Civil Engineering and Architecture 10(3): 1118-1128, 2022 http://www.hrpub.org
DOI: 10.13189/cea.2022.100328

Study of the Effect of Climatic Factors on Indirect Tensile Strength of Asphalt Mixtures Modified with a Mixture of /Polymer-Sulfur/

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Received January 27, 2022; Revised March 18, 2022; Accepted April 15, 2022

Cite This Paper in the following Citation Styles

(a): *[1] Ahmad Sameer ALsaleh , "Study of the Effect of Climatic Factors on Indirect Tensile Strength of Asphalt Mixtures Modified with a Mixture of /Polymer-Sulfur/," Civil Engineering and Architecture, Vol. 10, No. 3, pp. 1118-1128, 2022. DOI: 10.13189/cea.2022.100328.*

(b): *Ahmad Sameer ALsaleh (2022). Study of the Effect of Climatic Factors on Indirect Tensile Strength of Asphalt Mixtures Modified with a Mixture of /Polymer-Sulfur/. Civil Engineering and Architecture, 10(3), 1118-1128. DOI: 10.13189/cea.2022.100328.*

Abstract The asphalt paver must fulfill a set of basic requirements, from a sufficient bearing capacity for the expected loads, stability and good resistance to deformations resulting from the passage of large loads at high temperatures, and also securing an impermeable surface that achieves adequate and good drainage of water. Hence, it is necessary to search for permanently and continuously improved materials that are resistant to the influence of factors affecting the flexible paving in its upper layers, consisting of bituminous composites. Polymer-modified bitumen has been used to improve the performance of bituminous paving. I have designed asphalt mixtures using asphalt cement without modification, polymer-modified asphalt cement (polyethylene), and asphalt cement modified with a mixture of (polymer-sulfur). Next, I performed lab experiments simulating the effect of investment, weather and climatic factors during operation and investment (conditioning test). It is concluded that the change in the value of indirect tensile Strength for the Asphalt samples formed using an asphalt cement which was modified with a mixture of /polymer-sulfur/ was (4%) of its value after the conditioning test, and as for Asphalt samples formed using an asphalt cement which is modified with polyethylene (PE), the value was (14%) after the conditioning test.

Keywords Asphalt Mixtures Modified, Tensile Strength of Asphalt Mixtures, Modification of Bitumen with Sulfur

1. Introduction

Bituminous paving is the most widespread type of road, and that is widespread in all regions of the world, where the percentage of roads that depend on this type of paving is about 98% in the world, thanks to the ease and speed of its construction.

The asphalt paver must fulfill a set of basic requirements, from a sufficient bearing capacity for the expected loads, stability and good resistance to deformations resulting from the passage of large loads at high temperatures, and also securing an impermeable surface that achieves adequate and good drainage of water, in addition to safety and comfort for the passage of vehicles [1]. Investment conditions and climatic factors often lead to deformations, cracks and pits appearing on the pavement surface, which in turn leads to a reduction in paving life and a low level of safety, in addition to the high cost of frequent maintenance. Hence, it was necessary to search permanently and continuously, to resist the influence of the factors affecting the pavement in its upper layers, which consisted of bituminous pavement, and because its guaranteed protection for the lower classes [2], in addition to its role as a carrier layer, where it is exposed in general to thermal climatic carriers[3], and also to exposure to static loads, high stability, which leads to deformations, and the formation of pits and wood on the surface of the paving, reducing the life of the paving and causing the lack of safety and the cost of frequent maintenance[4]. Polymer modified bitumen has been used to improve the performance of bituminous paving in many ways [5-6], including reducing paving cracks caused by thermal stresses, repeated loads, increasing the resistance of the bituminous bond to the fatigue caused by high temperatures [7], associated with the construction, and giving the bituminous bond high strength at high service temperatures [8]. It has been observed that polymer-modified bitumen suffer from instability in the structural structure due to the influence of climatic weather factors and repeated loads in a short period of its implementation and investment. Due to the unsaturated structure of the polymers, they are subjected to plasticization, which has prompted a search for an additional reactant to enhance the cross linking of the polymer molecules. In order to maintain improved structural bitumen structures throughout the planting period of paved layers [8].

2. Literature Review

In 2006, researchers conducted a study by J. S. Chen, C. C. Huang entitled Fundamental characterization of sbs-modified asphalt mixed with sulfur [9]. The purpose of this study was to note the mechanical properties of asphalt modified by styrene-butadiene-styrene (SBS) and sulfur. Viscosity, microscopy, and rheological tests were performed to determine the engineering properties of polymer-modified asphalt (PMA). In addition to the addition of sulfur, the polymer-modified asphalt was micro heterogeneous and composed of two distinctly connected phases, mainly at high SBS concentrations. After the addition of sulfur, the PMA was found to have smaller tar zones and a uniform scattering of tar in the SBS matrix.

The interaction between polymer and asphalt produced an elastic network in asphalt. The addition of sulfur led to an excellent stretching program and greatly increased the rheological properties of the PMA. Due to the colloidal nature of asphalt cement, their engineering properties were greatly improved due to the SBS polymer reinforcement and the physical and chemical interactions between SBS and asphalt. The difference in the softening point between the upper and lower layers decreases significantly, and the elasticity increases when there is sulfur. The viscoelastic model was tested and proven to predict the rheological properties of the asphalt-SBS mixture mixed with sulfur.

In 2008, researcher N.F. Ghaly conducted a study entitled Effect of Sulfur on the Storage Stability of Tire Rubber Modified Asphalt [10]. The main objective of this study was to improve the properties of converted asphalt binder rubber structures and improve storage stability by incorporating Styrene-Butadiene-Styrene (SBS) and elemental sulfur (S). Low quality asphalt paving 60/70 entry distance was adjusted by 2, 3, 4, and 5% TR (with asphalt wt.) And equal parts of SBS and TR at 2, 3, 4 and 5% per asphalt wt. they too were repaired before and after the installation of the sulfur. Visual properties including the penetration of the lubrication point at 25°C and ductility at 4°C, the inclination temperature of the input (PTS) and the input indicator (PI) of the converted commitments were examined. The stability of the modified and unstable asphalt storage was tested at 140,1160 and 200°C for high and critical vulcanization temperatures. The effect of TR modified asphalt binder on the performance of the bitumen mixture before and after the addition of SBS or SBS/ S has been assessed using Marshall strength and flow testing. The effect of vulcanized blend to counteract the plasticity of the bitumen mixture has been tested by trace detection tests. Results indicated that PTS of modified asphalt before and after vulcanization was decreased largely. Storage stability of TR/ SBS converted asphalt after the vulcanization process reached at 160°C while the critical temperature reached 200°C. The best improvement was obtained at 4% TR / SBS / 1% S.

In 2017, researchers conducted a Ming Liang Jingtao Shi Shisong Ren study entitled Effects of polymerized sulfur on the rheological properties, morphology and stability of SBS modified asphalt [11]. His aim in this study was to investigate the effects of polymerized sulfur on viscosity, morphology and SBS converted asphalt storage properties, compared to the original sulfur. Viscosity functions including complex viscosity, stable viscosity flow and variable viscosity are measured with a dynamic shear rheometer (DSR) and a Brookfield viscosity rheometer. The morphology and microstructure of altered asphalt were detected using fluorescence microscopy and Fourier Transform Infrared spectroscopy (FTIR). The results revealed that the increase in viscosity of the converted tar containing polymerized sulfur was slower than that of elemental sulfur. The level of Vulcanization decreases with the increase of polymerized sulfur, i.e. the delayed effect of vulcanization. In morphology, large polymer domains gradually evolve into fine-grained SBS fragmentation with a small size such as extending the mixing time; and a fine polymer phase was found to be elemental sulfur in the first phase of mixing, which is important evidence of delayed vulcanization. In addition, the FTIR results confirm the reduction of poly-butadiene block filling and the formation of C single bond S bond. The viscosity of polymerized sulfur-containing asphalt remains lower than that of elemental sulfur and decreases with increasing polymerized sulfur content. The base of the SBS phase burned by polymerized sulfur is larger than that of elemental sulfur and is usually larger with an increase in the content of polymerized sulfur. Finally, modified SBS asphalt with high polymerized sulfur content enhanced storage stability.

From these studies and a series of other studies, we find the effect of using sulfur to improve the properties of polymer-modified bituminous ligands and to achieve greater potential benefits of polymers when mixed with bitumins. In our research, we tried to show the effect of sulfur use in maintaining a high rate of improvement in Indirect Tensile Strength, particularly after the conditioning test (AASHTO T 283).

3. Materials and Methods

In this research, I used three types of asphalt cement. The first type of asphalt cement (A) without modification is with an 85/100 penetration grade. The second type of asphalt cement (B) (type A modified of added 2 percent of polyethylene weight from the asphalt cement). The third type of asphalt cement (C) (type A modified with 2 percent of polyethylene and 2 percent of sulfur weight from the asphalt cement [12]. The conventional properties of this type are displayed in Table (1).

Crushed dolomite as fine aggregates and coarse and limestone as mineral fillers compliant with the AASHTO M-17 used for mixing hot bitumen. We will use ASTM Gradation (D-5) and the Marshal method of mixing the mixture. Marshall's test procedures have been measured and standardized by the American Society for Testing and Materials. Procedures are given by ASTM D 1559. Figure (1) shows the design gradation of the gravel materials used in the design of asphalt mixtures.

Table 1. The conventional properties of asphalt cement

Properties	Type of asphalt cement			Standard methods
	C	B	A	
	Values			
Penetration at 25°C 100 g, 5 seconds, 0.1 mm	63	68	95	ASTM D 5
Softening point °C (Ring and Ball)	55.75	54.75	52.3	ASTM D 36
Ductility at 25°C, 5 cm/min, cm	105.5	117.25	158.5	ASTM D 113
Flash point, °C (Cleveland open cup)	326	321	313	ASTM D92
Loss on heating wt %	0.12	0.14	0.19	ASTM D 6
After Thin oven Test (Tfot) ASTM D 1754				
Retained Penetration %	89	64	56	ASTM D 5
Increase in Softening point °C	1	2.75	6.95	ASTM D 36
Ductility at 25°C	98.5	105	127	ASTM D 113

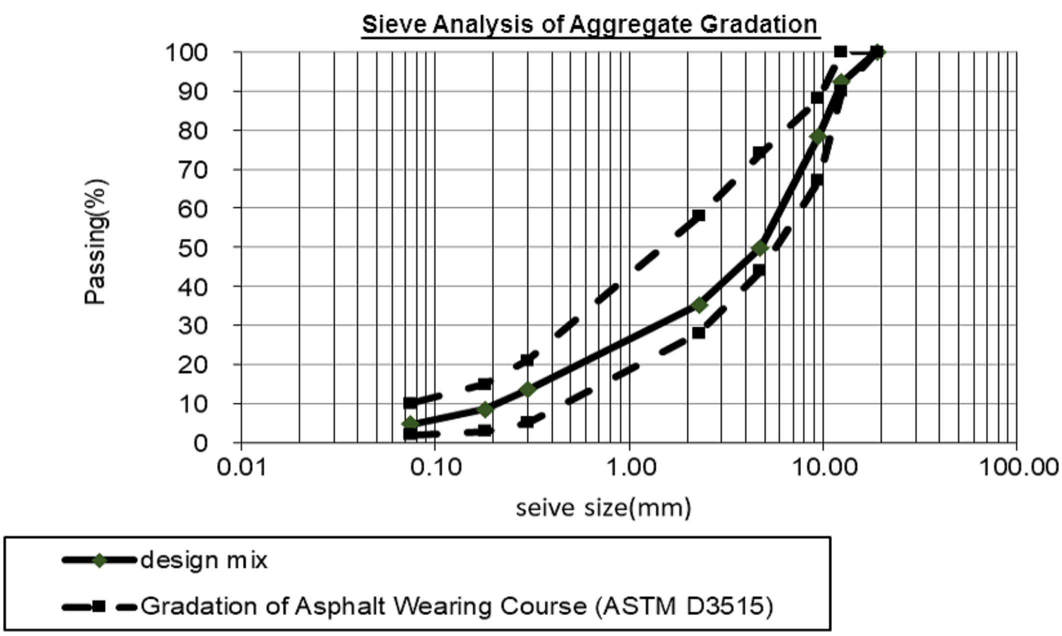

Figure 1. Design gradation of the gravel materials used in the design of asphalt mixtures

To describe the properties of the aggregate used, several laboratory tests were performed, these tests included: Sand equivalent (AASHTO T 176), Los Angles abrasion (ASTM C131), Specific gravity test (ASTM C127), Water absorption ASTM C128), properties of coarse aggregates in table (2).

Table 2. Properties of coarse aggregates

Los Angeles Abrasion Value/%	Sand Equivalent %	Water Absorption %	Apparent elative Density
16.5	74	1.24	2.711

4. Results and Discussion

4.1. Asphalt Mix Design

Marshall Method for designing hot asphalt mixtures was used to determine the optimum bitumen content to be added to specific aggregate blend resulting a mix where the desired properties of strength and durability are met. According to the standard 75-blow Marshal design method (AASHTO T 245-13) the total of 12 samples each 1200gm in weight was prepared using five different bitumen content (from 4 - 6% and 0.5% increase). Three types of asphalt mixtures are designed. The first mixture uses an asphalt cement type (A). Table (3) shows a Summary of the Test Results Marshal and Table (4) shows the characteristics of asphalt mixture using the asphalt cement type (A).

The second asphalt mixture using the asphalt cement type (B) which is modified with 2% of polyethylene. Table (5) shows Summary of Marshal Test results and Table (6) shows the properties of the asphalt mixture using the asphalt cement type (B).

Table 3. Summary of Marshal Test results (asphalt cement type A)

Bitumen %(by total weight)	Bluck Unit Weight (g/cm^3)	(VFB) (%)	(VMA) (%	Va (%)	Stability (Kg)	Flow (mm
4	2.356	55.72	16.58	7.34	1088	2.79
4.5	2.384	65.89	15.97	5.5	1145	3.22
5	2.396	73.14	16.06	4.31	1151	3.62
5.5	2.391	77.35	16.67	3.75	1113	3.9
6	2.376	79.32	17.62	3.64	1015	4.35

Table 4. Properties of the asphalt mixture using the asphalt cement type (A)

Asphalt Content (%)	5. 1
Stability (Kg)	1150.00
Flow (mm)	3.64
Air Voids (%)	4.20
VMB **(%)**	**73.50**
VMA (%)	**16.10**
Bluck Unit Weight (g/cm^3)	**2.396**

Table 5. Summary of Marshal Test results (asphalt cement type B)

Bitumen % (by total weight)	Bluck Unit Weight (g/cm^3)	(VFB) (%)	(VMA) (%)	Va (%)	Stability (Kg)	Flow (mm)
4	2.352	55.32	16.76	7.42	1312	2.92
4.5	2.381	65.04	16.16	5.62	1413	3.41
5	2.393	72.65	16.14	4.38	1426	3.88
5.5	2.387	76.56	16.84	3.91	1368	4.26
6	2.372	78.83	17.74	3.76	1240	4.58

Table 6. Properties of the asphalt mixture using the a asphalt cement type (B)

Asphalt Content (%)	5. 13
Stability (Kg)	1415
Flow (mm)	3.82
Air Voids (%)	4.30
VMB **(%)**	**73.00**
VMA (%)	**16.35**
Bluck Unit Weight (g/cm^3)	**2.391**

Table 7. Summary of Marshal Test results (asphalt cement type C)

Bitumen %(by total weight)	Bluck Unit Weight (g/cm^3)	(VFB) (%)	(VMA) (%)	Va (%)	Stability (Kg)	Flow (mm)
4	2.361	54.71	16.38	7.25	1338	2.98
4.5	2.391	66.19	15.72	5.39	1467	3.51
5	2.401	73.85	15.85	4.25	1510	3.93
5.5	2.395	76.53	16.53	3.8	1420	4.33
6	2.385	79.94	17.3	3.47	1307	4.65

Table 8. Properties of the asphalt mixture using the an asphalt cement type (C)

Asphalt Content (%)	5.07
Stability (Kg)	1505
Flow (mm)	3.95
Air Voids (%)	4.22
VMB **(%)**	**74.00**
VMA (%)	**15.90**
Bluck Unit Weight (g/cm^3)	**2.401**

The third asphalt mixture is using the asphalt cement type (C) which is modified with 2% polyethylene and 2% sulfur. Table (7) shows a summary of Marshal Test results and Table (8) shows the properties of the asphalt mixture using the asphalt cement type (C).

Figure 2. Creating asphalt mixtures according to the Marshall method

4.2. Effect of Adding (Polyethylene and Sulfur) on the Indirect Tensile Strength of Asphalt Mixture

Thirty samples of asphalt mixture were prepared according to Marshall's method, ten samples of asphalt mixture without additives /AC/, ten samples of asphalt mixture modified with polymer /PE/ at 2%, and ten samples of asphalt mixture modified with mixture of /polymer- sulfur/ at percentage /2%PE+2%S/ by weight of the asphalt cement, and an Indirect Tensile Strength (ITS) test was conducted on it [13-14-15], The ITS test was performed according to (ASTM D6931). To evaluate the ITS, the cylindrical specimen must be placed in the compression testing machine between the loading strips and be loaded diametrically along the direction of the cylinder axis with a constant speed of displacement until it breaks. The indirect tensile strength is the maximum tensile stress calculated from the peak load applied at break and the dimensions of the specimen according the following eqn (1):

$$ITS = \frac{2P}{\pi DH} \qquad (1)$$

where ITS is the indirect tensile strength, expressed in (N/mm^2); P is the peak load, expressed in newtons (N); D is the diameter of the specimen, expressed in millimeters (mm) (101.6 mm); and H is the height of the specimen, expressed in millimeters (mm).The tables (9) to (11) shows the results of the test:

Table 9. Results of ITS test of asphalt mixture without additives /AC/

Sample No.	Type of asphalt mixture	P (N)	H (mm)	ITS N/mm^2	Average of ITS N/mm^2
1	AC	11300	64.00	1.107	1.185
2	AC	13510	67.10	1.262	
3	AC	13610	63.40	1.346	
4	AC	11550	63.50	1.140	
5	AC	12190	63.30	1.207	
6	AC	10250	63.10	1.018	
7	AC	12340	66.90	1.156	
8	AC	12810	64.10	1.253	
9	AC	11650	63.50	1.150	
10	AC	12180	63.20	1.208	

Table 10. Results of ITS test of asphalt mixture modified with polyethylene/AC-PE/

Sample No.	Type of asphalt mixture	P (N)	H (mm)	ITS N/mm^2	Average of ITS N/mm^2
1	AC-PE	16210	62.10	1.636	1.647
2	AC-PE	17250	64.20	1.684	
3	AC-PE	18340	64.60	1.780	
4	AC-PE	15190	62.20	1.531	
5	AC-PE	16740	62.90	1.668	
6	AC-PE	17210	65.10	1.657	
7	AC-PE	16110	63.70	1.585	
8	AC-PE	16070	64.10	1.572	
9	AC-PE	17470	65.50	1.672	
10	AC-PE	16850	62.90	1.679	

Table 11. Results of ITS test of asphalt mixture which modified with Mixture of/ polyethylene - sulfur/ (AC-PE-S)

Sample No.	Type of asphalt mixture	P (N)	H (mm)	ITS N/mm^2	Average of ITS N/mm^2
1	AC-PE-S	17410	63.80	1.711	1.703
2	AC-PE-S	16540	63.10	1.643	
3	AC-PE-S	17190	63.14	1.707	
4	AC-PE-S	17890	62.40	1.797	
5	AC-PE-S	16740	63.19	1.661	
6	AC-PE-S	15930	62.50	1.598	
7	AC-PE-S	17940	65.20	1.725	
8	AC-PE-S	18820	65.70	1.796	
9	AC-PE-S	16840	62.80	1.681	
10	AC-PE-S	17260	63.40	1.707	

Table 12. Results of ITS test of asphalt mixture without additives /AC/ after AASHTO T283 test

Sample No.	Type of asphalt mixture	P (N)	H (mm)	ITS N/mm^2	Average of ITS N/mm^2
1	AC	7810	63.40	0.772	0.784
2	AC	8420	64.80	0.815	
3	AC	7540	63.60	0.743	
4	AC	7590	64.10	0.742	
5	AC	8680	64.70	0.841	
6	AC	7350	63.80	0.722	
7	AC	8840	62.40	0.888	
8	AC	7570	63.20	0.751	
9	AC	7980	64.10	0.780	
10	AC	8120	64.80	0.786	

Table 13. Results of ITS test of asphalt mixture which modified with polyethylene /AC-PE/after AASHTO T283 test

Sample No.	Type of asphalt mixture	P (N)	H (mm)	ITS N/mm^2	Average of ITS N/mm^2
1	AC-PE	15180	64.70	1.471	1.418
2	AC-PE	13960	62.60	1.398	
3	AC-PE	14880	64.10	1.455	
4	AC-PE	13240	63.20	1.313	
5	AC-PE	14780	62.80	1.475	
6	AC-PE	14530	63.40	1.437	
7	AC-PE	13820	63.10	1.373	
8	AC-PE	15120	64.20	1.476	
9	AC-PE	14260	63.80	1.401	
10	AC-PE	13740	62.50	1.378	

Table 14. Results of ITS test of asphalt mixture which modified with polymer- sulfur/ (AC-PE-S) after AASHTO T283 test

Sample No.	Type of asphalt mixture	P(N)	H (mm)	ITS N/mm^2	Average of ITS N/mm^2
1	AC-PE-S	18160	65.10	1.749	1.628
2	AC-PE-S	16510	64.40	1.607	
3	AC-PE-S	16260	63.70	1.600	
4	AC-PE-S	15050	62.90	1.500	
5	AC-PE-S	17310	63.60	1.706	
6	AC-PE-S	16570	64.10	1.621	
7	AC-PE-S	18140	64.40	1.766	
8	AC-PE-S	15780	62.60	1.580	
9	AC-PE-S	16230	63.80	1.595	
10	AC-PE-S	15720	63.40	1.554	

4.3. Conditioning Test

The AASHTO conditioning test, in particular R30 [16], aims to produce a sample of tar samples in special laboratory conditions, including thermal conditions and immersion in a certain number of cycles and degrees, to mimic the weather, investment conditions and the degree of impact of aging, moisture, and erosion of the mixture of bitumen will be exposed during operation and investment, which helps determine the characteristics of the pre-test and post-test samples and determine the degree of change in determining changes in tar samples during planting. The conditioning test is divided into a set of tests, including (AASHTO T 283, ASTM 4867, AASHTO T 324….)

4.4. Effect of adding on the Indirect Tensile Strength of Asphalt Mixture after Conditioning Test (AASHTO T 283)

A set of samples was prepared and subjected to one of the Conditioning test, which is AASHTO T 283, through which asphalt samples are exposed to a temperature of (-16°C) for 16 hours, then exposed to a temperature of 60°C for 24 hours, and finally the samples are placed at a temperature of 25°C for two hours, after that an indirect tensile Strength test is performed.

Thirty samples were prepared according to the Marshall Apparatus from asphalt mixtures. It was subjected to the AASHTO T283 test and the ITS test values were determined for the samples and the results were recorded in Table (12) to Table (14).

And figure (3) shows the values of Indirect Tensile Strength for asphalt samples before and after AASHTO T283 test and Figure (4) shows some asphalt samples that were formed to study changes in the properties of asphalt mixtures.

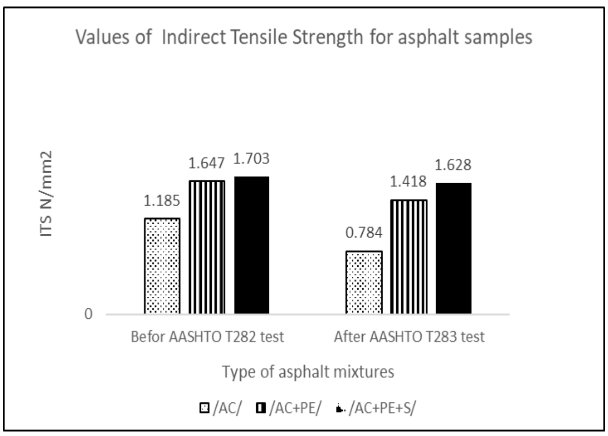

Figure 3. Values of Indirect Tensile Strength for asphalt

Figure 4. Some asphalt samples that were formed to study changes in the properties of asphalt mixtures

4.5. Determine of the Indirect Tensile Strength Ratio for Asphalt Samples (ITSR)

The Indirect Tensile Strength Ratio expresses the percentage change in Indirect Tensile Strength of asphalt samples after subjecting the samples to Conditioning test (AASHTO T 283), and it is symbolized by (ITSR),and its value is determined from the following [17-18]:

$$ITSR = \frac{\mathrm{ITS}_{conditioning}}{\mathrm{ITS}_{unconditioning}} x100 \qquad (2)$$

where $ITSR$ is the indirect tensile strength ratio (%); ITSun conditioning is the average indirect tensile strength before conditioning test (N/mm^2); and ITSconditioning is the average indirect tensile strength after conditioning test (N/mm^2). And Table (15) shows the ITSR values for asphalt samples.

Table 15. Values of ITSR for asphalt samples.

Type of asphalt mixture	Value of average ITS test		ITSR %
	Befor conditioning test	After conditioning test	
AC	1.185	0.784	66
AC-PE	1.647	1.418	86
AC-PE-S	1.703	1.628	96

And Figure (5) Shows Values of Indirect Tensile Strength Ratio (ITSR) for asphalt samples.

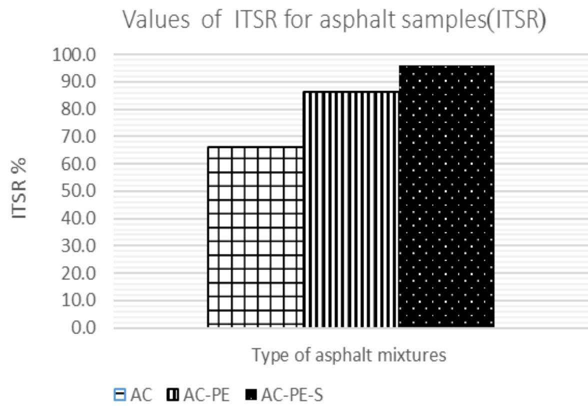

Figure 5. Values of Indirect Tensile Strength Ratio (ITSR)

And Figure (6) Preparation of asphalt samples for determination ITS.

Figure 6. Preparation of asphalt samples for determination ITS

5. Conclusions

From the results, we find the role of the use of a Mixture of /Polymer-Sulfur/ in modifying the asphalt cement and forming asphalt mixtures by maintaining a high proportion of asphalt sample resistance to Indirect Tensile Strength, especially after conditioning test (AASHTO T 283). We recommend future studies using sulfur with other types of polymers, such as Polypropylene (PP) and Ethylene-vinyl acetate (EVA), and studying the effect on the properties of asphalt mixtures. The Indirect Tensile Strength value of asphalt samples formed from asphalt mixtures modified with polyethylene has increased by 38 percent compared with samples formed from asphalt mixtures without modification. The Indirect Tensile Strength value of asphalt samples formed from asphalt mixtures modified with the mix of / polyethylene - sulfur/ has increased by 42 percent compared with samples formed from asphalt mixtures without modification. The decrease in Indirect Tensile Strength of asphalt samples formed from asphalt mixtures without modification was 34% after conditioning test (AASHTO T 283). The decrease in Indirect Tensile Strength of asphalt samples formed from asphalt mixtures modified with polyethylene was 14 percent after conditioning test (AASHTO T 283). The asphalt samples formed from asphalt mixtures modified with mixture of / polyethylene - sulfur/ has maintained 96 percent of their resistance to Indirect Tensile Strength after conditioning test (AASHTO T 283). This indicates a significant improvement in the resistance of asphalt samples formed from asphalt mixtures modified with mixture of / polyethylene - sulfur/ to climatic factors.

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