Effect of Fly-ash on The Performance of Asphalt Concrete Mixes

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Abstract

At last year, effectively fly ash has been used in producing high performance concrete mixes with limited used in asphalt pavements. This is possibly due to the performance advantage that fly ash equipped to asphalt mixes in now days. A bituminous paving mixture is a mix of coarse aggregate, fine aggregate and bitumen mixed in suitable proportion to result strong and durable mix to bear traffic load. In this paving mix, normally limestone and fly ash are used as filler material.

In this research , the performance of asphalt concrete mixes modified with fly ash as a partial replacement of limestone dust mineral filler were evaluated. Four replacement rates were used; 0, 1, 2, and 3 percent by weight of aggregate. Asphalt concrete mixes were prepared at their optimum asphalt content and then tested to evaluate their engineering properties which include moisture damage, resilient modulus, permanent deformation and fatigue characteristics. These properties have been evaluated using indirect tensile strength, uniaxial repeated loading and repeated flexural beam tests. Mixes modified with fly ash were found to have improved fatigue and permanent deformation characteristics, also showed lower moisture susceptibility and high resilient modulus. the result showed that a rate changed from 1 to 3 percent has shown an increase in resilient modulus for addition of fly ash as a filler substitute and the resilient modulus for mixes with 3 percent fly ash was 1.31 times that for mixes with 0 percent fly ash. The altering of fly ash as a filler substitute from a range (1-3) percent has modified the fatigue property of the asphalt concrete mixes as determined by flexural test, Significantly, to modify the asphalt concrete manner taken the percent of fly ash 2, and to produce the mixes more durable , higher resistance to distresses by adding the local knowledge.

Key word: fly ash, asphalt concrete ,performance, asphalt concrete

الخلاصة

في السنوات الاخيرة استخدمت مادة الرماد المتطاير بفعالية عالية في انتاج الخرسانة الاسفلتية عالية الاداء لرصف الطرق. في الوقت الحاضران تجهيز خلطات الخرسانة الاسفلتية بمادة الرماد المتطاير من المحتمل ان يؤدي الى الاداء العالي. هذه الخلطات مكونة من الركام الخشن والناعم ومادة الاسفلت حيث تخلط بنسب مناسبة لإعطاء خلطات ذات قوة وديمومة عالية قادرة على استيعاب الحمل المروري المسلط عليها وكذلك استخدمت مادة حجر الكلس ومادة الرماد المتطاير كمادة مالئة .

في هذا البحث تم تطوير هذه الخلطات باستخدام اربع نسب من مادة الرماد المتطاير بديل عن مادة حجر الكلس وهي (3,2,1,0)% من وزن الركام، تم تحضير هذه الخلطات بنسبة اسفلت مثلى واختبارها لتقييم الخواص الهندسية والمتضمنة نسبة الضرر بالرطوبة ،معامل المرونة ،التشوهات الدائمية وخواص الكلل باستخدام جهاز فحص نسبة مقاومة الشد غير المباشر وجهاز الحمل التكراري المحوري. بإضافة هذه النسب من مادة الرماد المتطاير تم تحسين خصائص التشوهات الدائمية والكلل وايضا بينت النتائج اقل قيمة للتأثر بالرطوبة واعلى قيمة لمعامل المرونة .اظهرت النتائج ان معدل التغير بمادة الرماد المتطاير من (1%) الى (3%) يؤدي الى زيادة بمعامل المرونة وكذلك تطوير خواص الكلل وان الخلطات التي تملك نسبه (3%) من مادة الرماد المتطاير ذات معامل مرونة اكبر ب (1.31) مرة من التي تملك (0%) من مادة الرماد المتطاير .وبشكل ملحوظ فان تطوير سلوك الخلطات الاسفلتية يكون بإضافة (2%) من مادة الرماد المتطاير وانتاج خلطات محلية ذات ديمومة ومقاومة عالية لتحمل الاجهادات.

الكلمات المفتاحية :– المادة الرماد المتطاير ، اداء خلطة الخرسانة ، الخرسانة الاسفلتية .

1-Introduction

Fly ash is a finely-divided residue which results from furnace-burned pulverized bituminous coal. Electric generation is the prime consumer of coal produced in the United States and, consequently, the prime producer of fly ash. In the United States, the annual production of fly ash has increased from about 43 million tons in 1975 to about 60 million tons in 1979, while the utilized amount has increased from about 5 million tons (10.6 percent of the production) to about 10.0 million tons (17.4 percent of the production), respectively .It is clear that there is a huge amount of unused fly ash which, has to be disposed of each year. This does not only cost power companies money, but also creates a disposal problem.

Asphalt pavement usually consists of three components - asphalt, aggregates, and air. Since nearly all asphalts used in road construction are of crude oil origin, the increase in crude oil prices in recent years has resulted in an increase in asphalt price. The dwindling world resources of oil have increased the concerns over the asphalt supply for highway pavements. In addition, a considerable portion of asphalt-type highways in the United States are deteriorating as a result of heavy loads and unfavorable weather conditions. All of this has led many researchers and concerned agencies to look for ways of reducing the amount of the required asphalt and improving pavement resistance against loading and moisture damage (Torrey,1978).

Based on the preceding ,it is clear that there is a real need for the development of modified asphalt concrete mixtures to improve the overall performance of pavements. The use of fly ash in pavement construction could be one of the possible steps taken in this direction. In the United States of America, fly ash has been added to hot mix asphalt pavements for over 30 years, improving the mixtures in many ways and increasing the life of highways. Extensive experimental studies have revealed that the use of fly ash in Hot-Mix Asphalt (HMA) mixtures can reduce permanent deformation, long-term aging, and moisture susceptibility of mixtures. In addition, it increases the stiffness and fatigue resistance of mixtures. The structure of fly ash consists of different size fractions. The larger size fraction performs as a filler and increases the stiffness of the bituminous mixture. The smaller size fraction increases the binder film thickness, enhancing viscosity of the binder, and improving the binder cohesion and stiffness(Capp and Spencer, 1970).

In this research , the primary objective is to evaluate the mechanical properties of asphalt concrete mixtures containing fly ash (as a partial replacement of limestone filler) based on the following tests, Marshall properties (Mix Design), Indirect tensile test (Moisture susceptibility) , uniaxial repeated load test (Resilient Modulus and permanent deformation) and repeated flexural beam test (fatigue characteristics).

Fly ash has successfully been used as a filler for asphalt mixes for a long time and has the advantage of increasing the resistance of asphalt mixes to moisture damage. In addition to filling voids, fly ash was reported to have the ability to work as an asphalt extender . It is the main purpose of this investigation to study the possibility of using wasted fly ash as an asphalt extender in bituminous paving mixes.

2-Background

Fly ash is a fine material resulting from furnace burned pulverized bituminous coal. As the finely-pulverized coal is burned, particles of fly ash are suspended in the gas stream that reaches the boiler. As the hot gases pass off into the atmosphere, these particles are collected on the plates of electrostatic precipitators located within the heating system. It is then processed or filtered and finally accumulated and stored (Chilcote *et.al.,* 1952;Torrey *et.al.,* 1978) .Fly ash is characterized by its low specific gravity, which is a function of its chemical composition and varies between 2.3 to 2.6 with an average of 2.4 (Faber *et.al.*,1976). The particle size distribution generally depends on the collector used. It was found that the ash collected by the electrostatic precipitator contains a greater percentage of very small particles (< 1.5 µ) (Torrey *et.al.,* 1978). In general, a typical fly ash particle size ranges between 0.5 µ and 100 µ (*4*). Fly ash particles are generally spherical in shape, however, a minor fraction consists of irregularly shaped particles (Capp and Spencer *et.al.*, 1970). Most types of fly ash have been successfully used as mineral fillers in hot-asphalt mixes (*4*-*6*). It was reported that fly ash does not differ materially from Trinidad Asphalt's mineral filler (Weinheimer *et.al.*, 1944). In another study (Minnick *et.al.*, 1949) fly ash was used as a replacement for limestone dust in asphalt concrete mixes with good results. The suitability of fly ash as a filler in sheet-asphalt mixes was investigated by the Detroit Edison Co. and reported by Zimmer (Zimmer *et.al.*,1970). It was found that stabilities of mixes containing fly ash were comparable with those containing limestone dust when the proportions were based on weight and that fly ash has virtually the same void-reducing properties as limestone dust.

Today there are increasing requirement on pavements infrastructure in terms of traffic loadings and service life .while the number of highway miles only increased by 5.8% from 1980 to 2010 ,the number of vehicles on the highway increased by 95.4% over the same period .the total vehicle miles travelled in United State is expected to increase by 50% in the 20 years and freight movement is expected to double by 2025.There is an urgent need for high performance paving materials incorporating substantial quantities of industrial by products (e.g., waste glass, fly ash) with improved performance and service live that meet sustainability objectives. The introduction of fly ash in to asphalt mixture was reported to improve the performance of asphalt binder at levels compared to those achieved through polymer modification (Sobolev *et.al.*,2012).

Researchers have extensively the use of by-products such as fly ash in the construction industry to improve material properties (Sobolev and Naik 2005).fly ash has been used extensively in concrete production; however ,there are limited applications in which fly ash has been used in asphalt pavements (Ali *et al*.1996;Churchill *et al*.2005; Faheem and Bahia, 2010).the use of fly ash in bitumen materials is attractive as it improves performance and reduces costs and environmental impacts (Tapkin,2008). (Carpenter,1952; Zimmer ,1970) determined that fly ash had an excellent effect on the retained compressive strength for asphalt concrete specimens immersed in water. Warden *et.al.*, (1952) determined that fly ash was a suitable filler material in terms of mixing , placing and compaction , stability, resistance to water damage and flexibility . (Sankaran and Roa,1973;Henning ,1974; Tapkin,2008) found that additions of fly ash provided higher stability for (asphalt *et.al.*, 1983) observed that fly ash improved asphalt hardening ,moisture and freeze – thaw resistance ,rutting resistance ,fatigue life, density, and tensile strength. (Suheibani,1986) evaluated fly ash as an asphalt extender and found that addition of this filler provided superior fatigue life ,rut depth resistance and tensile strength .based on workability index at various temperature ,(Cabrera and Zoorob,1994) found that fly ash could be mixed and compacted at temperature as low 110ºc and 85ºc ,respectively, without any detriment effect on engineering and performance properties. (Faheem and Bahia ,2010) reported on the interaction between the mineral filler and asphalt binder, where the stiffening effect of the filler on the binder follows a linear filling trend ,in which the interaction between filler and binder is minimal.

A report by(Rosner *et.al.*, 1982) indicated that the addition of up to six percent fly ash by weight of aggregate to asphalt concrete produced an acceptable mix. At the same time, asphalt requirements and VMA values were lower than those for mixes containing Portland cement or hydrated lime.

Tons investigated the use of fly ash as a replacement for asphalt cement in asphalt concrete mixes. The three types of fly ash used in the study were found to have positive effects on the physical properties of the evaluated mixes. Furthermore, the replacement of up to 30 percent of asphalt cement by fly ash improved most of the mix physical properties when a practical asphalt content was use (Tons *et.al.*,1983).

3-Material Characterzation

The materials used in this work ,namely asphalt cement ,aggregate ,and fillers were characterized using a routine type of tests and results were compared with State Corporation for Roads and Bridges specifications (SCRB,R/9 2003).

3-1 Asphalt Cement

In this work, the asphalt cement used is a 40-50 penetration grade. It was obtained from Al- Dura refinery, south-west of Baghdad. The asphalt properties are shown in Table (1) below.

Table 1. Properties of Asphalt Cement

Property	ASTM designation	Penetration grade 40-50	
		Test results	SCRB specification
1-Penetration at 25C,100 gm,5 sec. (0.1mm)	D-5	43	40-50
2- Rotational viscosity at 135◦C (cP.s)	D4402	519	……
2- Softening Point. (◦C)	D-36	48	……
3-Ductility at 25 C, 5cm/min,(cm)	D-113	>100	>100
4-Flash Point, (◦C)	D-92	240	Min.232
5-Specific Gravity	D-70	1.03	……
6- Residue from thin film oven test	D-1754		
- Retained penetration,% of original	D-5	57	>55
- Ductility at 25 C, 5cm/min,(cm)	D-113	54	>25

3-2 Aggregate

The aggregate used in this work was crushed quartz obtained from Amanat Baghdad asphalt concrete mix plant located in Taji, north of Baghdad, its source is Al-Nibaie quarry. This aggregate is widely used in Baghdad city for asphaltic mixes. The coarse and fine aggregates used in this work were sieved and recombined in the proper proportions to meet the wearing course gradation as required by SCRB specification (SCRB, R/9 2003). The gradation curve for the aggregate is shown in Figure (1).

Routine tests were performed on the aggregate to evaluate their physical properties. The results together with the specification limits as set by the SCRB are summarized in Table (2). Tests results show that the chosen aggregate met the SCRB specifications.

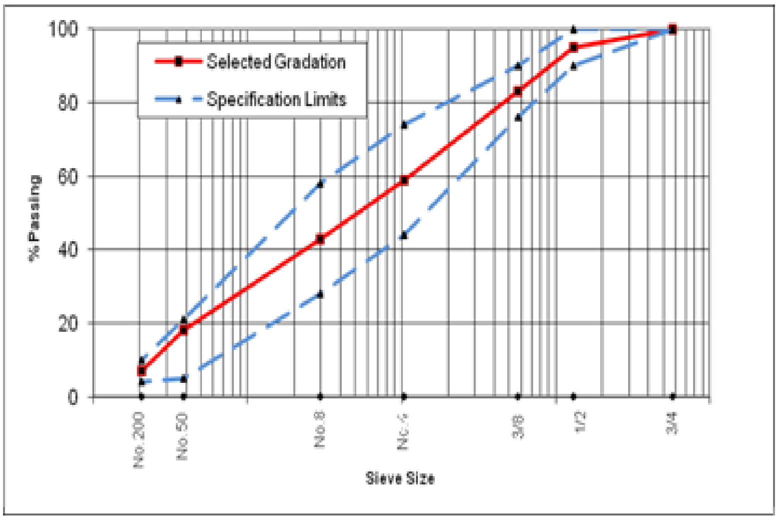

Figure 1. Aggregate Gradation.

Table 2. Physical Properties of Aggregates

Property	ASTM designation	Test results	SCRB specification
Coarse aggregate			
Bulk specific gravity	C-127	2.61	……
Apparent specific gravity		2.678	……
Water absorption,%		0.21	……
Percent wear by Los Angeles abrasion ,%			
Soundness loss by sodium sulfate solution,%	C-131	17.5	30 Max
Fractured pieces, %			
	C-88	3.83	10 Max
		96	90 Min
Fine aggregate			
Bulk specific gravity	C-127	2.621	……
Apparent specific gravity		2.683	……
Water absorption,%		0.4	……
Sand equivalent,%	D-2419	68.45	45 Min.

3-3 Filler

The filler is a non plastic material that passes sieve No.200 (0.075mm). In this work, the control mixes were prepared using fly ash as a mineral filler at a content of 7 percent, this content represents the mid-range set by the SCRB specification for the type IIIA mixes of wearing course. Mixes in which the limestone dust was partially replaced by fly ash were also prepared. The replacement percentages were 0, 1, 2 and 3% by total weight of aggregate. The limestone dust and fly ash were obtained from lime factory in Karbala governorate, south east of Baghdad. The chemical composition and physical properties of the fillers are presented in Table (3) below:

Table 3. Properties of Fillers

Filler Type	Chemical Composition ,%							Physical Properties		
	Cao	Sio_2	Al_20_3	Mgo	Fe_2o_3	So_3	L.O.I	Specific gravity	Surface area* (m^2/kg)	% Passing sieve No. 200(0.075)
Limestone Dust	68.3	2.23	-	0.32	-	1.20	27.3	2.41	244	94
Fly ash	0.88	61.9	28.82	0.34	2.67	<.07	0.86	2.00	500-750	97

* Blain air permeability method (ASTM C204)

4- Experimental Work

The experimental work was started by determining the optimum asphalt content for all the asphalt concrete mixes using the Marshall mix design method. asphalt concrete mixes were made at their optimum asphalt content and tested to evaluate the engineering properties which include moisture damage, resilient modulus, permanent deformation and fatigue characteristics. These properties have been evaluated using indirect tensile strength, uniaxial repeated loading and repeated flexural beam tests.

4-1 Marshall Mix Design

A complete mix design was conducted using the Marshall method as outlined in AI's manual series No.2 (AI, 1981) using 75 blows of the automatic Marshall compactor on each side of specimen. Based upon this method, the optimum asphalt content is determined by averaging the three values shown below:

Asphalt content at maximum unit weight

Asphalt content at maximum stability

Asphalt content at 4% air voids

For each percentage of fly ash content, six Marshall specimens were prepared with a constant increment rate in asphalt cement content of 0.2 percent. The selected asphalt cement content starts from 4.2 percent for the control and 0.5 percent fly ash mixes and increased 0.2 percent for each 1 percent increase in fly ash content, so for the mixes with 3 percent fly ash the starting value of asphalt cement content was 4.8 percent. This procedure is followed since it was found earlier in this work that the use of low asphalt content was not sufficient to provide proper coating for the aggregate with high content of fly ash.

4-2 Indirect Tensile Test

By using ASTM D 4867, The moisture susceptibility of the asphalt concrete mixtures was evaluated. The result of this test is the indirect tensile strength (ITS) and a tensile strength ratio (TSR). In this test, a set of specimens were prepared for each mix according to Marshall procedure and compacted to 7±1 % air voids using different numbers of blows per face that varies from (34 to 49) according to the fly ash replacement rate. The set consists of six specimens and divided into two subsets, one set (control) was tested at 25°C and the other set (conditioned) was subjected to one cycle of freezing and thawing then tested at 25°C. The test involved loading the specimens with the compressive load at a rate of (50.8mm/min) acting parallel to and along the vertical diametrical plane through 0.5 in. wide steel strips which are curved at the interface with specimens. These specimens failed by splitting along the vertical diameter. The indirect tensile strength which is calculated according to Eqn. (1) of the conditioned specimens (ITSc) is divided by the control specimens (ITSd), which gives the tensile strength ratio (TSR) as the following Eqn. (2).

$$ITS = \frac{2P}{\pi t D} \quad (1)$$

$$TSR = \frac{ITS_c}{ITS_d} \quad (2)$$

where
ITS= Indirect tensile strength
P = Ultimate applied load
t = Thickness of specimen
D = Diameter of specimen
Other parameters are defined previously

4-3 Uniaxial repeated loading test

The uniaxial repeated loading tests were conducted for cylindrical specimens, 101.6 mm (4 inch) in diameter and 203.2 mm (8 inch) in height, using the pneumatic repeated load system (shown below in plate(2)). In these tests, repetitive compressive loading with a stress level of 0.137 mPa (20 psi) was applied in the form of a rectangular wave with a constant loading frequency of 1 Hz (0.1 sec. load duration and 0.9 sec. rest period) and the axial permanent deformation was measured under the different loading repetitions. All the uniaxial repeated loading tests were conducted at 40°C (104°F). The specimen preparation method for this test can be found elsewhere (Albayati, 2006).

The permanent strain (εp) is calculated by applying the following equation:

$$\varepsilon_p = \frac{p_d \times 10^6}{h} \quad (3)$$

where
εp= axial permanent microstrain
pd= axial permanent deformation
h= specimen height

Also, throughout this test the resilient deflection is measured at the load repetition of 50 to 100, and the resilient strain (εr) and resilient modulus (Mr) are calculated as follows:

$$\varepsilon_r = \frac{r_d \times 10^6}{h} \quad (4)$$

$$M_r = \frac{\sigma}{\varepsilon_r} \quad (5)$$

where
εr= axial resilient microstrain
rd= axial resilient deflection
h= specimen height
Mr= Resilient modulus
σ = repeated axial stress

The permanent deformation test results for this study are represented by the linear log-log relationship between the number of load repetitions and the permanent microstrain with the form shown in Eqn. (6) below which is originally suggested by Monismith et. al., (1975) and Barksdale (1972).

$$\varepsilon_p = aN^b \quad (6)$$

where
εp= permanent strain
N=number of stress applications
a= intercept coefficient
b= slope coefficient

Plate 2. Photograph for the PRLS

4-4 Flexural Beam Fatigue Test

Within this study, third-point flexural fatigue bending test was adopted to evaluate the fatigue performance of asphalt concrete mixtures using the pneumatic repeated load system (shown below in plate (3)).,this test was performed in stress controlled mode with flexural stress level varying from 5 to 30 percent of ultimate indirect tensile strength applied at the frequency of 2 Hz with 0.1 s loading and 0.4 s unloading times and in rectangular waveform shape. All tests were conducted as specified in SHRP standards at 20°C(68°F)on beam specimens 76 mm (3 in) x 76 mm (3 in) x 381 mm (15 in) prepared according to the method described in (Al-khashaab, 2009). In the fatigue test, the initial tensile strain of each test has been determined at the 50th repetition by using Eqn. (7) shown below and the initial strain was plotted versus the number of repetitions to failure on log scales,the collapse of the beam was defined as failure, the plot can be approximated by a straight line and has the form shown below in Eqn. (8).

$$\varepsilon_t = \frac{\sigma}{Es} = \frac{12h\Delta}{3L^2 - 4a^2} \qquad (7)$$

$$N_f = k_1(\varepsilon_t)^{-k2} \qquad (8)$$

where

ε_t = Initial tensile strain

σ =Extreme flexural stress

Es =Stiffness modulus based on center deflection.

h =Height of the beam

Δ =Dynamic deflection at the center of the beam.

L = Length of span between supports.

a =Distance from support to the load point (L/3)

N_f = Number of repetitions to failure

k_1 = fatigue constant, value of Nf when ε_t= 1

k_2 = inverse slope of the straight line in the logarithmic relationship

Plate 3. Specimen Setup in the Testing Chamber

5- Test Results and Discussion

5-1 Effects of Fly ah on Marshall Properties

The variation of Marshall properties with fly ash content is shown in figure (4) which is based on the data presented in Table (4). Examinations of the presented data suggest that the mixes with higher fly ash content possess higher optimum asphalt cement content, the highest value of optimum asphalt content (5.35%) was obtained with 3% fly ash, while the lowest value (4.80%) was obtained with 0% fly ash which is the case that the mineral filler entirely consists of limestone dust.

Table 4. Summary of the Marshall properties of asphalt concrete mixes at optimum asphalt content

Fly ah Content* , %		0	1.0	2.0	3.0
Optimum Asphalt Content, %		4.80	4.91	5.15	5.35
Marshall Properties	Stability, kN	8.76	10.03	11.13	11.20
	Flow, mm	3.36	3.67	3.58	3.43
	Density, gm/cm^3	2.324	2.334	2.342	2.335
	Air Voids, %	4.22	4.12	3.95	4.35
	VMA , %	15.60	15.45	15.16	15.81

* As a partial replacement of limestone dust, 4 percent filler content is constant.

These differences can be attributed to the higher surface area fly ash as compared to that of limestone dust. As shown earlier in this study, the surface area of fly ash is 1.63 times that of limestone dust, and hence the demand for asphalt has increased with increasing the replacement rate of limestone dust with fly ash. With respect to stability, the results indicate that the stability increases with the increasing fly ash content, also the increment rate varies with fly ash content, the maximum rate obtained is 1.1 kN/1 percent of the fly ash content ranged from 1 to 2 percent, whereas for the fly ash content ranged from 0 to 0.5 percent and from 2 to 3 percent the rate was 0.44 and 0.15 kN/1 percent, respectively. From the stability plot, it may be possible to argue that the maximum benefit can be obtained with the use of 2 percent fly ash since further increase in fly ash content associated with just slight increases in stability value and require more asphalt cement content as compared to mixes with 2 percent fly ash.

The results of flow as a function of varying the fly ash content is shown in plot "c", it's obvious that the flow value increases as the fly ash content increases from 0 to 2 percent, and then decreases as the fly ash content increases. This is due to the fact that air voids are too low at 2 percent fly ash content, addition of fly ash higher than this value tend to increase air voids due to the insufficient compaction effort so the flow value decrease. The relationship between fly ash content and density, which is shown in plot "d" follow the same trend of that between the fly ash content and Marshall flow, an optimum fly ash content which yields the highest Marshall density is 2 percent, further increases in fly ash content tend to decrease the Marshall density. As demonstrated in plot "e", the trend observed for the effect of fly ash content on air voids values is exactly opposite to that observed between fly ash e content and flow , for a fly ash content from 0 to 2 percent, the air voids decreases with a rate of -0.135 percent for each 1 percent change in fly ash content, beyond 2 percent, the air voids content increases rapidly with a rate of +0.40 percent for each 1 percent change in fly ash content, this can be easily explained by the fact that the fly ash is finer than limestone dust so it can efficiently fill the voids pockets and stiffens the mixes for a certain amount beyond which there will be a lack in the compaction effort resulting in high air voids content. Plot "f" demonstrates the effect of fly ash content on voids in mineral aggregate (VMA), as it's clear from the plot until a 2 percent of fly ash content the VMA decreases as the fly ash content increases, the minimum VMA value corresponding to 2 percent fly ash is 15.12 percent ,which means less space to be accommodated by asphalt cement, after 2 percent fly ash content, an addition of fly ash result in increasing the VMA values.

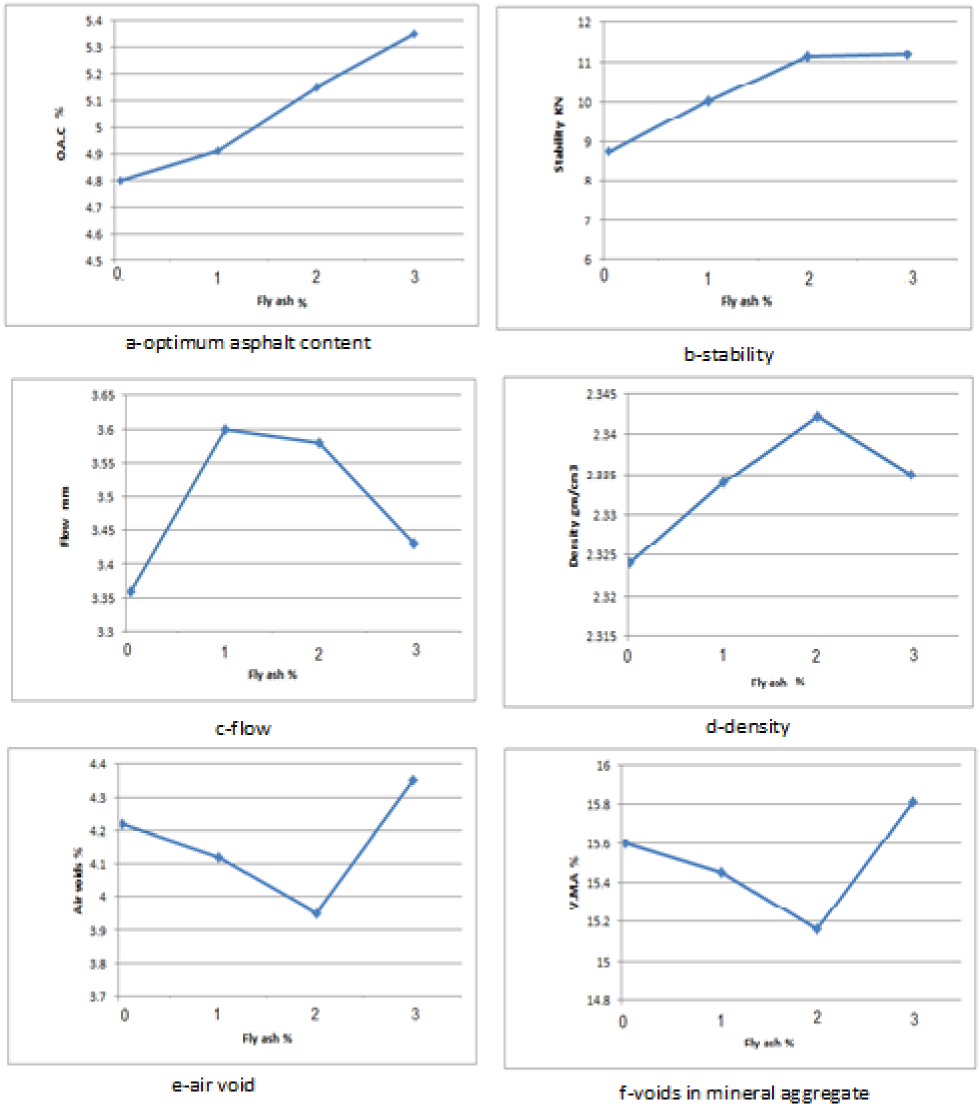

Figure 4. Effect of fly ash content on Marshall properties

5-2 Effects of Fly ash on Moisture Susceptibility

Based on the data shown in Table (5) and Figure (5), it appears that the examined fly ash contents have an influence on the moisture susceptibility of the asphalt concrete mixes. The indirect tensile strength results for both control and conditioned mixes approximately linearly proportional to the fly ash content with constants of proportionality of +85 for the former and +157.5 kPa per 1 percent change in fly ash content for the latter. It is interesting to note that the improvement rate in the indirect tensile strength for the mixes with fly ash, added as part of the mineral filler, is higher in the case of conditioned mixes than that of control mixes. These findings beside that related to the tensile strength ratio shown in figure (5) confirm that the resistance to moisture induced damage is enhanced in asphalt concrete pavement modified with fly ash.

Table 5. Moisture susceptibility test results

Fly ash Content, %	ITS, kPa		TSR, %
	Control	Conditioned	
0	1293	1055	81.6
1.0	1407	1162	82.5
2.0	1514	1343	88.7
3.0	1545	1460	94.5

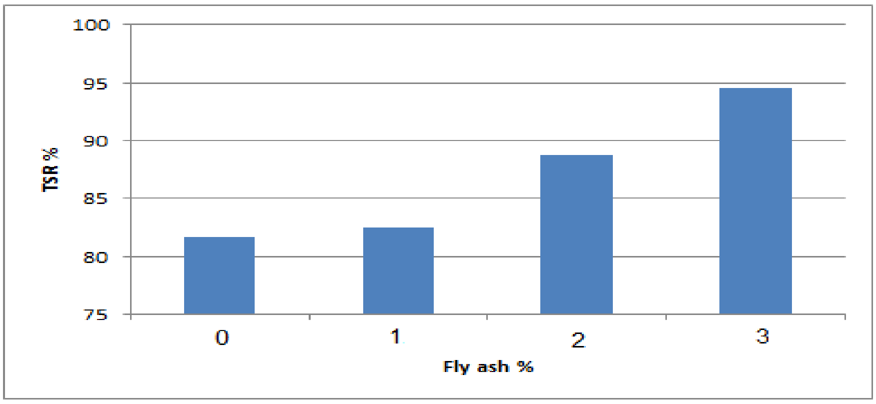

Figure 5. Effect of fly ash content on tensile strength ratio

5-3 Effects of Fly ash on Resilient Modulus

Table (6) as well as figure (6) exhibit the variation of the resilient modulus values with the fly ash content. The relation is in reverse order up to 1 percent content of the fly ash (i.e., as the the fly ash content increases the resilient modulus decreases), but further increase in hydrated lime content reflects this relation, the resilient modulus of the mixes with 3 percent the fly ash (1110 mPa) is 1.4 times the value for mixes with 1 percent the fly ash which was 773 mPa, these results can be explained as follow; since the test was conducted under relatively high temperature (40°C (104°F)), so the low level of the fly ash content (below 1 percent) is insufficient to stiffening the asphalt concrete mixes whereas the higher values of resilient modulus resulted from the high level of the fly ash content (above 1 percent) indicate that the the fly ash did increase the stiffness of the asphalt concrete mix.

Table 6. Resilient modulus test results

Fly ash Content , %	0	1.0	2.0	3.0
Resilient Modulus, mPa	850	773	982	1110

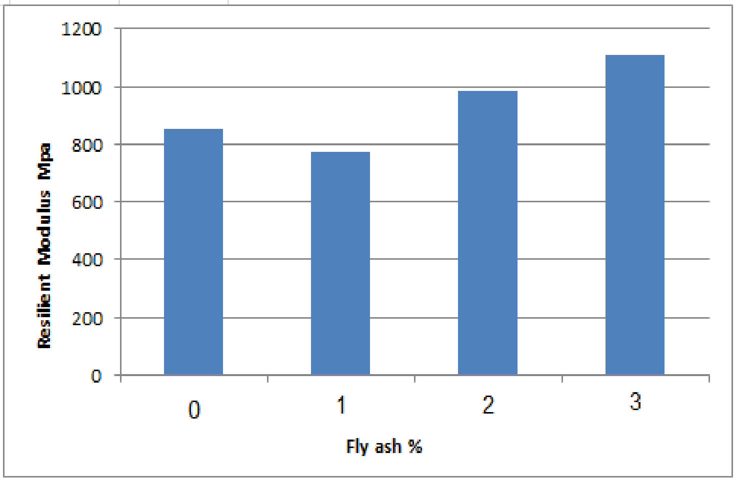

Figure 6. Effect of fly ash content on resilient modulus

5-4 Effects of Fly ash on Permanent Deformation

The result of permanent deformation tests is shown in figure (7) which is based on the data presented in table (7), Examinations of the presented data suggests that the permanent deformation parameters intercept and slope generally improved with the use of fly ash, for mixes containing 0 percent fly ash, the slope value which reflects the accumulation rate of permanent deformation is approximately 24 percent higher than that of mixes with 3 percent fly ash. For the intercept, the value is slightly increased as the fly ash content increases from the 0 to 1 percent, but then the addition of extra amount of fly ash tends to decrease the intercept value in a rate of 20 microstrain per each 1 percent change in fly ash content. This finding confirms that the rutting mode of failure in asphalt concrete pavement which is enhanced at hot summer temperature can be reduced in large extent with the introduction of fly ash to asphalt concrete mixtures.

Table 7. Permanent deformation test results

Fly ash Content , %	0	1.0	2.0	3.0
Intercept	121	107	83	67
Slope	0.244	0.240	0.324	0.162

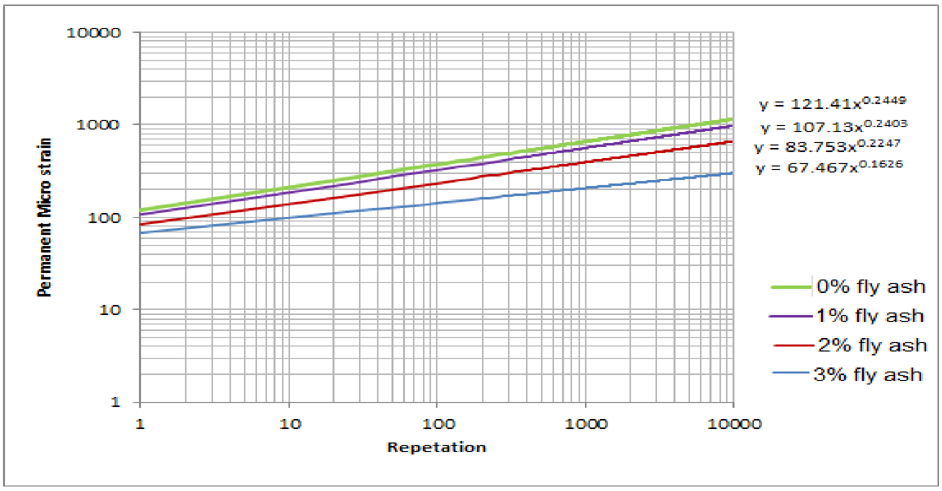

Figure 7. Effect of fly ash content on permanent deformation

5-5 Effects of Fly ash on Fatigue Performance

The fatigue characteristic curves for all mixtures are presented in Fig. 8. The fatigue parameters k1 and k2 are shown in Table 8. Values of k1 and k2 can be used as indicators of the effects of fly ash on the fatigue characteristics of a paving mixture. The flatter the slope of the fatigue curve, the larger the value of. k2 If two materials have the same k1 value, then a large value of k2 indicates a potential for longer fatigue life. On the other hand, a lower k1 value represents a shorter fatigue life when the fatigue curves are parallel, that is, k2is constant. Test results indicate that the use of fly ash with a rate of content ranged from 0 to 1 percent does not have a significant effect on fatigue life, but the mixes with more than 1 percent fly ash showed better fatigue performance, the k2 value for mixes with 2 and 3 percent fly ash was more than that of 1 percent fly ash by 36.5 and 38.6 percent, respectively. Considering k1, it can be concluded from the data shown in table (8) that there is an agreement between the results of k1 and k2 in the field of fatigue resistance, k1 has the smallest value (3.821x E-11) when the fly ash content was 3 percent and it was increased as the fly ash content decreased from 3 percent, but for the mixes with 1 percent fly ash content, k1 value was more than that of 0 percent fly ash. Using vesys5w software for analyzing pavement section consisted of a 150 mm asphalt concrete layer over a 400 mm base course layer with 1 million ESALs application during 10 years service life, the crack index value which is a dimensionless parameter providing an estimate for the amount of fatigue cracking is obtained and shown in table 8 below. 0 percent fly ash result in crack index value of 5.34 (severe cracking) whereas the use of 2 and 3 percent fly ash result in crack index value of 2.71 (moderate cracking) and 1.50 (light cracking), respectively.

Table 8. Fatigue parameters result

Fly ash Content , %	0	1.0	2.0	3.0
k_1	1.561 x E-7	2.454 x E-7	6.721 x E-9	3.821 x E-11
k_2	4.65	3.67	5.01	5.91
Crack Index	5.40	3.26	2.71	1.50

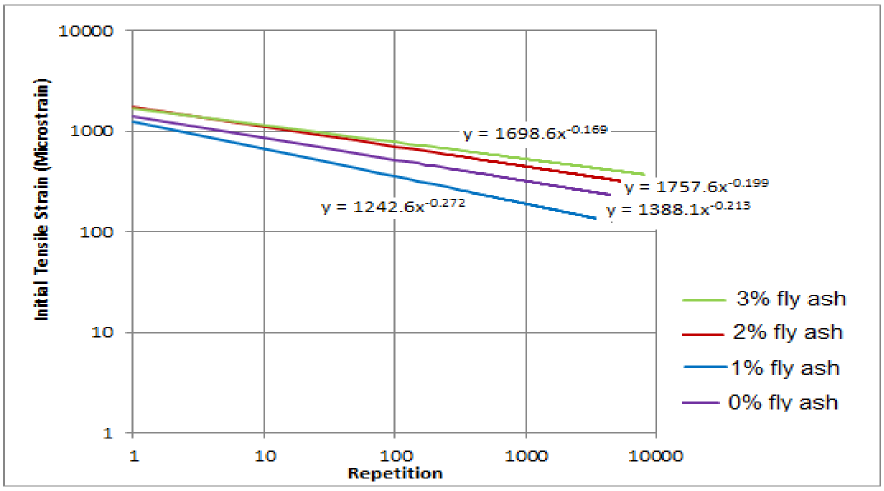

Figure 8. Effect of fly ash content on fatigue performance

6- Conclusions and Recommendations

The following conclusions and recommendations are based on the results of the laboratory tests and analysis presented in this study:

1. The addition of different percentages of fly ash as a filler replace has a large impact on volumetric mixture properties, some of the obtained results can be summarized as follows:

- The higher optimum asphalt content is given by mixes with higher fly ash content, the highest value of optimum asphalt content (5.35%) was obtained with 3 percent fly ash, while the lowest value (4.80%) was obtained with 0 percent fly ash.
- The maximum density is 2 percent, also increases in fly ash content tend caused decrease the density.
- At a rate of -0.135 percent for each 1 percent change in fly ash content ,a fly ash content altered from 0 to 2 percent, the air voids decreases. In 2 percent, the air voids content increases with a rate of +0.40 percent for each 1 percent change in fly ash content

2. To improve the indirect tensile strength for both control and conditioned mixes by adding a fly ash with a rate of +85 and +157.5 kPa per 1 percent increase in fly ash content, respectively. The resistance to moisture damage is improved in asphalt concrete pavement modified with fly ash.
3. A rate changed from 1 to 3 percent has shown an increase in resilient modulus for addition of fly ash as a filler substitute. The resilient modulus for mixes with 3 percent fly ash was 1.31 times that for mixes with 0 percent fly ash.
4. The adding of different percentages of fly ash given the significantly effected of permanent deformation parameters, slope and intercept, and when the percentage

of fly ash is increased as a filler substitute ,the modified mixes show higher resistance to permanent deformation .

5. The altering of fly ash as a filler substitute from a range (1-3) percent has modified the fatigue property of the asphalt concrete mixes as determined by flexural test. The value of k_2 changed from 2 and 3 percent of fly ash given value more than 0 percent of fly ash by 7.7 and 27.1 percent, respectively.
6. Significantly, to modify the asphalt concrete manner taken the percent of fly ash 2, and to produce the mixes more durable , higher resistance to distresses by adding the local knowledge.

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