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Full Length Research Paper

Fatigue Potential after Rutting of Sustainable Asphalt Concrete

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Abstract. Recycling is the process of reusing the existing pavement materials that no longer serve the traffic effectively. In this work, the durability of reclaimed asphalt pavement after recycling was investigated in terms of rutting resistance and fatigue life. Three types of recycling agents (soft asphalt cement, soft asphalt cement blended with silica fumes and soft asphalt cement blended with fly ash) have been implemented in the construction of roller compacted asphalt pavement slab samples. Slab samples were subjected to wheel tracking test, and the rutting resistance was determined. Beam specimens were obtained from the slab samples after practicing the wheel tracking test at selected locations (wheel path, outside the wheel path), and subjected to fatigue resistance test under repeated loading. The evaluation of fatigue life was discussed through three selected parameters, the slope, intercept, and the Rut depth, which was measured at 5000 cycles. It was concluded that the control mixture has higher resistance to Rutting as compared with the recycled mixture, the Rut depth for recycled mixtures with Soft Ac, Soft Ac + Fly ash, Soft Ac + Silica Fume were (3.13, 2.76 and 2.53)mm, respectively, while it was 0.99 mm for control mixture. The tensile strain at 2000 load repetition was selected as reference for fatigue life comparison. At the wheel path, the lowest tensile strain could be figured at the control mix, while the recycled mixes exhibits higher tensile strain. Recycled sample with Soft Ac + Fly ash exhibits the highest tensile strain.

Keywords: Asphalt concrete, fatigue, rutting, recycled, sustainable pavement

1. INTRODUCTION

The recycling of pavements can be seen as a sustainable option, as it is a production process with environmental and economic benefits. When the pavement mixture reaches the end of its service life it may be disposed or recycled. Using Reclaimed Asphalt Pavement (RAP) is considered as an economical and environmental friendly process; it preserve the natural resources and could produce similar structural performance when compared with virgin asphalt mixtures, (Sarsam and AL-Zubaidi, 2014). The most important properties which should be investigated are the rutting resistance and fatigue behavior of recycled asphalt concrete to improve serviceability, reduce maintenance costs and impair safe operations, (Sarsam, 2005).

Most of the research works on recycling concentrates on the physical properties of recycled mixes (Baghaee et al., 2011; Hussain, and Yanjun, 2012); little attention has been paid on the durability issue of recycled mixes (AL-Qadi et al., 2007; Copeland, 2011). In fact, using RAP in pavement construction has now become common practice in many countries. In Iraq, most of asphaltic pavement needs maintenance or rehabilitation; therefore, asphalt pavement recycling is suggested to be the maintenance, rehabilitation or even reconstruction process at economical basis with acceptable properties. In this work, a detailed investigation was carried out to evaluate the durability of recycled asphalt concrete in terms of fatigue life and rutting potential. Three types of recycling agents (soft asphalt cement, soft asphalt cement blended with silica fumes and soft asphalt cement blended with fly ash) have been implemented in this investigation.

The pavement will not experience fatigue and rutting at the same time, rutting occurs during the summer time where the pavement temperature rises to 60° C. On the other hand, the pavement will experience fatigue during winter, which increases when the temperature drops to 20° C or below. Such process will continue for the whole design life of the pavement. It was felt that the fatigue behavior of recycled pavement after practicing wheel-tracking process could simulate the actual field conditions, and it was the main goal of this investigation.

2. MATERIALS

Materials adopted in the research were insured to be locally available, and economically beneficial. They could be classified into three sections: virgin material (mineral filler), reclaimed materials (control), and recycling agents.

2.1. Aged Materials

The Reclaimed asphalt mixture was obtained by the rubblization of full depth asphalt concrete from highway section at Babylon province; this highway was constructed during 1982 and was heavily deteriorated with various cracks and ruts existing on the surface. The rubblized section involves asphalt stabilized base coarse layer and two layers of binder course. Reclaimed asphalt mixture obtained was assured to be free from deleterious substances and loam that gathered on the top surface. The reclaimed mixture was heated, combined and reduced to testing size. Representative sample was subjected to Ignition test according to (AASHTO T 308, 2013) procedure to obtain binder and filler contents, gradation and properties of aggregate. Table 1 presents the properties of aged materials after Ignition test. The full depth reclaimed material consists of three asphalt concrete layers of 26 cm total thickness, and two tack coat applications.

Table 1: Properties of Aged Materials after Ignition Test

Material	Property		Value
Asphalt binder	Binder content %		4.94%
Coarse aggregate	Bulk specific gravity		2.560
	Apparent specific gravity		2.619
	Water absorption %		1.057%
	Wear% (Los Angeles abrasion)		22%
Fine aggregate	Bulk specific gravity		2.590
	Apparent specific gravity		2.819
	Water absorption %		1.91%
Mineral filler	Percent passing sieve no.200		98%
	Specific gravity		2.820
Aged Mixture	Marshall Properties	Stability	19.2 kN
		flow	3.3 mm
		Air voids	6.14%
		Bulk density	2.322 gm/cm3

Gradation for the reclaimed aggregate obtained from rubblized mixture was determined; six samples have been selected randomly from the rubblization process of material stack. These samples were subjected to Ignition test to isolate binder from aggregate and then aggregate was sieved and separated to various sizes to calculate gradation for each sample. The differences between samples were in a minor extent, the variations were within the confidence level of 95%, and probability of error of 0.05. The average gradation of the six samples obtained to be the reclaimed aggregate gradation is shown in Table 2.

Table 2: Gradation of reclaimed Aggregate

Sieve no.	Sieve size (mm)	% passing by weight	SCRB Specification, 2003	
			Base Course	Binder Course
1½"	37.5	-----	100	----
1"	25.4	100	90-100	100
3/4"	19	99	76-90	90-100
1/2"	12.5	94	56-80	70-90
3/8"	9.5	85	48-74	56-80
No.4	4.75	61	29-59	35-65
No.8	2.36	49	19-45	23-49
No.50	0.3	19	5-17	5-19
No.200	0.075	4	2-8	3-9

2.2. Mineral Filler

Mineral filler used in this study is limestone dust obtained from Erbil; the physical properties of the filler are listed in Table 3.

Table 3: Physical Properties of Mineral Filler

Property	Value
Bulk Specific Gravity	2.870
% Passing Sieve No.200	99

2.3. Recycling Agents

Three types of recycling agent based on available literature (Sarsam 2013; Sarsam and Al-Zubaidi, 2014; Sarsam and AL-Janabi, 2014), have been implemented in this study. They are soft grade asphalt cement, soft grade asphalt cement blended with silica fumes and soft grade asphalt cement blended with Fly ash.

Soft grade Asphalt cement of penetration (200-300) obtained from Al-Dura refinery was adopted for recycling in this study. Soft asphalt cement will be referred as "soft AC" in this study. The Asphalt cement of penetration grade (200-300) was blended with 4% silica fumes which were obtained from local market based on (Sarsam, 2013) work. It is an ultra-fine powder consisting of nearly spherical particles around 100 times smaller than a grain of cement. Soft Asphalt was heated to nearly 110ºc, and the silica fumes were added gradually to the asphalt cement with stirring until homogenous blend was achieved; the mixing and stirring continued for 30 minutes by a mechanical blender. On the other hand, Asphalt cement of penetration grade (200-300) was blended with 6% of Fly ash which was obtained from local market based on (Sarsam, 2013) work. Soft Asphalt was heated to nearly 110ºc, and the Fly ash was added to the asphalt cement gradually with stirring until homogenous blend was achieved.

The mixing and stirring continued for 30 minutes by a mechanical blender. Soft asphalt cement blended with Fly ash will be referred as "Soft AC+Fly ash" in this study. Table 4 shows physical properties of recycling agents. Soft asphalt cement blended with silica fume will be referred as "Soft AC+Silica fumes" in this study. Table 5 presents the physical properties of additives.

Table 4: Physical Properties of Recycling Agents

Property	Test Conditions	ASTM Designation No.	Test Value of recycling agent		
			Soft asphalt	Soft asphalt + 4% silica fumes	Soft asphalt + 6% fly ash
Penetration	25ºc, 100gm, 5sec	D5-06	260	253	278
Softening Point	(ring & ball)	D36-95	36	38	34
Ductility	25ºc, 5cm/min	D113-99	80	105	65
After thin film oven test properties D1754-97					
Retained Penetration of Residue	25ºc, 100gm, 5sec	D5-06	51%	47%	35%
Ductility of Residue	25ºc, 5cm/min	D113-99	45	35	22
Loss on Weight	163ºc, 50g,5 hrs		0.37	0.22	0.27

Table 5: Physical Properties of Silica Fumes and fly ash

Property	Value	
	Silica Fumes	Fly ash
Bulk specific gravity	2.140	2.000
% Passing Sieve No.200	100	99
Specific surface area (m²/ kg)	200000	650

2.4. Preparation of Reference Mixture

Two types of mixtures have been introduced in the study; reclaimed (control) mixture and recycled mixtures. Reclaimed mixture was obtained from the rubblized pavement in field. It was heated to 145ºC and specimens were prepared for further testing to investigate the improvement in performance after recycling. Recycled mixture consists of reclaimed mixture (RAP), with virgin mineral filler and recycling agent added and mixed together at specified percentages according to the mixing ratio. First, RAP was heated to approximately 140ºC, mineral filler was heated to 160ºC and recycling agent was heated to 130ºC separately before it was added to the heated RAP and filler at the desired amount. The required amount of filler is 3% by weight of mixture while the amount of recycling agent was 1.5 % by weight of mixture. The recycling agent was added and mixed for two minutes until all mixture was visually coated with recycling agent as addressed by (Sarsam, 2007).

2.5. Accelerated Short Term Aging of Recycled Mixture

Recycled mixtures was heated to 130°C to become loose and then spread in shallow trays with 3cm thickness and subjected to one cycle of accelerated aging process by storage inside an oven at 135°C for 4 hours as per Superpave procedure (SHRP, 1992). The mix was stirred every 30 minutes during the short-term aging process to prevent the outside of the mixture from aging more than the inner side because of increased air exposure.

2.6. Preparation of Roller Compacted Slab Sample

The Pneumatic Roller Compactor was used in this study according to European Standard (EN 12697 – 33, 2007). It provides a pneumatically powered means of compacting slabs of asphaltic material with dimension of (300x400) mm, 60 mm thick in the laboratory under controlled conditions, which simulate in-situ compaction. The levels of vertical force was (30) kN As the width of the Roller is (300) mm, The precise depth of a slab was preset to compact a certain mass of material to a selected volume thus providing a target Marshal mix density. Asphalt concrete mixture was heated to (150˚C) and then the mix was poured into the preheated slab mold of the Roller Compactor, leveled with a spatula and then it was placed into the device and prepared for compacting according to (EN 12697 – 33, 2007). Optimum number of (30) cycles was obtained after preparation of two trial slab samples by applying (20, 30) cycles. Cycles were controlled, with a vertical load of (5) kN and vibration at air supply of (10) bar and (1200) Nl/min. Roller Slabs were compacted; then each slab was kept (24) hours in the mold for cooling and after that withdrawn from the mold. Design number of (30) cycles were obtained based on target optimum bulk density of 2.322 gm/cm^3 of Marshall Specimens. In the same way, four slabs were prepared and compacted.

3. TESTING PROGRAM

3.1. Wheel Tracking Machine and Rut Depth Test

The Wheel tracking machine is used for rut depth test of asphalt slab sample according to the British Standard (BS EN 12697-22, 2003). Fig. 1 shows the wheel-tracking machine. It consists of a loaded wheel, which bears on a sample held on a moving table. The table reciprocates with simple harmonic motion through a distance of 230±10 mm with a frequency of 26.5±1 load cycle per minute. The wheel is fitted with a solid rubber tire of outside diameter (200 – 205) mm. The width of the wheel is (50) mm. The wheel load under standard conditions is 700 ± 10 N. The wheel tracker is fitted with a temperature-controlled cabinet with a temperature of 60°C, and a 20 mm stroke LVDT transducer is included for monitoring rut depth in the center of slab sample during a test. The size of slab is (230 x 300) mm and thickness is 100 mm. The deformation and sample temperature are recorded by the internal data acquisition and control system. Fig.2 shows the wheel tracking process.

Fig. 1: The wheel tracking machine

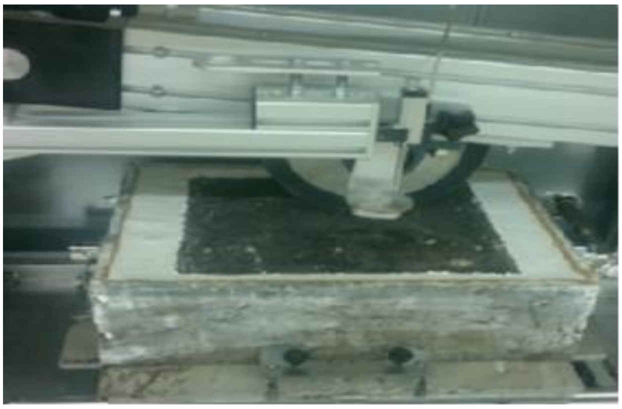

Fig. 2: The wheel tracking process

Four slab samples were cut to the testing size using diamond saw, each slab was fixed into the test tray, and the space between slab and edges was filled with plaster of Paris and then kept until dry. Slab samples were mounted simultaneously into the wheel track device, and then subjected to load repetitions of 5000 cycle at 60˚C. The deformation was recorded every 500 cycle by the software shown on the screen of the device every 20 minute. Four slabs with dimension of (300x260) x 60mm thick were tested by wheel tracking device. Fig.3 shows the slab condition before and after the wheel-tracking test.

After conducting the wheel tracking test, slab samples were withdrawn from the tray and five beam specimens were obtained from each slab. Fig. 4 shows the sequence of obtaining beam specimens. One beam (A) was obtained from the wheel path caused by the wheel-tracking machine. Two beams (B1, B2) were obtained from the area outside the wheel path and adjacent to the wheel path. The impact of shear failure due to the expected lateral movement of aggregate could be detected at that location. Another two beams (C1, C2) were obtained outside the wheel path area, and far from the wheel path, these beams may represent the unaffected area of the slab by shear failure. All beams above were of the dimension of (300x50) mm and average thickness of (60) mm.

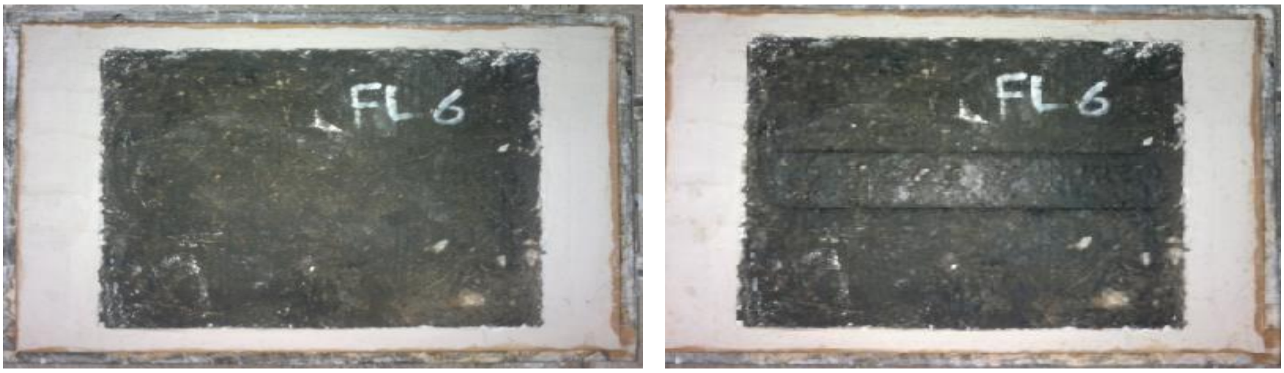

Fig. 3: The slab condition before and after the wheel-tracking test

3.2. Repeated Flexural Beam Fatigue Testing After Conducting the Wheel Tracking Test

The four point loading test with free rotation beam holding fixture at all loading and reaction point was used to estimate the flexural beam fatigue test. The purpose of using four points loading was to get pure bending in the third middle area of the beam. The number of cycles (fatigue life) that caused complete failure of the beam was considered as an indicator of fatigue cracking potential (Huang, 2004; SHRP, 1994).

The details of the factorial variables in the experimental design of the flexural beam fatigue test includes a Stress Level of 0.138 MPa which was selected as a target control stress, loading time of 0.1second and rest period of 0.9 second. A range of stress was selected so that the specimens would fail within a range from 100 to 100,000 repetitions. The test Temperature of 20 ± 1°C was used because the fatigue cracking occurs at an intermediate temperature of around 20°C (Sarsam and Al Zubaidi, 2014).

In order to use third point loading for flexural test, the beam specimen with dimension of (300x50) mm and thickness of (60) mm was left in chamber for two hours at (20^{o}C) to allow uniform distribution of temperature within the specimen; a digital camera was used for recording the deflection at mid span of the beam until failure. An aluminum steel rod supporting the LVDT was fixed at the upper point of the beam to sense the difference in deflection as shown in Fig. 5. The vertical deflection during the test of the beam at the mid span was measured with LVDT, which in turn was connected to data acquisition system where the deflection at various time intervals was stored and analyzed for finding strain at any number of cycles desired for every test.

The repetitive flexural stress was applied (0.1 second load duration and 0.9 second rest period) on the specimen and the flexural deformation at the central third of the specimen is measured under each load repetitions.

Fig. 4: Sequence of obtaining beam specimens

Fig. 5: Beam Specimen during test

4. RESULTS AND DISCUSSIONS

4.1. Effect of Recycling Agent Types on Rut Depth Test

Rutting in asphalt mixes under traffic loading occurs predominantly at elevated temperature. Control stress is selected as a mode of loading for rutting test; the response data is permanent displacement and number of repetition to rutting failure (Nf) achieved using Wheel-tracker tester. One slab sample with dimension of (300x260)mm for every mixture type was tested at (60˚C) and wheel load under standard conditions is 700 ± 10 N with simple harmonic motion through a distance of 230±10 mm with a frequency of 26.5±1 load cycle per minute according to the British Standard (EN 12697-22, 2003).

To evaluate the Rut depth test, the three parameters selected were slope, intercept, and the Rut depth which was measured at 5000 cycles. The results of these parameters for all the specimens are shown in Table 6. On the other hand, Fig.6 shows the impact of recycling agent on rutting formation. The control mixture shows higher resistance to Rutting as compared with the recycled mixtures, the Rut depth at 5000 repetitions for recycled mixtures with Soft Ac, Soft Ac + Fly ash, Soft Ac + Silica Fume were (3.13, 2.76 and 2.53)mm, respectively, while the control mixture shows (0.99)mm of rut depth. The increment in rut depth was (216%, 178% and 155%) respectively which indicates the impact of recycling agent.

Based on the data shown in Table 6, it appears that the recycled mix with Soft Ac had the highest Rut depth value when compared to other recycled mixtures, while the recycled mix with Soft Ac + Silica Fumes had the lowest Rut depth value as compared to the other recycled mixtures.

Table 6: Slops, Intercepts, and Rut depth at 5000 Cycle Value for Aged and Recycled Mixtures

Mix. Type	Intercept mm	Slope	Rut depth at 5000 cycle (mm)
Control	3.02E-02	0.4107	0.99
Soft Ac	10.83E-02	0.3952	3.13
Soft Ac + Silica Fume	10.34E-02	0.3755	2.53
Soft Ac + Fly ash	13.41E-02	0.3553	2.76

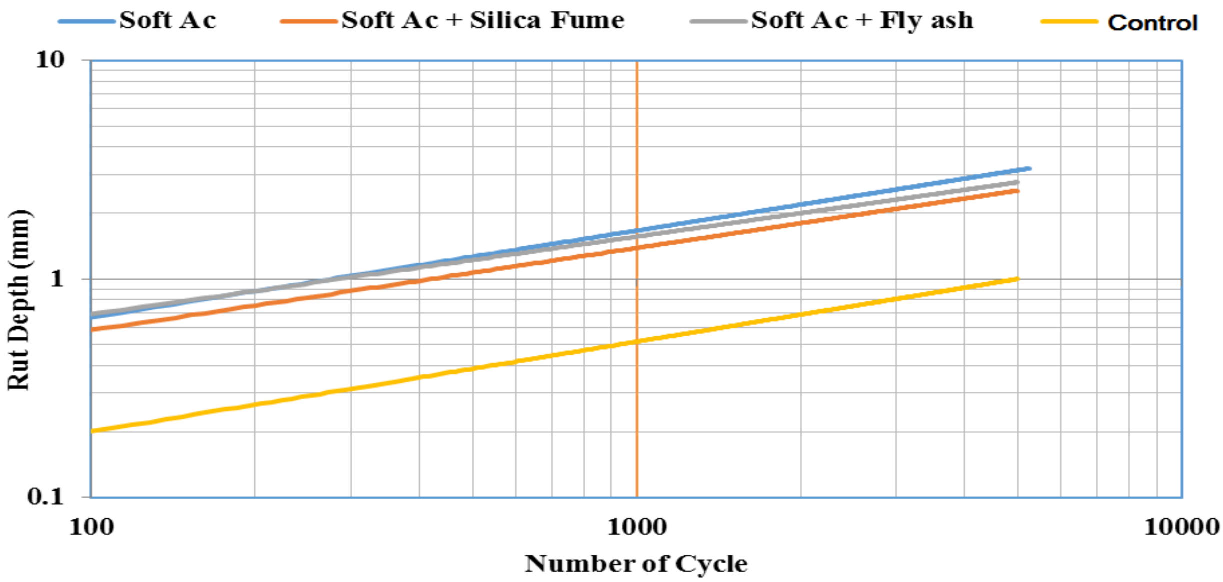

Fig. 6: Rut Depth and Number of Load repetition Cycle for (control and Recycled Mixtures)

4.2. Effect of Recycling on Fatigue Life of Asphalt Concrete after Practicing the Wheel Tracking Test Impact.

Fatigue life was measured at stress level of 0.138 MPa, test temperature 20˚C, frequency of load application used is 1 Hz with load duration of 0.1 sec and resting period of 0.9 sec. Fatigue life test was conducted on five beam specimens of dimension (300x50)mm and (60)mm thickness. Beams were obtained from each slab for each mixture type after practicing the wheel tracking test.

To evaluate the permanent deformation, the tensile strain at 2000 load repetition was selected as reference for comparison. Table 7 depicts the effect of recycling agents on tensile strain. It appears that at the wheel path (beam A), the lowest tensile strain at 2000 load repetition cycles could be figured for the control mix condition, while the recycled mixes exhibits higher tensile strain. This could be attributed to stiff nature of the reclaimed asphalt concrete pavement. Recycled mix with Soft Ac + Fly ash exhibits the highest tensile strain as demonstrated in Fig.7. While at (beam B) location, which represent area outside the wheel path, similar behavior could be detected. The possible movement of material outside the wheel path and the flow of aggregates from the wheel path location to outside the wheel path shows higher tensile strain as compared to reference mix. An exception to that behavior is the case of recycled asphalt concrete with Soft Ac. At (beam C) location, that represents area outside the wheel path and far from the wheel path, the total tensile strain was expected to practice minor impact of loading as shown for control mix. The addition of recycling agent other than soft Ac exhibit negative impact on pavement resistance to tensile strain and to the expected fatigue life.

Table 7: Total Tensile Strain at 2000 Cycle for control and Recycled Mixtures

Mix. Type	Total Tensile Strain at 2000 Cycle (microstrain)		
	Beam A	**Beam B**	**Beam C**
Soft Ac	3976	2392	3510
Soft Ac + Silica Fumes	2485	2982	5094
Soft Ac + Fly ash	6088	8883	6647
Control	1491	1957	1708

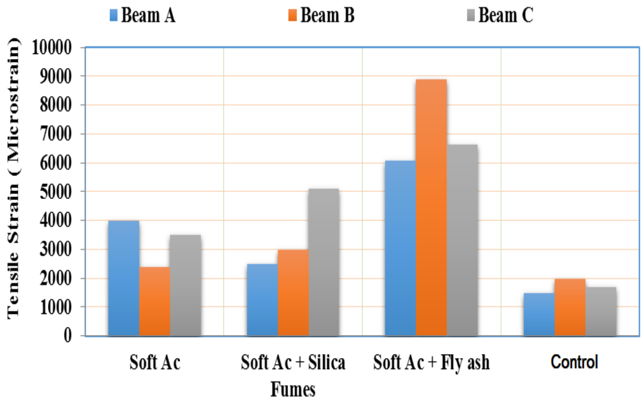

Fig. 7: Total Tensile Strain at 2000 load repetition Cycles for control and Recycled Mixtures

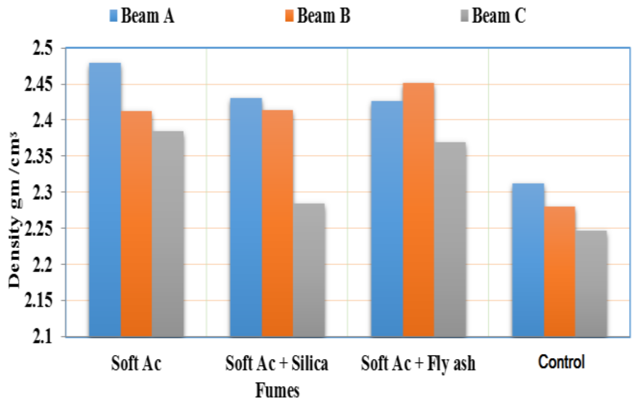

Fig. 8: Variation of Density of control and Recycled Mixtures After practicing Wheel Tracking Test

Table 8 shows the effect of recycling agents on density. It appears that at the wheel path which is represented by beam A, the density increases for all of the slab samples. At beam B, which represents area outside the wheel path, the decrease of density indicates that shear failure occurs at the wheel path and the material had moved in the lateral direction and caused uplift of the material, which reduces the density. At beam C, which represents area outside the wheel path and far from the wheel path, the density is considered typical for the slab samples and the variations among the slab samples are according to the mix variables. The target density for the control asphalt concrete of 2.322 gm/cm^3 could be maintained under the wheel path, while it changes due to possible lateral movement of material toward outside the wheel path.

When soft AC recycling agent was introduced, beam C exhibit minimal changes in density, indicating the restricted effect of loading at that location, the major impact could be noticed under the wheel path and at beam B location. When the recycled mixtures with Soft Ac + Silica Fumes and Soft Ac + Fly ash are considered, similar behavior could be detected. Recycled mixture with Soft AC + Fly ash exhibits the highest impact of loading outside the wheel path as demonstrated in Fig.8.

Table 8: Variation of Density of control and Recycled Mixtures After practicing Wheel Tracking Test

Mix. Type	Density gm/cm^3		
	Beam A	**Beam B**	**Beam C**
Soft Ac	2.479	2.413	2.385
Soft Ac + Silica Fumes	2.431	2.414	2.285
Soft Ac + Fly ash	2.426	2.452	2.370
Control	2.322	2.280	2.247

5. CONCLUSIONS

Based on the limited testing program, the following conclusions may be drawn:

1. The control mixture shows higher resistance to Rutting as compared with the recycled mixtures, the Rut depth at 5000 repetitions for recycled mixtures with Soft Ac, Soft Ac + Fly ash, Soft Ac + Silica Fume were (3.13, 2.76 and 2.53) mm, respectively, while the control mixture shows (0.99)mm of rut depth.
2. At the wheel path, the lowest tensile strain of 1491 microstrain at 2000 load repetition cycles could be figured for the control mix condition, while the recycled mixes exhibits higher tensile strain. Recycled mix with Soft Ac + Fly ash exhibits the highest tensile strain of 6088 microstrain.
3. At the area outside the wheel path and far from the wheel path, the addition of recycling agent other than soft Ac exhibit negative impact on pavement resistance to tensile strain and to the expected fatigue life.
4. At the wheel path, the density increases for all of the slab samples, while at the area outside the wheel path, the decrease of density indicates that shear failure occurs at the wheel path and the material had moved in the lateral direction and uplifted outside the wheel path, which reduces the density.
5. Soft AC recycling agent exhibit minimal changes in density, indicating the restricted effect of loading outside the wheel path, while its major impact could be noticed under the wheel path. When the recycled mixtures with Soft Ac + Silica Fumes and Soft Ac + Fly ash are considered, similar behavior could be detected. Recycled mixture with Soft AC + Fly ash exhibits the highest impact of loading on density outside the wheel path.

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