Effect of Additives Types and Contents on the Properties of Stone Matrix Asphalt Mixtures

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Abstract

Stone Matrix Asphalt (SMA) is a gap-graded mix that is gaining popularity worldwide. SMA does not application in Iraq; in order for adopt the use of SMA mixtures particularly on high volume roads such as highways and urban intersections in Iraq. So, the new methodology has to be evaluated using Iraq materials and conventional laboratory methods to insure good performance in the Iraq's highway. The purpose of this study is to evaluate the effect of additives type and content on the performance of stone matrix asphalt mixtures. A detailed laboratory study is carried out by preparing asphalt mixtures specimens using aggregate from Al-Nibaay, (40-50) grade asphalt from dourah refinery and two types of fiber (carbon fiber and polypropylene fiber) with percentages (0.2, 0.3, 0.4, 0.5%) by weight of total mix and two types of polymer (phenol and polyethylene) with percentages (7.5, 10, 12.5, 15%) by weight of total mix were tested in the laboratory. Compacted mixtures were tested to evaluate the effects on SMA bulk specific gravity, maximum specific gravity, void content, Marshall Stability, Indirect Tensile Strength (ITS) and permanent deformation. Three different tests temperatures (20, 40,60C°) were employed in the creep test and two temperatures (5, 25 C°) were used in indirect tensile test to investigate the susceptibility of these mixes to change in temperature. The results clearly indicate the importance of using the proper type of stabilizing additive. According to the study results, polymers additives were found to be more effective than fibers additives. SMA Mix modified with phenol additives can be used in cold and normal temperature area, whereas SMA Mix modified with polyethylene additive can be used in high temperature area.

Keywords: SMA, Polymer modification, Phenol resin, creep test, tensile strength.

تأثير أنواع المضافات والمحتوى على خصائص مزيج الإسفلت ذو الصنف الفجوي

الخلاصة

خليط الركام الخشن الإسفلتي هو مزيج ذو الصنف الفجوي ولقد اكتسب شعبية كبيره حول العالم. لم يتم العمل بخلطات الركام الخشن الإسفلتي في العراق ولأجل استعمال خلطات الركام الخشن الإسفلتي في الطرق ذات الإحجام العالية من المرور مثل الطرق السريعة والتقاطعات الحضرية في العراق. لذلك ، سيتم تطبيق هذه الخلطات باستخدام المواد المحلية وسيتم تقييمها باستخدام الطرق المختبريه التقليدية لتأمين الأداء الجيد في طرق العراق . إنّ الغرض من هذه الدراسة هو تقيّيم تأثير أنواع المضافات ومحتواها على أداء خلطات الركام الخشن الإسفلتي. تم عمل دراسة مختبريه تفصيلية بتحضير نماذج خلطات اسفلتيه وذلك باستعمال الركام من مقلع النباعي ، وإسفلت ذو تدرج (40-50) من مصفاة الدورة, واثنان من أنواع الألياف (ألياف الكربون وألياف البولي بروبلين) كنسبة مئوية (0.2,0.3,0.4,0.5 %) من الوزن الكلي

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للخليط واثنان من أنواع البوليمرات (الفينول و البولي اثيلين) كنسب مئوية (7.5,10,12.5,15 %) من الوزن الكلي للخليط حيث تم اختبارهما في المختبر. تم اختبار الخلطات الاسفلتيه لتقييم التأثير على الوزن نوعي للمزيج , أعلى وزن نوعي، محتوى الفجوات، ثبات مارشال، قوّة الشدّ غير المباشرة والتشوه الدائم. تم اختبار ثلاث درجات حرارة مختلفة (20, 40,60) في اختبار فحص الزحف وتم اختبار درجتي حرارة (5, 25) في فحص الشدّ الغير المباشر لتحرّي سهولة تأثر هذه الخلطات للتغيير في درجة الحرارة. تشير النتائج إلى أهمية استعمال النوع المناسب كمضاف في خلطات الركام الخشن. وتبعا لنتائج الدراسة،تبين بان إضافة مضافات البوليمر أكثر فعّالية من مضافات الألياف. يمكن استخدام خلطات الركام الخشن الاسفلتي المحسنه بمضافات الفينول في مناطق درجة الحرارة الباردة والطبيعية، بينما يمكن استخدام خلطات الركام الخشن المحسن بمضاف البولي اثيلين في مناطق درجة الحرارة العالية.

Introduction

Asphalt pavements in general are facing serious distress problems worldwide. So much has been done to improve the quality of the mix through research and innovations,[1]. Stone Matrix Asphalt (SMA) has been used successfully in Europe for over 20 years to provide better rutting resistance. Since 1991, the use of SMA has increased steadily in the United States, [2]. SMA is a tough, stable, rut-resistant mixture that relies on stone-on-stone contact to provide strength and a rich mortar binder to provide durability. These objectives are usually achieved with a gap-graded aggregate coupled with fiber or polymer modified, and high asphalt content matrix, [3]. SMA has a high Skeleton to resist permanent deformation. The stone skeleton is filled with mastic of bitumen and filler to which fibers are added to Provide adequate stability of bitumen and to prevent drainage of binder during transport and placement. Typical SMA composition consists of 70–80% coarse aggregate, 8–12% filler, 6.0−7.0% binder, and 0.3 per cent fiber, [4]. SMA, due to its high asphalt binder content,Requires fibers such as stabilizing additiveso that segregation or exudation does not occur during the mixing process and placement. The utilized fibers do not produce any chemical alteration in the asphalt cement, but physical properties are altered. The fibers are classified as organic or inorganic. The organic fibers are classified as natural (cellulose) or artificial (polyester, polypropylene, polyetilene). The inorganic fibers are also subdivided as natural or artificial; a fiber-designated amianthus is an example of a natural inorganic fiber. Steel fibers, carbon, and glass are examples of artificial inorganic fibers. The proportion of coarse aggregate that interlocks to form a stone on-stone cellulose fibers are the most commonly applied in the production of SMA, [5]. A study conducted in Ontario, Canada, by the Ministry of Transportation on SMA pavement slabs trafficked with a wheel-tracking machine gave less rut depths in comparison to that occurring in a dense friction coarse [6]. Coarse aggregate have the most important role in obtaining high rutting resistance of SMA and that's why regulations emphasize on type and quality of aggregate [7]. Interlock between coarse aggregates, which constitute the skeleton of SMA, is an important factor of rutting performance of these mixtures. The interlock can be improved through better selection of fiber type and content, volume of bitumen or filler used and grading of aggregates,[8].

Objective of the Study

1) Evaluate SMA properties for various additives types and contents.
2) Predicting the performance of SMA mixes.
3) To identify the influence of modifiers on the performance of HMA

Materials

The Materials used in this research 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).

Aggregates

An AL-Nibaay aggregate was used in this research. Table (2) and Figure (1), shows specifications and selected aggregate gradation used in SMA construction.

Stabilizing Additives

The high asphalt contents in SMA binder made it draindown; therefore, a stabilizing additive must be used to hold the binder on the coarse aggregate during mixing and placement. In order to prevent unacceptable draindown, each fibers or polymers can be added to the binder. Two types of fiber (carbon fiber and polypropylene fiber) with percentages (0.2, 0.3, 0.4, and 0.5%) by weight of total mix and two types of polymer (phenol and polyethylene) with percentages (7.5, 10, 12.5, and 15%) by weight of total mix were tested in the laboratory.

Fiber stabilizer

Fiber types (carbon fiber and polypropylene fiber) shown in Figure (2), were used in this study. Fibers were pre-blended in (40-50) binder. They are typically added to the mix at percentage (0.2, 0.3, 0.4, and 0.5%) by weight of total mix. Carbon fiber is produced by the carbonization of suitable organic fibers and can be made in either short or continuous lengths. Difficulties arise in the addition of carbon fiber to SMA. Properties of two type of fiber shown in Tables (3),(4).

Polymer Stabilizer

One purpose of the polymer stabilizer is to increase the stiffness of the AC at high, in service temperature and/or to improve the low temperature properties of the binder material. Two types of Polymers (phenol and polyethylene) shown in Figure (3) were used. Their properties were shown in Table (5). They are typically added to the mix at Percentage (7.5, 10, 12.5, 15%), by weight of asphalt cement. The polymers are pre blended with the asphalt cement and added to the mix during the mixing process.

Mineral Filler

Mineral filler is essentially stiffening the rich binder SMA. A higher Percentage of filler may stiffen the mixture excessively, making it difficult to compact and may be resulting in a crack susceptible mixture, [2]. In general, amount of material passing the No. 200 sieve is relatively 8-12 percent of the total amount of aggregate in the mix. One type of mineral filler (Ordinary Portland Cement) has been used in this study. The physical properties of filler used are shown in Table (6).

Indirect tensile strength test

The indirect tensile strength test is used to determine the tensile properties of the asphalt concrete which can be further related to the cracking properties of the pavement. Low temperature cracking, fatigue and rutting are three major distress mechanisms. Numerous researches have been conducted relating the tensile strength of asphalt mixtures to the performance of asphalt pavements [9]&[10]. This test is summarized in applying compressive loads along a diametrical plane through two opposite loading strips. This loading configuration develops a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametral plane which ultimately causes the specimen to fail by splitting along the vertical diameter [11]. The test was performed at (5, 25 C°), the test provide information on:

1- Tensile strength
2- Fatigue characteristics and,
3- Permanent deformation characteristics of pavement materials.

The indirect tensile strength (I.T.S) is calculated, as follows:

$$I.T.S = \frac{2Pult}{ptD} \quad \text{..........(1)}$$

Where:

Pult = Ultimate load up to failure (N).

t = Thickness of specimen (mm), and

D = Diameter of specimen (mm).

Creep Test

Creep is a second important measure of modified asphalt performance, its ability to elastically recover deformation. Since asphalt pavement are designed to be flexible, they must quickly return to their original configuration after loading. [12]. The Static Creep test method was performed at (20, 40, 60C°) with applied stress 0.1 MPa to determine the resistance to permanent deformation of SMA at temperatures and loads similar to those experienced in the field.

Materials and Methods

This paper presents a mixture design procedure for SMA mixtures laboratory study conducted with various samples of stabilizing additives. Cylindrical Specimens of 100 mm diameter were prepared with asphalt contents 6%, twelve specimens were prepared for each type of additive at different percentages. All specimens were prepared using the Marshall Compacting procedure of 50 blows [13].

The compacted specimens were tested by marshal test and the results are shown in Figure (4). The selected optimum additive content was determined by testing the samples for stability, flow, bulk specific gravity and air voids. SMA samples made by 0.3% as selected optimum additive content for fibers and 15% has selected as optimum additive content for polymers. In this study in order to examine type and selected additive optimum content on resistance performance of SMA mixtures. Compacted mixtures were examined for indirect tensile strength test as an indicator of strength and adherence against fatigue, temperature cracking and rutting. Also, specimens rutting were examined by creep test. The performance of the selected additive content showed a varied trend.

Results and Discussion

Marshall Mix design results

Marshall Specimens were compacting by Marshall Method with 6% of bitumen weight and different percentage of additives types. In order to determine optimal additive percent, 12 specimens were produced for each additive. All specimens were compacted with energy 50 blows. The results of Marshall Test are presented in Figure (4). Stability, flow and void content were considered to obtain optimum additive content for each additive type and the optimum contents are presented in Table (7).

Tensile Test Results

The indirect tensile strength test is used to determine the tensile properties of the asphalt concrete which can be further related to the cracking properties of the pavement. According to tensile results been shown in Figures (5), specimens with phenol additive resulted in higher tensile strength if compared with polyethylene specimens. The flow value for phenol and polyethylene specimens is similar approximately. Whereas specimens with carbon fiber additive have higher tensile strength from polypropylene in temperature degree 5C°, but polypropylene specimens have higher tensile strength from carbon fiber in temperature degree 25C°. This behavior is because that tensile strength is related primarily to a function of the modified binder properties, and its stiffness influence the tensile strength. Furthermore the results shows flow for carbon fiber specimens is higher than polypropylene specimens.

Creep Test Results

From the results shown in Figures (6), permanent deformation for polyethylene specimens is lower than phenol in temperature (20, 40 C°). In temperature 60 C°, phenol specimens are failure in creep test, whereas polyethylenes specimens are succeed in this test at mentioned temperature. For other specimens, the permanent deformation for carbon fiber specimens showed higher than polypropylene specimens in temperature 20 C°. Carbon fiber specimens are failure in creep test at (40, 60 C°), this behavior related to higher amount of carbon fiber into the mixture may not have beneficial effect and might deteriorate its deformation properties, however, large amount of fiber leads to higher surface area that must be coated by bitumen; consequently, the aggregate particles and fiber would not be fully coated with bitumen and thereby looser and failure is happen. While polypropylene specimens are failure at temperature 60 C° only. In general, polyethylene specimens express the best results in creep test. It can be concluded that polyethylene specimens demonstrate higher rutting resistance.

Conclusions

Specific conclusions from this study were: gap graded mixes are thought to be weak in rutting resistance at high temperature. SMA mixes were found high fatigue performance at lower temperature. The fatigue life and rutting resistance increased to a maximum when polymer content was used. According to the study results, polymers additives were found to be more effective than fibers additives, but it need more research to prove this point. SMA

Mix modified with phenol additives can be used in cold and normal temperature area, whereas SMA Mix modified with polyethylene additive can be used in high temperature area.

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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	45
Absolute Viscosity at 60°C (*)	Poise	D2171	2065
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

Table (2): Gradation and Specification of Aggregate.

Sieve Size (mm)	Passing% by weight	FHWA Specification %
19	100	100
12.5	95	100-85
9.5	68	75-60
4.75	30	34-25
2.36	22	24-18
1.18	16	20-14
600	14	17-12
300	12	15-10
150	10	13-9
75	9	12-8

Table (3) Properties of Carbon Fiber (*).

Properties	Results
Fiber length	2.54 cm cut
Density	1.8 gm/cm^3
Tensile modulus	29 MSI

(*) Results from Al-Furat Beirut

Table (4) Physical properties of polypropylene fibers (PPF) brought from Fosroc

Form	Virgin Polypropylene Fiber
Specific gravity	0.91
Alkali content	Nil
Sulfate content	Nil
Chloride content	Nil
Fiber thickness	(18-30) microns
Young modulus	(5500-7000) MPa
Tensile strength	350 MPa
Melting point	160 C^O
Fiber length	19 mm

Table (5) Physical Properties of Phenol Resin and Polyethylene Polymer.

Novolac phenol Resin	
Specific Gravity	1.11
Reaction Temperature	High 90-130C°
Resin Form	Solid (powder)
Hardening Process	Hardening reaction with addition of HMTA and by heating
Polyethylene Polymer	
Melt Index	G/10 Min
Density	0.921-0.924 g/cc

Table (6) Physical Properties of Filler (Cement).

Property	Results
Specific Gravity	3.12
% Passing sieve No.200 ASTM C117	96

Table (7) Selected Optimum Additive Content

Additive Type	Optimum Percent
Phenol	15% by weight of asphalt
Polyethylene	15% by weight of asphalt
Polypropylene	0.3% by weight of total mix
Carbon Fiber	0.3% by weight of total mix

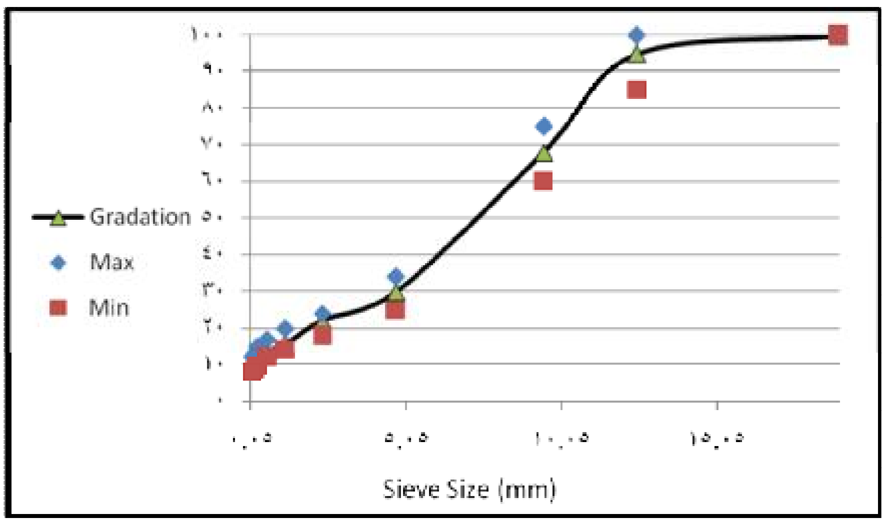


Figure (1) Selected Gradation of Aggregate.

A, Carbon Fiber

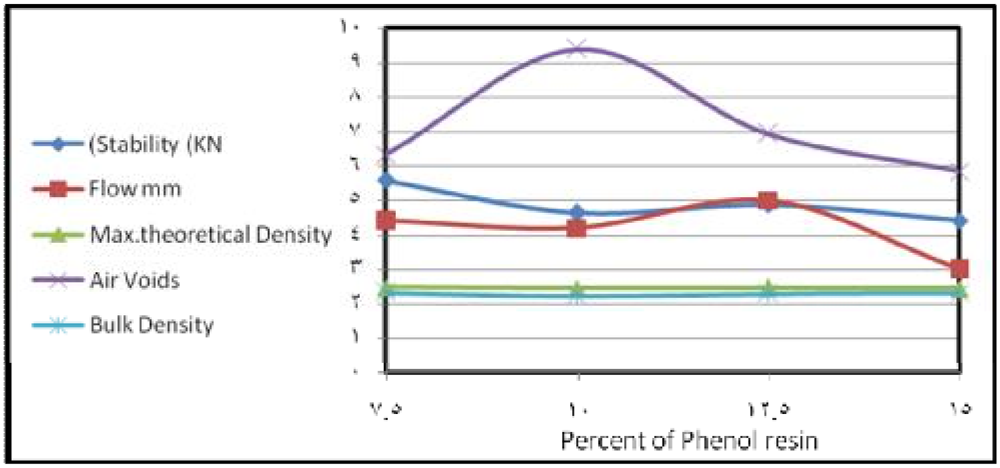
B, Polypropylene Fiber

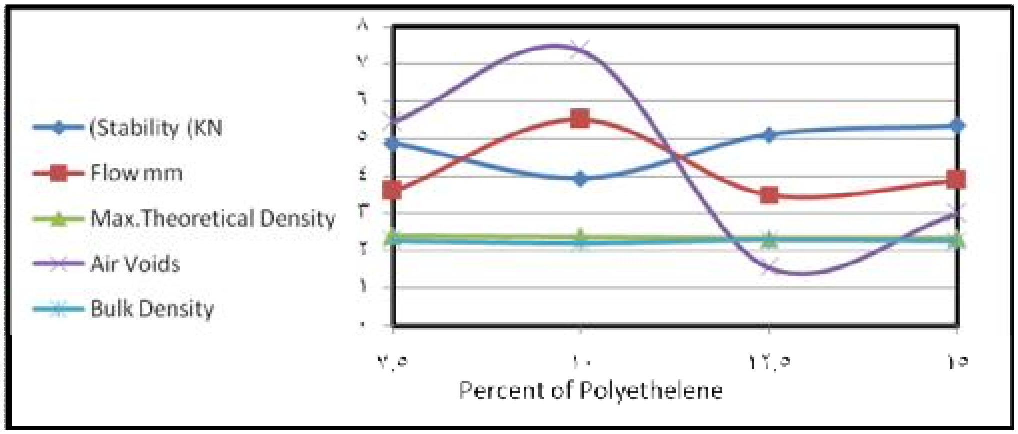
Figure (2) Fibers used in this Study

A, Polyethylene Polymer

B, Phenol Polymer

Figure (3) Polymers used in this study.


(Stability (KN
Flow mm
Max.theoretical Density
Air Voids
Bulk Density
٧,٥
١٠
١٢,٥
١٥
Percent of Phenol resin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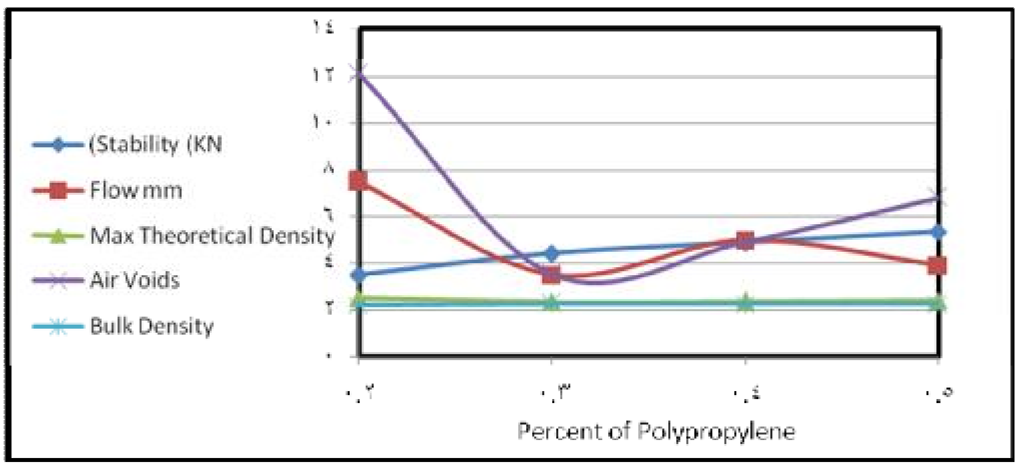
Percent of Polyethelene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Percent of Polypropylene

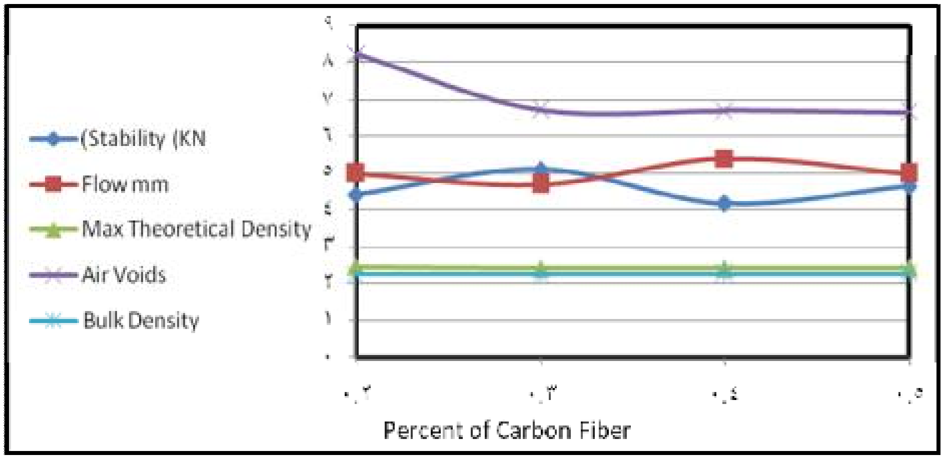
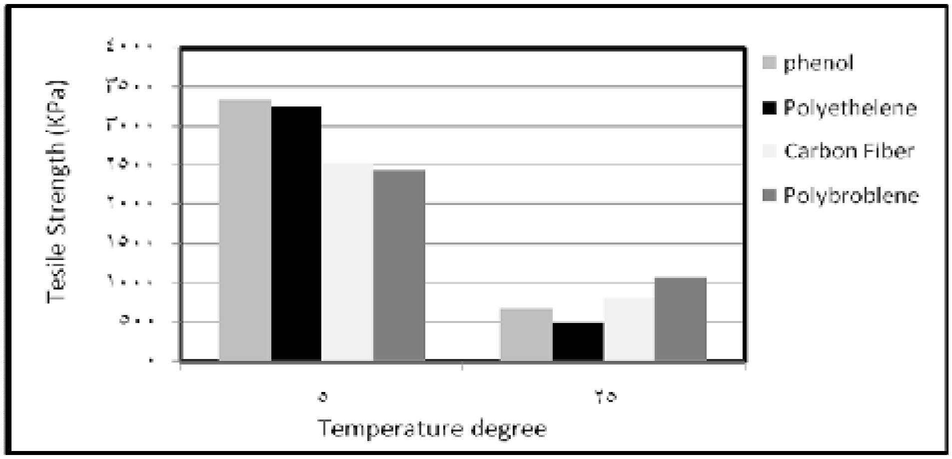


Figure (4) Marshall Properties of Stone Matrix Asphalt.



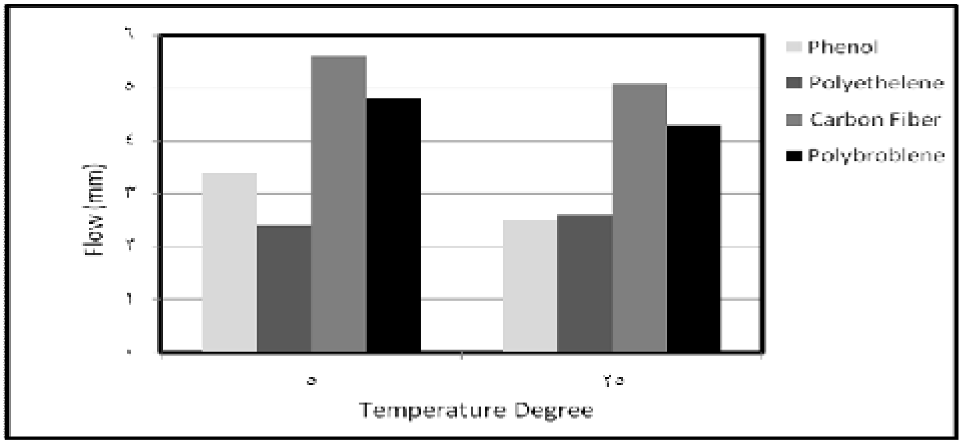


Figure (5) Tensile Strength and Flow value of Stone Matrix Asphalt.

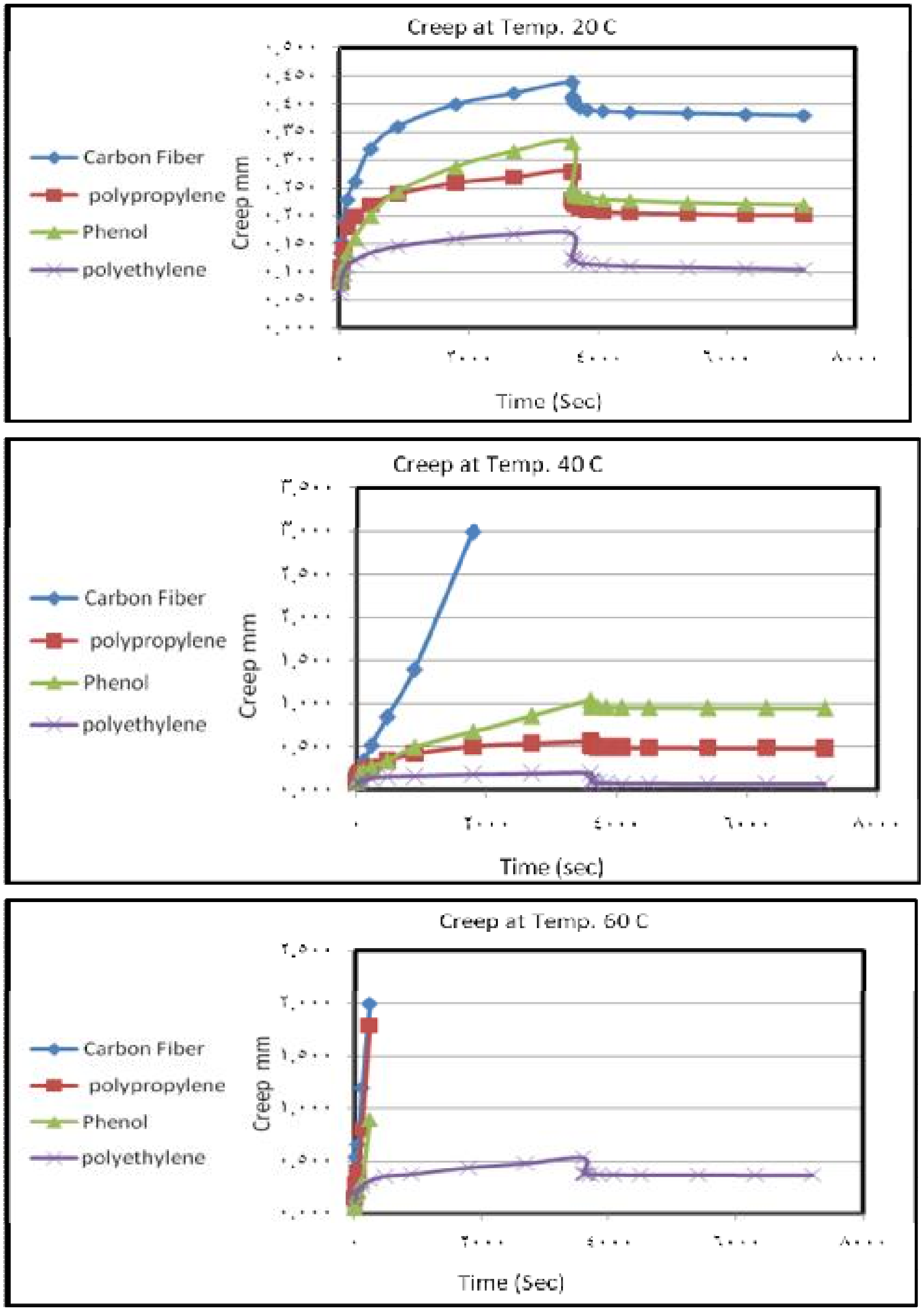


Figure (6) Creep Test at different Temperature