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Assessing Fatigue Life of Reclaimed Asphalt Concrete Recycled with Nanomaterial Additives

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Abstract

Fatigue Behavior of recycled asphalt concrete is considered as one of the most important properties, which should be investigated. In this work, the impact of three types of recycling agents with nano materials on Fatigue Behavior of recycled asphalt concrete has been investigated. Roller compacted asphalt concrete slab samples with dimension of (300x400) mm, 55 mm thick were prepared in the laboratory under controlled conditions, forty beams with dimension of 400mm long, 57mm wide and 55mm high obtained from sawed Roller compacted slabs were implemented for fatigue test in repetitive four points loading under constant strain level. Half of the beams were directly tested at 20° C (unconditioned), while the remaining 20 beam specimens were placed in water bath at 25˚C for 15 minutes then removed and placed in deep freeze at -18˚C for (16) hours. The frozen specimens were then moved to a water bath for 24 hours at (60˚C), then were placed in a water bath at 25˚C for one hour, and then were tested in the 4-point loading machine, (conditioned). It was concluded that fatigue life decreases after conditioning by (-61.34%, -63.68% and -36.55%) at 250µƐ, for recycled mixtures with (Soft Ac), (Soft Ac + Silica Fumes) and (Soft Ac + Fly ash), respectively. Fatigue life at 250µƐ (Unconditioned) increased by (608.57%, 599.64% and 265.89%) for recycled mixtures with Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash as compared with aged mixture.

Keywords

Asphalt Concrete, Fatigue Life, Nanomaterial, Recycling

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1. Introduction

Most of the research work on recycling concentrates on the mechanical properties of recycled mixes; little attention has been paid on its fatigue issue.

The recycling of pavements is considered as a sustainable option, since it is a process with environmental and economic benefits. Using Reclaimed Asphalt Pavement (RAP) in reconstruction of pavement could produce an economical and environmental friendly process, [1]. In Iraq, most of asphaltic pavement infrastructure are in the stage of maintenance or rehabilitation.

In this work, a detailed investigation was carried out to evaluate the durability of recycled asphalt concrete in terms of fatigue life. The feasibility of using Nanomaterials as an additive to the soft asphalt cement (to form recycling agent) was investigated, and its impact on fatigue life before and after moisture damage process was discussed.

1.1. Fatigue Failure of Road Pavement

This type of failure generally occurs when the pavement has been stressed to the limit of its fatigue life by repetitive axle load applications. It is often associated with loads, which are too heavy for the pavement structure or more repetitions of a given load than provided for in design, [2]. Fatigue life of

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pavement is affected by different properties of the mixture including type and amount of binder used in the mixture, temperature and air voids [3]. Fatigue cracks are initiated due to repeated traffic loading and it occurs in asphalt pavements when repeated stress or strain having a maximum value generally more than the ultimate strength of the material, [4]. Fatigue Behavior of the asphalt concrete mixtures can be characterized by Beam Fatigue test in controlled stress or strain modes, [5] and [6].

1.2. Mode of Fatigue Failure

Two types of fatigue modes occur in flexible pavement, when the tensile stresses at the bottom of base or HMA layer is higher than the stiffness of these layers the bottom-up cracking generate, and with continuous repeated traffic load application, it propagates to the top of the layer, [3] and [7]. The other cracking (top-bottom) occurs when HMA becomes brittle with aging and increases stiffness; then these cracks propagate downwards through the pavement structure as traffic load causing shear strain exceed the design level for the pavement.

2. Material Characteristics and Testing Methods

2.1. Reclaimed Asphalt Concrete

The reclaimed asphalt mixture was obtained by the rubblization of full depth asphalt concrete from highway section at Babylon province. The rubblized section consists of asphalt stabilized base coarse layer and two layers of binder coarse, with total layers thickness of 22 cm.

The reclaimed mixture was heated, combined and reduced to testing size as per AASHTO specifications [8]; a representative sample was subjected to Ignition test according to [8] procedure to obtain asphalt binder and filler content, gradation and properties of aggregate. Table 1 presents the properties of reclaimed materials after Ignition test; it also presents gradation of reclaimed aggregate obtained from mixture. The gradation is finer that that specified by [9] for base and binder courses, this might be attributed to the possible degradation of aggregate under traffic through the pavement life.

Table 1. Properties of reclaimed materials after ignition test

Material	Property		Value	Gradation of reclaimed aggregate	
Asphalt binder	**Asphalt Binder content %**		**4.94%**	**Sieve size (mm)**	**% finer**
Coarse aggregate	Bulk specific gravity		2.56	37.5	100
	Water absorption %		1.057%	25.4	100
	% (Los Angeles abrasion)		22%	19	99
Fine aggregate	Bulk specific gravity		2.590	12.5	94
	Water absorption %		1.91%	9.5	85
Mineral filler	Percent passing sieve no.200		98%	4.75	61
	Specific gravity		2.82	2.36	49
Aged Mixture	Marshall Properties	Stability	19.2 kN	0.3	19
		flow	3.3 mm	0.075	4
		Air voids	5.6%		
		Bulk density	2.322 gm/cm^3		

2.2. Mineral Filler

Mineral filler used in this work is limestone dust obtained from Karbala governorate. The physical properties of the filler are presented in Table 2.

Table 2. Physical properties of filler (lime stone).

Property	Value
Bulk specific gravity	2.87
% Passing Sieve No.200	99

2.3. Nanomaterial

Silica fumes and fly ash have been implemented as additives to soft asphalt cement. Silica fumes is an ultra-fine powder consisting of nearly spherical particles around 100 times smaller than a grain of cement. Fly ash is a by-product from combustion of coal. Physical properties of nanomaterials additives are illustrated in table 3.

Table 3. Physical properties of nanomaterials

Property	Silica fumes	Fly ash
specific gravity	2.14	2.0
% Passing Sieve No.200	100	100
Specific surface area (m²/ kg)	20000	650

2.4. Soft Grade Asphalt Cement

Asphalt cement of penetration grade 200-300 obtained from Al-Dura refinery was adopted for recycling in this work. Soft asphalt cement will be referred as "soft AC" in this study. Physical properties of soft asphalt cement are shown in table 4.

2.5. Recycling Agents

Soft grade asphalt cement was implemented as major recycling agent; two types of nanomaterials were blended with soft asphalt cement to form another two types of recycling agent. Table 4 shows the physical properties of the recycling agents.

2.5.1. Soft Grade Asphalt Cement Blended with Silica Fumes

Asphalt cement of penetration grade 200-300 was blended with 4% of silica fumes, which were obtained from local market based on previous work by [10]. 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. Table 4 presents physical properties of soft asphalt cement 200-300 blended with silica fumes. Soft asphalt cement blended with silica fume will be referred as (Soft AC+ Silica fumes) in this work.

2.5.2. Soft Grade Asphalt Cement Blended with Fly Ash

Asphalt cement of penetration grade 200-300 was blended with 6% of Fly ash which was obtained from local market based on previous work by [10]. 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. Table 4 presents physical properties of soft asphalt cement 200-300 blended with Fly ash. Soft asphalt cement blended with Fly ash will be referred as (Soft AC+ Fly ash) in this work.

Table 4. Physical properties of recycling agents

Property	Test Conditions	ASTM [11] Designation	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

3. Experimental Program

3.1. Preparation of Reclaimed Mixtures (Reference Mixture)

Reclaimed mixture was obtained from the full depth reclamation of pavement material in the field. It was heated to 150ºC for further roller compaction and testing to investigate the performance before recycling. Reference mix will be referred as aged mixture in this work.

3.2. Preparation of Recycled Mixture

Recycled mixture consists of reclaimed mixture (RAP) 100%, virgin mineral filler and recycling agent mixed together at specified percentages according to the mixing ratio. RAP was heated to approximately 160ºC, while the mineral filler was heated to 160ºC. Recycling agent was heated to 130ºC separately, and then it was added to the heated RAP and filler at the desired amount. 3% by weight of mixture of the mineral filler, and 1.5 % by weight of mixture of the recycling agents were added and mixed for two minutes until all mixture was visually coated with recycling agent as addressed by [12]. The recycled mixture was prepared using three types of recycling agents: soft asphalt cement, soft asphalt cement blended with silica fume and soft asphalt cement blended with Fly ash.

3.3. Preparation of Accelerated Short Term Aged Recycled Mixture

Recycled mixtures were heated to 130°C to became 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 [13] and [14]. 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.

3.4. Preparation of Slab Samples

Recycled 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 [15]. Optimum number of (30) load cycles was obtained after preparation of two trial slab samples by applying (20, 30). Cycles were controlled with a vertical load of (5) kN and vibration at air supply of (10) bar. 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 was obtained based on target bulk density of Marshall Specimens as mentioned in table 2. Eight slab samples were sawed into the (40) beam specimens by the Diamond-cutter of a dimension (400 x 57) mm and thickness (55) mm and used in the Flexural Fatigue test. The standard beam fatigue procedure as per [8] was implemented for determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending. Fig.1 shows the roller compaction devise.

Fig. 1. Preparation of roller compacted slab

Fig. 2. Sawing beam specimens from slab

3.5. Preparation of Flexural Fatigue Test Specimens

Specimens for flexural fatigue testing were prepared using Roller Compactor Device according to, [15], because this method of compaction simulates field compaction in a progressive way. Five beam specimens were sawed from the slab samples as shown in fig.2. Forty beams with (400mm long, 57mm wide and 55mm high) size were sawed. Beams were used for the flexure fatigue test, under constant strain level. Fig.3 shows part of the sawed beam specimens.

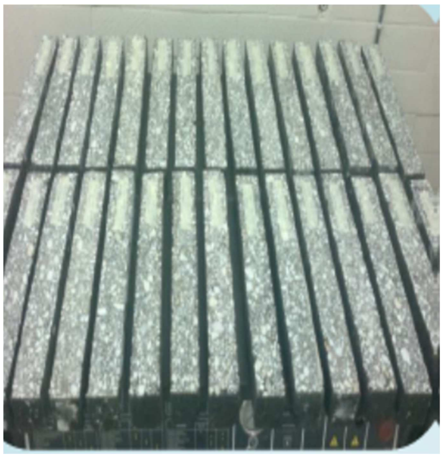


Fig. 3. Part of the sawed beams

Fig. 4. Conditioning the beams in Water Bath

3.6. Flexural Fatigue Test Principles

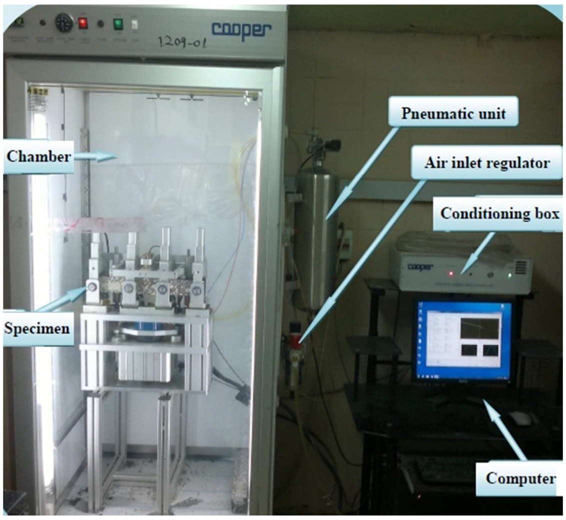


Fig. 5. Flexural Fatigue Testing Equipment

Beam specimens were divided into two groups, the first group of 20 specimens was conditioned by immersion in water bath at 25˚c for 15 minutes, then placed in deep freeze at (-18˚c) for 16 hours. The frozen specimens were then, moved to a water bath, and immersed for 24 hours at 60˚C as shown in Fig.4. Then they were placed in a water bath at (25˚C) for one hour, and they were tested by placed in a 4-point loading machine, which subjects the beam to a repeated load, This procedure was developed to evaluate the behaviour of fatigue of asphalt concrete as explained by [16] and [17]. The second group of 20 specimens was tested directly by being placed in a 4-point loading machine, which subjects the beam to a repeated load (unconditioned specimens). The flexural fatigue test is performed by placing a beam of HMA in repetitive four points loading at a specified strain level. During the test, the beam is held in place by four clamps and a repeated haversine (sinusoidal) load is applied to the two inner clamps while the outer clamps provides a reaction load as shown in Fig.5. This setup produces a constant bending moment over the centre portion of the beam (between the two inside clamps). The deflection caused by the loading is measured at the centre of the beam. The test end value was selected as 50 % reduction in stiffness, which means that the initial stiffness is reduced to 50 percent the test end.

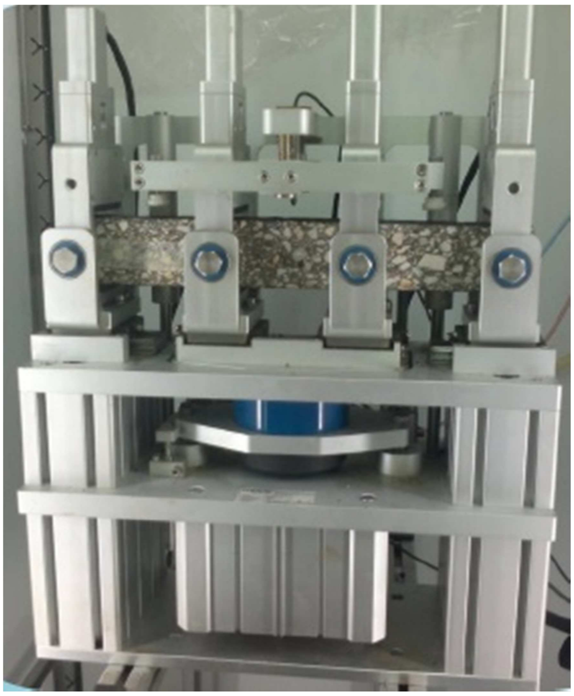
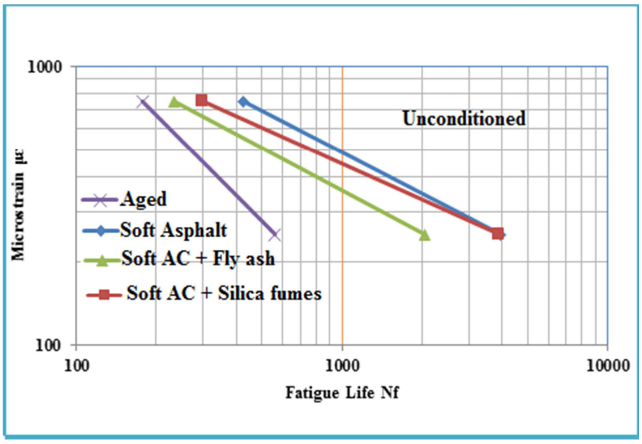


Fig. 6. Flexural Fatigue Test in process

After application of 100 load cycles, the beam stiffness at the 100th Cycles was determined and was recorded as the initial stiffness of the beam. Test results were monitored, and recorded at the selected load cycle intervals and the test was terminated when the beam has reached a 50 percent reduction in stiffness. The number of loading cycles to failure can then give an estimate of a particular HMA mixture's fatigue life. Beam fatigue testing was performed at intermediate temperature of 20°C, because fatigue cracking is thought to be a primary HMA distress at these intermediate temperatures. Fig.6 demonstrates the Flexural Fatigue test in process.

4. Discussion of Test Results

Fatigue life was measured at strain level of 750με and 250με, frequency level 5Hz, Test temperature 20˚C, on two stage (Unconditioned and Conditioned). Three beam specimens of every mixture type were tested at (250με) and the average value was obtained for each stage, while the remaining two beam specimens of every mixture type were tested at (750με) and the average value was obtained for each stage. Fig. 7 shows the (life cycles-Deformation) relationship for unconditioned and conditioned beam specimens.



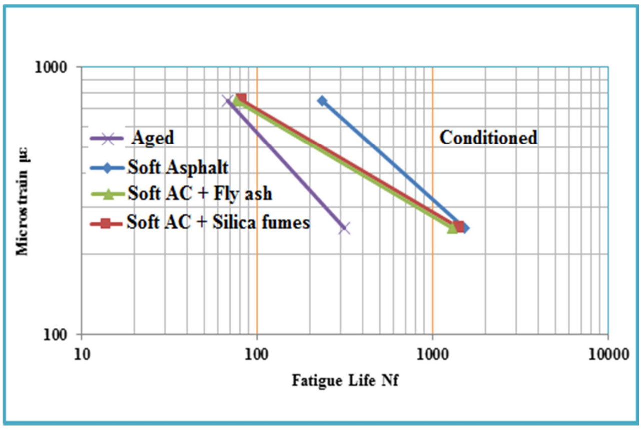


Fig. 7. Fatigue Life of Recycled Mixtures

To evaluate the fatigue life test, the three parameters selected were K1, K2, and number of cycles that reduces the stiffness to 50% (Nf). The most important variables from the fatigue test are the intercept and the slope of the fatigue curve, K1 and K2, respectively. The fatigue parameters K1 and K2 vary from one model to another. Usually, K2 values vary in a range between (1- 3) microstrain, while K1 may vary by several magnitudes. Such findings agrees well with [18] and [19]. The fatigue parameters K1 and K2 can be used as indicators of the effects of recycling agents on the fatigue characteristics of a paving mixture. The flatter the slope of the fatigue curve, the smaller the value of K1. Low value of K2 indicates lower potential for deformation and longer fatigue life. On the other hand, a lower K1 value represents a shorter fatigue life when the fatigue curves are parallel, that is, K2 is constant.

Tables 5 and 6 depict the effect of recycling agents on fatigue life. The fatigue life at 20ºC of aged (reference mix) for both of (Unconditioned and Conditioned) mixes was lower than that of recycled mixtures.

Table 5. Parameter K1, K2, and Fatigue life for Recycled Mixtures (Unconditioned)

Mix. Type	K1	K2	Fatigue Life (Nf)	
			250µƐ	750µƐ
Aged	9.398E-02	1.048	560	177
Soft Ac	2.172E-04	2.016	3968	433
Soft Ac + Silica Fumes	1.436E-05	2.342	3919	299
Soft Ac + Fly ash	1.524E-04	1.979	2049	233

Table 6. Parameter K1, K2, and Fatigue life for Recycled Mixtures (Conditioned)

Mix. Type	K1	K2	Fatigue Life (Nf)	
			250µƐ	750µƐ
Aged	2.973E-03	1.395	315	68
Soft Ac	1.117E-03	1.704	1535	236
Soft Ac + Silica Fumes	6.83E-07	2.587	1422	83
Soft Ac + Fly ash	6.35E-07	2.585	1301	76

This may be attributed to the fact that aged mixture contains hardened asphalt (higher viscosity) which will lead to increased stiffness and then decreases fatigue life value. Soft asphalt shows longer fatigue life when compared to other recycling agents at both microstrain levels. Table 8 shows the impact of specimen conditioning on fatigue life. It is obvious that recycling agents have positive impact on fatigue life, but implementation of Nanomaterials does not appear to exhibit superior quality. The mixture with Soft Ac had higher fatigue life value than other recycled mixtures for both unconditioned and conditioned test. In addition, it can be seen that the fatigue life of the Conditioned mixes was lower than the that of the Unconditioned mixtures. Table 7 shows the positive impact of recycling on fatigue life. percent of reduction in fatigue life for recycled mixtures at Conditioned test as compared to the same mixtures at Unconditioned test. On the other hand, Table 8 presents the negative impact of conditioning on fatigue life.

Table 7. Improvement in fatigue life of recycled mixtures as compared to the aged mixture.

Test of mixture at	Fatigue life improvement (%) of Recycled mixtures		
	Soft Ac	Soft Ac + Silica Fumes	Soft Ac + Fly ash
250µƐ Unconditioned	608.57	599.64	265.89
750µƐ Unconditioned	144.63	68.93	31.64
250µƐ Condition	386.98	351.75	312.70
750µƐ Condition	247.06	22.06	11.76

Table 8. Reduction in fatigue life of recycled mixtures due to beam Conditioning as compared to unconditioned case.

Test at	(%) Impact of conditioning on Fatigue life		
	Soft Ac	Soft Ac + Silica Fumes	Soft Ac + Fly ash
250µƐ	-61.34	-63.68	-36.55
750µƐ	-45.5	-72.24	-67.38

5. Conclusions

1 The results of repeated four point flexural fatigue beam testing indicates that fatigue life at 250µƐ (Unconditioned mix) increased by (608.57%, 599.64% and 265.89%) for recycled mixtures with Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash as compared with aged mixture.

2 At 750µƐ, fatigue life of unconditioned mix increased by (144.63%, 68.93% and 31.64%) for recycled mixtures with Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash.

3 The percent of improvement in fatigue life for conditioned recycled mixtures with Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash was (386.98%, 351.75% and 312.7%) at 250µƐ, while at 750µƐ, it was (247.06%, 22.06% and 11.76%) for the same mixtures as compared with aged mixture.

4 The reductions in fatigue life of recycled mixtures after Conditioning were (-61.34%, -63.68% and -36.55%) for recycled mixtures with Soft Ac, (Soft Ac + Silica Fumes) and (Soft Ac + Fly ash) respectively at 250µƐ, as compared to unconditioned mixes.

5 At 750µƐ, the reduction in fatigue life of the mixes after conditioning was (-45.5%, -72.24% and -67.38%) for recycled mixtures with Soft Ac, (Soft Ac + Silica Fumes) and (Soft Ac + Fly ash) respectively.

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