Effect of Polymers on Permanent Deformation of Flexible Pavement

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ABSTRACT

The permanent deformation of flexible pavement represent serious problem in hot climate region. Numerous efforts are devoted to mitigate this distress such as modifying asphalt binder by polymers. The present study demonstrate the effect of utilizing four types of polymers to reduce the permanent deformation, these polymers are **P**oly**e**thylene **W**ax (**PEW**), **S**tyrene **B**utadiene **R**ubber (**SBR**), **E**thylene **P**ropylene **D**ien **M**onomer (**EPDM**) and **E**thylene **V**inyl **A**cetate (**EVA**). The prepared mixtures composed of 4.9 % of 40/50 asphalt binder, 12.5 mm nominal aggregate maximum size and limestone dust as filler. The permanent and resilient strains have been recorded when the cylindrical specimens, 101.6 mm in diameter and 203.2 mm in height, tested by repeated loading system. The main conclusions exhibit that SBR and EPDM with the same concentration (15 % by weight of asphalt binder) reduced the permanent deformation by 30.20 % and 30.46 % respectively. Although, the PEW and EVA reduced permanent deformation by lower values, 13.24 % and 17.35 % respectively, but the incremental percentage of their action are higher. The influences of testing temperature and stress level on permanent deformation were investigated. Linear regression model was established to correlate the values of permanent deformation and the resilient modulus of asphalt mixtures.

Key words: asphalt pavement, permanent deformation, polymers, resilient modulus

تأثير البوليمرات على التشوه الدائمي للتبليط المرن

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الخلاصة

يمثل التشوه الدائمي للتبليط المرن مشكلة جدية في مناطق المناخ الحار، جهود عديدة وجهت لتقليل هذا الضرر مثل تعديل الرابط الاسفلتي بالبوليمرات. تعرض الدراسة الحالية تاثيراستخدام اربع انواع من البوليمرات لتقليل التشوه الدائمي، هذه البوليمرات هي شمع البولي اثيلين **(PEW)**، مطاط الستايرين بوتادين **(SBR)**، إيثيلين بروبيلين دیين مونومر **(EPDM)** و خلات فينيل الاثيلين**(EVA)**. الخلطات المعدة تتكون من 4.9% رابط اسفلتي 50/40، 12.5 مم مقاس اقصى اسمي للركام وغبار حجر الكلس كمادة مالئة. الانفعالات الدائمية والمرنة تم تسجيلها عندما فحصت النماذج الاسطوانية بقطر 101.6مم وارتفاع 203.2مم بنظام الاحمال المتكررة.اظهرت النتائج الرئيسة بان SBR و

EPDM ولنفس نسبة التركيز (15% من وزن الرابط الاسفلتي) قللتا التشوه بمقدار 30.20% و 30.46% بالتعاقب. رغم ان PEW و EVA قللتا التشوه بقيم اقل، 13.24% و 17.35% بالتعاقب ، لكن النسبة التزايدية لفعلهما كان اكبر. تم بحث تاثير حرارة الفحص ومستوى الاجهاد. تم تكوين انموذج انحدار خطي لربط قيم التشوه الدائمي ومعامل المرونة للخلطات الاسفلتية.

1. INTRODUCTION

Generally, polymer modified asphalt binder are become more widespread in road construction to meet today's high traffic loading. Furthermore, many efforts are devoted toward modifying asphalt mixtures by various types of polymers to enhance the resistance of asphalt paving to high and low temperatures consequences, allowing reduction in common failure mechanisms as rutting and cracking.

Permanent deformation termed as rutting is one of the most considerable load-associated distress types affecting the performance of asphalt concrete pavement, **Alavi, et al., 2011**.

Based on comprehensive survey carried out by Federal Highway Administration in 1998, rutting was considered to be the first ranking distress mechanisms in flexible pavement, followed by fatigue cracking and then by thermal cracking **, FHWA, 1998**.

The research conducted by **Pardhan, 1995,** depicted that rutting usually appears as longitudinal depression in the wheel path accompanied by small upheavals to the side. **Kaloush, 2001,** revealed that repetitive action of heavy traffic loads caused an accumulation of permanent deformations in asphalt pavement.

An extensive work in this field has been carried out by **Sousa, et al., 1991**, they reported that permanent deformation expressed by rutting occupied a major concern for at least two reasons; ruts trap water and hydroplaning which represent threat particularly for passenger cars, and ruts that develop in depth make steering increasingly become difficult, leading to major safety concerns.

Mirzahosseini, et al., 2011, as well as many other researchers deduced that rutting decreases the useful service life of the pavement and by affecting vehicle handling characteristics; it creates serious hazards for highway users, consequently, it can decrease drainage capacity of pavement structure resulting in accumulation of water. Another negative effect of permanent deformation as declared by **Bahuguna, 2003,** is the reduction of pavement thickness, which boosts the occurrence of pavement failures through fatigue cracking.

1.1 Objective of the Study

This study tends to characterize the role of utilizing different types of polymers in order to improve the resistance of asphalt mixtures against permanent deformation. For this purpose, four types of polymers have been added by different concentrations to the asphalt binder to compose mixture that will be tested under repeated loading system to record the permanent deformation. These synthetic polymers are **P**oly**e**thylene **W**ax (**PEW**), **S**tyrene **B**utadiene **R**ubber (**SBR**), **E**thylene **P**ropylene **D**ien **M**onomer (**EPDM**) and **E**thylene **V**inyl **A**cetate (**EVA**).

2. REVIEW OF LITERATURES

Basically, polymer is a long string (or net) of small molecules connected together through chemical bonds. The chain connectivity of the polymer can give the chain great strength and at the same time, they can be very flexible, **Hakseo, et al., 2012**.

Vonk and **Valkering, 1996,** conducted laboratory track test to determine the effect of Styrene Butadiene Rubber (SBR) addition on rutting resistance at 40 °C and 50 °C; their work results deducted that unmodified asphalt mixture has higher rutting rate comparing to SBR modified asphalt mixtures. **Arnold** and **Pidwerbesky, 1996,** performed testing to evaluate the SBR modified asphalt rutting, the SBR was mixed with an optimum asphalt content of 6 % by total mix weight, the mix was applied at four different sections by different residual rate of asphalt and the results remarked that flushing is less in the section where less asphalt cement has been used.

According to **Boza** and **Gallegos, 2009**, the addition of 1.0 and 2.0 percent of high density Polyethylene (HDPE) to asphalt binder is not able to modify the mechanical behavior of asphalt mixture effectively. **Ahmadinia, et al., 2012,** used polyethylene terephthalate; the appropriate amount of polyethylene terephthalate was determined to be 4.0 to 6.0 percent by weight of asphalt binder content, however, the result of the study indicated that modified mixture had lower trend to rut when compared to the non- modified asphalt mixtures.

The research published by **US Army Corps of Engineers, 2011,** pointed out that for optimal economy; it is desirable to choose an asphalt modifier that resists multiple distresses such as rutting, it was found that the choice of polymer might have significant impact on rutting properties and that mixtures boasting the highest rutting life contained reactive Styrene-Butadiene cross linked polymers. Research carried out by **Kumar** and **Veerara, 2011,** conformed the improvement in rutting resistance due to modify the asphalt concrete by Styrene Butadiene Rubber.

Ganesh, et al., 2011, monitoring the behavior of asphalt mixture at varying temperatures from 30°C to 50°C in steps of 5°C, they depicted that the performance of modified binders in the asphalt concrete mixtures is superior than plain binders, hence, the use of modified binders in the asphalt concrete mixtures increases the life of the pavement during adverse climatic conditions.

The work conducted by **Pareek, et al., 2012,** demonstrated the results of elastic recovery and rutting resistance of mixtures modified by Styrene Butadiene Rubber, they founded that modified mixtures have a 79 percent increase of elastic recovery and 54 percent increase of rutting resistance.

Xu, et al., 2010, investigated the effect of EPDM on rutting properties of asphalt mixtures; the results showed that asphalt binder with 3.5 percent of EPDM had the lowest rutting depth after 2500 cycles of load repetitions, which is reduced by 32.56 percent in comparison with unmodified mixtures.

EVA polymer has been widely used in the road construction industry for more than 40 years, where it improves both the workability of the asphalt during compaction and its deformation resistance in service. EVA polymers significantly improve the bitumen properties but to a different extent depending on the bitumen source and the polymer characteristics **, Haddadi, et al., 2008.**

The results of experimental work conducted by **Ahmed, 2012,** revealed that polyethylene with its optimum content of 5 percent by weight of binder is a useful modifier for increasing the stiffness of asphalt concrete and confer additional pavement stability at elevated temperatures to minimize rutting.

3. MATERIALS AND METHODS OF TESTING

3.1 Asphalt Mixtures

Essentially, all of asphalt mixtures materials were assiduously brought from locally well known sources. Concerning the asphalt cement binder, it was originally brought from Al-Daurah refinery and has 40/50 penetration grade, which is recommended to be used in hot region. The common test results are summarized in **Table 1**.

Regarding aggregates portion, the conventional source for the coarse aggregate was Al-Nibaee quarry while Karbala province was the exporter for both of river sand and limestone dust that was servant as mineral filler. For appropriate production of dense asphalt mixtures, the mid limit gradation selection is consent with the recommended values offered by **SCRB R/9, 2003**. It was established to use the 12.5 mm nominal aggregate maximum size, which is suitable for wearing course pavement.

The demonstration of available characterizations of aggregates and mineral filler are listed in **Tables 2** and **3** respectively whilst the gradation path selection and sieve analysis are summarized in **Table 4** and portrayed in **Fig.1**.

3.2 Polymers

The SBR and EPDM polymers have been brought from Babylon Tires Factory in Al-Najaf province, while the source of the PEW and EVA polymers was the State Company for the Petrochemical Industries in Basra. **Fig.2** display samples of these polymers.

Based on previous studies mentioned in literature review, the quantity of polymers blended with asphalt cement hold constant by three categories with different concentrations, thus, the PEW and EVA have been added by 2, 4 and 6 percent of asphalt cement weight and for SBR and EPDM the percent became 5,10 and 15.

The specified percent of polymer was mixed with toluene in a flask (500 ml vol.) by the ratio of 1gm/1 ml and placed in air for approximately 24 hours. This procedure increased the polymers digestion and swelling as well as decreased the time of mixing. The homogenous slurry was added to the heated asphalt and mixed using an electrical stirrer at 1200 r.p.m for one hour at approximately 180 ^{o}C.

The first phase of asphalt mixture preparation involved: washing, drying, separating and recombined the aggregates particles with limestone dust to obtain the required gradation. Subsequently, both of aggregates and asphalt modified cement were heated to suitable mixing temperature, in this case, the mixing temperature was relatively high (160 ^{o}C, due to the presence of polymers substances) .

The binder content was held constant by 4.9 percent of total mixture weight throughout the forming of asphalt mixtures specimens. Each cylindrical testing specimen has dimensions of 101.6 mm in diameter and 203.2 mm in height, which required approximately 3800 g of asphalt mixture raw materials.

The specimens were compacted by double plunger method with a load of 16600 kg. The load was applied to each end of the specimen for one minute. Finally, the specimen was carefully transferred to a smooth and flat surface, allowed to cool by standing it overnight at room temperature and then removed from the mold using a hydraulic extractor. The specimens were then numbered and placing in testing chamber for two hours at the desired temperature as shown in **Fig.3**.

The axial repeated load test was conducted using the Pneumatic Repeated Load System **, Albayati, A.H, 2006**. In this test, repetitive compressive loading was applied to the specimen and the axial deformation was measured under the different loading repetitions. Compressive loading was applied in the form of rectangular wave with a constant loading frequency of 60 cycles per minute including 0.1 sec loading time and 0.9 sec rest period.

The experiment is commenced by application of repeated axial stress and recording the vertical deformation. Upon completion of test after 3000 load repetitions or any number for load repetition when the specimen failed earlier (as demonstrated in **Fig.4)**, the recording is terminated and the specimen is removed from the test chamber.

The permanent deformation is expressed as vertical microstrain and calculated by using Eq.(1);

$$\boldsymbol{\varepsilon}_{\mathrm{p}} = \frac{\Delta \boldsymbol{H}}{\boldsymbol{H}} \qquad (1)$$

where;
ε_p = vertical microstrain, mm/mm
ΔH = vertical deformation at the specified load repetition, mm
H = original height of the specimen, 203.2 mm

The resilient modulus of asphalt mixture , **ASTM D-4123**, can be applied as indicator of flexible pavement ability to resist the harmful effects of high axle loading and elevated temperature conditions. According to **Huang, 2003**, the resilient modulus is the elastic modulus based on recoverable strain in repeated load test and can be expressed by Eq.(2);

$$\mathbf{M}_{\mathrm{R}} = \frac{\boldsymbol{\sigma}_{\mathrm{d}}}{\boldsymbol{\varepsilon}_{\mathrm{r}}} \qquad (2)$$

where;
M_R = resilient modulus of asphalt mixture, psi
σ_d = deviator stress, which is the axial stress for unconfined compression test, 20 psi
ε_r = recoverable vertical strain corresponding to the 200 th repetition of load application.

4. RESULTS AND DISCUSSIONS

4.1 Effect of Temperature on Permanent Deformation and Resilient Modulus

The temperature has a significant influence on both of permanent deformation and resilient modulus of asphalt mixture. As demonstrated in **Fig.5** and **Fig.6,** increasing the test temperature from 40 ^{o}C to 50 ^{o}C produce an increase in permanent deformation by 25.8 % and a reduction in resilient modulus by 40.1 %. These two percentages became 69.2 % and 64.3 % respectively when the temperature raised to 60 ^{o}C. This behavior is quite understood and logically accepted because the stiffness of asphalt binder is adversely affected by the temperature increasing.

4.2 Effect of Stress Level on Permanent Deformation

One of the most important factor that affect the permanent deformation is the stress level, to put light on this point, the repeated load test conducted at three stress levels; 10, 20 and 30 psi. The outcome of the test is portrayed in **Fig.7**, which clearly shows that increasing stress level from 10 psi to 20 psi yields mixtures with higher deformation value by 13.8 %, in the same way, the percent of deformation increase reached 31.8 % as the stress level increased to 30 psi.

4.3 Effect of Polymers on Resilient Modulus

The resilient modulus test of asphalt mixtures have been performed as outlined by **Huang, 2003** at 40 ^{o}C and by applying stress magnitude equal to 20 psi, the elastic strain recorded at 200 th No of repetitions. **Fig.8** depicts the effect of incorporating a specified amount of PEW on the resilient modulus, inspecting this figure deliver the message that the maximum resilient modulus occurred at 4.0 % polymer content , furthermore, the total percent of modulus increase reached 3.74 with an incremental value equal to 0.62 % for each percent of PEW addition.

This behavior is quite similar in the case of SBR usage, herein, adding SBR with a value up to 15 %, elevate the resilient modulus by 7.39 % and by an incremental value equal to 0.49 % for each 1.0 % of added polymer, as clearly shown in **Fig.9**. This improvement in resilient modulus is just similar to the situation when the EPDM is act as additive, in the same way, and within the range of polymer dosage, the enhancing percent in resilient modulus recorded 0.46 % for each 1.0 % of EPDM addition with total percent of increase equal to 6.92 as demonstrated in **Fig.10**. The justification of this similarity deduced his credibility from the fact that both of these polymers lie in the same polymer category of elastomer.The influence of blending asphalt binder with EVA polymer is portrayed in **Fig.11,** which declare that, this polymer also increase the resilient modulus by total amount of 4.64 % and with incremental magnitude of 0.77 %.

4.4 Effect of Polymers on Permanent Deformation

The particular concern of this study is to investigate the role of modifying asphalt binder with certain polymers in improving asphalt mixture resistance against permanent deformation. The participations of experimental work devoting to reach this goal are visualized in Figures 12, 13, 14 and 15.

The general remark triggered to mind by observing these figures, is that all of these polymers succeed in the purpose of permanent deformation reduction, which follow the same path of other researchers results. Good demonstration of PEW amount influence on microstrain magnitude can be understood by monitoring **Fig.12**, as the PEW dosage increased up to 6.0 %, the total microstrain reduced by 13.24 % with an incremental value of 2.20 % for each one percent of PEW dosage. Content of **Fig.13** display clearly the relationship between SBR and microstrain, as shown; increasing this polymer concentration from 0.0 % to 15 % caused a decreasing in microstrain by 30.20 %.The value of incremental reduction equal to 2.01%. **Fig.14** focus on the role of EPDM content on microstrain, again, increasing EPDM value up to 15 % reduced the microstrain by total amount of 30.46 % and by 2.03 % of incremental value. This similarity in results is not surprisingly as mentioned previously.**Fig.15** explicit the effect of EVA concentration increase on the microstrain, herein, expanding the amount of polymer in mixture spectrum up to 6.0 %, lower the total microstrain value by 17.35 % with 2.89 % of incremental decrease for each one percent increase of EVA.

The relationship between the resilient modulus of asphalt mixtures and the permanent deformation expressed by microstrain can be found as portrayed in **Fig.16**. By monitoring this figure, it is obvious that resilient modulus improvement play an important role in enhancing the resistance of asphalt mixture toward permanent deformation. To support this opinion, a linear regression analysis conducted to the data displayed in the mentioned figure. As a result, the following empirical equation has been established:

$$\boldsymbol{\varepsilon}_{\mathbf{p}} = 14329 - 3.0\ M_R \quad , \quad R^2 = 0.80 \qquad (3)$$

where;

ε_p = vertical microstrain, mm/mm
M_R = resilient modulus of asphalt mixture, psi

5. CONCLUSIONS

- It is invariably found that, all four types of polymers used in this study succeed in improving the ability of asphalt mixture to resist the permanent deformation, however, the degree of success vary from one type to other. whereas, the SBR and EPDM polymers are sharing approximately the same value of permanent deformation reduction by 30.20 % and 30.46 % respectively and at the same polymer content of 15 % by weight of asphalt binder. On other hand, the PEW and EVA polymers reduce the permanent deformation microstrain by 13.24 % and 17.35 % respectively at the 6 % polymer content.

- The resilient modulus of asphalt mixture clearly effected by the participation of polymers as additives. In other words, incorporating PEW substance into the mixture increased the resilient modulus by 3.74 % at 6.0 % content of PEW. The SBR and EPDM polymers seems to be more effective in this activity, their percentages of extended the resilient modulus raised to 7.39 and 6.92 respectively and at exact 15 % of polymer content. The EVA polymer exhibit an improvement value equal to 4.64 % at 6.0 % of material content.

- Elevating the test temperature from 40 ^oC to 50 ^oC produce an increase in permanent deformation by 25.8 % and a reduction in resilient modulus by 40.1 %. These two percentages became 69.2 % and 64.3 % respectively when the temperature raised to 60 ^oC.

- Increasing stress level from 10 psi to 20 psi yields mixtures with higher deformation value by 13.8 %, in the same way, the deformation percent of increase reached 31.8 % as the stress level increased to 30 psi.

- Simple linear regression model has been established to correlate the influence of resilient modulus on permanent deformation resistance.

REFERENCES

- Ahmadinia , I., Zargar, M., Karim, M. R., Abdelaziz, M., and Ahmadinia, E., 2012, *Performance Evaluation of Utilization of Waste Polyethylene Terephthalate (PET) in Stone Mastic Asphalt*, Journal of Construction Building Materials, Vol.364, PP. 984-989.

- Ahmed, A. I., 2012, *Influence of Polymers on the Properties of Asphalt Concrete Paving Materials*, Journal of Babylon University/Engineering Sciences, Vol.20, No.1.

- Alavi, A. H., Ameri, M., Gandomi, A. H., and Mirzahosseini, M. R., 2011, *Formulation of Flow Number of Asphalt Mixes Using a Hybrid Computational Method*, Journal of Construction and Building Materials, Vol. 25, No.3, PP. 1338-1355.

- Albayati, A. H., 2006, *Permanent Deformation Prediction of Asphalt Concrete Under Repeated Loading*, Ph.D Thesis, Civil Engineering Department, College of Engineering, University of Baghdad.

- American Society for Testing and Materials, *Annual Book of ASTM Standards. Road and Paving Materials, Volume 04.03, 2006.*
- Arnold, G., and Pidwerbesky, B., 1996, *Polymer-Modified Bitumen in Chip Seals for High Stress Conditions,* Proceedings of the 18 th Combined ARRB Transport Research Conference, New Zealand, PP. 197-208.

- Bahuguna, S., 2003, *Permanent deformation and Rate Effects in Asphalt Concrete: Constitutive Modeling and Numerical Implementation*, Ph.D. Thesis. Case Western Reserve University.

- Boza, F. J., Gallegos, O., Muñoz, M.E., and Santamaría, A., 2009, *Influence of the Processing Conditions on the Rheological Behavior of Polymer Modified Bitumen*, Fuel Journal, Vol (82), PP.1339-1348.

- FHWA, (1998). Interim Task Report of Preliminary Recommendations for the Simple Performance Test. Report No. DTFH 61-94-R-00045.

- Ganesh, K., Jagadeesh, H. S., and Sathyamurthy, R., 2011, *Effect of Temperature on the Rutting Characteristics of Bituminous Concrete Mix with Plain and Modified Binders*, International Journal of Earth Sciences and Engineering, Vol. 4, PP. 922-929.

- Haddadi, S., Ghorbel, E., and Laradi, N., 2008, *Effects of the Manufacturing Process on the Performances of the Bituminous Binders Modified with EVA,* Construction and Building Materials, Vol.22, PP.1212-1219.

- Hakseo, K., Soon, J. L., and Serji, N. A., 2012, *Influence of Warm Mix Additives on PMA Mixture Properties,* Journal of Transportation Engineering, ASCE, Vol.138, PP. 991-997.

- Huang, Y. H., 2003, Pavement Analysis and Design.” 2 nd Edition, Prentice Hall, New Jersey.
- Kaloush, K. E., 2001, *Sample Performance Test for Permanent Deformation of Asphalt Mixtures*, Ph.D. Thesis, Arizona State University.

- Kumar, S. A., and Veerara, G. A., 2011, *Dynamic Mechanical Characterization of Asphalt Concrete Mixes with Modified Asphalt Binders*, Journal of Materials Science and Engineering, Vol.528, PP. 6445-6454.

- Mirzahosseini, M., Aghaeifar, A., Alavi, A., Gandomi, A., Seyednour, R., 2011, *Permanent Deformation Analysis of Asphalt Mixtures Using Soft Computing Techniques*, Journal of Expert Systems with Applications, V0l.38, No.5, PP. 81-100.

- Pardhan, M. M., 1995, *Permanent Deformation Characteristics of Asphalt-Aggregate Mixture Using Varied Material and Modeling Procedure with Marshall Method*. Ph.D. Thesis, Montana University.

- Pareek, A., Gupta, T., and Sharma, R. K., 2012, *Performance of Polymer Modified Bitumen for Flexible Pavements*, International Journal of Structural and Civil Engineering Research, Vol.1.
- PP.77-86.

- SCRB, 2003, *General Specification for Roads and Bridges,* Section R/9, Hot-Mix Asphalt Concrete Pavement, Reverse Edition, State Corporation of Roads and Bridges, Ministry of Housing and Construction, Republic of Iraq.

- Sousa, J. B., Craus, J., and Monismith, C. L., 1991, *Summary Report on Permanent Deformation in Asphalt Concrete*, Strategic Highway Research Program (SHRP), National Research Council, Institute of Transportation Studies, University of California.

- US Army Corps of Engineers, 2011, Investigation of the Design and Control of Asphalt paving Mixtures.

- Vonk, W. C., and Valkering, C. P., 1996, *Extension of the Service Temperature Range of Road Binders with SBS Thermoplastic Elastomers*, Proceedings of the 18th Combined ARRB Transport Research Conference, New Zealand, PP. 267-277.

- Xu, Q., Chen, H., and Prozzi, J. A., 2010, *Performance of Fiber Reinforced Asphalt Concrete Under Environmental Temperature and Water Effects*, Journal of Construction Building Materials, Vol.24, PP. 2003-2010.

NOMENCLATURE

ASTM = american Society for Testing and Materials

EPDM = ethylene Propylene Dien Monomer

EVA = ethylene Vinyl Acetate

ε_p = vertical microstrain, mm/mm

ε_r = recoverable vertical strain corresponding to the 200 th repetition of load application.

FHWA=Federal Highway Administration

H = original height of the specimen, 203.2 mm

M_R = resilient modulus of asphalt mixture, psi

σ_d = deviator stress, which is the axial stress in an unconfined compression test, 20 psi

PEW = polyethylene Wax

SBR = styrene Butadiene Rubber

SCRB = state Corporation of Roads and Bridges

ΔH = vertical deformation at the specified load repetition, mm

Table 1. The physical properties of asphalt cement.

Test	Unit	Result	Specification Requirement
Penetration (25 ^oC, 100 g, 5 sec). ASTM D 5	1/10 mm	42	40-50
Softening Point (Ring & Ball). ASTM D 36	^oC	49	…….
Ductility (25 ^oC, 5 cm/min). ASTM D 113	cm	102	≥ 100
Flash Point (Cleveland open Cup) ASTM D-92	^oC	283	≥ 230
Specific Gravity (25 ^oC). ASTM D-70	…..	1.03	…..

Table 2. The physical properties of aggregates.

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity, ASTM C-127 and C-128	2.51	2.64

Apparent Specific Gravity, ASTM C-127 and C-128	2.54	2.68
Percent Water Absorption, ASTM C-127 and C-128	0.382	0.514

Table 3. The physical properties of limestone dust.

Property	**Unit**	**Result**
Specific gravity	-----	2.69
Passing No.200	%	96

Table 4. The Gradation selection of combined aggregates

Sieve Size	Sieve Opening (mm)	Specifications limit (SCRB R/9,2003)	Selected Gradation
3/4′	19	100	100
1/2′	12.5	90-100	95
3/8′	9.5	76-90	83
No.4	4.75	44-74	59
No.8	2.36	28-58	43
No.50	1.18	5-21	13
No.200	0.075	4-10	7

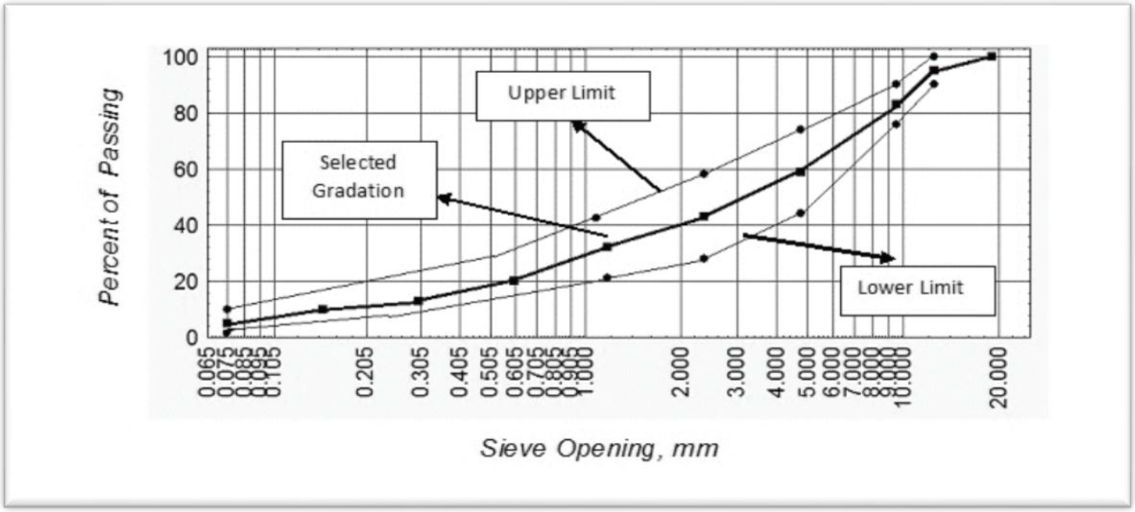

Figure.1 Sieve size analysis of combined aggregates.

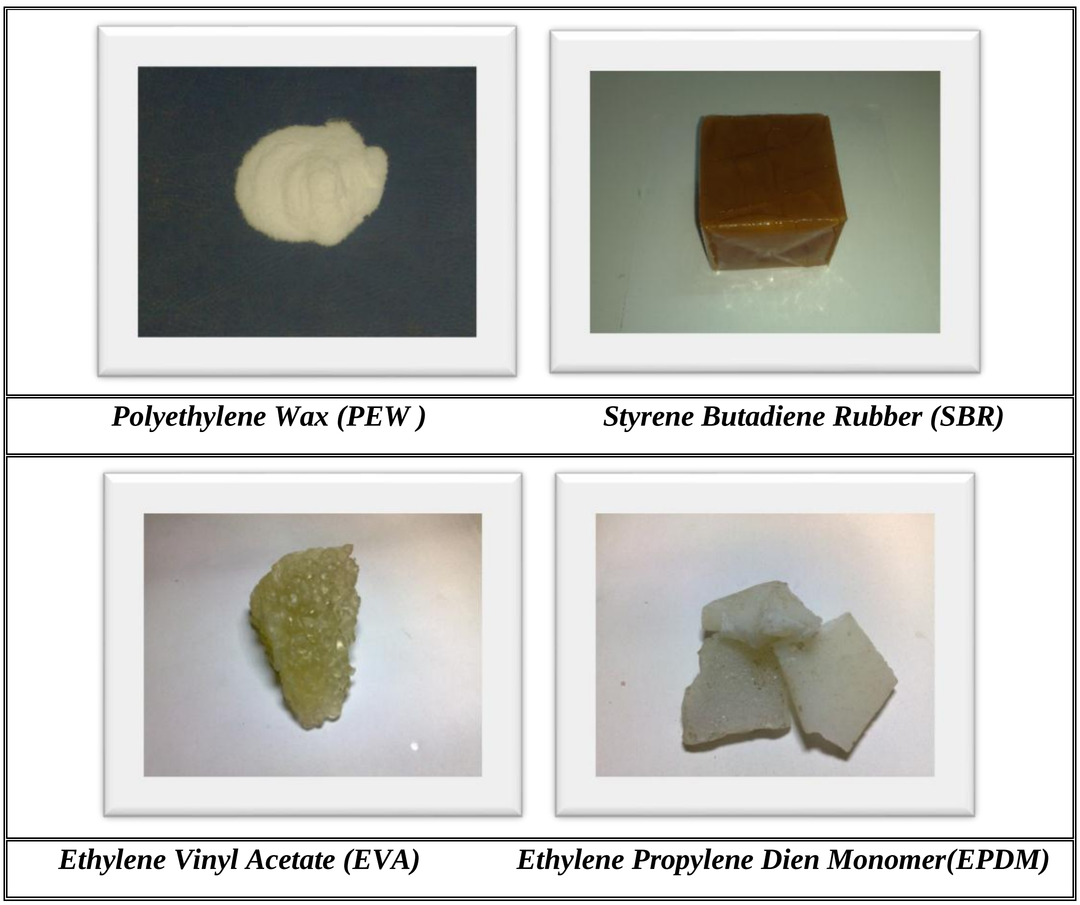

Figure.2 Samples of the polymers.

Figure.3 Specimen in the testing chamber.

Figure.4 Specimen at the end of test.

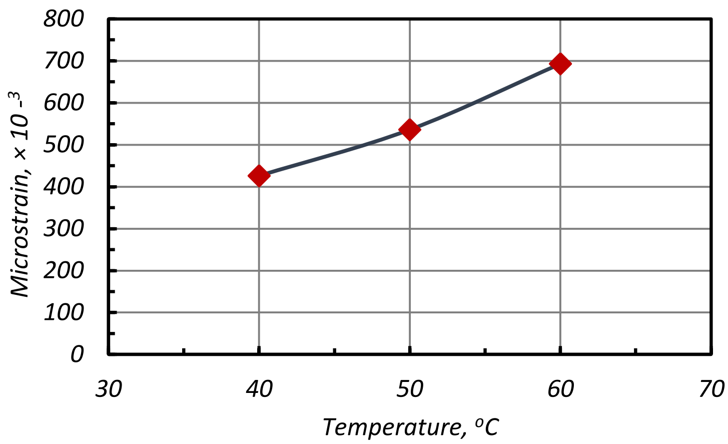

Figure 5. Effect of test temperature on permanent deformation (@ stress level=10 psi, 1000 load repetitions) .

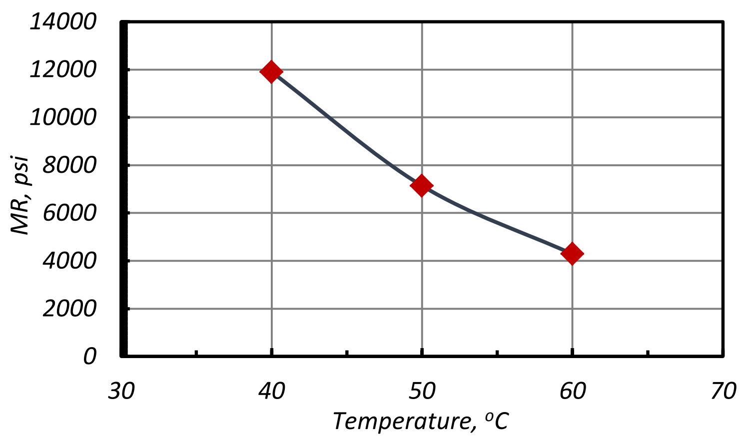

Figure 6. Effect of test temperature on resilient modulus (@ stress level=20 psi, 200 load repetitions, T=40 °C).

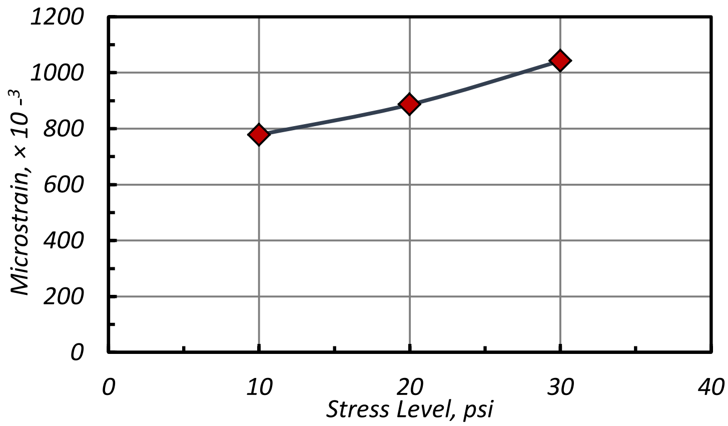

Figure 7. Effect of stress level on permanent deformation (@3000 load repetitions, T= 40 °C) .

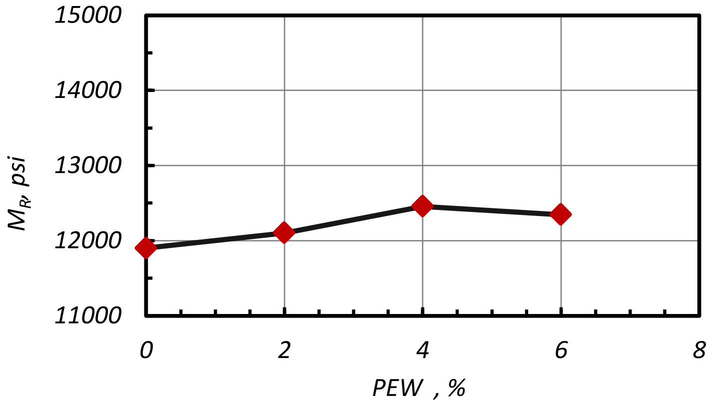

Figure 8. Effect of PEW on resilient modulus
(@ stress level= 20 psi, 200 load repetitions, T= 40 ^oC) .

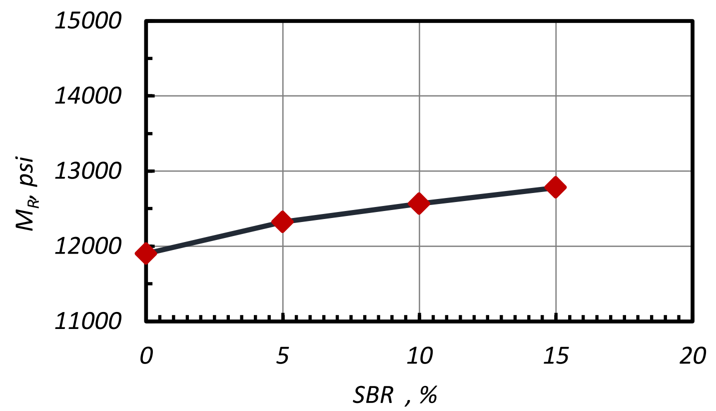

Figure 9. Effect of SBR on resilient modulus
(@ stress level= 20 psi, 200 load repetitions, T= 40 ^oC).

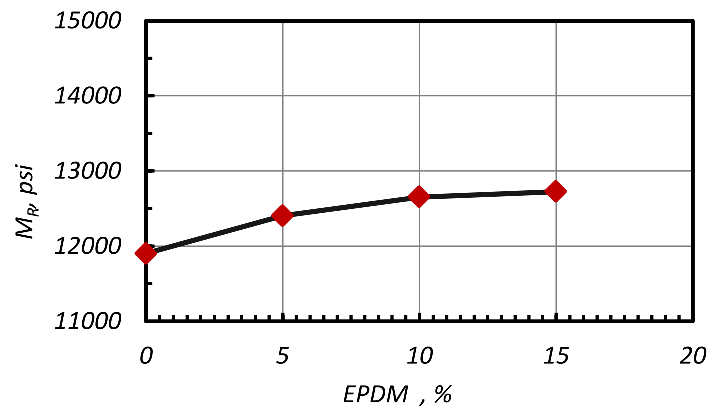

Figure 10. Effect of EPDM on resilient modulus
(@ stress level= 20 psi, 200 load repetitions, T= 40 ^oC).

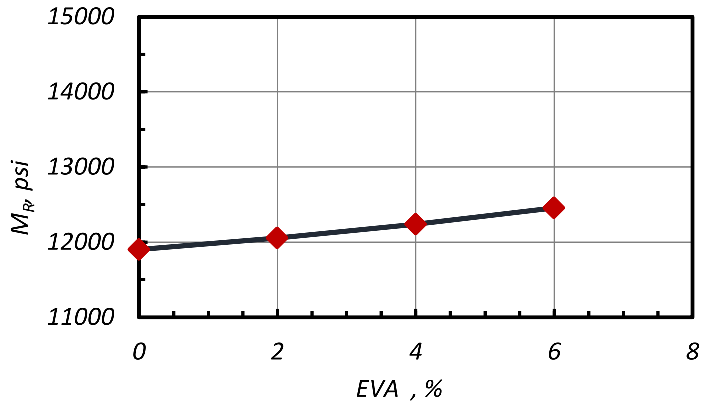

Figure 11. Effect of EVA on resilient modulus
(@ stress level= 20 psi, 200 load repetitions, T= 40 °C) .

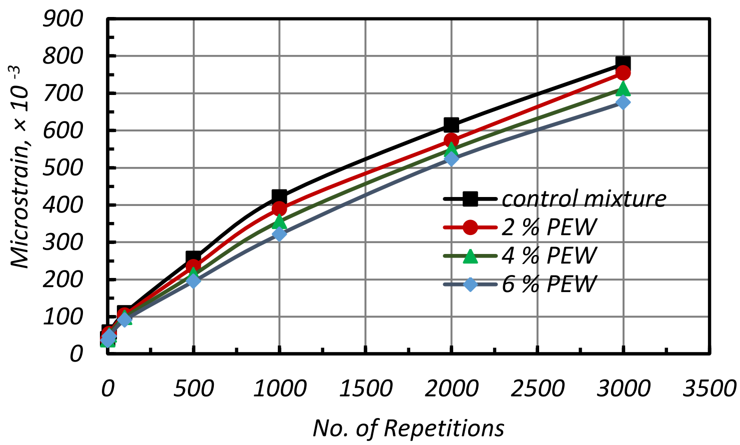

Figure 12. Effect of PEW on permanent deformation
(@ stress level= 10 psi, T= 40 °C) .

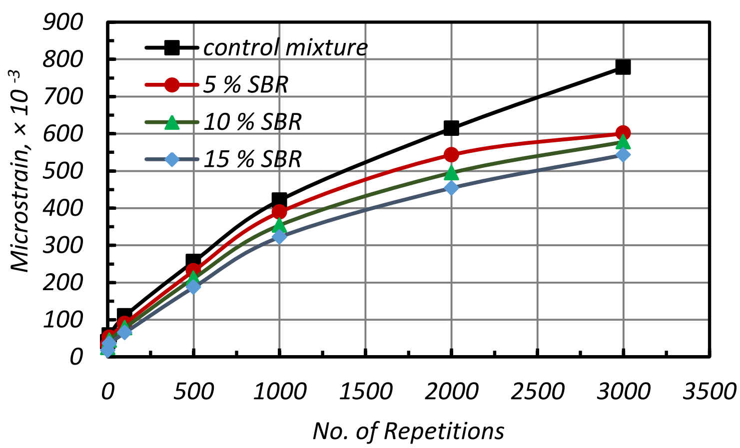

Figure 13. Effect of SBR on permanent deformation
(@ stress level= 10 psi, T= 40 °C) .

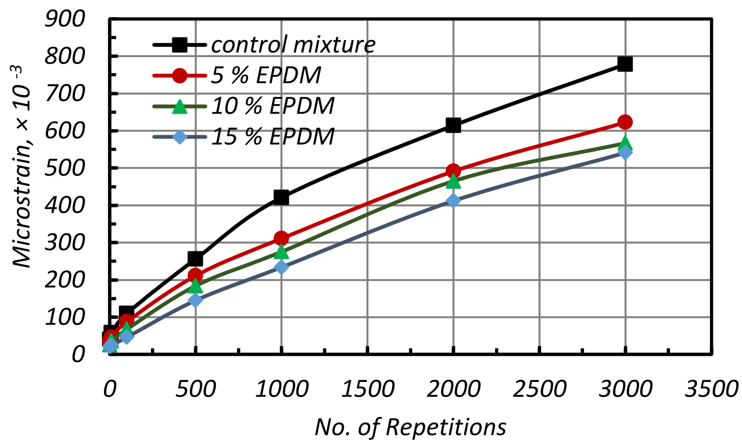

Figure 14. Effect of EPDM on permanent deformation (@ stress level= 10 psi, T= 40 ^{o}C) .

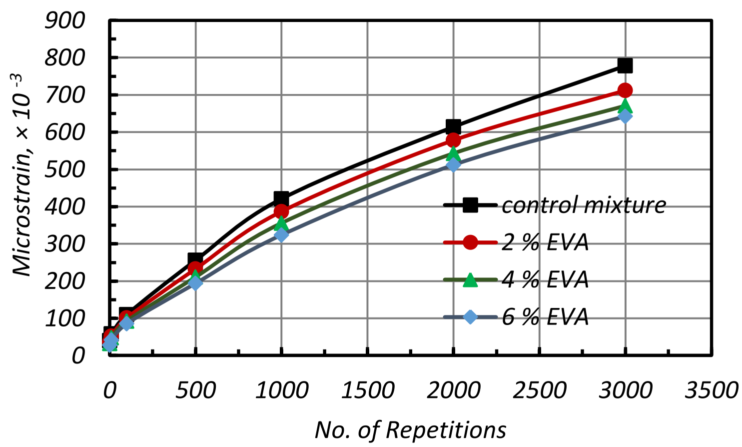

Figure 15. Effect of EVA on permanent deformation (@ stress level= 10 psi, T= 40 ^{o}C) .

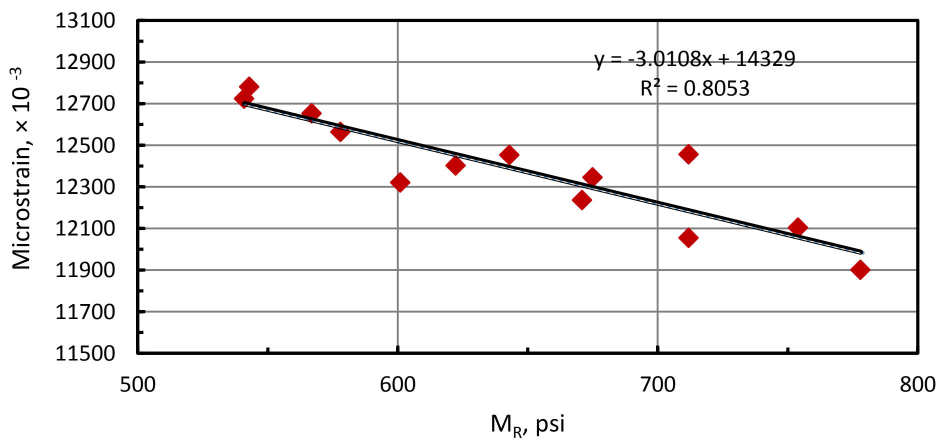

Figure 16. Relationship between permanent deformation and resilient modulus .