EFFECT OF MINERAL FILLER TYPE AND CONTENT ON PROPERTIES OF ASPHALT CONCRETE MIXES

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ABSTRACT

Some of the newly constructed highway pavements in Iraq have shown premature failures with consequential negative impacts on both roadway safety and economy. Major types of these failures are permanent deformation (rutting) and cracking. Fillers were suspected to be a major contributor to these failures. The objective of this study is to evaluate the influence of new different fillers extracted from different local sources on the performance of asphalt mixtures. The effect of filler type and content on the failures potential of asphalt concrete as well as other mixes properties was investigated. A detailed laboratory study is carried out by preparing asphalt mixtures specimens using aggregate from Al-Taji quarry, (40-50) grade asphalt from dourah refinery and three different types of fillers (Portland cement, Silica fume, and Fly ash) were tested in the laboratory. Marshal Mix design was made using all types of fillers and different ratios to evaluate the performance of different types and filler quantities in the asphalt mixture. The mechanical properties of mixes were studied using indirect tensile strength, creep and marshal tests. Three different tests temperature (15,30,45C°) were employed in the indirect tensile test to investigate the susceptibility of these mixes to change in temperature. Results of this study indicate that replacement of Portland cement by 9.8% of silica fume aggravates resistance of the mixes to rutting and cracking. Furthermore, coal fly ash cannot be used as mineral filler in hot mix asphalt paving applications.

الخلاصة

البعض مِنْ أرصفةِ الطرق المَبْنيةِ حديثاً في العراق تحدث بها حالاتَ فشل لها تأثيراتِ سلبيةِ على كل من الأمان واقتصاد الطرق. النوع الرئيسي لحالاتِ الفشل هذه الأخاديد والشقوق. المواد المالئة تُعتبر من العوامل المساهمة في حدوث مثل حالاتِ الفشل هذه. إنّ هدفَ هذه الدراسةِ هو تُقييّمَ تأثيرَ المواد المالئة المختلفِة الجديدِة المستخرجة مِنْ المصادرِ المحليّةِ المختلفةِ على أداءِ الخلطاتِ الإسفلتية. إن تأثير النوعِ ومحتوى المواد المالئة على إمكانيةِ حدوث حالاتَ فشل الخرسانةِ الإسفلتية بالإضافة إلى خواص الخلطات الأخرى قد تم التحُقّق منها. تم عمل دراسة مفصلة بتحضير نماذج خلطات إسفلتية باستعمال ركام من مقلع التاجي و إسفلت (40–50) من مصفاة الدورة و ثلاثة أنواعِ من المواد المالئة (الاسمنت البورتلندي، دخان السيليكا، رماد الفحم) قد تم اختبارها في المختبر. تم عمل تصميم مارشال باستعمال مختلف أنواع المواد المالئة والنِسَبِ المختلفةِ لتَقييم أداءِ الأنواعِ المختلفةِ وكمياتِ المادة

المالئة في الخَلِيْطِ الإسفلتي. تم دراسة الخواص الميكانيكية للخلطات باستعمال فحص الشدِّ الغير مباشر، فحص الزحف وخواص مارشال. ثلاثة من درجات الحرارة المختلفةِ (15,30,45C°) قد إستخدمتْ في فحص الشدِّ الغير مباشرِ لتَحرّي سهولةِ تأثّر هذه الخلطات بالتغير بدرجةِ الحرارة. نَتائِج هذه الدراسةِ تُشيرُ بان استبدالِ الإسمنتِ البورتلندي ب الـ9.8 % مِنْ دخانِ السيليكا يحسن مقاومةَ المزيجِ إلى الزحف والشقوق. علاوة على ذلك، إن رماد الفحم لايمكن استعماله كمالئ معدني في تطبيقات خلطات التبليط الاسفلتي .

KEY WORD: Mineral Filler, Silica Fume, Fly Ash.

INTRODUCTION

Pavement systems in Iraq are exposed to a multitude of severe environmental factors, mainly the heavy axle load applied on the road, the high traffic and the excessive high temperature. Road usually show excessive failures at an early stage of the pavement life. A major step in the improvement of the existing performance of roads starts with modification of mix design. The filler plays a major role in the properties and behavior of bituminous paving mixtures *(Ilan Ishai, et al, 1980*). The mechanical properties of bituminous road pavement depend decisively upon the properties of its filler-bitumen (*S.Huschek,et al,1980*). For modification of asphalt paving materials, the high quality additives are quit expensive for the mass production of bituminous mixtures, a solution to this problem can be obtained by considering the influence of natural mixture ingredients, such as filler (*Ilan Ishai, Joseph Craus, 1980*). Mineral fillers were originally added to dense-graded HMA paving mixtures to fill the voids in the aggregate skeleton and to reduce the voids in the mixture (*Brian D. Prowell, et al, 2005*). Filler used in the asphalt mixture are known to affect the mix design, specially the optimum asphalt content. The term (filler) is often used loosely to designate a material with a particle size distribution smaller than #200 sieve. The filler theory assumes that "the filler serves to fill voids in the mineral aggregate and thereby create dense mix", (*I.Abdulwahhab, 1981*). Filler particle are beneficial because of increased resistance to displacement resulting from the large area of contact between particles. It was found that fillers increase compactive effects required to compact specimens to the same volume or air void content. This effect becomes more pronounced with increasing concentration of fillers. An early study made by Clifford Richardson, concluded that the role of the filler was more than void filling, implying that some sort of physical – chemical interaction occurred. Increasing amount in excess of upper limits produced pavements that cracked and checked while being rolled. In warm weather traffic tests, the pavement with excessive filler showed more cracking and checking under load. The cold weather tests showed no detrimental effects resulting from the excessive filler (*Ervin L. Dukatz, et al, 1980*). It is believed that the filler had a dual role: a) a portion participates in the particle to particle contact, and b) the rest floats in the asphalt, forming a high consisting binder. High filler concentration introduced non_newtonian flow behavior.(*Ervin L. Dukatz, et al, 1980*). The addition of filler to the mixture can improve adhesion and cohesion substantially. The effect of the addition of filler is directly related to their characteristics and the degree of concentration of the filler in the bitumen-filler system. The addition of filler might benefit the reduction of hardening by age and improve the property of flow at low temperature. The function of mineral filler is essentially to stiffen the binder. A higher percentage of very fine filler may stiffen the mixture excessively, making it difficult to work with and resulting in a crack susceptible mixture. According to various studies, the properties of mineral filler especially the material passing 0.075mm (No. 200) sieve (generally called P200 material) have a significant effect on the performance of asphalt paving mixtures in terms of permanent deformation, fatigue cracking, and moisture susceptibility. (*Kandhal, et al ,1998*)

OBJECTIVE OF THE STUDY

- To determine the effect of filler type and content on the mechanical properties of asphalt concrete paving mixture.
- To study the effect of new material of mineral filler on the properties of asphalt mixtures and compared it with traditional filler (Portland cement)

MATERIALS

The Materials used in this study are locally available and selected from the currently used materials in road construction in Iraq.

Asphalt Cement

One type of asphalt cement with penetration graded of (40-50) was used in this study; it is obtained from Dourah refinery. The physical properties of this type of asphalt cement are shown in Table (1).

Table (1): Physical Properties of Asphalt Cement.

Test	Unit	ASTM	Results D (40-50)
Penetration 25°C,100 gm , 5 sec.	1/10 mm	D5	43
Absolute Viscosity at 60°C (*)	Poise	D2171	2070
Kinematics' Viscosity at 135C (*)	C St.	D2170	370
Ductility (25°C, 5 cm/min.)	Cm.	D 113	>100
Softening Point (Ring & Ball)	C°	D 36	50
Specific Gravity at 25°C (*)	…….	D 70	1.04
Flash Point	C°	D 92	332

(*) The test was conducted in Dourah refinery

Aggregate

One type of crushed aggregate was used in this study, which was brought from Mix plant of Amanat Baghdad. The source of this type of aggregate is Al-Taji quarry. The physical properties of the aggregate are shown in Table (2). One nominal maximum size (12.5) was selected with two selected aggregate gradations; these two gradations were selected to compare the effect of restricted zone on the mix performance. Where G2 gradation is passing through the Superpave limitation control points and restricted zone, while, the gradation G1 is located out of the Superpave restricted zone requirement. Mixes design were prepared for heavy traffic level using the traditional Marshall methodology. These gradations are shown in Figure (1) and presented in Table (3). Three Selected Combined Gradations of Aggregate and Filler are shown in Table (4).

Table (2): Physical Properties of Al-Taji Quarry Aggregate.

Property	Coarse Aggregate		Fine Aggregate	
	G1	G2	G1	G2
Bulk specific gravity ASTM C 128	2.52	2.53	2.6	2.61
Apparent specific gravity ASTM C127 and C128	2.525	2.528	2.632	2.651
Percent water absorption ASTM C 127 and C 128	0.54	0.55	0.62	0.933

Table (3): Job Mix Formula's for Wearing Course of the Selected Gradation.

Sieve opening (mm)	Percent Passing Gradation Shape	
	G1	G2
19	100	100
12.5	94	91
9.5	85	79
4.74	70	57
2.75	42	43.4
1.18	29	34
0.6	20.2	27
0.3	14.4	16
0.15	11.6	12.2
0.075	9.8	9.8

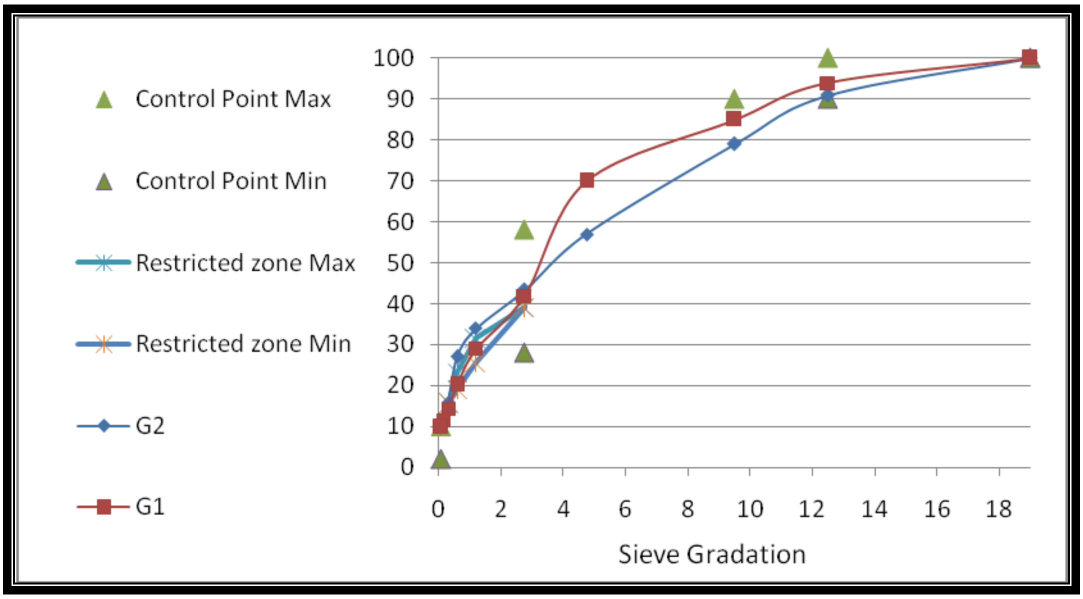


Figure (1) Gradation of Wearing Course for two selected gradation.

Table (4) Selected Combined Gradations of Aggregate and Filler

Sieve Size (mm)	Percent Filler					
	5.8% (C)		7.8% (B)		9.8% (A)	
	Percent Passing					
	Gradation Shape					
	G1	G2	G1	G2	G1	G2
19	100	100	100	100	100	100
12.5	94	91	94	91	94	91
9.5	85	79	85	79	85	79
4.74	70	57	70	57	70	57
2.75	42	43.4	42	43.4	42	43.4
1.18	29	34	29	34	29	34
0.6	20.2	27	20.2	27	20.2	27
0.3	14.4	16	14.4	16	14.4	16
0.15	11.6	12.2	11.6	12.2	11.6	12.2
0.075	5.8	5.8	7.8	7.8	9.8	9.8
Mix Composition						
Asphalt	4.75%	4.55%	4.75%	4.55%	4.75%	4.55%
Gmm of Mix when Silica Fume is used						
Gmm	2.4082	2.4044	2.406	2.4023	2.404	2.4
Gmm of Mix when Fly Ash is used						
Gmm	2.314	2.3105	2.28	2.278	2.2498	2.2462
Gmm of Mix when Portland Cement is used						
Gmm	2.4339	2.4301	2.4409	2.437	2.449	2.445

Mineral Filler

It has long been recognized that the filler plays a major role in behavior of the asphalt mixtures. The importance of fillers in asphalt mixtures has been studied extensively. In this study three types of fillers (Portland cement, silica fume, and fly ash) has been used, which is obtained from the different local sources. The physical properties of different fillers are shown in Table (5).

Table (5): Physical Properties of Mineral Fillers.

Property	**Portland cement**	**Silica fume**	**Fly Ash**
Specific Gravity	3.12	2.5	1.41
% Passing sieve No.200 ASTM C117	90	90	90

Characterization of the Mineral Filler

Fillers fill voids between coarse aggregates in the mixture and alter properties of the binder, (*Yong-Rak Kim et al ,2003*). Mineral filler increase the stiffness of the asphalt mortar matrix, improving the rutting resistance of pavements. Mineral filler also help reduce the amount of asphalt drain down in the mix during construction which improve durability of the mix by maintain the amount of asphalt initially used in the mix. The addition of fillers is known to stiffen asphalt. The degree of stiffening is a function of several filler and asphalt properties, which are not well understood (*Naga Shashidhar[1], Pedro Romero[1] 1998*). The fillers used in this study are:

Portland cement

Portland cement is essentially a calcium silicate cement, which is produced by firing to partial fusion, at a temperature of approximately 1500C°,(*John Newman, Ban Seng Choo, 2003*).

Fly Ash

Since the first edition of Fly Ash Facts for Highway Engineers is in 1986. Fly ash is the finely divided residue that results from the combustion of pulverized coal. It can be used as cost-effective mineral filler in hot mix asphalt (HMA) paving applications. Where available locally, fly ash may cost less than other mineral fillers. Also, due to the lower specific gravity of fly ash, similar performance is obtained using less material by weight, further reducing the material cost of HMA.,(*American coal ash association, 2003*).

Silica Fume

Silica fume is a by-product resulting from the reduction of high purity quartz with coal in electric arc furnaces in the manufacture of silicon and ferrosilicon alloys.

Silica fume is an ultra-fine powder consisting of nearly spherical particles around 100 times smaller than a grain of cement. A size distribution of silica fume, relative to portland cement and fly ash, is shown in the following Figure(2), (*Prof.Zongjin Li,2007*).

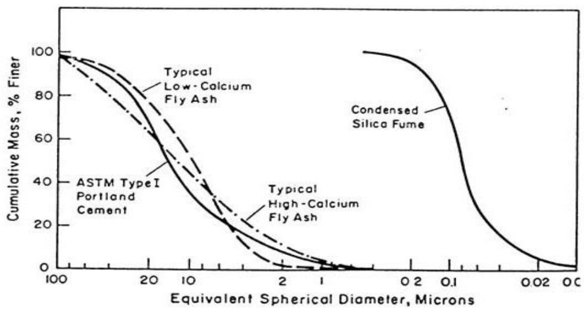


Figure Comparison of particle size distributions of portland cement, fly ashes, and condensed silica fume.

Figure(2), Size Distribution of Silica Fume, Fly Ash, and Portland Cement.

Preparation of Mix Design

In the work reported in this paper a series of minus No. 200 (75 m) mineral fillers were used to prepare and characterize hot-mix asphalt concrete. The same mix design methods that are commonly used for hot mix asphalt paving mixtures are also applicable to mixes in which different filler is used. The percentage of filler to be incorporated into the design mix is the three percentage (5.8%, 7.8%, 9.8%), denoted as C, B, A respectively, to determine which percentage satisfy all the required design criteria. The mix proportions and aggregate gradation for the asphalt mixtures tested are shown in Table(3) and Table (4). During the mixing in the laboratory, it is noticed that the mixtures with fly ash became so stiff that it could not be mixed by hand, and silica fume shows good dispersion throughout the mixture.

Testing Procedures

Indirect Tensile (IDT) Strength Test

The indirect tensile test was developed to determine the tensile properties of cylindrical concrete and asphalt concrete specimens through the application of a compression load along a diametrical plane through two opposite loading heads. This type of loading produces a relatively uniform stress acting perpendicular to the applied load plane, causing the specimen to fail by splitting along the loaded plane, (*Ahmed, et al , 2006*). Test specimens 2.5 inches thick and 4 inches diameter were compacted and then tested using curved steel loading strips 0.5 inch wide. The maximum load carried by the specimen was found, and the indirect tensile stress at failure was determined and presented.

Static Creep Test

The Static Creep test method is used to determine the resistance to permanent deformation of HMA at temperatures and loads similar to those experienced in the field. Measured creep properties include strain_time relationship and stiffness. According to TxDOT, the main disadvantage of this test is that the results do not seem to be repeatable. The main advantage of this test is that it can be performed within a day and test results reasonably predict the field performance (*Rajpal Sugandh, et al, 2007*).

Test Result and Discussion

Effect of Mineral Fillers on the Volumetric Properties of HMA

The HMA specimens were prepared in the laboratory; it were tested in the laboratory to determine the properties of asphalt concrete mixtures, such as, Marshall properties (bulk density, air voids, voids filled with asphalt, voids in mineral aggregate), to evaluate their effect on the HMA behavior. Figures (3,4,5) shows that the relations between filler content and Marshall properties is typical to common trend in asphalt content mixes. It can be seen from Figures, that these volumetric properties are checked against the requirements. For silica fume and Portland cement, all the requirements are satisfied. For the silica fume, increasing the filler content increased the air voids. This abnormal effect may be due to the stiffening of the mixture by silica fume. It can be seen from Figures, that the volumetric properties of fly ash filler shows, that VTM, VMA values are higher if compared with Marshall properties values and lower VFA values. The specific gravity of fly ash is low, therefore, a given weight percentage of fly ash will usually occupy a greater volume than that of a conventional filler material.

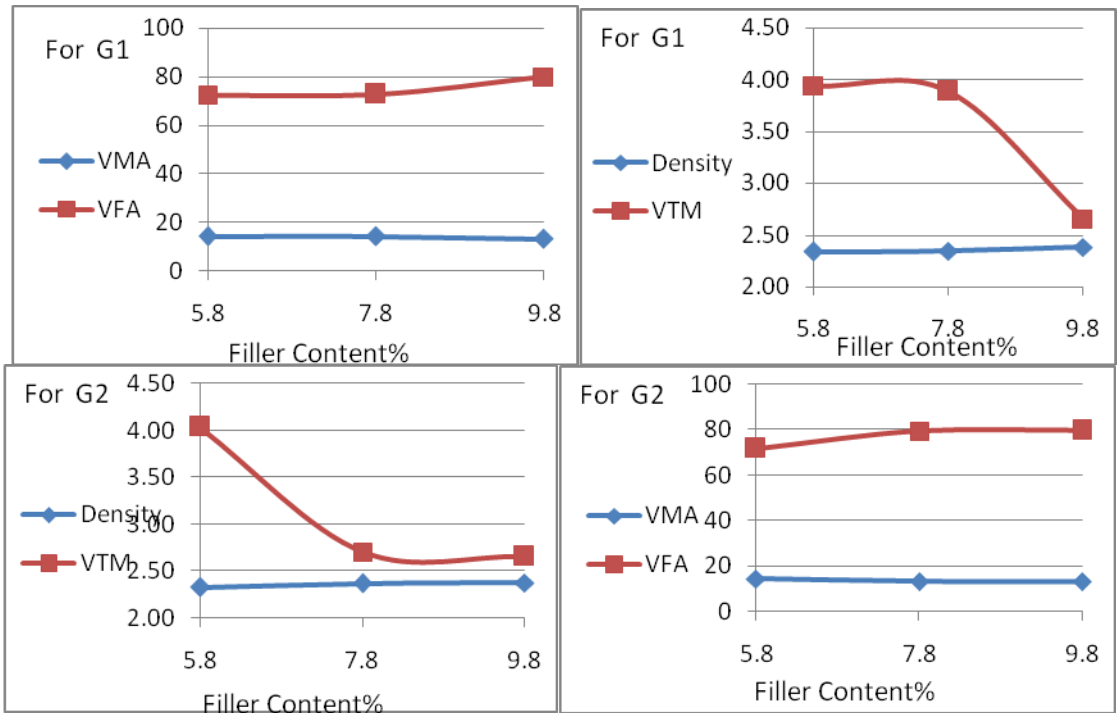


Figure (3) Effect of Portland Cement on volumetric properties.

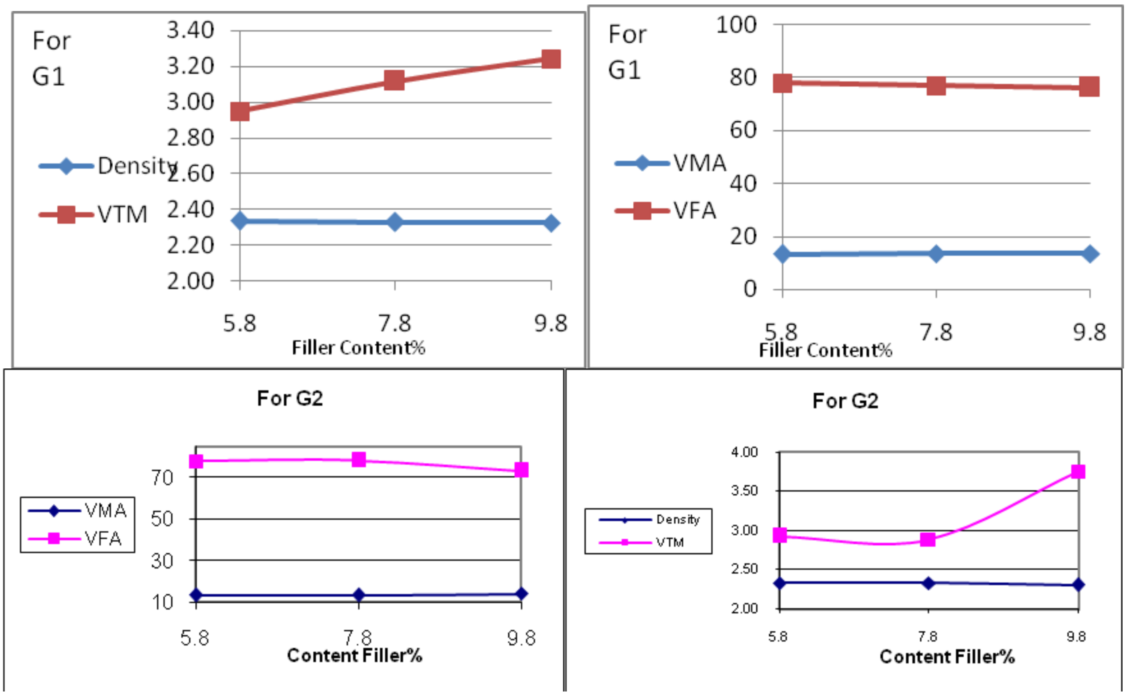


Figure (4) Effect of Silica Fume on volumetric properties.

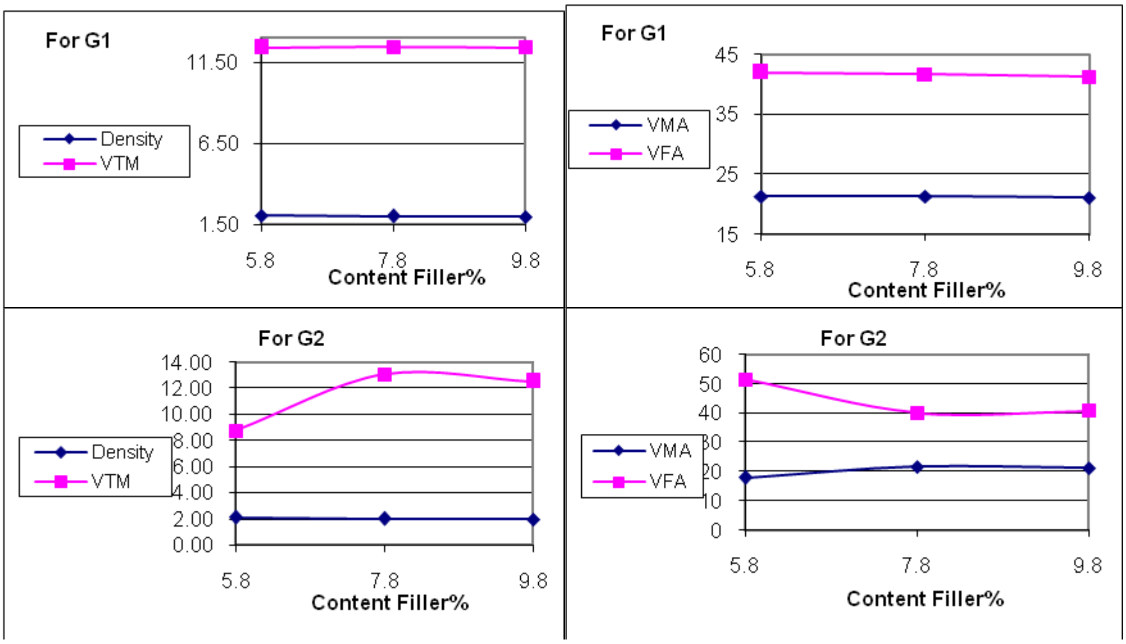
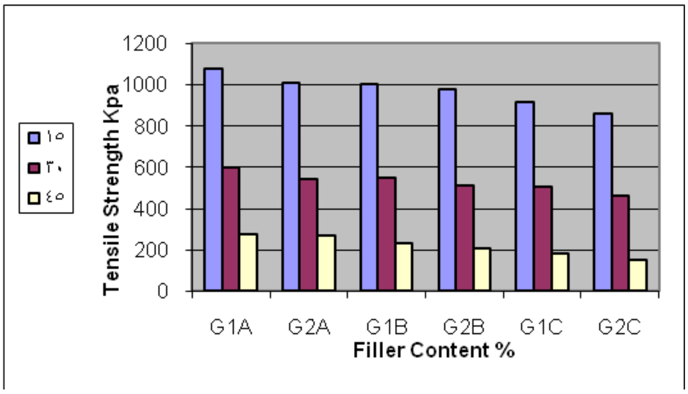


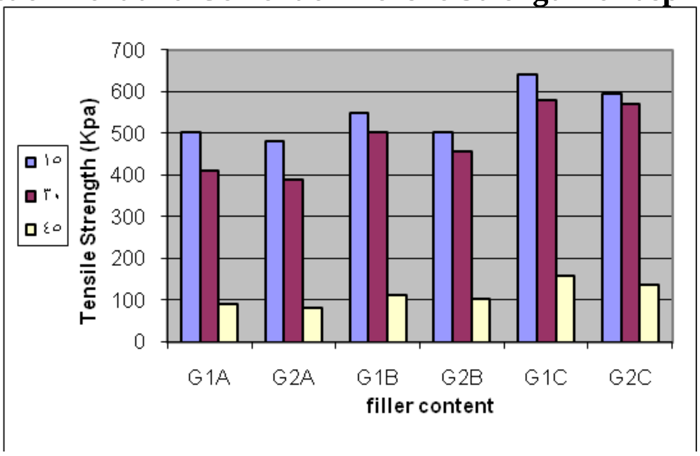
Figure (5) Effect of Fly Ash on volumetric properties.

EFFECT OF MINERAL FILLERS ON THE PERFORMANCE OF HMA

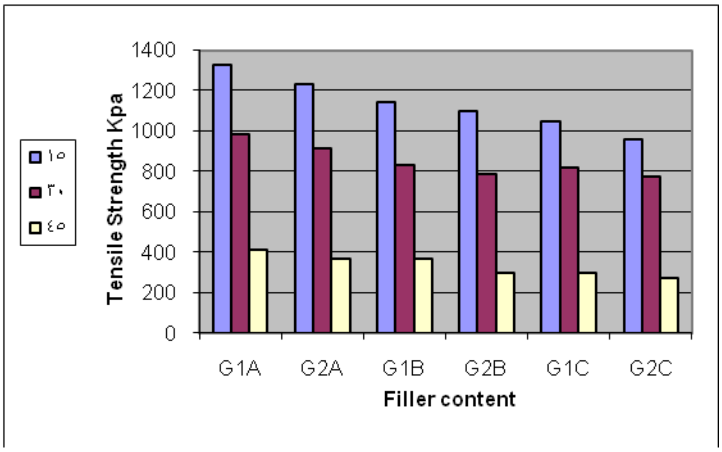
Filler content have a considerable effect on the mixture making it act as a much stiffer, and thereby affect the HMA pavement performance including its fracture behavior. The indirect tensile strength has been used to evaluate the mixture resistance to cracking. To study the effect of varying test temperature on the quantity of mixture, three different temperatures (15, 30 and 45C°) are used in the indirect tensile strength test. Figures from (6) to (8) show the influence of mineral fillers on tensile strength at different test temperatures. For filler type, from figure (8) shows that mixture with silica fume has the highest tensile strength at all test temperatures. And it indicated higher value of temperature susceptibility than other fillers, indicating that silica fume can be expected to provide excellent resistance to stripping. Figure (7) shows that mixtures with fly ash have the lowest tensile strength. Amount in excess of filler content of fly ash produced pavements that cracked and checked while being rolled. The failure in the tensile strength is attributed to the many voids that weaken the cross-section. The success of Portland cement as a filler was believed to be caused partly by its high specific gravity.



Figure(6) Effect of Portland Cement on Tensile Strength for asphalt mixtures

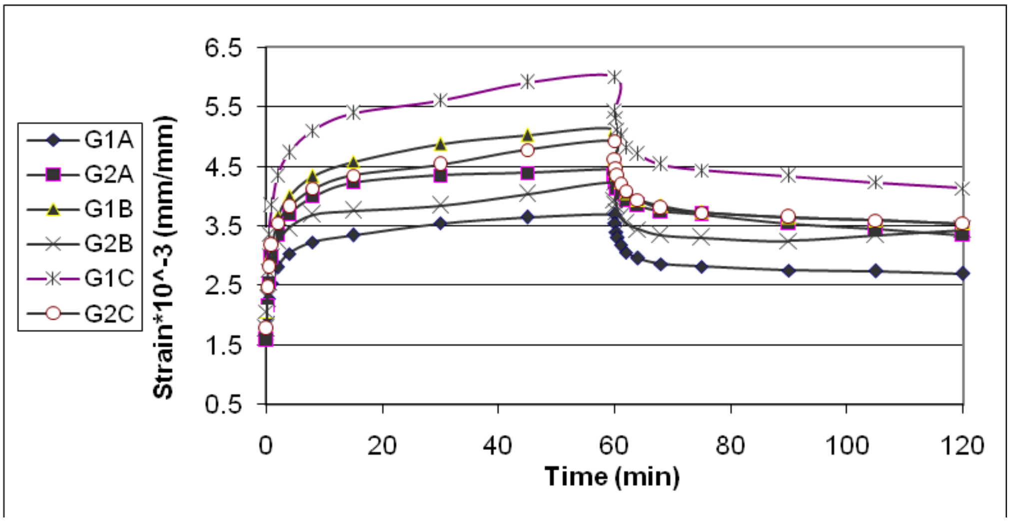


Figure(7) Effect of Fly Ash on Tensile Strength for asphalt mixtures

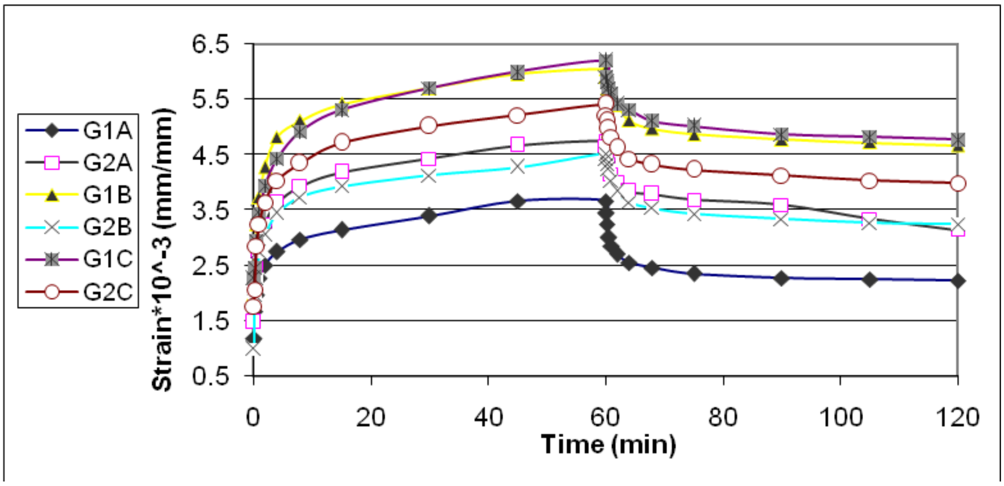


Figure(8) Effect of Silica Fume on Tensile Strength for asphalt mixtures

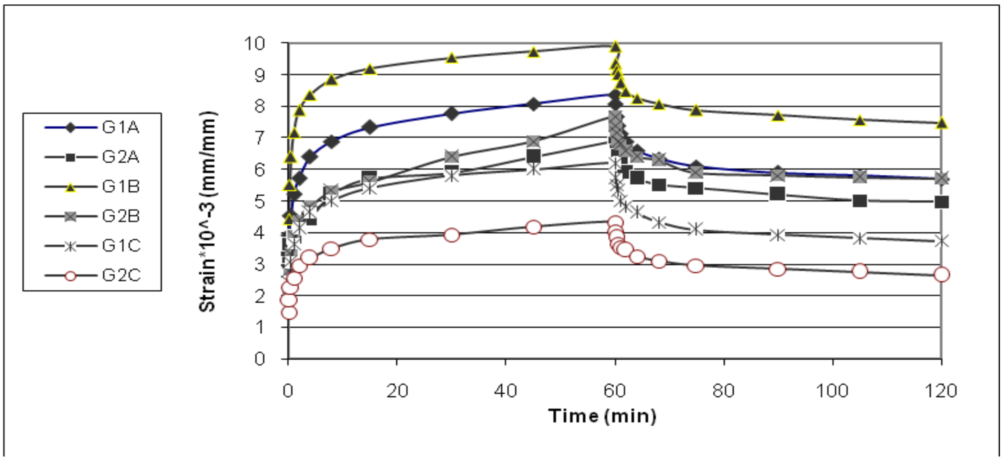
The rheological properties of the material resulting from the incorporation of mineral filler into mixture may differ substantially from those of the traditional mixture. The creep test results, reported in Figures (9,10,11) and presented in the form of strain_time curves for various mixes. From Figures, it can be conclude, that fly ash had a very significant effect on the creep properties of the asphalt concrete mixtures. At 5.8% and 7.8% percent, Portland cement have the less permanent strain when comparing with silica fume, but when the percent is increased to 9.8%, the silica fume has the lowest permanent strain.



Figure(9) Strain-Time relationship for Cement filler in asphalt mixtures.



Figure(10) Strain-Time relationship for Silica fume filler in asphalt mixtures.



Figure(11) Strain-Time relationship for Fly ash filler in asphalt mixtures.

CONCLUSIONS

Based on the experiment employed in this study, the following conclusions could be made.

- Fly ash has less workability and less tensile strength of asphalt concrete mixtures when compared to other asphalt concrete mixes.
- Silica fume and Portland cement have more workability and higher tensile strength in asphalt concrete mixes.
- The compaction effort required to achieve density increases as the concentration of filler in asphalt concrete mixtures is increased.
- The incorporation of fly ash filler in the mixture will always cause a significant reduction in mixtures mechanical properties.
- The percentage of fly ash filler to be incorporated into the mix design is the lowest percentage that will enable the mix to satisfy all the required design criteria.

REFERENCES

- Ilan Ishai, Joseph Craus, and Arieh Sides, "A Model for Relating Filler Properties to Optimal Behavior of Bituminous Mixtures", AAPT, 1980, Vol.49.
- S.Huschek and CH.Angst, "Mechanical Properties of Filler-Bitumen Mixes at High and Low Service Temperatures", AAPT,1980,Vol.49.
- Ilan Ishai, and Joseph Craus , "Effect of the Filler on Aggregate-Bitumen Adhesion Properties in Bituminous Mixtures", AAPT, 1977, Vol.46.
- Brian D Prowell, Jingna Zhang, and E.Ray Brown," Aggregate Properties and the Performance of Superpave-Designed Hot Mix Asphalt", National Center for Asphalt Technology, 2005.
- Ervin L.Dukatz and David A.Anderson, ' The Effect of Various Filler on the Mechanical Behavior of Asphalt and Asphaltic Concrete",AAPT,1980,Vol.49.
- Prithvi S.Kandal, Cynthia Y.Lynn, Frazier Parker, " Characterization Tests for Mineral Fillers Related to Performance of Asphalt paving Mixtures", National Center for Asphalt Technology, 1998.
- Yong-Rak Kim and Dallas N.Little, Injun Song, "Mechanistic Evaluation of Mineral Filler on Fatigue Resistance and Fundamental Material Charateristics",2003.
- Naga Shashidhar[1], Pedro Romero, 1998 "Factors Affecting the Stiffening Potential of Mineral Fillers"
- American coal ash association, "Fly Ash Facts for Highway Engineers"2003.
- Lecture by Prof.Zongjin Li," Construction Material",2007
- Hassan Y. Ahmed, Ayman M. Othman and Afaf A. Mahmoud,2006 " Effect of Using Waste Cement Dust as A Mineral Filler on the Mechanical Properties of Hot Mix Asphalt"
- Rajpal Sugandh, MS, Manuel Zea, BS, Vivek Tandon, PhD, PE, Andre Smit, PhD, Jorge Prozzi, PhD"Performance Evaluation of HMA Consisting of Modified Asphalt Binder", 2007.
- Hamad I. Al-Abdulwahhab, "The Effects of Baghouse Fines and Mineral Fillers on Asphalt Mix Properties in the Eastern Province of Saudi Arabia", Thesis, 1981.