Evaluation of Polymer Modified Asphalt Mixtures in Pavement Construction

تقييم خلطات الإسفلت المعدلة بالبوليمر في انشاء الرصف

I. Amin[1], R. Alabasey[2], A. Azam[3], S.El-Badawy[4] and A.Gabr[3]

[1]Master Student, Public Works Engineering Department, Faculty of Engineering, Mansoura University, Egypt
[2]Graduate Student, Public Works Engineering Department, Faculty of Engineering, Mansoura University, Egypt
[3]Assistant Professor, Public Works Engineering Department, Faculty of Engineering, Mansoura University, Egypt, Abdelhalim.azam@mans.edu.eg
[4]Associate Professor, Public Works Engineering Department, Faculty of Engineering, Mansoura University, Egypt

الملخص

من المتوقع أن تتغير خصائص البيتومين التقليدي عند تعرضه لدرجات الحرارة المنخفضة وبالتالي قد تصبح الخلطات الاسفلتية عرضة الي حدوث شروخ تحت التحميل المروري المتكرر أو نتيجة التغيرات الحرارية. من ناحية أخرى في درجات الحرارة العالية، تكون تلك الخلطات عرضة للتخدد. علاوة على ذلك، فإن البيتومين غير المحسن غير قادر على مواجهة الزيادة في أحجام/ أحمال المرور. إن استخدام الإسفلت المعدل بالبوليمر (PMA) في الخلطات الأسفلتية الساخنة قد يحسن أداء الرصف ويمكن أن يزيد من عمر الطريق.

في هذه البحث، تم تقييم خلطات أسفلتية ساخنة معدلة بالبوليمر ومقارنتها بخلطات تقليدية. تم إجراء اختبارات معملية شاملة بمعمل هندسة الطرق والمطارات بجامعة المنصورة .تم تصميم الخلطات الاسفلتية بطريقة مارشال، وتراوحت نسبة البوليمر المضافة بين 0 و 6 ٪ من وزن البتومين. يتضمن برنامج الاختبارات المعملية اختبار الاختراق واختبار درجة التليين واختبار مقياس اللزوجة الدوراني الذي أجري على البتومين المعدل بالبوليمر. بالنسبة للخلطات الاسفلتية فتم اجراء الشد غير المباشر(IDT) والفقد في الثبات.

أظهرت النتائج أن خليط الإسفلت المعدل بنسبة 4٪ بوليمر قد حقق أعلى ثبات مارشال وكثافة. بشكل عام ، أظهرت نتائج هذه الدراسة أن استخدام البوليمر في خلطات الإسفلت يقلل من الشروخ ويزيد من عمر الرصيف

ABSTRACT

Traditional bitumen is expected to become brittle material at low temperatures therefore it may crack easily under repeated traffic loading or by thermal changes. On the other hand at high temperature, it is a soft material that ruts under traffic loading. Furthermore, the bitumen is not able to cope with the increase in traffic volumes/loading on roads. The use of the Polymer Modified Asphalt (PMA) in hot asphalt mixtures may improve the pavement performance and can increase the service life of the road.

In this paper, the characterization of hot mix asphalt (HMA) modified with the PMA was evaluated and compared with the conventional mixtures. A comprehensive laboratory testing was conducted at Mansoura University Highway and Airport Engineering Laboratory (H&AE-LAB). The asphalt mixtures were designed by Marshall method and the percentage of the PMA ranged between 0 and 6% by the weight of the binder. The laboratory testing program include penetration test, softening point test, rotational viscometer test which was conducted on the PMA. For the asphalt mixtures, the experimental programs are the indirect tensile strength (IDT) and the percentage of loss of stability.

The results showed that the asphalt mixture with 4% percentage PMA had the highest Marshall Stability and mix bulk density. In general, the findings of this study demonstrated that the use of PMA in asphalt mixes decrease the pavement rutting and increase the pavement life.

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Keywords: Polymer, IDT, loss of stability, modified asphalt mixes

INTRODUCTION

Asphalt mixture is composed of asphalt, graded aggregates and air voids. Asphalt is a time–temperature viscoelastic material and its behaviors depend on both temperature and loading time. Traditional bitumen has been widely used over years in road construction. At low temperatures this material is prone to become brittle thus it may crack easily under repeated traffic loading or by thermal changes only. At high temperature it is a soft material that ruts under traffic loading. Nowadays, there is a problem in the characteristics of the traditional bitumen used in road construction. The bitumen is not able to cope with the increase in traffic volumes/loading on roads where the traffic loads are doubled epically at high temperature and slower speeds (Shafii et al 2011). Different kinds of additives have been tried to modify the base asphalt in order to increase the resistance to pavement distress. In general, fibers and polymers are two main materials used in the asphalt modification (Lie and Wu 2011).

Numerous researchers have reported that the use of the Polymer Modified Asphalt (PMA) improves the pavement performance and can increase the service life of the road (FHWA 2012; Shafii et al 2011; Al-Hadidy and Tan 2011; Lewandowski, 1994; Yildirim, 2007). Tayfur et al (2007) found that PMA exhibited great resistance to rutting and thermal cracking and decreased fatigue damage, stripping and temperature susceptibility.

Polymer is a natural or synthetic high-molecular weight organic compound, which consists of a chain of smaller, simpler repeating units known as monomers (FHWA 2012). SUPERPLAST is a polymeric compound of selected polymers made of flexible granules.

The Egyptian government spends millions of pounds every year on the maintenance, reconstruction of deteriorated roads, and construction of new roads. However, these roads suffer from sever rutting and cracking. Rutting and cracking depend on several factors such as excessive loading, harsh weather conditions, the use of traditional methods for binder characterization, and mix and structural design of the roads. The binder properties also an important factor. Pavement distresses cause user discomfort, increase in accident rates, damage the vehicles, and increase gas consumption thus increasing the transportation cost. Moreover, pavements deteriorate faster and the service lives of the roads decrease dramatically. Figures 1 and 2 demonstrated examples of these pavement distresses for roads in the delta region. Modification of bitumen by adding polymers may improve the asphalt characteristics, which will produce asphalt mixtures less prone to rutting and fatigue cracking

Figure 1. Excessive Alligator Fatigue Cracking (New Damitta- to Damitta Port Road)

Figure 2. High Severity Rutting (Mansoura-Gamsa Road)

The main objective of this research proposal is to characterize hot mix asphalt (HMA) modified with the SUPERPLAST (PMA). The outcome of this research will be reflected on enhancing the binder characterization, mix design and performance of road and airport pavements against the traffic loading and environmental effects. The findings of this research will give better understanding about the PMA mix performance, which will help in increasing the service life of the pavement, and reduce the maintenance and construction costs. Millions of pounds are expected to be saved and hence can be spent towards extending and improving the current road network in Egypt.

Laboratory Experimental Work

A sample of the bitumen used in Egypt which is Pen 60-70 was characterized at Mansoura University Highway and Airport Laboratory (H&AE-LAB). The sample was tested for the Penetration test (ASTM D 5-06) and tested Softening Point test (ASTM T 53-96). For the asphalt mixtures, the experimental programs are the indirect tensile strength (IDT) and the percentage of loss of stability.

Conventional and modified asphalt mixture was designed by Marshall method (ASTM D 6927-06). The percentage of the SUPERPLAST polymers in the mix will be ranged between 2% and 6% by the weight of the binder.

Bitumen Testing

The penetration was conducted in accordance with ASTM 5-06. A sample of the bitumen was tested at 25 ^oC. The penetration value was 63 which within the allowable range 60-70. The same test was performed of the modified bitumen with the SUPERPLAST. The results indicated that the addition of SUPERPLAST improve the penetration grade of the bitumen.

The softening point was carried out according to ASTM T 53-96 on the bitumen sample. The softening point for the bitumen was 38 ^oC. On the other hand the modified bitumen recorded a higher value of softening point.

Conventional Asphalt Mixture

The conventional wearing surface (4C) asphalt job mix formula (JMF) mixture was designed by Marshall method (ASTM D 6927-06). The grading curve of the mixture compared with the upper and lower limits is provided in Figure 3. The percentage of each material in the blend is shown in Table 1.

Five different asphalt content (4.5, 5.0, 5.5, 6.0, and 6.5) was chosen for the mixture design. The required weight of the aggregates was calculated then was heated to 180 ^oC. The required amount of bitumen was heated to 180 ^oC. After that, the aggregates and the bitumen were blended together for sufficient time to make a homogenous mix. The mixture was compacted in cylindrical mould of 100 mm diameter and height of 63.5 mm. Each face of the sample was compacted by 75 blows for heavy traffic case. Three samples were made for each asphalt content.

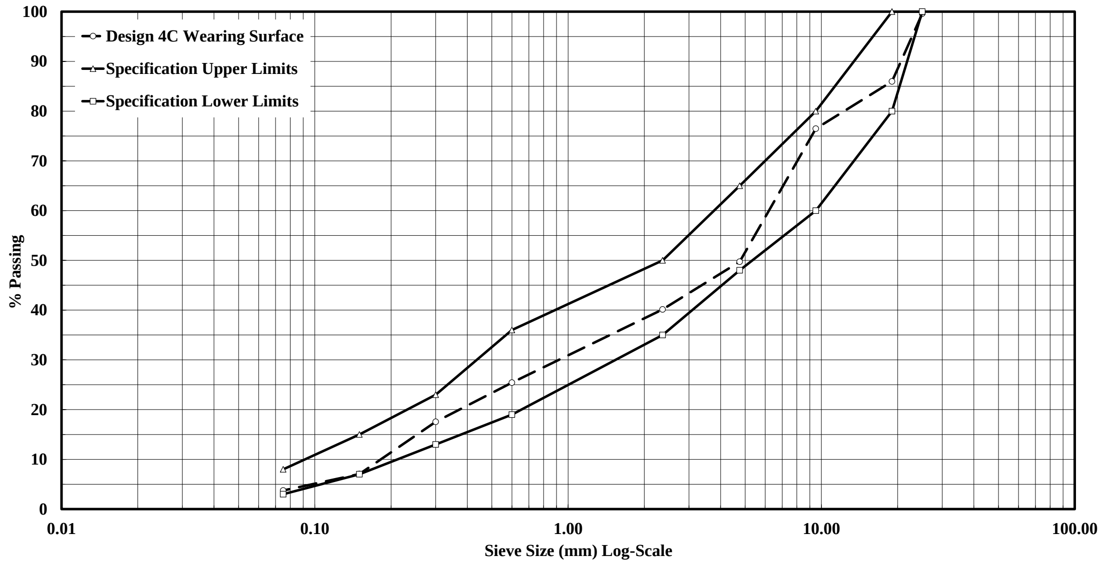

Figure 3 Gradation curve for the wearing surface asphalt mixture

Table 1 Materials Proportions

Bin	*JMF (%)*
Aggregate #2	*23*
Aggregate #1	*40*
Sand	*31*
Filler	*6*

After the compaction, the samples were extracted from the mould using a hydraulic jack. The samples were weighed in air and water and the saturated surface dry weight of the samples was recorded. The samples were cured in bath for 3 hours at 60 ^{o}C before testing. The cylindrical samples were placed in Marshall apparatus as illustrated in Figure 4. Then, the load was applied and the maximum stability and the corresponding flow were recorded. Marshall mixture properties are presented in Table 2.

Table 2 Conventional Asphalt Mixture Properties

Property	*Design*	*Minimum*	*Maximum*
Marshall Bulk Density (t/m^3)	*2.337*	-----	-----
Stability (kg)	*980*	*800*	-----
Flow (mm)	*2.10*	*2*	*4*
Air Voids (AV) %	*4.15*	*3*	*5*
Voids in Mineral Aggregates (VMA) %	*13.8*	*13*	-----
Voids Filled with Binder (VFB) %	*70*	-----	-----
AC[1]	*5.2*	-----	-----

1= Asphalt Cement, Percentage by Total Aggregate Weight

Modified Asphalt Mixture

The conventional mixture was modified using SUPERPLAST polymer ranging from 2% to 6% by the weight of the binder. Five different polymer percentages was chosen (2%, 3%, 4%, 5% and 6%). Three samples were prepared for each percentage of the polymer. The aggregate was heated to 180 C^{o} then SUPERPLAST was added. After that, the binder at 160 C^{o} was added to the aggregate. It should be noted that the mixing time was longer compared to the mixing time for conventional mixtures. The same procedure as explained before was followed. Table 3 shows the Marshall parameters for the modified asphalt mixtures.

Table 3 Modified Asphalt Mixture Properties

Polymer	sample No	Bulk specific gravity	Air void (%)	VMA (%)	VFA (%)	Stability (kg)	Flow (mm)
2%	1	2.351	3.913	15.84	75.294	1167	2.18
	2	2.362	3.458	15.44	77.604	917	1.74
	3						
	Average	2.357	3.69	15.64	76.45	1042	1.96
3%	1	2.370	3.1	15.167	79.3	1313	2.75
	2	2.386	2.5	14.583	83.0	1480	2.46
	3	2.380	2.8	14.824	81.4	1524	3.28
	Average	2.379	2.8	14.80	81.23	1439	2.83
4%	1	2.350	3.96	15.32	74.12	1684	3.45
	2	2.344	4.20	15.58	72.65	2114	2.22
	3	2.338	4.45	15.67	72.09	1600	2.64
	Average	2.344	4.20	15.52	72.95	1800	2.77
5%	1	2.373	3.0	15.1	80.0	1527	1.97
	2	2.361	3.5	15.5	77.4	1335	2.98
	3	2.356	3.7	15.7	76.2	1662	1.96
	Average	2.363	3.0	15.4	77.9	1508	2.30
6	1	2.343	4.24	15.66	72.30	1658	2.11
	2	2.334	4.61	15.98	70.56	1642	3.23
	3	2.347	4.08	15.23	74.46	1529	2.7
	Average	2.341	4.31	15.62	72.44	1610	2.68

A comparison between the conventional asphalt mixture and the modified mixes was made. Figures 5 to 10 provide the relationship between the marshall parameters for the mixture and the percentage of polymer. It can be noted from the Figures that, the samples prepared with 4% of polymer yielded the maximum stability compared to the other samples. However the bulk specific gravity of the mixture prepared with 4% polymer was slightly lower than the other mixtures. The air voids content was within the range (3-5%) for all samples except the samples containing 3% of polymer which was 0.2% less than the lower limits. The addition of the polymer to the mix increase the voids in mineral aggregates and the flow of the mixture (refer to Figures 8 and 9)

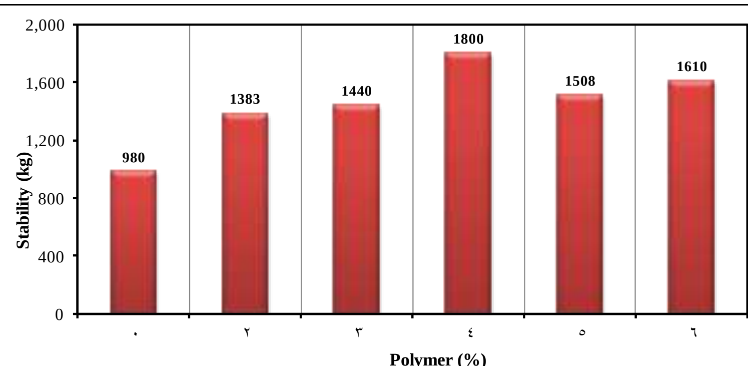

Figure 5 Stability against the percentage of polymer

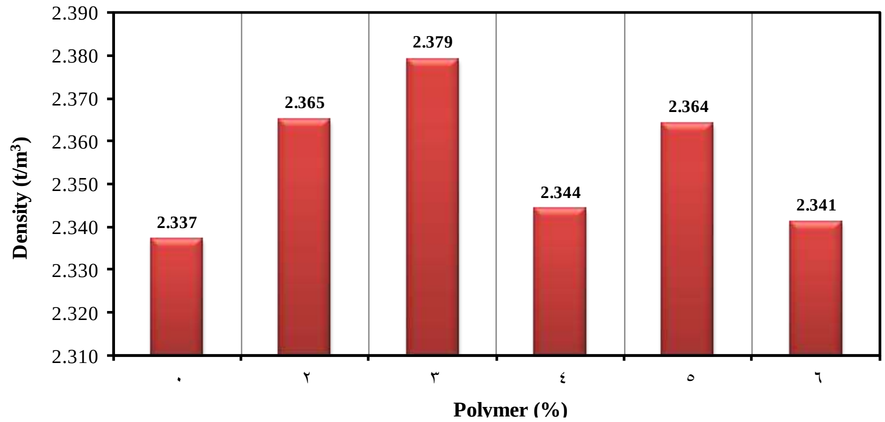

Figure 6 Bulk specific gravity of the mix against the percentage of polymer

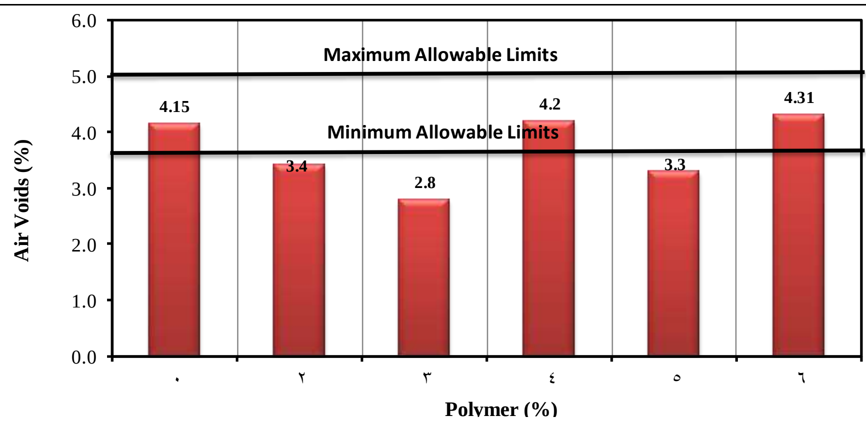

Figure 7 Air voids against the percentage of polymer

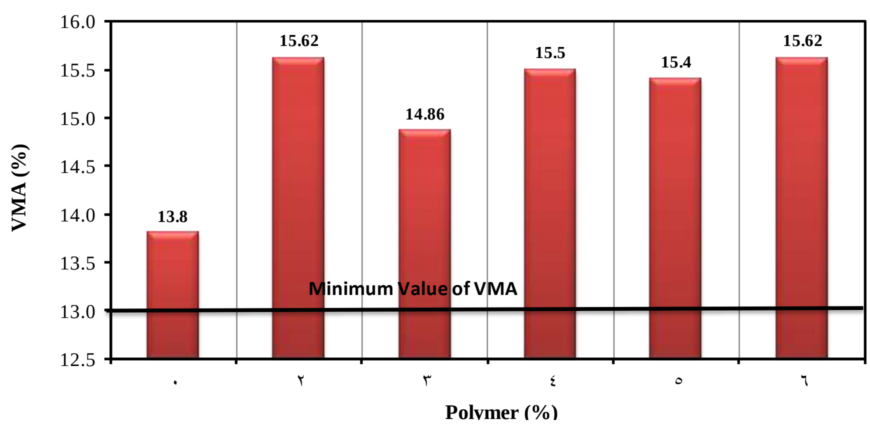

Figure 8 Voids in Mineral aggregates (VMA) against the percentage of polymer

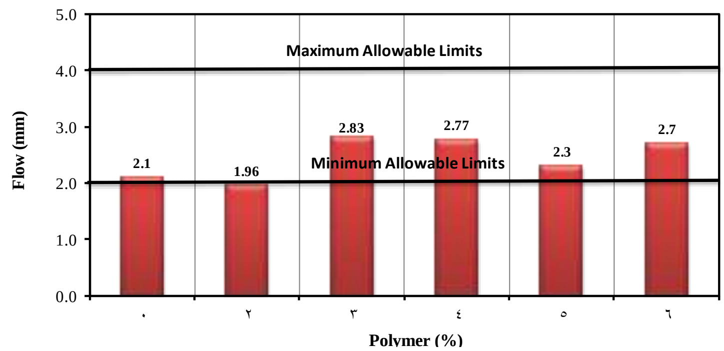

Figure 9 Flow of mixtures against the percentage of polymer

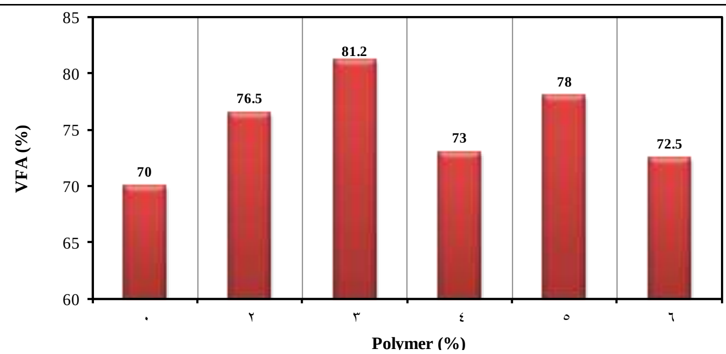

Figure 10 VFA for mixtures against the percentage of polymer

Loss of Stability

As displayed before, the percentage of 4% seems to have the maximum stability; it was decided to investigate the loss of stability for the mixture containing this percentage. The loss of stability test was conducted according to ASTM (??). Three samples were prepared. The samples were compacted by Marshall compactor and then left soaked in water for 24 hours. After that, the samples were tested in Marshall apparatus and the stability was recorded. A comparison was made between the stability before soaking and after soaking as presented in Figure 11. It can be observed that the loss of stability for the three samples was less 25% which compiles with the standards (??).

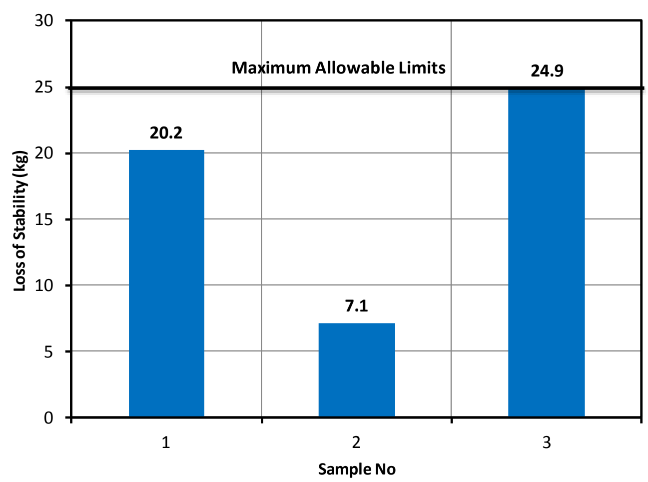

Figure 11 Loss of stability for the samples

Indirect Tensile Strength (IDT)

The indirect tensile strength is a tool to evaluate the effect of water on the tensile strength of the asphalt concrete mixtures. The test was conducted according to ASTM D 4867/D4867M for the sample prepared with 4% of the SUPERPLAST. Serval trial were made to compact the sample to the design air voids level by adjusting the number of blows in Marshall hammer. Six samples were prepared and compacted, three samples were maintained dry while the other half was partially saturated with water and moisture conditioned. The dry set was kept at the room temperature however; the partially saturated set was soaked in water bath for 24 hours at 60 C^{o}. Before testing, the dry samples were soaked in water bath for 20 minutes at 25 C^{o} and the partially saturated samples were placed in water bath for one hour at 25 C^{o}. Then, the samples were placed into the loading apparatus and a diametric load was applied with the rate of 2 inches per minute until fracture and the maximum load was recorded.

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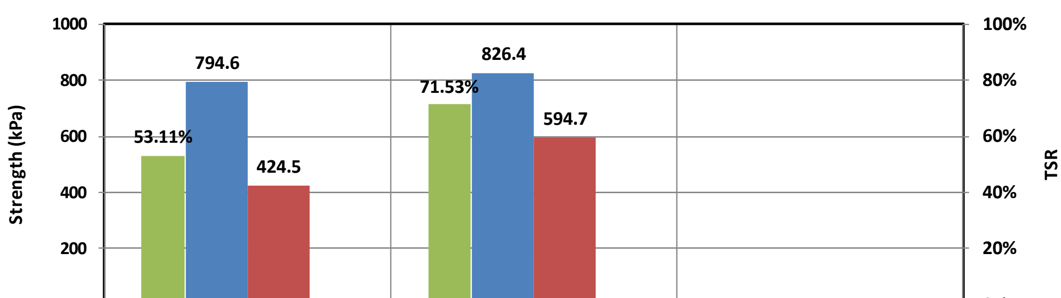
The average tensile strength was calculated for the dry set (S_{TD}) and for the moisture conditioned set (S_{Tm}) then the tensile strength ratio (TSR) was determined by dividing the S_{Tm} by S_{Td}.

Figure 12 shows the results of the IDT for the modified mixture compared with the control mixture (without polymer). It can be noted that the modified mixture has tensile strength for the dry set slightly higher than the control mixture. The tensile strength for moisture conditioned set for the modified mixture was 40% higher than the value for the control asphalt mixture. The value of the TSR for the control mixture was less than the requirements (which was 70% minimum, ref). On the other hand the addition of polymer was improved the value of TSR and made it within the range



	Control Mix	4.0% Polymer Mix	
Std,kPa	794.6	826.4	
Stm,kPa	424.5	594.7	
TSR (%)	53.1%	71.5%	

Figure 12 comparisons between IDT for the modified mixture (4% polymer) against the control mix

Conclusions

This paper presents the characterization of the modified asphalt mixture containing the SUPERPLAST. The findings show the addition of SUPERPLAST with percentage of 3% to 5% improves the mechanical properties and the durability of the asphalt such as Marshall Stability, the bulk specific gravity, the loss of stability and the IDT. The modification of the asphalt mixture with polymer will increase the pavement design life on the long term. Furthermore, the using modified asphalt mixture in the pavement construction will have a significance effect on the reduction of pavement thickness, which will be economical.

Reference

1. Al-Hadidy AI and Tan Y-q (2011). The effect of SBS on asphalt and SMA mixture properties. Journal of Materials in Civil Engineering V23, 504.
2. ASTM D5 (2006) "Standard Test Method for Penetration of Bituminous Materials", ASTM, USA.
3. ASTM T53 (1996) "Standard Method of Test for Softening Point of Bitumen (Ring and Ball Apparatus)", ASTM, USA.
4. ASTM D4402 / D4402M (2013) Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer, ASTM, USA.
5. ASTM D6927 (2006) "Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures", ASTM, USA.
6. M. A. Shafii, M. Y. Abdul Rahman and J. Ahmad (2011) Polymer Modified Asphalt Emulsion. International Journal of Civil & Environmental Engineering IJCEE-IJENS Vol. 11 No. 6.
7. L. H. Lewandowski (1994) Polymer Modification of Paving Asphalt Binders. Rubber Chemistry and Technology: July 1994, Vol. 67, No. 3, pp. 447-480.
8. Liu, X. and Wu, S. (2011) Study on the graphite and carbon fiber modified asphalt concrete. Construction and Building, 25(4):1807–1818.
9. FHWA (2012) Polymer Modified Asphalt Emulsions Composition, Uses, and Specifications for Surface Treatments. Publication No. FHWA-CFL/TD-12-004, USA.
10. Y. Yildirim (2007) Polymer modified asphalt binders. Construction and Building Materials, 21, 66–72.
11. S. Tayfur ,H. Ozen, and A. Aksoy (2007) Investigation of rutting performance of asphalt mixtures containing polymer modifiers. Construction and Building Materials, 21, 328-337