Evaluating the Effect of Lucobit on Moisture Susceptibility and Mechanical Performance of Bitumen and Asphalt Mixtures

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Abstract

The use of polymer in hot mix asphalt production has remarkably in recent decades. Destruction due to moisture in hot mix asphalt is of basic matters about flexible pavement durability. In recent decades different ways have been used to evaluate moisture Sensitivity of HMA which some of them are simple with low cost and some are complicated with more reliable results. In this research the effect of polymer Lucobit on striping was investigated and boiling test and image processing technic and modified Lottman test that is the most popular test for moisture sensitivity were executed. Marshall Test, indirect tensile strength and dynamic shear rheometer (DSR), were done as additional tests. The results show that use of this polymer has a remarkable positive effect on moisture sensitivity and has improved other parameters of bitumen and hot mix asphalt. The results showed that 2%, 4% and 6% Lucobit, by which the PG 58-** will be upgraded to PG 64-**, PG 70-** and PG 76-**, respectively. In addition, the addition of 6% Lucobit has led to improvement of high temperature performance by 14.7 ºC and enhancement of three grades from PG 58-** to PG76-**. Also, the addition of 6% Lucobit has led to enhancement complex modulus by an average of 53.7 %.

Keywords: Moisture Sensitivity, hot mix asphalt, Polymer Lucobit, stripping, bitumen.

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1. Introduction

The adhesiveness and cohesiveness amount of bitumen and aggregate materials considerably influence the asphalt pavement function while moisture plays an important role in stripping and bleeding [Behiry, 2013; Goli, Ziari, 2016]. Stripping is considered to be one of the important distresses of asphalt pavement. Generally, the presence of moisture exacerbates the extent and severity of the existing distresses [Anderson, Dukatz and Petersen, 1989]. The basic reason for moisture sensitivity that leads to pavement destruction happens because of these two mechanisms:

1- Reduction in cohesion 2- Reduction in Adhesion [Tunnicliff and Root, 1995]. The reduction happens because of water penetration between bitumen and aggregate that leads to stripping, it is possible that two mechanisms act together simultaneously and cause moisture sensitivity in pavement. Moreover defects due to moisture may happen because of change in asphalt bitumen, reduction in bitumen accompanied by increase in traffic, change in aggregate quality and poor construction quality [Terrel, and Shute, 1989; Kakara, Othman, Valentin, 2015; Mehrara and Khodaii. 2015].

Increased moisture susceptibility levels separate bitumen from aggregates with the ultimate result of decreased internal resistance and efficiency of asphalt mixtures [Kok and Yilmaz, 2009]. Although there is little information available on the mechanism of moisture susceptibility, it has been proven that various factors such as bitumen characteristics, the quality of aggregates, loading methods and the type of applied anti-stripping additives contribute to the development of this detrimental phenomenon [Kiggundu and Roberts, 1998].

In the presence of water, asphalt-aggregate mixtures can loss of bond between the bitumen and the aggregate (adhesion). Loss of bond or changes, or both, in the properties of the asphalt bitumen can result in significant engineering property changes in hot-mix asphalt mixtures and premature distress in pavements [Lu, Harvey, 2006; Kringos, Scarpas, 2008]. Historically, six contributing mechanisms to moisture damage have been identified: detachment, displacement, spontaneous emulsification, pore pressure–induced damage, hydraulic scour, and the effects of the environment on the aggregate–asphalt system [Shakiba, Darabi, Rashid and Al-Rub, Dallas, 2014]. Moisture damage can be defined as the reduction of strength and durability in asphalt mixtures due to the effects of moisture. It can be occurred because of a loss of bond between the bitumen or the mastic and the fine and coarse aggregate [MoghadasNejad, Arabani, Hamedi, Azarhoosh, 2013]. Moisture damage also occurs because moisture permeates and weakens the mastic, making it more susceptible to moisture during cyclic loading [Kim., Zhang, Ban, 2012; Xie, Wu, Peng, Lin, Zhu, 2012].

The aim of this research is to investigate the polymer Lucobit's effect as a bitumen modifier on stripping reduction due to moisture, and quality control of materials and aggregates to make a better pavement.

2. Materials and Method

2.1 Lucobit

Polymer Lucobit is a petrochemical wide spread product the basic part of this petrochemical substance is a special PE (copolymer) that has been registered as DIN 16729 In granule in German standard. The polymer characteristics of Lucobit cause its rapid combination with bitumen. Because Lucobit has high viscosity and for its elasticity it can tolerate heat up to 300° c and coldness of -20°(without structural damage) and is a thermoplastic (Table 1). It should be noted that these thermoplastics can be added to bitumen or HMA directly.

2.2 Bitumen

The bitumen used in this project on the base bitumen was 60/70 from Isfahan refinery with specifications shown in table 2.

2.3 Aggregates

The HMA samples were made in accordance to ASTM-D1559, Iran pavement regulation [Code No.234] was used for grading which specification is shown in Figure 1 and aggregate specifications are shown in table 3.

Table1. Characteristics of Lucobit

Typical Properties	Unit	Lucobit
Density (23 °C)	g/cm3	0.97
Apparent Density	g/l	~ 500
Elongation at Break (23 °C)	%	700 - 800
Modules of Elasticity	MPa	17
Softening Range	°C	80 - 100
Embrittlement Range	°C	< - 30

Table2. Characteristics of used bitumen.

Test properties	Test result	Standard
Penetration @ 25°C (0.1 mm)	66	ASTM D5
Softening Point (°C)	52	ASTM D36
Viscosity @ 135°C (Pa.s)	0.367	AASHTO T72
Ductility (cm)	Over 100	ASTM D113
Specific gravity (g/cm3)	1.032	ASTM D70
Flash point (ºC)	317	ASTM D92

Table 3. Engineering properties of aggregates used in this study

Aggregate	Abrasion lost (Los Angeles) (%)	Compressive strength (kg/cm^3)	Absorption of water (%)	Specific gravity (gr/cm^3)	Sand Equivalent (%)
Standard No.	ASTM C-131	ASTM D-692	ASTM C-127	ASTM C-127	ASTM D-2419
Result	23	400	0.96	2.58	63.8

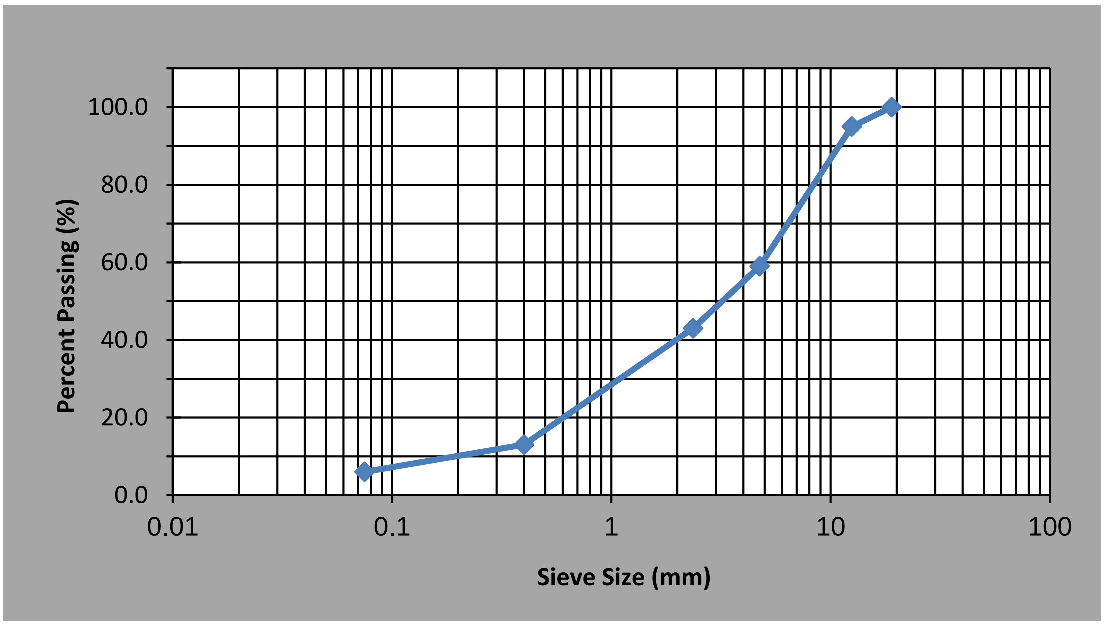


Figure 1. Aggregate gradation curves

2.4 Method

The reduction of strength and durability because of moisture is called moisture defect moisture can ruin asphalt mixes in two different mechanisms. One leads to lack of cohesion between bitumen and mastic with aggregate and one weakens mastic cohesion in presence of bitumen. Since 1930 difference kinds of laboratory methods have been developed to evaluate moisture sensitivity. In this study that used the standard practice for effect of water on bituminous-coated aggregate using boiling water [ASTM D-3625].

It is a simple and low-cost test to evaluate water effect on bitumen and aggregate this test is for uncompacted mixes. In this test a specials amount of bitumen and aggregate is boiled in hot water under special circumstances to evaluate moisture sensitivity. The modified Lottman test is the most popular method for moisture sensitivity evaluation in the world. Iran code introduces this test as a method to measure HMA durability against water [Lottman, 2001]. But the basic and better way for moisture sensitivity evaluation is indirect tensile strength according to AASHTO T-283 which its application and result consistency with pavement performance that use in this study too.

The Marshall Stability and flow tests of the asphalt mix for both type of aggregates were carried out at various asphalt concentrations according to ASTM D1559. In addition, Marshall Quotient (MQ) which is the ratio of stability (KN) to flow (mm), and an indicator of the mixture stiffness as well is presented.

Furthermore, to determine their rheological properties, dynamic mechanical analysis was performed on the base bitumen and Lucobit modified bitumen, using a dynamic shear rheometer (DSR). Rheological tests were performed under controlled-strain conditions at 30 to 80 °C with fixed frequencies of 0.1 and 100 rad/s.

4. Results and Discussion

4.1 Image Processing

After boiling test, as you see in following picture (Figure 2 to Figure 5) stripping in mixes with higher percent of Lucobit is much less than base bitumen. These pictures have been taken with precise microscopes and zoomed out to 5000 microns that was provided after deletion of light reflection and processing with soft wares mentioned in last chapter. The picture in left was taken from specimen before boiling test and the pictures in right are taken after changes due to boiling test with microscope.

Because in AASHTO T-283 test, average strength of three samples is used, in this research for more accuracy, the boiling water test was done with three times of repetition and then stripping percent was determined by visual and microscopic evaluation. As you see in pictures 2 to 5 investigation of boiling water test with microscope has more accuracy and bitumen and aggregate detachment is much more visible. Results are shown in Table 4.

Table 4. Result of boiling test

Polymer %	Result (Stripping) %
0%	2 %
2%	< 1%
4%	< 0.5%
6%	0%

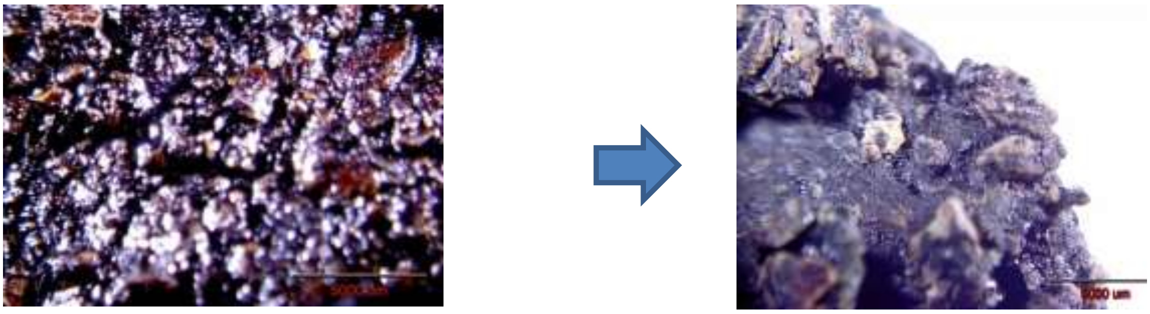


Figure 2. Micro image after boiling test with base bitumen (Left: Normal, Right: Microscope image)

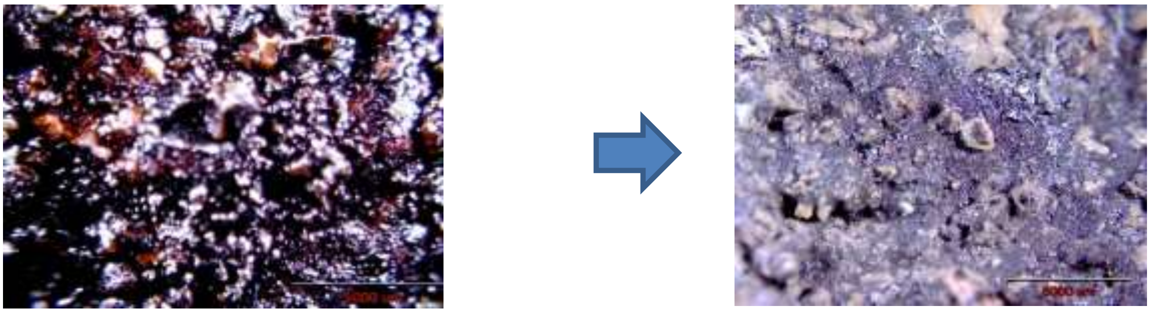


Figure 3. Micro image after boiling test with PMB with 2% Lucobit (Left: Normal, Right: Microscope image)

Figure 4. Micro image after boiling test with PMB with 4% Lucobit (Left: Normal, Right: Microscope image)

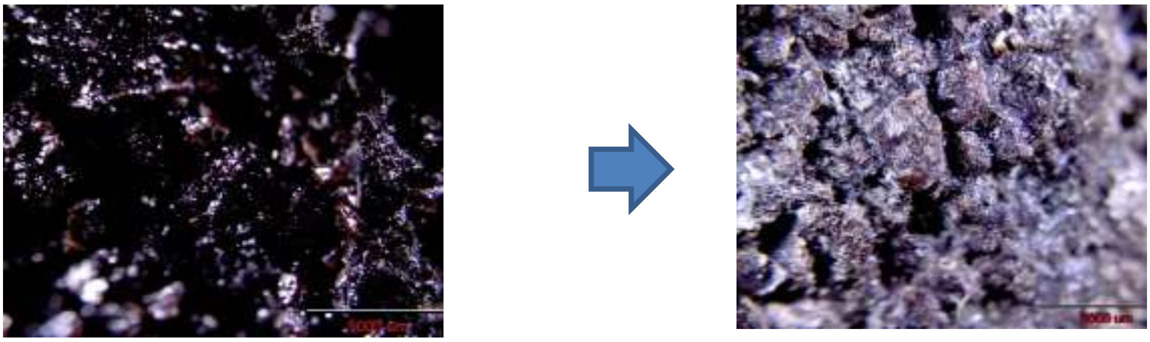


Figure 5. Micro image after boiling test with PMB with 6% Lucobit (Left: Normal, Right: Microscope image)

5. Bitumen Tests

5.1 Dynamic Sheer Rheometer (DSR) Test

Since a bitumen is a viscoelastic material, its rheological behavior depends on both temperature and loading frequency. Accordingly, it may vary from purely viscous to purely elastic. Complex modulus (G*) a property of viscoelastic materials is the ratio of the absolute value of the peak-to-peak shear stress (τ) to the absolute value of the peak-to-peak shear strain (γ). As illustrated in Figure 5, adding Lucobit results in improved complex modulus (G*) and reduced phase angle (δ). For Lucobit modified bitumens, increasing Lucobit to 2%, resulted in a minor increase in G*, while a significant increase was observed when Lucobit content was changed 2% to a 6%. In fact, the addition of Lucobit resulted in the enhancement of rutting resistance to permanent deformation. Phase angle shows the transition from viscous to elastic behavior in bitumens. Lucobit can reduce δ of the base bitumen. In addition, an increase in the amount of Lucobit led to a decrease in δ of bitumen.

Table 5 presents high performance temperature of Lucobit modified bitumens. As can be observed 2% Lucobit will upgrade PG 58-** to PG 64-**. The same is true for these grades of bitumens with 4% and 6% Lucobit, by which the PG 58-** will be upgraded to PG 70-** and PG 76-** respectively. The results shown in Table 5 indicate positive effect of Lucobit on the high-Performance Grade (PG) temperature of modified bitumens, and thus increase in rutting resistance of the modified bitumens. As the amount of Lucobit increases, one can notice that the trend continues to exist. The significant improvement in the bitumen performance at high temperatures is worth mentioning. For example, according to results, high performance temperature of 2% Lucobit modified bitumen increases 5.1 ºC. Similarly, this process occurs for modified bitumen for 4% Lucobit and 6% Lucobit, their high performance temperature increase by 10.4 ºC and 14.7 ºC, respectively.

In order to investigate the effect of Lucobit on the rutting properties of the bitumen, a samples with different temperatures and frequencies were used. Figure 6 presents the effect of Lucobit on complex shear modulus (G*) of Lucobit modified bitumens at three different Lucobit concentrations (2, 4 and 6%) and six different temperatures. As depicted in Figure 4, Lucobit modified bitumens show higher G* than the base bitumen. Increasing the concentration of Lucobit by 6 % in the base bitumen, increases G* by an average of 53.7%. Furthermore, phase change angle in bitumen is an important parameter in bitumen behavior under pavement loads, and bitumen with small change in phase angle have better performance especially in high temperatures. Besides small phase angle means less permanent deformation in hot weather. The slope of these diagrams shows its performance. As you can see in Figure 7 higher percent of Lucobit leads to smaller phase angle that shows better performance of modified bitumen in high temperatures (summer).

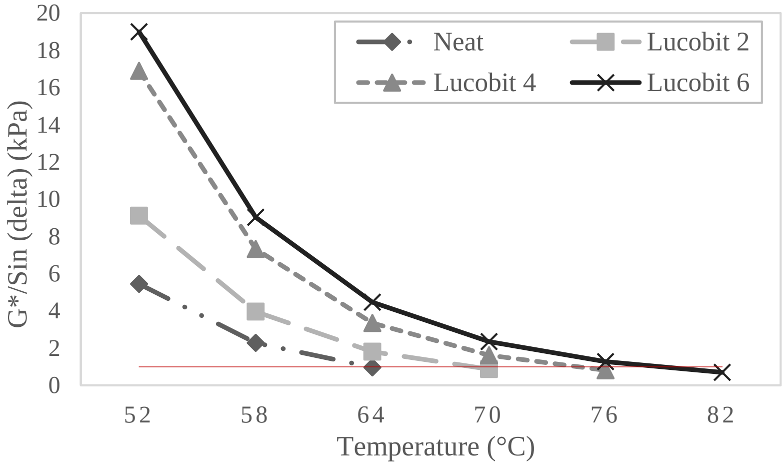
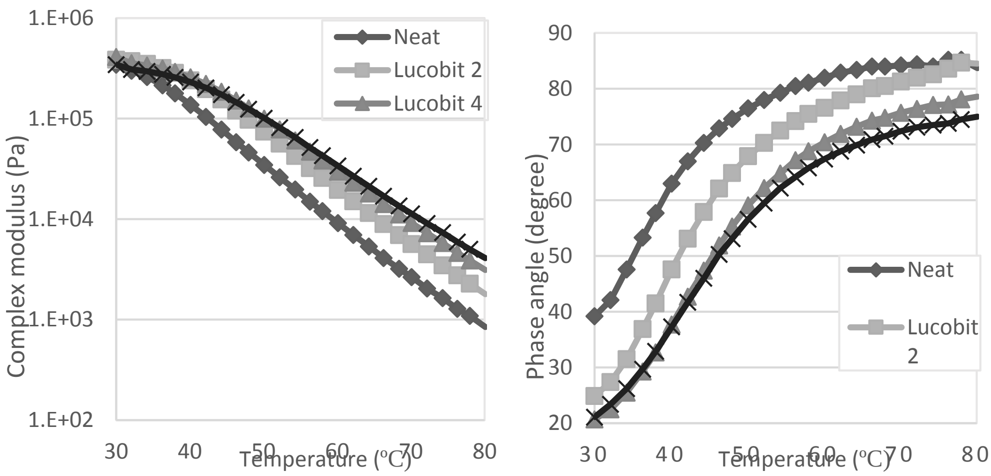


Figure 6. Result of DSR test.



(a) (b)

Figure 6. Rheological properties of Lucobit modified bitumen; (a) complex modulus; (b) phase angle.

Table 5. The DSR test results of neat and modified bitumens.

Bitumen Code	Temperature (ºC)	G* (kPa)	Phase Angle (δ)	Pass–Fail Temperature (ºC)	High-Performance Grade Temperature (ºC)	High Temperature improvement (°C)
Neat	52	5.39	82.0	63.8	58	-
	58	2.27	84.7			
	64	0.96	86.6			
Lucobit 2	52	8.92	77.9	68.9	64	5.1
	58	3.91	81.2			
	64	1.79	82.8			
	70	0.86	83.5			
Lucobit 4	52	16.1	71.9	74.2	70	10.4
	58	7.15	77.4			
	64	3.30	79.9			
	70	1.60	81.0			
	76	0.80	81.7			
Lucobit 6	52	17.5	67.4	78.5	76	14.7
	58	8.56	69.8			
	64	4.26	72.3			
	70	2.22	71.2			
	76	1.20	69.9			
	82	0.66	70.9			

The parameter G*/sin δ is used as a measure of rutting resistance at high temperatures. This means that the bitumen that is the most resistant to rutting has the highest G*/sin δ. Figure 8 shows the effect of Lucobit on G*/Sin (δ) of modified bitumen at different Lucobit concentrations and four six temperatures and 0.1- 100 HZ frequency. According to the results, rutting resistance increased the loading frequency increased. These can be due to the rheological behavior of bitumens as they exhibit elastic behavior under shorter loading periods. In addition, at the same frequency level, the increase in temperature caused a decrease in the rutting resistance. As can be seen in Figure 8, the Lucobit modified bitumens demonstrate greater G*/sin δ values compared to the base bitumen. It can be inferred from Figure 7 that, the addition of 2%, 4% and 6% Lucobit to the neat bitumen can increase G*/Sin (δ) values by an average of 61%, 96% and 126%, respectively. It is obvious that, as modifier dosage goes up, G*/Sin (δ) values go up as well. The results show that, the addition of Lucobit to the bitumen leads to improved bitumen properties at high temperatures, increasing pavement rutting resistance against permanent deformation. These enhancements can be attributed to a network of Lucobit formed within the bitumen that leads to changes in asphalt microstructure.

In order to evaluate the efficiency of the Lucobit modified bitumen, a modification index was defined as the ratio of the rutting resistance of the Lucobit bitumen to the rutting resistance of the neat bitumen. Fig. 4a shows the effect of Lucobit content and temperature on the modification index. For bitumens modified with Lucobit, the modification index increases with increasing temperature at 80 °C. This indicates that, at low frequencies at especially this temperature, the Lucobit modified bitumens show decreased thermal susceptibility compared to the base bitumen In addition, Fig. 4b indicates the influence of Lucobit content and loading frequency on the modification index. For bitumens modified with Lucobit, the modification index decreases with increasing loading frequency. Despite the fact that bitumen possesses good adhesion, it has limited continuity. In addition, it is limited between fracture and softening points in terms of temperature. The use of this polymer leads to the expansion in the endurable temperature range by two times as well as continuity improvement.

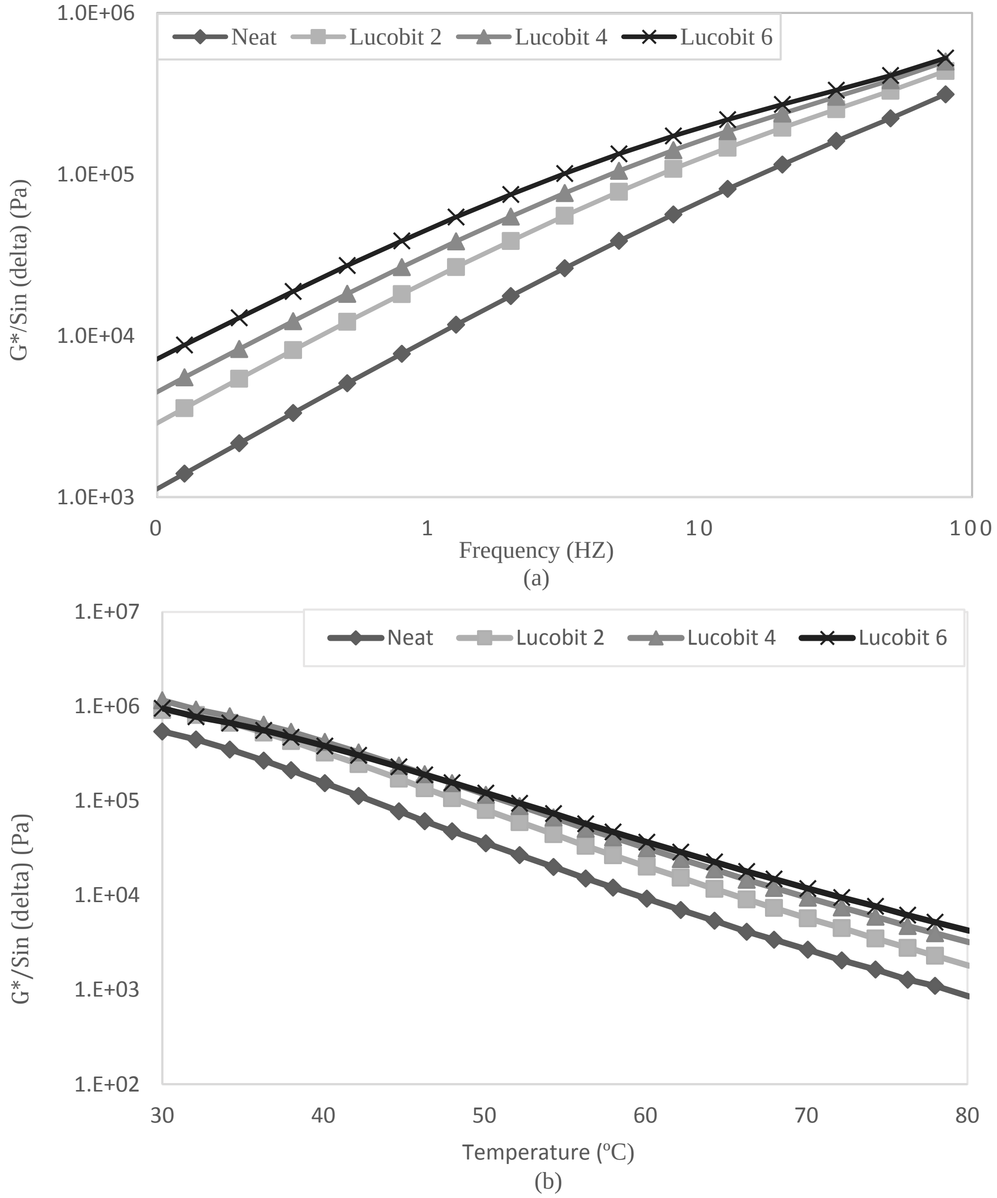


Figure 8. Phase angle of Lucobit modified bitumen in different frequencies.

This issue itself results in an improvement in the resistance of bitumen to fluency, softening point, a higher viscosity in service conditions, and a decrease in thermal sensitivity. This matter shows that this type of bitumen can have more desirable properties in areas with high temperature difference [Guia, Zhang, Sun, Yongzhong, 2003]. Marshall Stability experiment is conducted according to ASTM-1559. This experiment is performed to investigate the stability and persistence of asphalt mixtures by measuring Marshall Stability, Flow and Marshall Quotient (MQ) which is the ratio of stability (KN) to flow (mm), and an indicator of the mixture stiffness as well is presented. As it is depicted in Figure 10, with increasing the percentage of polymer, Marshall Stability has also increased so that this increase is approximately 13% for the samples prepared by adding 6% of Lucobit polymer in comparison to those prepared by the neat bitumen, while the fluency of all samples is within the standard range. The last matter can be indicative of a greater performance of asphalt under traffic loading. Moreover, the better cohesion of bitumens modified with Lucobit might be the cause of higher stability results of modified mixture compared to unmodified mixture.

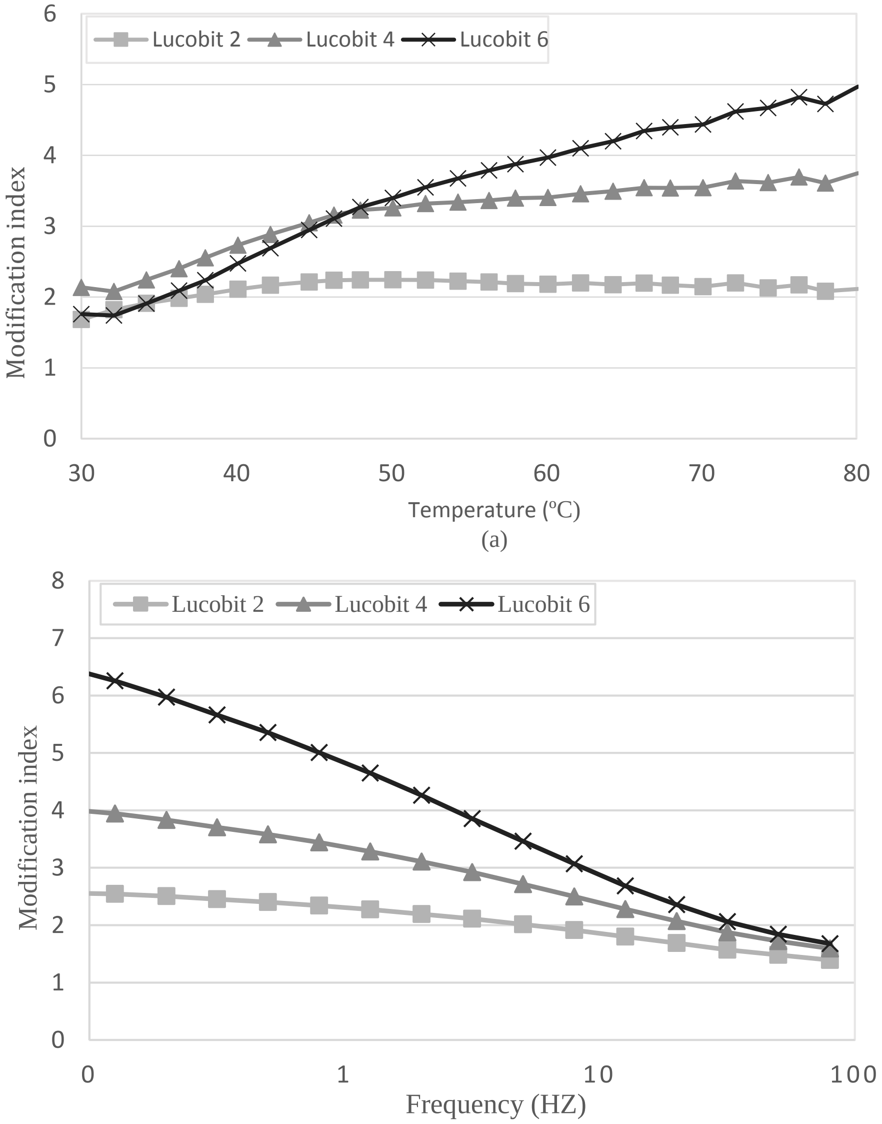


Figure 9. Modification index for base and Lucobit bitumens at: (a) 30-80 ºC. (b) 0. 1-100 Hz.

A total number of 24 specimens were indiscriminately selected and put into two categories. The first group was labelled as conditioned specimens and were soaked in a water bath for 24 h at a temperature of 60 ºC while the other group was labelled as unconditioned specimens and were immersed in the water bath at a temperature of 60 ºC for 40–45 min. Then, both conditioned and unconditioned samples were loaded at a rate of 50 mm/min and the Marshall Stability values were recorded. The Marshall Stability Ratio (MSR) for all types of mixtures is presented in Figure 10d samples. Mixtures containing Lucobit have better moisture susceptibility than unmodified mixture. Furthermore, Lucobit which leads to enhancement the adhesion of bitumen and aggregate aggravates the moisture susceptibility of asphalt mixtures. sample due to the specific loading conditions. Since the major part of the tensile stress in asphalt is sustained by bitumen, as the bitumen of aggregates, the binding between bitumen and aggregates can be deduced from the result of this experiment. As it is observed in Figure 11, as the percentage of Lucobit increases, the values regarding the experiment of indirect tensile strain increase, too. This issue reveals that adding polymer to bitumen makes the bonding between bitumen and aggregates stronger which is effective in preventing aggregates from striping.

As it can be noted from above diagrams cured (wet) specimen have less stability and flow than dry specimen, and with increase in polymer amount moisture sensitivity of modified asphalt mixes has improved from 85 to 92 percent which shows using this polymer improves the strength against stripping.

6. Conclusion

Bitumen has limited capabilities and a specific servicing-time due to its restricted physical and mechanical properties. Polymers, as the most significant family of bitumen modifiers, are added to improve the performance of bitumen. In this study, Lucobit polymer, as one of the plastomeric modifiers from the complex of polyolefin, has been mixed with the standard bitumen in different weight percentages (2%-6%) and its effect on different properties of bitumen has been investigated through classical and functional experiments. Based on the tests and calculations executed, the results are as follows:

The results of the functional experiments done on the bitumen samples show that the functional properties of bitumen including the complex modulus, elastic modulus, rutting parameter, and phase change angle of modified samples of bitumen with this polymer have improved in comparison to the standard bitumen. Furthermore, the results of the experiments done on the asphalt samples indicate that the use of this polymer has improved the Marshal stability, shear modulus and indirect tensile strain.

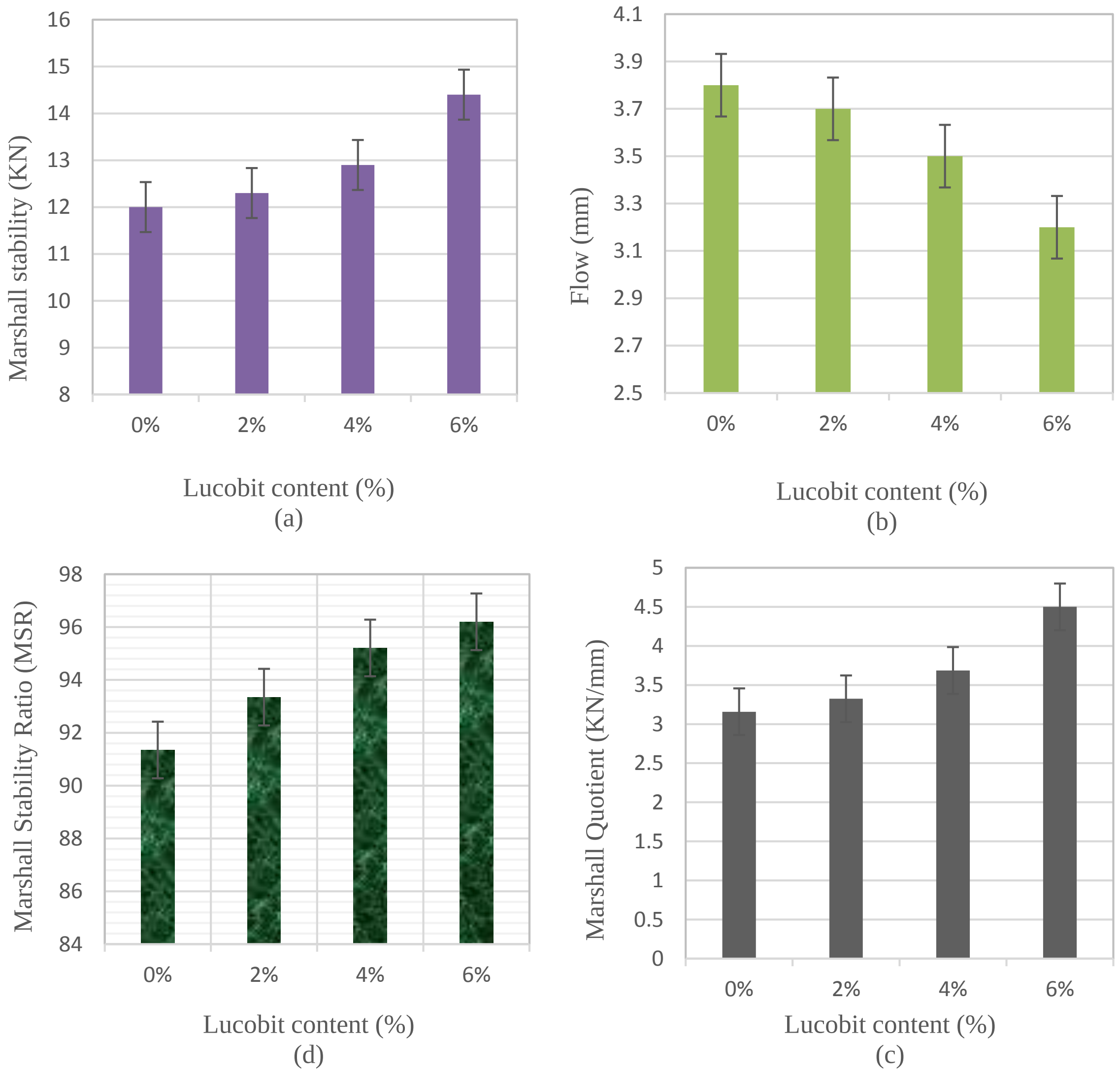
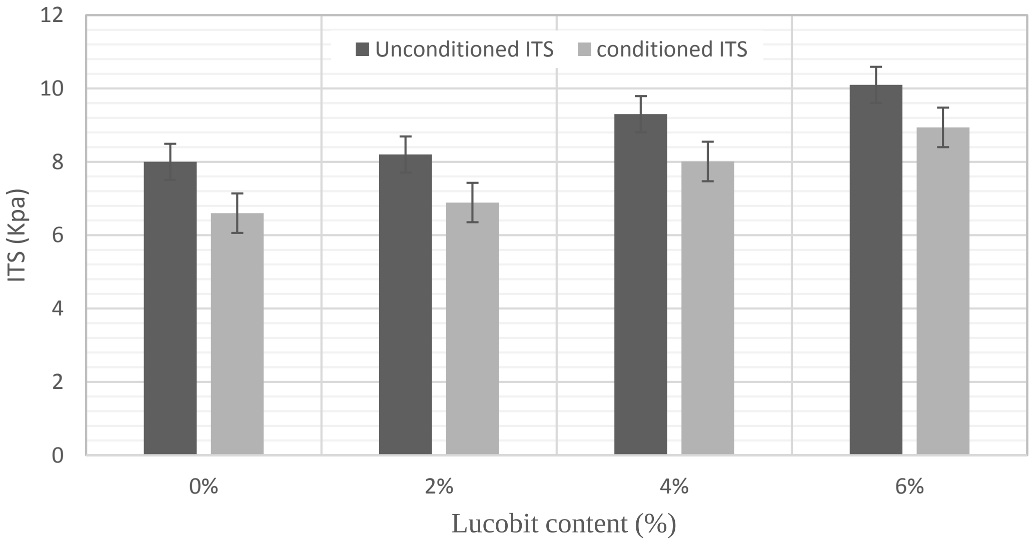


Figure 10. Marshall Stability (KN), flow (mm) and Marshall Quotient values for different cases.



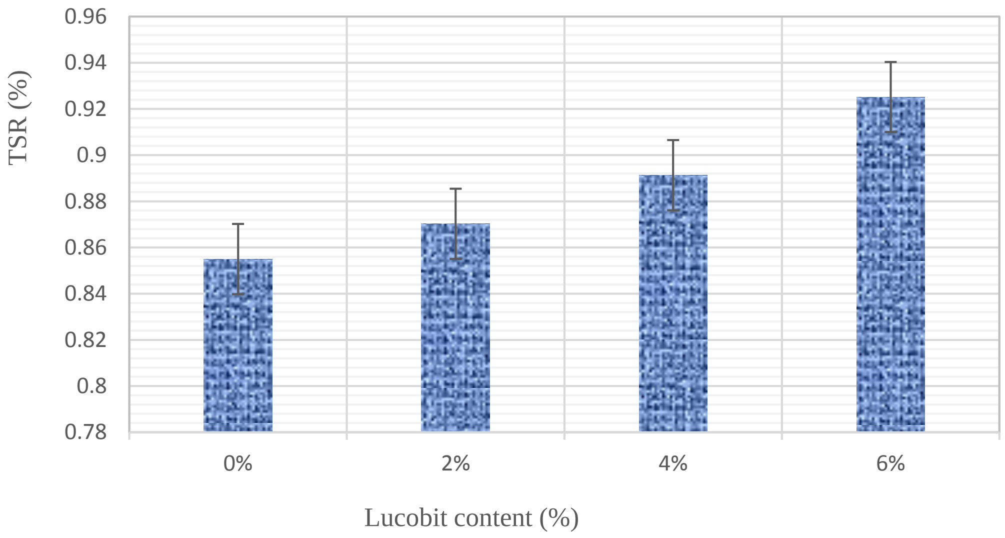


Figure 11. ITS and TSR values of modified and unmodified asphalt mixtures.

According to modified Lottman test, it's understood that using Lucobit in dry and wet condition can improvement in worst condition. The results of boiling test and pictures processing showed that Lucobit is effective in moisture sensitivity reduction. The results of Lottman and Marshall Stability and flow for moisture destruction showed that by using this polymer high strength in dry and wet status is achievable that means Lucobit can be used in humid areas. Increase of Lucobit improves cohesion between bitumen and aggregate according to indirect tensile test. According to Marshall Stability in comparison with base bitumen, the bitumen with 6% of Lucobit has increases in strength which indicates better performance.

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