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Comparative Assessment of Rutting Resistance between Porous and Stone Matrix Asphalt Concrete

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ABSTRACT

Porous asphalt concrete pavement is the pavement with high voids content that allows water to infiltrate through its surface. This could support the skid resistance at heavy rainfall areas and assess in fast drainage of the rainfall. Stone Matrix Asphalt Concrete (SMA) is known as mixture with a gap-graded aggregate. The SMA design concept relies on stone-on-stone contact to provide strength and a rich mortar binder to provide durability. It tough, stable, rut-resistant mixture usually used to support heavy traffic. In this investigation, the resistance to permanent deformation (rutting) under repeated compressive stresses of both types of asphalt concrete pavement was assessed. Asphalt concrete specimens of 102 mm height and 102 mm of diameter have been prepared in the laboratory at optimum binder content of 5.2 %. Specimens were subjected to three levels of repeated compressive stresses of (0.068, 0.138 and 0.206) MPa in the Pneumatic Repeated Load System PRLS at 20°C. The permanent deformation was monitored with the aid of LVDT (Linearly Variable Differential Transformer). Compressive stress level of (138) kPa was implemented. The loading cycle consists of load repetitions application for 0.1 second followed by 0.9 seconds of rest period. It was observed that the permanent deformation of porous mixture is higher by (22.5, 61.2, 34.1) % than that of SMA under Stress level of (0.068, 0.138, 0.206) MPa respectively. It was concluded that high rutting susceptibility of porous asphalt concrete exists as compared to SMA. The coarser gradation of porous asphalt mixture with lower fines content as compared to SMA mixture exhibit significant influence on aggregate particles interlock which can resist the initial deformation regardless of the applied stress level.

Keywords: *Asphalt concrete, Porous, SMA, Rutting, Compressive stress*

INTRODUCTION

Porous and stone matrix asphalt concrete are both have high voids content and used for surface course layer of the pavement.

Putman and Kline, [1] stated that porous asphalt concrete pavement mixture is usually designed with an open graded aggregate gradation to increase the number of fully permeable air voids, this allows water to penetrate through the voids in a proper drainage process, removing it from the surface of a roadway much faster than traditional dense-graded pavement. The mixture of such pavement surface layer can have a void index ranging between 16% and 22%, to allow proper drainage, WAPA, [2]. Kanitpong *et al.*, [3] studied and quantified the effect of air void content, specimen thickness, aggregate shape, and aggregate gradation on hydraulic conductivity of porous asphalt concrete.

The results of the investigation have indicated that air void content is the predominant factor controlling hydraulic conductivity; however, aggregate shape and gradation also have a statistically significant influence. Miradi *et al*, [4] reported that the behavior of asphalt concrete under load as degeneration of the material and the limit of elasticity can be described by the stress-strain relationship for asphalt concrete in compression. Qin, [5] stated that porous friction course has the advantages of improving the riding quality and noise reduction effectiveness. However, it was reported that because of the large voids in the pavement, this could give rise to the asphalt binder more vulnerable to the air, the sun, the rain, and other negative factors. This will cause rapid declines of the binder properties soon and cause the early damage such as loosen and stripping.

Chairuddin *et al.*, [6] focuses to examine the compressive strength and the stress strain relationship of porous asphalt. It was found that the stress strain curve of compression test results for asphalt concrete was same with stress strain curve of the porous asphalt while the compressive strength was 2.4 MPa and the voids ratio was 19.2 %. Ma *et al.*, [7] evaluated the approaches of implementing additives to improve the durability and strength of the porous asphalt through laboratory testing. It was found that fiber enhanced its durability and anti-cracking performance at low temperature; hydrated lime improved its moisture stability while weakening its durability.

Norhidayah *et al.*, [8] reported that addition of carbon fibers to asphalt concrete mixture can significantly improve its mechanical properties, improve the performance of asphalt pavement, and prolong the fatigue life of a pavement structure. Shukla *et al.*, [9] concluded that fiber modified asphalt mixtures have shown increased stiffness and resistance to permanent deformation. Fatigue characteristics of the mixtures were also improved. Kumar *et al.* 2009 [10] reported that the permanent deformation decreases with an increase in fibers content, indicating a decrease in rutting potential. Mahrez *et al.* [11] found that the addition of fiber has the potential to resist structural distress that occur in road pavement as result of increased traffic loading, thus improving fatigue life by increasing the resistance to cracking and permanent deformation.

On the other hand, and as reported by Cooley and Brown, [12], Stone matrix asphalt (SMA) has been used and have had either a (12.5 or 19.0) mm nominal maximum aggregate size (NMAS). Fine SMA mixes were rut resistant and thus should be more durable. Permanent deformation test on SMA was conducted by Awanti, [13] using immersion wheel tracking test. It was concluded that SMA shows 42% higher rut resistance when compared to control mixture. Two aggregate gradations, with nominal maximum aggregate sizes (NMAS) 16 and 13 mm were adopted to prepare SMA mixtures and their laboratory performances were compared by Sarang *et al.*, [14].

Polymer-modified bitumen (PMB) was used as the binder material and no stabilizing additive was used. Specially prepared slab specimens were used to check the rutting resistance of SMA mixtures. It was concluded that the first SMA mixture was better resistant to rutting, and in wheel-tracking test, deformations were 0.4–0.7 mm less than the second SMA slab for all wheel passes. After 10,000 passes, rut depth was 4.1 mm and 4.8 mm for the first and second SMA slab respectively. Sarsam and Khalil, [15] studied the behavior of SMA under repeated tensile stress, It was concluded that Resilient modulus Mr of SMA mixture with stabilizing agent (coal fly ash) is higher than the values attained for SMA mixture without fly ash by 30% in general, while Mr decalin by 50% after moisture damage. The aim of the present investigation is to comparatively assess the permanent deformation under repeated compressive stresses of SMA and porous asphalt.

MATERIALS AND METHODS

Asphalt Cement

Asphalt cement was obtained from Dora refinery; the physical properties are demonstrated in Table 1.

Table1. Physical Properties of Asphalt Cement

Test procedure as per ASTM, [16]	Result	Unit	SCRB, [17] Specification
Penetration (25□C, 100g, 5sec) ASTM D 5	43	1/10mm	40-50
Ductility (25□C, 5cm/min). ASTM D 113	156	Cm	≥ 100
Softening point (ring & ball). ASTM D 36	49	□C	50-60
After Thin-Film Oven Test ASTM D-1754			
Retained penetration of original, % ASTM D 946	31	1/10mm	< 55
Ductility at 25 □C, 5cm/min, (cm) ASTM D-113	147	Cm	> 25
Loss in weight (163□C, 50g,5h) % ASTMD-1754	0.175		-

Coarse and Fine Aggregates

Coarse and fine aggregates were obtained from Al-Nibaee quarry, Table 2 shows the physical properties of aggregates.

Table 2. Physical Properties of Al-Nibaee Coarse and Fine Aggregates

Property as per ASTM, [16]	Course Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C 127 and C 128)	2.610	2.631
Apparent Specific Gravity (ASTM C 127 and C 128)	2.641	2.6802
Percent Water Absorption (ASTM C 127 and C 128)	0.423	0.542
Percent Wear (Los-Angeles Abrasion) (ASTM C 131)	20.10	-

Mineral Filler

The mineral filler passes sieve No.200 (0.075mm). The filler used in this work is limestone dust and was obtained from Karbala governorate. The physical properties of the filler are presented in Table 3.

Table 3. Physical Properties of Filler (Limestone Dust)

Property	Value
Bulk specific gravity	2.617
% Passing Sieve No.200	94

Stabilizing Additive

Coal Fly ash was used for SMA in this work. Fly ash was added at 1% by weight of aggregate, the chemical properties for fly ash are listed in Table 4. Table 5 shows physical properties of Fly ash.

Table 4. Chemical Properties of Fly As

Property	Percent %	ASTM, 2015- C 618 Specifications	
		Class F	Class C
SiO3	54.70	SiO3 + Al2O3 + Fe2O3 ≥ 70%	SiO3 + Al2O3 + Fe2O3 ≥ 50%
Al2O3	31.91		
Fe2O3	8.79		
SO3	0.06	≤ 5%	≤ 5%
CaO	1.50	----	----

Table 5. Physical Properties of Fly Ash

Property	Value
specific gravity	2.0
Passing Sieve No.200	99%
Specific surface area (m²/ kg)	650

Carbon Fibers

Carbon Fibers were added to porous asphalt concrete at a rate of 0.3% by weight of mixture. The length of the fibers is (2 cm) as demonstrated in Figure 1. These fibers were obtained by using a paper shredder machine. The physical properties are shown in Table 6.

Selection of Asphalt Concrete Combined Gradation

The selected gradation for SMA follows the Gap gradation suggested by many researchers, Asi, [18]; Myers, [19]; Nejad et al., [20]; and Bernard, [21]. Figure 2 demonstrates the gradation adopted with 12.5 (mm) nominal maximum size of aggregates. The selected gradation for porous pavement follows ASTM D-7064, [16] specification, the nominal maximum size of aggregate is 12.5 mm for wearing course. Many trial aggregate gradations were selected and tried. The final adopted gradation is demonstrated in Figure 2.

Fig. 1 The Carbon Fibers Implemented

Table 6. Physical characteristics of carbon fibers

Test Properties	Typical Value
Nominal thickness (mm)	0.167
Fiber Length (mm)	Can be produce any length
Color	Black
Density gm/cm3	1.82
Tensile Strength (N/mm^2)	40000
Elongation-at-Break, %	1.7
Tensile Modulus of elasticity (KN/mm^2)	225
Base	Polyacrylonitrile
Temperature of Carbonization	1400 °C

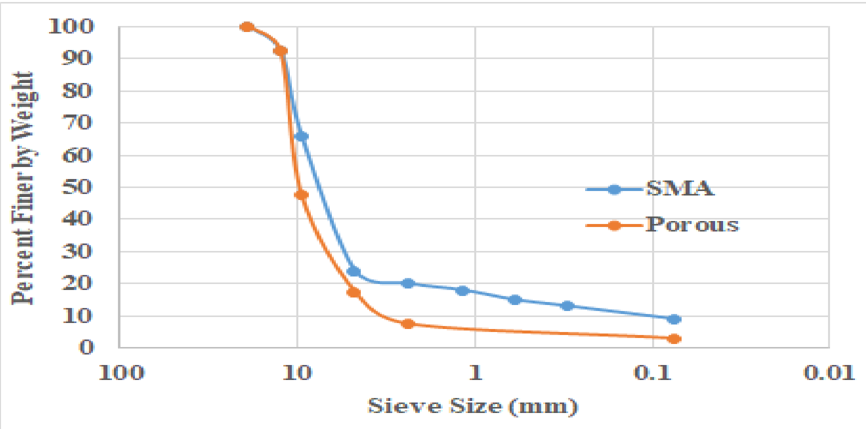

Fig. 2 Grain Size Distribution OF Asphalt Concrete

Preparation of Porous Asphalt Concrete Mixture

The aggregate was dried in an oven to a constant weight at 110˚C, and then separated by sieving to different sizes. Coarse and fine aggregates were combined with the required amount of mineral filler to meet the selected gradation. The combined aggregates mixture (coarse, fine and filler) was then heated to (150˚C) in an oven. The asphalt cement was heated to (150˚C) to produce a kinematic viscosity of (170±20) centistokes. Then the desired amount of asphalt binder was added to the heated aggregate, and thoroughly mixed by hand for two minutes using a spatula until all the aggregate particles were covered with thin film of asphalt cement. In the case of specimens that contain carbon fibers, the carbon fibers are cut to the prescribed length of 2 cm and added as 0.3% of the total asphalt concrete mixture weight. The fibers were added to the aggregate before heating and mixed thoroughly. Details of mixture design can be found in Sarsam and Majeed, [22].

Preparation of SMA Mixture

The aggregate was dried to a constant weight at 110 ºC, then sieved to different sizes, and stored. Coarse and fine aggregates were combined with mineral filler to meet the specified gradation. The combined aggregate mixture was heated to a temperature of 150 ºC before mixing with asphalt cement, then fly ash was added to the aggregate. The asphalt cement was heated to the same temperature of 150 ºC, then it was added to the heated aggregate to achieve the desired amount and mixed thoroughly using mechanical mixer for two minutes until all aggregate particles were coated with thin film of asphalt cement.

Preparation of Porous Asphalt Concrete and SMA Specimens

Specimens of 102 mm in height and 102 mm in diameter were prepared. Mold and spatula were heated to a temperature of (140˚C) on a hot plate. Apiece of non- absorbent paper, cut to size, was placed in the mold bottom prior to the introduction of the mixture. The asphalt mixture was placed in the preheated mold and then vigorously spaded 15 times around the perimeter and 10 times around the inside with a heated spatula. The compaction temperature of mixture was monitored to be within (150˚C). Each specimen was subjected to a static compaction to the target bulk density of 2.018 gm/cm^3. The specimens were left overnight in mold to cool at room temperature and then it was extracted from the mold with the aid of mechanical jack. Figure 3 exhibit part of the prepared specimens. The optimum asphalt content was 5.2 % by weight of aggregates. The optimum asphalt content was determined as per Marshall method. Details of obtaining the asphalt content for each mixture could be found at Sarsam and Khalil, [15] for SMA, and Sarsam and Majeed, [22] for porous pavement.

Repeated Compressive Stresses test

The prepared Specimens of both mixtures were subjected to the repeated compressive strength test at 20 ºC under various stress levels using the pneumatic repeated load system PRLS. The load assembly applies repetitive compressive stresses on the specimen in the form of rectangular wave with constant loading frequency of (60) cycles per minutes. A heavier sine pulse of (0.1) sec load duration and (0.9) sec rest period was applied over the test duration. Before the test, the LVDT was assembled and set to zero and the pressure actuator was adjusted to the specific stress level of (0.068, 0.138, 0.206) MPa. The average deformation of triplicate specimens was calculated and considered for obtaining the permanent deformation. Similar procedure was reported by Sarsam and Jasim, [23]. Test was conducted as per ASTM, [16]. Figure 3 exhibit the repeated compressive stress setup.

Fig. 3 Repeated compressive stress in the PRLS

RESULTS AND DISCUSSION

Permanent Deformation Behavior of Asphalt Concrete

Permanent deformation is one of the common forms of pavement distress and is mainly generated by accumulation of deformation under repetitive compressive stress due to traffic loading. Specimens were exposed to repeated compressive stresses using the PRLS device under the implemented stress levels of (0.0689, 0.1379, and 0.2068) MPa (at 20°C). The permanent deformation of the mixtures was monitored and calculated throughout the loading process. Table 7 exhibits the values of permanent deformation of the mixtures.

Table 7. Permanent Microstrain under Repeated Compressive Strength at Different Levels of Stress.

Mixture Type	Permanent Deformation (Microstrain)		
	Compressive Stress level		
	0.068 MPa	0.138 MPa	0.206 MPa
Porous Asphalt Concrete	4900	12900	16100
Stone Matrix Asphalt Concrete SMA	4000	8000	12000

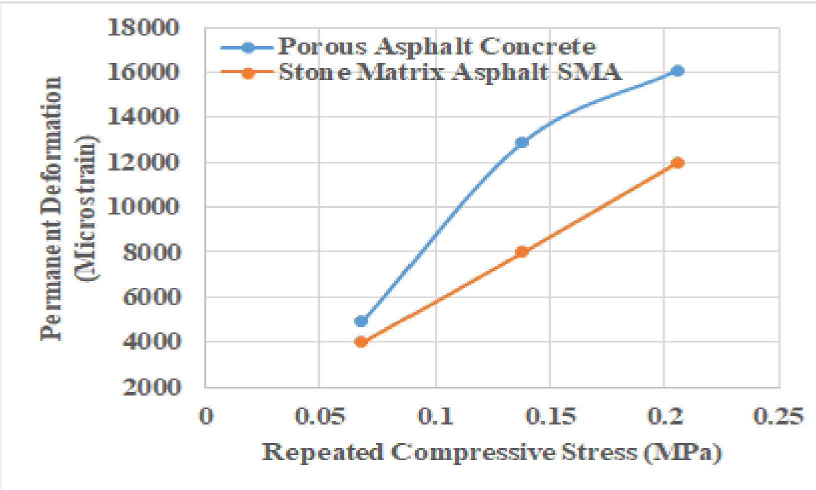

Fig. 4 Variation of permanent deformation for both mixtures under various stress levels.

It can be noted that the development of permanent deformation is highly dependent on the level of stress, and the permanent deformation increases with the increment of repeated compressive stress regardless of the mixture type. Higher permanent deformation could be observed for porous asphalt concrete as compared to SMA. The permanent deformation of porous mixture is higher by (22.5, 61.2, 34.1) % than that of SMA under Stress level of (0.068, 0.138, 0.206) MPa respectively. Such finding may indicate high rutting susceptibility of porous asphalt concrete exists as compared to SMA. On the other hand, Figure 4 exhibits the variation of permanent deformation for both mixtures under various stress levels. It can be observed that the deformation increases by (163.2 and 258.5) % when the stress level changes from (0.068 to 0.138, and 0.206) MPa respectively for porous mixture while the deformation increases by (100 and 200) % when the stress level changes from (0.068 to 0.138, and 0.206) MPa respectively for SMA mixture. Similar findings were reported by Hamzah and Yatim, [24]. Table 8 demonstrates the permanent deformation parameters of the mixtures. The intercept represents the permanent deformation (microstrain) after the first load repetition, while the slope is the rate of deformation throughout the repeated loading period. The intercept of porous mixture increases by (81.6, and 160) % when the Stress level increases from (0.068 to 0.138, and 0.206) MPa respectively. However, the intercept of SMA mixture increases by (237, and 788) % when the Stress level increases from (0.068 to 0.138, and 0.206) MPa respectively. On the other hand, the slope become steeper in general as the stress level increase for porous mixture while it exhibits gentle impression as the stress level increase for SMA mixture. The slope for porous mixture increases by (18.5 and 16.2) % when the Stress level increases from (0.068 to 0.138, and 0.206) MPa respectively, while the slope of SMA mixture decreases by (15.5 and 31.8) % when the Stress level increases from (0.068 to 0.138, and 0.206) MPa respectively. Such behavior can indicate the significant susceptibility of porous mixture to deformation under repeated loading and lower fatigue life when compared to SMA mixture. Similar findings were reported by Chairuddin *et al.*, [6] and Mashaan et al., [25].

Table 8. Permanent Deformation Parameters

Stress level	**0.068 MPa**		**0.138 MPa**		**0.206 MPa**	
Mixture type	**Intercept Microstrain**	**Slope**	**Intercept Microstrain**	**Slope**	**Intercept Microstrain**	**Slope**
Porous Asphalt Concrete	464.7	0.302	844	0.358	1210	0.351
Stone Matrix Asphalt Concrete	141.6	0.481	477.1	0.406	1258.3	0.328

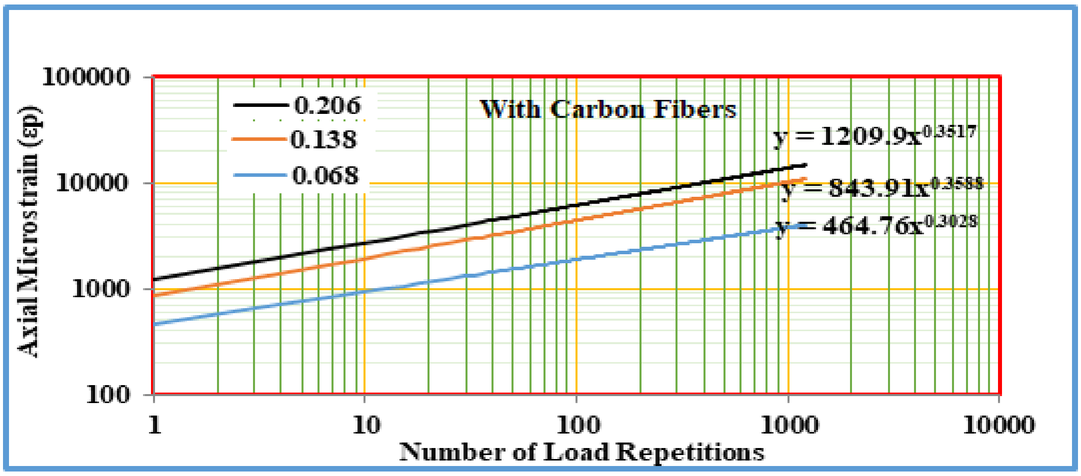

Fig. 5. Relationship between Permanent Deformation & Loading Cycles for Porous Mixture

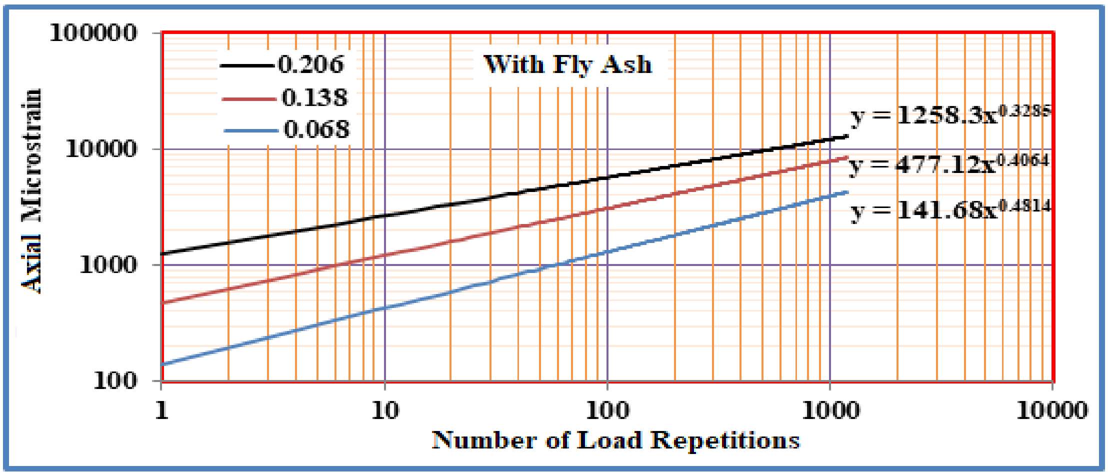

Fig. 6 Relationship between Permanent Deformation & Loading Cycles for SMA Mixture

Figure 5 demonstrates the permanent deformation and loading cycles relationship for porous asphalt concrete mixture, while Figure 6 exhibit the deformation under loading cycles of SMA mixture. It can be noted that the development of permanent deformation is strongly dependent on the stress level. The initial permanent deformation after the first load repetition exhibit significant influence on the rate of deformation and on total deformation which increases with increasing stress. The coarser gradation of porous asphalt mixture with lower fines content as compared to SMA mixture exhibit significant influence on aggregate particles interlock which can resist the initial deformation regardless of the applied stress level. This behavior of materials agrees with the results of Patil *et al.*, [26] and Qiu and Lum, [27].

CONCLUSION

Based on the limitation of materials and testing methods adopted, the following conclusions may be drawn.

1) The permanent deformation increases with the increment of repeated compressive stress regardless of the mixture type. Higher permanent deformation could be observed for porous asphalt concrete as compared to SMA. High rutting susceptibility of porous asphalt concrete exists as compared to SMA.
2) The permanent deformation of porous mixture is higher by (22.5, 61.2, 34.1) % than that of SMA under Stress level of (0.068, 0.138, 0.206) MPa respectively.
3) The deformation increases by (163.2 and 258.5) % when the stress level changes from (0.068 to 0.138, and 0.206) MPa respectively for porous mixture while the deformation increases by (100 and 200) % when the stress level changes from (0.068 to 0.138, and 0.206) MPa respectively for SMA mixture.
4) The intercept increases by (81.6, and 160) % and (237, and 788) % when the Stress level increases from (0.068 to 0.138, and 0.206) MPa for porous and SMA mixtures respectively.
5) The slope increases by (18.5 and 16.2) % and decreases by (15.5 and 31.8) % when the Stress level increases from (0.068 to 0.138, and 0.206) MPa for porous and SMA mixtures respectively.
6) The coarser gradation of porous asphalt mixture with lower fines content as compared to SMA mixture exhibit significant influence on aggregate particles interlock which can resist the initial deformation regardless of the applied stress level.

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