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Dynamic Behavior of Stone Matrix Asphalt Concrete (SMA)

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ABSTRACT

Stone Matrix Asphalt concrete (SMA) is one type of road pavement material which was developed to be more resistant to permanent deformation. it is a gap graded mix with higher proportion of coarse aggregate, lower proportion of middle size aggregate and higher proportion of mineral filler and binder content. In this investigation, an attempt has been made to implement coal fly ash as a binder absorbent and stabilizing agent against drain down of binder. Specimens of 102 mm diameter and 63.5 mm height were compacted using Marshal method. Specimens were subjected to repeated indirect tensile stress under controlled environment of (25 and 40) °C. The deformation was monitored with video capture, and the resilient modulus was calculated. It was concluded that the fly ash exhibits a positive influence on deformation and modulus as compared to the control SMA mixture. 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.

Keywords: *Resilient modulus, SMA, Deformation.*

INTRODUCTION

Durability of the stone-mastic asphalt concrete (SMA), containing various stabilizing additives: Armidon and Viatop was investigated by Yastremsky et al, [1]. The rutting in the SMA containing these additives was investigated. Experiments showed that the SMA containing Armidon has the increased values of operational properties. Its ability to resist the plastic deformation during repeated wheel loads is higher than the same ability of SMA with Viatop by 6%. The influence of adding various percentages of waste crumb rubber WCR on the stiffness and fatigue properties of stone mastic asphalt (SMA) mixtures have been investigated by Mashaan et al, [2].

The results show that the stiffness modulus of rubber stabilized SMA samples containing various contents of WCR is significantly high in comparison with that of non-stabilized samples, and it is less severely affected by the increased temperature compared to the non-stabilized samples. Bernard, [3] demonstrated that SMA is a gap graded hot mix asphalt HMA used to maximize rutting resistance and durability in heavy traffic conditions. SMA has a high coarse aggregate content that interlocks to form a stone skeleton that resists permanent deformation. Relatively higher amount of bitumen is used in such pavements to which fibres are added to provide stability of bitumen and to prevent the drain down of binder. It was concluded that typical SMA composition consists of 70-80% coarse aggregates, 8-12% filler, 6-7% binder and 0.3% fibre. Mixing and paving methods are like HMA. The SMA mixes were found by Talati and Talati, [4] to be having good stone-on-stone contact. Addition of crumb rubber and modified aggregates decreased the drain down value and hence the stabilizer additives can be avoided. The test proved that there is no stripping in the SMA mix prepared using modified aggregates and 10% stripping in the mix with crumb rubber.

TSR was found to be more than 80% for all the SMA mixes used in the study. It was concluded that Higher TSR is obtained for SMA Mix using modified aggregates which indicate better cohesive strength of this mix as compared to SMA mix using crumb rubber. Asi, [5] compared the performance of HMA and SMA mixtures. Samples from both mixtures were fabricated at their optimum asphalt contents of 5.3% for HMA and 6.9% for SMA mixtures. Tests that included Marshall stability, loss of Marshall stability, split tensile strength, loss of split tensile strength, resilient modulus, fatigue, and rutting testing were performed on both mixtures. Test results showed that although the HMA have higher compressive and tensile strengths, SMA mixtures have higher durability and resilience properties. laboratory investigations were carried out by Awanti, [6] on SMA mixes prepared using SBS (styrene-butadiene-styrene) and polymer modified bitumen PMB with coconut fibres as stabilizer, results are compared with SMA mixes prepared with neat bitumen using coconut and cellulose fibres as stabilizers. The performance studies such as static indirect tensile strength test at different temperatures, Indirect tensile fatigue test at different stress levels and permanent deformation test at 12 mm rutting were carried out on SMA mix and results were compared with SMA mix prepared using neat bitumen grade and coconut fibre as stabilizer. It was concluded that stone matrix asphalt mix with modified bitumen and coconut fibre shows higher static indirect tensile strength at different temperatures, higher fatigue life and higher rut resistance when compared to control mix of SMA. Liu et al, [7] investigated the effects of nominal maximum aggregate size (NMAS) on the performance of stone matrix asphalt (SMA). The volumetric characteristics and performance properties obtained from wheel tracking tests, permeability test, beam bending test are compared for SMA mixes with different NMAS. The results indicated that voids in mineral aggregate and voids filled with asphalt of SMA mixtures increased with a decrease of aggregate size in aggregate gradation. Increase of NMAS contributed to improvement of the rutting resistance of SMA mixtures. However, a decrease of NMAS showed better cracking and ravelling resistance. In a study by Sarang et al, [8] shredded waste plastics (SWP) are used as stabilizing additive, to prepare SMA mixtures with conventional viscosity graded 30 bitumen. Mixtures were prepared with four different levels of SWP content, and another mixture without any stabilizers was also prepared using polymer-modified bitumen (PMB). Tensile strength, moisture susceptibility, rutting resistance and fatigue behaviour were determined for all mixtures. From the available results, the optimum level of SWP in SMA mixture was determined as 8% by weight of bitumen. The study showed that even though mixture with PMB performed the best, SMA with 8% SWP provided comparable results. The Stone Matrix Asphalt mixtures (SMA) were investigated by Bindu and Beena, [9] using triaxial shear strength testing to investigate the effect of additives, waste plastics and polypropylene on strength properties. The test was conducted at 0, 50, 75 and 100 kPa confinements. Analysis using Mohr-Coulomb failure theory shows that the stabilized SMA had highest cohesion and shear strength as compared to control mixture (SMA without additive). SMA with waste plastics shows the highest cohesion and shear strength at 7% waste plastics. Influence of adding recycled glass powder (RGP) and styrene butadiene styrene (SBS) polymer to the base bitumen with the penetration grade of 60/70 and to modify stone matrix asphalt SMA in flexible pavement was investigated by Ghasemia and Marandi, [10]. Asphalt mixture performance tests including Marshall Stability, indirect tensile strength and resilient modulus were performed on the modified and control asphalt samples. The results of the evaluation showed that SMA mixtures modified by 3.5% RGP and 1.5% SBS presented the best results in the experiments conducted and considerably increased mechanical and physical properties of asphalt and bitumen. Drain down sensitivity tests were conducted by Bindu and Beena, [11] to study the bleeding phenomena and drain down of SMA mixtures. Based on the drain down characteristics of the various stabilized mixtures it was inferred that the optimum fibre content is 0.3% by weight of mixture for all fibre mixtures irrespective of the type of fibre. For waste plastics and polypropylene stabilized SMA mixtures, the optimum additive contents are respectively 7% and 5% by weight of mixture. Due to the absorptive nature of fibres, fibre stabilizers are found to be more effective in reducing the drain down of the SMA mixture. Suaryana, [12] evaluated the performance of the SMA that uses the asbuton stabilizer. The results obtained showed that asbuton can prevent asphalt drain down as well as increase the proportion of filler. Drain down asphalt can be prevented by using binder absorbers with fibre cellulose and viscosity boosters with asbuton. Dynamic modulus indicates the SMA mix is relatively stiffer at high temperatures, but relatively less stiff (less brittle) at low temperatures. It was concluded that the addition of asbuton improves the performance of the SMA mix by increase in the value of dynamic stability. In terms of resistance to fatigue, SMA with cellulose as stabilizer and SMA with asbuton as stabilizer, relatively have the same performance. Sarang et al, [13] investigated two aggregate gradations of SMA, with nominal maximum aggregate sizes (16 and 13) mm. Polymer-modified bitumen (PMB) was used as the binder material and no stabilizing additive was used, since drain down was within permissible limits for both mixtures with PMB. For SMA mixtures, tensile strength was (28–31) % higher than the other mix, and moisture resistance was also slightly better. Coarser mixture was better resistant to rutting, and in wheel-tracking test, deformations were 0.4–0.7 mm less than finer mixture for all wheel passes. After 10,000 passes, rut depth was (4.1 and 4.8) mm for coarse and fine mixtures respectively. It was concluded that fatigue life of coarse mixture was about 10 % higher than fine mixture, whereas at constant tensile stress, the improvement can be minimum 21 %. The aim of this investigation is assessing the influence of implementing coal fly ash as stabilizing additive on the dynamic properties of SMA in terms of resilient modulus, resistance to moisture damage, and permanent deformation under repeated indirect tensile stress.

MATERIALS AND METHODS

Asphalt Cement

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

Table1. *Physical Properties of Asphalt Cement*

Test procedure as per ASTM [14]	Result	Unit	SCRB Specification [15]
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) % ASTM D-1754	0.175	%	-

Coarse and Fine Aggregates

Coarse and fine aggregates were obtained from Al-Nibaee quarry, their physical properties are illustrated in Table 2.

Mineral Filler

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

Table2. *Physical Properties of Al-Nibaee Coarse and fine Aggregates*

Property as per ASTM [14]	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	-

Table3. *Physical Properties of Filler (Limestone dust)*

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

Stabilizing Additives

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

Table4. *Chemical Properties of Fly Ash*

Property	Percent %	ASTM C 618, [14] 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	----	----

Table5. *Physical Properties of Fly ash*

Property	Value
specific gravity	2.0
Passing Sieve No.200%	99%
Specific surface area (m^2/ kg)	650

Selection of Asphalt Concrete Combined Gradation

The selected gradation in this work follows the Gap gradation suggested by many researchers, [5, 16, 17, and 18]. “Figure 1” demonstrates the gradation adopted with 12.5 (mm) nominal maximum size of aggregates for wearing course.

Preparation of Hot Mix Asphalt Concrete

The aggregate was dried to a constant weight at 110 °C, then sieved to different sizes, and stored. Coarse and fine aggregates were combined with mineral filler to meet the specified gradation shown in “Figure 1”.

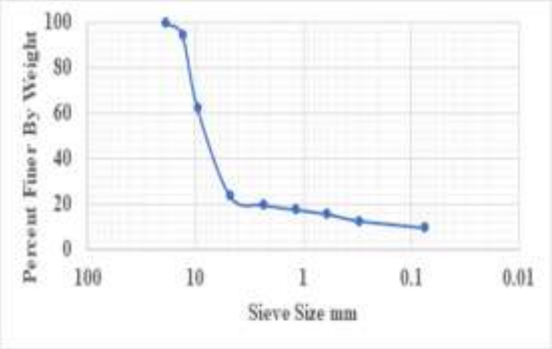

Figure1. *The SMA gap gradation implemented*

The combined aggregate mixture was heated to a temperature of 150 ºC before mixing with asphalt cement. 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. Marshall Size specimens were prepared in accordance with ASTM D1559, [14] using 75 blows of Marshall hammer on each face of the specimen. The optimum asphalt content was determined as per the procedure above to be 5.1% by weight of aggregates. The prepared Marshall Size Specimens were divided into two sets, the first set (labelled as unconditioned) was subjected to the repeated indirect tensile stresses at 25ºC, using the pneumatic repeated load system PRLS, while the second set was subjected to moisture damage as per the procedure by AASHTO, [19] (labelled as conditioned). Additional asphalt concrete specimens have been prepared using asphalt cement of 0.5% above and below the optimum asphalt content. Specimens were tested in triplicate, and the average value was considered for analysis.

Moisture Damage Test Process

This test was performed to assess the resistance to moisture damage of SMA mixtures; and the procedure of test was according to (ASTM D4867), [14] and AASHTO, [19]. A group of six specimens for each binder content were prepared, three specimens were tested for indirect tensile strength after storage in a water bath at 25ºC for half an hour; the average strength was considered as (un-conditioned specimens). The additional three specimens were conditioned through placing in volumetric flask (4000-ml) heavy weight- wall glass filled with water at room temperature 25˚C, and a vacuum of 3.74 kPa (28mm Hg) was applied to the flask for 10 minutes in order to attain (55 to 80 %) level of saturation. The specimens were covered with plastic sheets and stored in deep freezer at (-18˚C) for (16 hours). Then the specimens were placed to a water bath for (24 hours) at (60ºC) for thawing. After that, specimens were retained in a water bath on (25ºC) for (1 hour). Finally, specimens were tested for indirect tensile strength. The average value was considered as (conditioned specimens).

Repeated Indirect Tensile Stress Test

Specimens were subjected to the repeated indirect tensile stresses according to the procedure of ASTM, [14]. In this test, the specimen was stored at room temperature of 25 ºC for one day; then the specimen was transferred to the PRLS chamber and fixed on the vertical diametrical level between the two parallel loading bands (12.7 mm) in width as demonstrated in “Figure 2”.

Figure2. *Repeated ITS in the PRLS Chamber*

Asphalt concrete specimens were subjected to repeated indirect tensile stress for 1200 load repetitions at 25˚C. Such timing and test conditions were suggested by Sarsam and Husain, [20] and Sarsam and AL-Shujairy, [21]. The load assembly applies indirect tensile stress 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, dial gage of the deformation reading was set to zero and the pressure actuator was adjusted to the specific stress level equal to 0.138 MPa. A digital video camera was fixed on the top surface of the (PRLS) to capture dial gage reading. The average deformation of duplicate specimens was calculated and considered for obtaining the resilient modulus.

Results And Discussions

Influence of Stabilizer on Resilient Modulus (Mr) Under ITS

Resilient modulus is a measure of materials responses to load and deformation. Generally, higher modulus indicates greater resistance to deformation. Mr was determined at stress level 0.138 MPa, and temperature of 25°C on (Unconditioned and Conditioned) specimens. As demonstrated in Table 6, 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. This may be attributed to more surface area provided by fly ash to be covered with a film of binder which increase the stiffness of SMA.

Table6. *Resilient Modulus for SMA*

SMA Mixture without Stabilizing Additive		
Asphalt Content	**Resilient Modulus (Conditioned) MPa**	**Resilient Modulus (Unconditioned) MPa**
OAC-0.5	114.912	229.825
OAC	196.993	284.907
OAC+0.5	81.114	172.369
SMA Mixture with Stabilizing Additive (fly ash)		
OAC-0.5	153.216	313.398
OAC	255.361	370.686
OAC+0.5	125.359	255.361

On the other hand, the impact of moisture damage on resilient modulus can be noted to generally decalin Mr by 50% as compared to the case before moisture damage. Similar findings were reported by Babagoli et al, [22].

Influence of Asphalt Content on Resilient Modulus (Mr) Under ITS

As demonstrated in “Figure 3”, The Mr of SMA without fly ash (Conditioned) at 25 ^{0} C decreased by (58.82 and 41.66) % when the asphalt content increased and decreased by 0.5 % from OAC respectively, while the Mr of SMA without fly ash (Unconditioned) at 25 ^{0} C decreased by (39.5 and 19.3) % when the asphalt content increased and decreased by 0.5 % from OAC respectively. On the other hand, the Mr of SMA with fly ash (Conditioned) at 25 ^{0} C decreased by (50.9 and 39.9) % when the asphalt content increased and decreased by 0.5 % from OAC respectively, while the Mr of SMA with fly ash (Unconditioned) at 25 ^{0} C decreased by (31.1 and 15.4) % when the asphalt content increased and decreased by 0.5 % from OAC respectively.

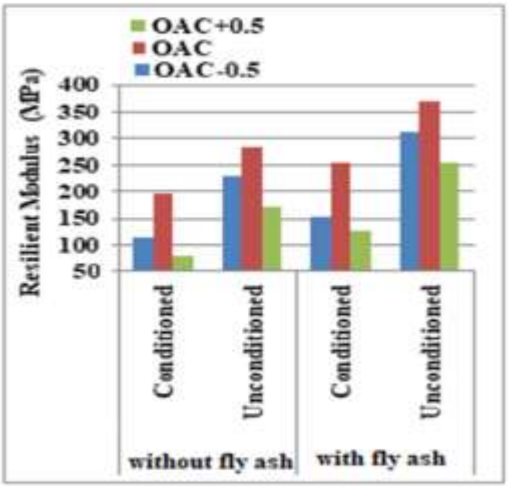

Figure3. *Impact of Asphalt Content on Mr*

Influence of Stabilizer on Deformation Parameters of SMA Under Repeated ITS

The permanent strain at N=1 is represented by the intercept (a), where N is the load cycles number. The higher the value of intercept, the larger the strain and hence the larger the potential for permanent deformation. While, the slope (b) represents the rate of change in the permanent strain as a function of the change in loading cycles N in the log-log scale, high slope values for a mix indicate an increase in the material deformation rate hence less resistance against rutting, GUL, [23]. To calculate the permanent deformation, the three selected parameters were considered (intercept, slope and deformation measured at 1200 cycles). “Figure 4” exhibit the permanent deformation (microstrain) of SMA under various asphalt content and additive usage.

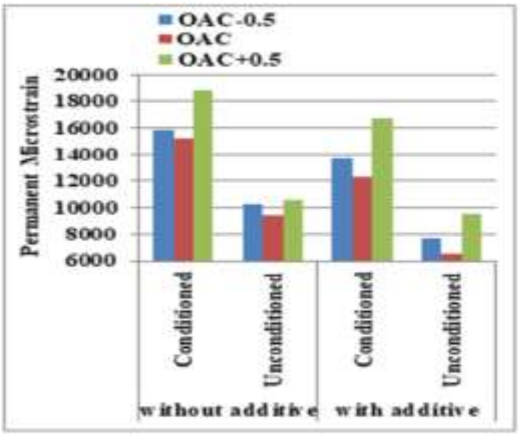

Figure4. *Permanent Deformation of SMA*

The SMA without fly ash (Conditioned) show that the permanent deformation increased by

(23.68 and 3.94) % when the asphalt content increased and decreased by 0.5 % from OAC respectively, while SMA without fly ash (Unconditioned) show that the permanent deformation were increased by (12.76 and 8.51) % when the asphalt content increased and decreased by 0.5 % from OAC respectively. On the other hand, The SMA with fly ash (Conditioned) show that the permanent deformation were increased by (36.58 and 12.19) % when the asphalt content increased and decreased by 0.5 % from OAC respectively, while the SMA with fly ash (Unconditioned) show that the permanent deformation were increased by (46.15 and 18.46) % when the asphalt content increased and decreased by 0.5 % from OAC respectively. This behaviour of materials agrees with the work reported by Awanti, [6]. Figure 5 demonstrates the behaviour of SMA under repeated ITS loading.

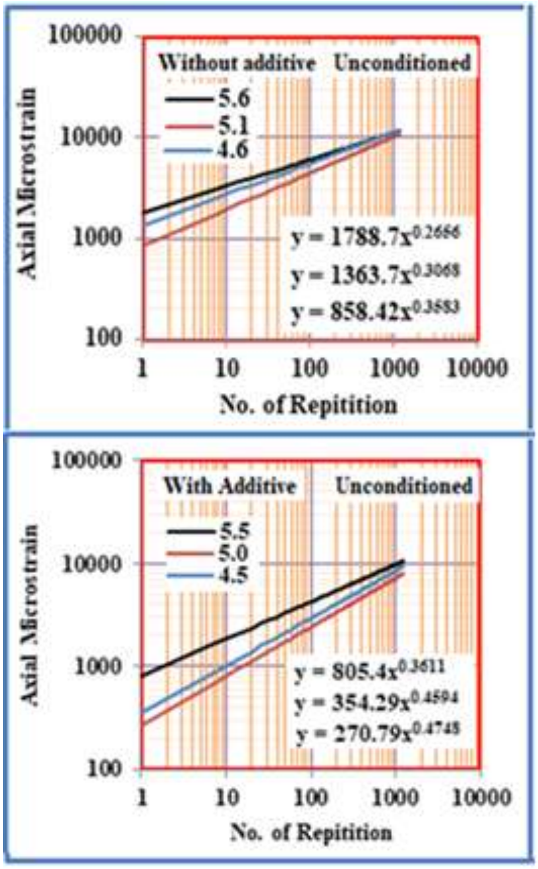

Figure5. *Impact of additive Before Moisture Damage*

It can be observed that the unconditioned specimens (before facing moisture damage) exhibit higher intercept (permanent deformation) before implementation of fly ash as compared to the case after the addition of fly ash. On the other hand, the variation in the slope is not significant. The optimum binder content exhibits the lowest permanent deformation while the SMA is sensitive to the variation in asphalt content. “Figure 6” demonstrates the behaviour of SMA under repeated ITS after it was subjected to moisture damage (conditioned).

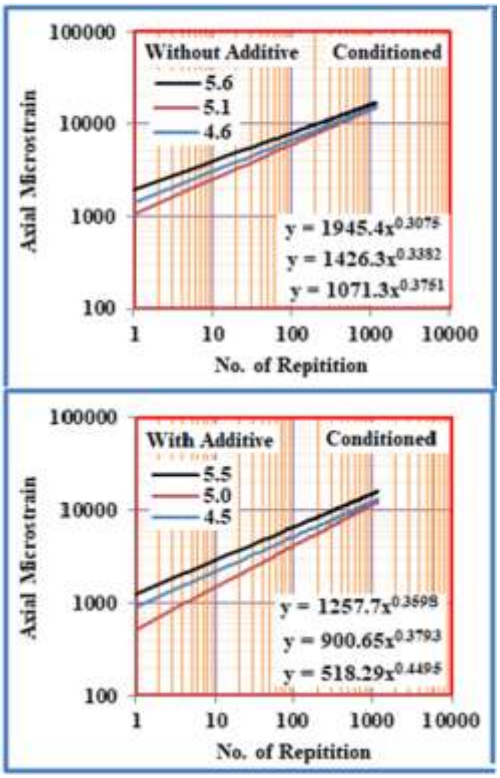

Figure6. *Impact of additive After Moisture Damage*

It can be noticed that similar influence of fly ash (additive) could be detected on decreasing the permanent microstrain (deformation) after its implementation. Identifying the fact that the lower permanent deformation is correlated to the lower sensitivity for corrugation and rutting, it can be stated that the resistance to permanent deformation for Stone Matrix Asphalt mixture with additive is higher than Stone Matrix Asphalt mixture without additive. On the other hand, the impact of moisture damage is more pronounced as the loading proceeds.

CONCLUSIONS

Based on the testing program, the following conclusions may be drawn.

- 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.
- The moisture damage influence on resilient modulus can be noted to generally decalin Mr by 50% as compared to the case before moisture damage.
- When fly ash was not implemented, The Mr of SMA decreased by (58.82 and 41.66) % and (39.5 and 19.3) % for conditioned and

unconditioned mixtures respectively when the asphalt content increased and decreased by 0.5 % from OAC.

- When fly ash was implemented, The Mr of SMA decreased by (50.9 and 39.9) % and (31.1 and 15.4) % for conditioned and unconditioned mixtures respectively when the asphalt content increased and decreased by 0.5 % from OAC.
- When fly ash was not implemented, the permanent deformation increased by (23.68 and 3.94) % and (12.76 and 8.51) % for conditioned and unconditioned mixtures respectively when the asphalt content increased and decreased by 0.5 % from OAC.
- When fly ash was implemented, the permanent deformation was increased by (36.58 and 12.19) % and (46.15 and 18.46) % for conditioned and unconditioned mixtures respectively when the asphalt content increased and decreased by 0.5 % from OAC.
- The optimum binder content exhibits the lowest permanent deformation while the SMA is sensitive to the variation in asphalt content. The resistance to permanent deformation for Stone Matrix Asphalt mixture with additive is higher than Stone Matrix Asphalt mixture without additive.

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