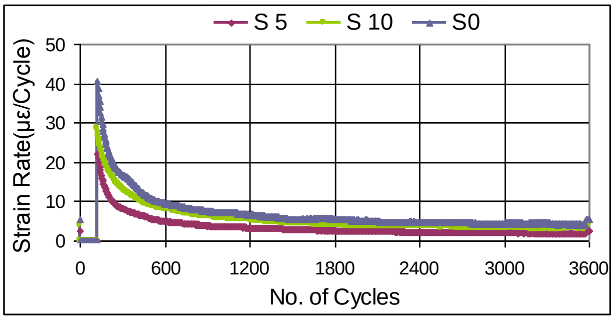

Fig 14. RLAT Strain Rate versus number of load cycles for SMA Mix with steel slag filler

The results in Table 7 and Figure 11 - 14 clearly showed the superior rutting resistance (in terms of minimum strain rate) of the steel slag (S5) SMA mixtures with 50/50 proportion (medium size particles) as demonstrated by lower value of strain rate compared to the control mixtures containing the limestone filler (L5) for the same SMA mixtures. However, this improvement was substantially significant for the ceramic waste dust (C5 and C10) and coal fly ash (F5 and F10) with 50/50 and 100/0 proportions of SMA mixtures. In terms of number of cycles to failure coal fly ash (F10) with 100/0 proportion demonstrates the superior rutting resistance followed by ceramic waste (C0 and C5) and steel slag (S0 and S10).

Conclusions

Two approaches have been used in this paper to quantify the relative performance of a series of SMA Mixtures containing different type of fillers and different particle sizes. The approaches have consisted of practical mechanical property SMA asphalt mixture testing with laboratory measurements of asphalt mixture Resilient Modulus (stiffness modulus) and Permanent Deformation (Rutting) performance.

Firstly, the Resilient Modulus or Stiffness Modulus is considered to be a very important performance characteristic of the pavement. It is a measure of the load-spreading ability of the bituminous layers and controls the level of traffic induced tensile strains at the underside of the road base, which are responsible for fatigue cracking together with the compressive strains induced in the subgrade that can lead to permanent deformation. The results of resilient modulus testing of SMA mixtures showed that the medium size particle had caused the highest stiffening effect among the other particle size proportions regardless filler type.

Secondly, The RLAT test was carried out in dynamic mode of loading. This test gives results, which allow the characterizations of the mixtures in terms of their long-term deformation behavior and it is important to shed valuable insight into asses rutting. General trend was observed regardless the filler type that, the SMA mixtures with medium particle size filler proportions (S5, C5, F5, and L5) experienced higher rut resistance compared to the coarse and fine size filler proportions. This is consistent with the results of resilient modulus testing of SMA mixtures which showed that the medium size particle has caused the highest stiffening effect among the three particle sizes proportions, this kind of behavior is expected since the medium size particles when combined with asphalt fill up the voids between coarse aggregates more than the large size alone, which effectively increase the mastic content and increase the stiffness of the bituminous mixtures while the smaller sized fraction increases binder film thickness enhancing viscosity of the binder and improving the binder cohesion.

General trend was observed that, the SMA mixtures (regardless of filler type) with small size filler experienced lower resilient modulus and lower rut resistance compared to the other two particle size proportions, this could be attributed to the influence of the fine particles serving or acting as binder extenders, which effectively increasing the mastic content in the mixtures resulting in an over-rich asphalt mixture. This could result in a situation where the voids would be overfilled with binder, resulting in a potentially unstable mix and can lead to flushing and rutting. As the filler particle size increases, the larger sized fraction forms part of the aggregate skeleton structure resulting in stiffer mix and enhancing rutting resistance. Based on the results of this study the following conclusions are made:

1. The analysis of the fundamental parameters of resilient modulus as measured with the UTM, have indicated the improved stiffness of laboratory blended and proprietary of SMA mixtures compared to the control mix and mixtures prepared with 50/50 filler proportion passing the 75/20 micron sieve (medium size filler particles) have the highest stiffness modulus regardless the filler type.
2. For the test temperature of 50°C and based on minimum strain rate; improvement in rutting resistance was observed for the medium particle size filler mixtures regardless the filler type.
3. Based on accumulated strain, the rutting resistance of the SMA mixtures under study is in the order, limestone (LS50/50), ceramic waste (CW100/0), steel slag (SS50/50), and coal fly ash (CFA 50/50).
4. In the SMA asphalt concrete testing regardless the filler type, the small size particles showed the highest strain rate which indicating low resistance to rutting as well as the lowest resilient modulus which indicating low load spreading ability.
5. All the fillers used in this study play an important role in improving the rutting resistance of SMA. These filler materials significantly enhance the potential high temperature performance in SMA and are being encouraged for use in hot climates.
6. As the filler size increased (medium to large) the stiffening effect was much more significant than the increased lubrication effect, which resulted in stiffer mixtures as indicated by the performance of steel slag, ceramic waste, and coal fly ash. Therefore, the rut resistance was significantly improved compared to the control filler.

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Table 1. Physical properties of Asphalt

Parameter measured	Test method	Value
Specific gravity at 25°C, (g/cm³)	ASTM D70	1.03
Penetration at 25°C, (0.1mm), 100 g, 5s	ASTM D5	84
Softening point (R&B), °C	ASTM D36	48
Viscosity at 135°C,Pascal second (Pa.s)	ASTM D4402	0.413
Viscosity at 165°C, Pascal second (Pa.s))	ASTM D4402	0.100
Ductility at 25°C, (cm)	ASTM D113-07	>100

Note: 1 Pascal second (Pa.s) = 1000 centipoise (cP)

Table 2. Properties of coarse and fine aggregate

Test	Standard used	Results
Los Angeles Abrasion (%)	ASTM C 131	22.3
Aggregate Impact Value	BS 812: Part 3	7.84%
Flakiness Index	ASTM D 4791, BS 812	14.89%
Elongation Index	ASTM D 4791, BS 812	1.55%
Coarse aggregate Angularity One or more fractured face Two or more fractured face	ASTM D 5821	 97% 93%
Fine aggregate Angularity, Air voids % (loose)	ASTM C 1252	53%
Water absorption (%)	AASHTO T 85	0.5
Specific Gravity of Coarse Aggregate	ASTM C 127	2.62
Specific Gravity of Fine Aggregate	ASTM C 128	2.58

Table 3. Aggregate gradation

Sieve size (mm)	19.00	12.5	9.50	4.75	2.36	0.60	0.30	0.075
% passing (NAPA) Specification Limits	100	85 -95	Max. 75	20 -28	16 - 24	12 -16	12 - 15	8 -10
% passing used	100	90	70	24	20	14	13	10

Table 4. SMA mixtures abbreviations used in the study

Mix Type	*Abbreviation*
Limestone (LS) filler fraction 100% passing 75 micron sieve	*L10*
Limestone (LS) filler fraction 50/50% passing 75/20 micron sieve	*L5*
Limestone (LS) filler fraction 100% passing 20 micron sieve	*L0*
Ceramic waste (CW) filler fraction 100% passing 75 micron sieve	*C10*
Ceramic waste (CW) filler fraction 50/50 % passing 75/20 micron	*C5*
Ceramic waste(CW) filler fraction 100% passing 20 micron sieve	*C0*
Coal fly ash (CFA) filler fraction 100% passing 75 micron sieve	*F10*
Coal fly ash (CFA) filler fraction 50/50 % passing 75/20 micron	*F5*
Coal fly ash (CFA) filler fraction 100% passing 20 micron sieve	*F0*
Steel slag filler (SS) fraction 100% passing 75 micron sieve	*S10*
Steel slag filler (SS) fraction 50/50 % passing 75/20 micron sieve	*S5*
Steel slag (SS) filler fraction 100% passing 20 micron sieve	*S0*

Table 5. Set up parameters for RLAT Test

Loading function	Cyclic loading stress	Cycle duration	Cycle repetition time	Preload time	Termination cycle count	Termination strain
Haversine	200kPa	100 ms	1000 ms	60 sec	3600	9 %

Table 6. Resilient modulus test results

Mix type	LSD			CWD			CFA			SSD		
	L10	L5	L0	C10	C5	C0	F10	F5	F0	S10	S5	S0
RM	3600	3672	3568	3679	3785	3627	3140	3152	3075	3437	3583	3498

Table 7. The RLAT Permanent Deformation Properties Test Results

SMA Mix Type	Deformation Properties of SMA Mixture					
	Strain %	Minimum Strain Rate (με/cycle)	Loading Cycles	Ranking by		
				Strain %	Minimum Strain Rate	No. of Cycles
L10	3.213	3.875	2556	11	8	10
L5	1.690	3.730	2224	1	7	11
L0	2.936	4.975	3060	10	11	7
C10	2.390	3.243	3185	6	6	6
C5	1.816	2.735	2898	2	2	9
C0	2.524	3.975	3448	9	9	2
F10	2.226	3.173	2933	5	5	8
F5	2.491	2.830	3468	8	4	1
F0	2.026	6.390	1496	4	12	12
S10	2.483	2.793	3414	7	3	4
S5	1.839	1.801	3294	3	1	5
S0	3.317	4.020	3418	12	10	3