Studying the effect of using a mixture (synthetic polymer: natural polymer) on the rheological properties of asphalt

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Abstract: -
The rheological modification of asphalt is currently the most important concern of workers in this field, whether a person is a chemist or a civil engineering worker. Several methods are used in rheological modulation processes. The rheological modification with polymeric materials is still the one that has taken the largest space in this field. In this study, we dealt with the rheological modulation processes with polymeric mixtures. It used a mixture of materials that have proven effective in the field of rheological modulation and others that did not give the desired results. In this study, a mixture of a synthetic polymer, which is ethylpene vinyl acetate, and a natural polymer, which is wood, were used. Use this mixture with different weights of both polymers and for a total of 1 gram. The asphalt was treated with the above mixture with 1% by weight of sulfur at 180 °C for a period of one hour. The rheological properties of the modified samples were measured, which included measuring the ductility, penetration and softening point as well as calculating the penetration index coefficient and the percentage of the separated asphaltens.

After that, the best sample obtained from the above treatment was taken and several interactions were conducted on it in order to determine each of: The optimum percentage of sulfur, The optimum temperature for modification process, The optimal time to perform the rheological modification processes, The effect of the addition process sequences on the properties of the axis asphalt was also studied. After that, the best sample obtained from this study was taken and was measured (Marshal, chemical immersion and as well as studying the effect of aging on this sample). The study gives good results in the field of asphalt resistance to the deformation processes that were carried out on it.

Key word: - Polymeric Additive, Paving Asphalt, Chemical Modification.

Introduction: -
Asphalt is a liquid or semi-solid material and exists in different colors, including black or dark brown, and has a high viscosity in normal temperatures(¹). It is the heavy hydrocarbon component that is produced from direct distillation of crude oil(²).

Asphalt has a complex chemical composition consisting of hydrocarbon compounds with high molecular weights (300-2000) g / mol and a high density ranging from (1.0-1.1) g / cm³(³,⁴,⁵).

Asphalt has multiple names according to its geographical location, where the term bitumen material is used in Europe, while in North America the word asphalt is used(⁶).
Asphalt is characterized by its chemical inertness and compatible with its physical properties, which made it a material of great use in industry and construction since ancient times, as the nature of the use of asphalt is determined by the nature of its physical characteristics$^{5,7}$.

As a result of the availability of asphalt, its physical nature, the diversity of its sources and its wide uses, many studies have been conducted on it to improve its rheological properties such as penetration, ductility and softening point by additives or chemical modification using various methods such as:

(Cunha) and others$^{8}$ have studied the rheological characteristics of modified asphalt with natural fibers taken from rain forests in the Amazon, where they noticed that these additives significantly improve the physical properties and fluidity, as they used TG and DSR tests.

(YU.G) and others$^{9}$ were able to study the effect of adding thermoplastic polyurethane (TPU), as they noticed that this polymer improves thermal properties and stabilizes storage at high temperatures, and upon natural analysis of infrared rays, the results showed an improvement in resistance to aging.

(Srikanth ) and others$^{10}$ used warm asphalt WMA instead of hot asphalt mixture HMA to reduce the emission of hazardous gases fumes, as different materials such as emulsions, waxes, , etc. were added. Researchers were able to achieve all the characteristics similar to hot asphalt and considered this achievement a new trend and then it developed in Europe, After this Success in Europe, The United States accepted the use of the warm asphalt mix technology.

(Eskandarsefat) and his group$^{11}$ have studied the effect of adding cellulose fibers with the use of elastic polymer (rubber) and without the use of polymers to asphalt. As this study showed that adding cellulose fibers increased the viscosity and softening point, but when the rubber, the viscosity and softening point decreased and thus it can be concluded from this study.

Among them is what(Ahmed,Hamdoon)$^{12}$ has done to study the effect of adding lignin on the rheological properties of asphalt, as this study gave asphalt with rheological properties different from the original one. Sample have been obtained that can be used in the field of paving.

Researcher (Hadadi) and his group$^{13}$ improved the rheological and thermal properties of the asphalt by adding sawdust to the asphalt. We were used polyethylene with malik to increase the bond between the asphalt and sawdust.

(Chaopeng) and his group$^{14}$ studied the effect of waste motor oil and waste polyethylene on UV resistance to asphalt, as the researcher showed that WEO waste motor oil and VPE waste polyethylene can replace a portion of asphalt and improve the resistance to ultraviolet rays.

(Ahmed,Hamdoon)$^{15}$ studied the rheological properties of ethylene-vinyl-acetate (EVA) commercial asphalt and the process of aerobic oxidation, using different proportions of anhydrous aluminum chloride as a catalyst, where they were able to produce asphalt with properties enabling it to be used in the field of paving.

(Mashaan) and others$^{16}$ have studied the engineering properties of modified asphalt binders with plastic waste, as they use polyethylene terephthalate (PET).

The focus of our study is to find a mixture of a synthetic and a natural polymer for the purpose of modulating the rheological properties of the asphalt. The reason for choosing wood as a natural
axis material along with (EVA) is the presence of a previous study in which wood was used as a modified material for asphalt materials\(^{17}\). The use of wood in these did not give the desired results within the field of obtaining good rheological properties.

**Experimental**

The experimental part included the following:

A known weight of asphalt was taken and a mixture (EVA, wood) was added to it in the presence of 1% by weight of sulfur and by a thermal heating process for one hour at 180 °C. The rheological properties of the models obtained from one step were measured, penetration\(^{18}\), ductility\(^{19}\), and softening point\(^{20}\) as well as the calculation of the combustion index\(^{21}\) and the ratio of asphaltens\(^{22}\). The optimum conditions for the reaction were determined in terms of temperature, percentage of added sulfur, reaction time and the best ratio of the mixture, in addition to studying the effect of the addition sequence on the rheological properties of asphalt, as well as measuring the marshal test\(^{23}\), chemical immersion\(^{24}\) and aging\(^{25}\) were measured of the sample.

**Results and Discussion**

The process of obtaining asphaltic materials in terms of the possibility of using them for various purposes is not an easy process. The use of asphalt for different purposes varies from one place to another, depending on the environment and the climate of the country or place. The focus of our study was on trying to find a mixture of a natural and a synthetic polymer. The reason for choosing both polymer above is due to the fact that many studies have proven the success of the synthetic polymer (EVA) in the rheological modification of asphalt offset by the failure of wood in that. Table (1) shows the results obtained using a mixture of (synthetic polymer : natural polymer)i.e.(EVA:WOOD).

**Table (1): Rheological properties of treated asphalt with different mixtures of (wood: EVA) with 1% by weight of sulfur at 180 °C for one hour.**

| Samples | Additive (gm) | Ductility (cm.25°c) | Softening point(°c) | Penetration (100gm.5sec.25°c) | Penetration index | Asphaltens % |
|---------|---------------|---------------------|--------------------|-------------------------------|-------------------|--------------|
| AS\(_0\) | 0 0 | 150< | 50 | 46.7 | -1.349 | 16.8 |
| AS\(_1\) | 0.1 0.9 | 50 | 63 | 39.34 | +1.037 | 32.2 |
| AS\(_2\) | 0.2 0.8 | 53 | 61.5 | 39.81 | +0.814 | 31.6 |
| AS\(_3\) | 0.3 0.7 | 55 | 61 | 40.77 | +0.778 | 31 |
| AS\(_4\) | 0.4 0.6 | 82 | 59 | 42.42 | +0.464 | 30.2 |
| AS\(_5\) | 0.5 0.5 | 101 | 57 | 42.61 | +0.413 | 29.8 |
| AS\(_6\) | 0.6 0.4 | 112 | 55 | 42.60 | -0.393 | 26 |
| AS\(_7\) | 0.7 0.3 | 107 | 58 | 42.65 | +0.235 | 26.5 |
| AS\(_8\) | 0.8 0.2 | 106 | 53 | 42.71 | -0.844 | 27 |
| AS\(_9\) | 0.9 0.1 | 150< | 56 | 42.99 | -0.138 | 24.2 |

**AS\(_0\) : Original Asphalt**

It is evident from the table that increasing the percentage of wood in the mixture had a negative effect on the rheological properties of the asphalt, especially the ductility values. It was noticed that the proportion of equal mixture of both additives (AS\(_5\)) then began to improve the rheological properties of asphalt and became within the values in the standard tables of paving asphalt.
The ductility values continued to rise with the increase in the amount of (EVA) in the mixture until it reached the highest value of the sample AS$_9$ (0.9 g EVA +0.1g wood). As for the permeability values for most of the sample, they were within the exact range of the paving asphalt, as well as the ductility values.

As for the values of asphalt, we note that it is directly proportional to the weight of the wood in the mixture.

After obtaining the best mixture that can be used in the rheological modulation, the two samples (AS$_5$), which represent the beginning of the shift towards improvement of the rheological properties, and the (AS$_9$) sample, which represents the best obtained rheological properties, were selected for the purpose of determining the optimum temperature used in the reaction and the two tables (2,3) explain the results obtained.

### Table (2): Rheological properties of the sample (AS$_9$) at different temperatures

| Samples | Temp (°C) | Ductility (cm.25°c) | Softening point(°c) | Penetration (100gm. 5sec.25°c) | Penetration index | Asphaltens % |
|---------|-----------|---------------------|---------------------|---------------------------------|------------------|---------------|
| AS$_0$  | 0         | 150°<               | 50                  | 46.7                            | -1.349           | 16.8          |
| AS$_10$ | 120       | 75                  | 59                  | 41.41                           | +0.38            | 30            |
| AS$_11$ | 150       | 90                  | 58                  | 42.50                           | +0.238           | 28.9          |
| AS$_12$ | 180       | 101                 | 57                  | 42.61                           | +0.413           | 29.8          |
| AS$_13$ | 200       | 60                  | 60                  | 40.63                           | +0.04            | 32.3          |

**AS$_0$: Original Asphalt**

### Table (3): Rheological properties of the sample (AS$_9$) at different temperatures

| Samples | Temp (°C) | Ductility (cm.25°c) | Softening point(°c) | Penetration (100gm.5sec.25°c) | Penetration index | Asphaltens % |
|---------|-----------|---------------------|---------------------|--------------------------------|------------------|---------------|
| AS$_0$  | 0         | 150°<               | 50                  | 46.7                            | -1.349           | 16.8          |
| AS$_14$ | 120       | 136                 | 56.2                | 42.73                           | -0.163           | 26.2          |
| AS$_15$ | 150       | 142                 | 55                  | 42.67                           | -0.384           | 25.1          |
| AS$_16$ | 180       | 150°<               | 56                  | 42.99                           | +0.138           | 24.2          |
| AS$_17$ | 200       | 63                  | 61                  | 41.78                           | +0.814           | 30.5          |

**AS$_0$: Original Asphalt**

It is evident from the two tables above that the temperature that was chosen as the temperature for the reaction (180 °C) was the best temperature that could be used for this purpose.

The temperature (180 °C) represents the optimum traction for the transformation of the added sulfur into free radicals, and thus its ease of attachment to the reaction mixture, and thus its positive effect on the modification process (26).

After determining the optimum temperature, the best percentage by weight of sulfur that can be used in the rheological modulation was determined. The two tables (4,5) show the results obtained.

### Table (4): Rheological properties for choosing the best sulfur percentage by weight for the sample AS$_9$

| Samples | Sulfur % | Ductility (cm.25°c) | Softening point(°c) | Penetration (100gm.5sec.25°c) | Penetration index | Asphaltens % |
|---------|----------|---------------------|---------------------|--------------------------------|------------------|---------------|
| AS$_0$  | 0        | 150°<               | 50                  | 46.7                            | -1.349           | 16.8          |
| AS$_18$ | 0.25     | 60                  | 60.5                | 41.40                           | +0.678           | 32            |
| AS$_19$ | 0.5      | 55                  | 61                  | 40.48                           | +0.777           | 32.8          |
It is evident from both tables that choosing the weight percentage (1%) of sulfur represents the best percentage that can be used in the rheological modification process and obtain the desired results from the modification process.

Sulfur plays at the present time an important role in the rheological modification process due to the improvement it performs in the rheological properties, and the literature is full of research in which sulfur is used in the modification process. Important correlations from the interaction mix leading to improved rheological properties and give the sample flexibility.\(^{(27)}\)

After that, the optimal time for performing the rheological modification process was determined for both the selected samples and tables (6, 7) illustrate the results obtained.

**Table (5): Rheological properties for choosing the best sulfur percentage by weight for the sample AS\(_0\)**

| Samples | Sulfur % | Ductility (cm.25\(^\circ\)C) | Softening point(\(^\circ\)C) | Penetration (100gm.5sec.25\(^\circ\)C) | Penetration index | Asphltens % |
|---------|----------|-------------------------------|-----------------------------|----------------------------------|------------------|-----------|
| AS\(_0\) | 0        | 150<                          | 50                          | 46.7                             | -1.349           | 16.8      |
| AS\(_22\) | 0.25    | 60                            | 64                          | 40.84                            | +1.348           | 34        |
| AS\(_23\) | 0.5     | 85                            | 61                          | 42.25                            | +1.075           | 31        |
| AS\(_24\) | 1        | 150<                          | 56                          | 42.99                            | -0.138           | 24.2      |
| AS\(_25\) | 2        | 55                            | 63                          | 39.87                            | +1.192           | 35.2      |

**Table (6): Rheological properties to choose the best time for sample AS\(_5\)**

| Samples | Time (min) | Ductility (cm.25\(^\circ\)C) | Softening point(\(^\circ\)C) | Penetration (100gm.5sec.25\(^\circ\)C) | Penetration index | Asphltens % |
|---------|------------|-------------------------------|-----------------------------|----------------------------------|------------------|-----------|
| AS\(_0\) | 0          | 150<                          | 50                          | 46.7                             | -1.349           | 16.8      |
| AS\(_26\) | 30       | 65                            | 63                          | 40.60                            | +1.121           | 31        |
| AS\(_27\) | 60       | 101                           | 57                          | 42.61                            | +0.413           | 29.8      |
| AS\(_28\) | 90       | 50                            | 64                          | 39.84                            | +1.269           | 33        |
| AS\(_29\) | 120      | 40                            | 67                          | 37.65                            | +1.680           | 36        |

**Table (7): Rheological properties to choose the best time for sample AS\(_9\)**

| Samples | Time (min) | Ductility (cm.25\(^\circ\)C) | Softening point(\(^\circ\)C) | Penetration (100gm.5sec.25\(^\circ\)C) | Penetration index | Asphltens % |
|---------|------------|-------------------------------|-----------------------------|----------------------------------|------------------|-----------|
| AS\(_0\) | 0          | 150<                          | 50                          | 46.7                             | -1.349           | 16.8      |
| AS\(_30\) | 30       | 150<                          | 56                          | 42.94                            | -0.138           | 24.2      |
| AS\(_31\) | 60       | 80                            | 60                          | 41.44                            | +0.641           | 26        |
| AS\(_32\) | 90       | 40                            | 66                          | 38.32                            | +1.538           | 32        |

AS\(_0\) : Original Asphalt
It is evident from the two tables that the time chosen at the beginning of the reaction was the optimal time leading to obtaining asphalt with good rheological properties. The reaction time is one hour, a moderate time in that it led to obtaining a desired rheological modification. The effect of the weight of the added polymeric mixture was also studied and from both samples (0.5: 0.5) (wood: EVA) and (0.1: 0.9) (wood: EVA) and tables (8,9) illustrate.

**Table (8): Rheological properties of asphalt treated with different weights of mixture (0.5: 0.5) (Wood: EVA) with 1% by weight of sulfur at 180 °C and at (1) hour**

| Samples | Weighted percentage | Ductility (cm.25°C) | Softening point(°C) | Penetration (100gm.5sec.25°C) | Penetration index | Asphltens % |
|---------|---------------------|---------------------|---------------------|-----------------------------|------------------|-------------|
| AS₀     | 0                   | 150<                | 50                  | 46.7                        | -1.349           | 16.8        |
| AS₄₅    | 0.5                 | 77                  | 58                  | 41.21                       | +0.172           | 30          |
| AS₅₅    | 0.75                | 93                  | 56                  | 42.27                       | -0.223           | 29.5        |
| AS₆₆    | 1                   | 101                 | 57                  | 42.61                       | +0.413           | 29.8        |
| AS₇₇    | 2                   | 45                  | 62                  | 39.33                       | +0.890           | 32          |
| AS₈₈    | 3                   | 37                  | 64                  | 38.61                       | +1.307           | 38          |

AS₀ : Original Asphalt

**Table (9): Rheological properties of asphalt treated with different weights of mixture (0.1: 0.9) (Wood: EVA) with 1% by weight of sulfur at 180 °C and at (1) hour**

| Samples | Weighted percentage | Ductility (cm.25°C) | Softening point(°C) | Penetration (100gm.5sec.25°C) | Penetration index | Asphltens % |
|---------|---------------------|---------------------|---------------------|-----------------------------|------------------|-------------|
| AS₀     | 0                   | 150<                | 50                  | 46.7                        | -1.349           | 16.8        |
| AS₄₀    | 0.5                 | 100                 | 60                  | 42.68                       | +0.842           | 26          |
| AS₄₀    | 0.75                | 110                 | 58                  | 42.73                       | -0.840           | 25.5        |
| AS₄₁    | 1                   | 150<                | 56                  | 42.99                       | -0.138           | 24.2        |
| AS₄₂    | 2                   | 101                 | 59                  | 42.64                       | +0.445           | 25.8        |
| AS₄₃    | 3                   | 86                  | 62                  | 41.88                       | +0.725           | 29.9        |

AS₀ : Original Asphalt

It is evident from both tables that the elongation values increase until the weight of the mixture is reached 1%, then after that the values begin to decrease with the increase in the weight of the polymeric mixture in the asphalt medium. We also note that the values of permeability and ductility in general were within the required values for the standard samples. The two tables show that the percentage of asphalt increases exponentially with the increase in the weight of the polymeric mixture in the asphalt medium.

For the purpose of covering the research from all aspects, the effect of the addition sequence on the rheological properties of the asphalt was studied. Tables (10.11) illustrate the results obtained.
Table (10): shows the sequence of addition of a mixture (0.5: 0.5) (wood: EVA) on the rheological properties of asphalt in the presence of 1% by weight of sulfur for one hour at 180 ° C.

| Samples | Added sequence | Ductility (cm.25°C) | Softening point(°C) | Penetration (100gm.5sec.25°C) | Penetration index | Asphltens % |
|---------|----------------|----------------------|---------------------|-------------------------------|------------------|-------------|
| AS₀     | 0              | 150<                 | 50                  | 46.7                          | -1.349           | 16.8        |
| AS₄₄    | All additions at first half | 95 | 57.5 | 42.43 | -0.965 | 28.5 |
| AS₄₅    | Wood at first half hour and EVA at second half | 77 | 59 | 41.37 | +0.453 | 30.1 |
| AS₄₆    | EVA at first half hour and wood at second half | 101 | 57 | 42.61 | +0.413 | 29.8 |

AS₀ : Original Asphalt

Table (11): shows the sequence of addition of a mixture (0.1: 0.9) (wood: EVA) on the rheological properties of asphalt in the presence of 1% by weight of sulfur for one hour at 180 °C.

| Samples | Added sequence | Ductility (cm.25°C) | Softening point(°C) | Penetration (100gm.5sec.25°C) | Penetration index | Asphltens % |
|---------|----------------|----------------------|---------------------|-------------------------------|------------------|-------------|
| AS₀     | 0              | 150<                 | 50                  | 46.7                          | -1.349           | 16.8        |
| AS₄₇    | All additions at first half | 128 | 54 | 42.64 | -0.595 | 25.2 |
| AS₄₈    | Wood at first half hour and EVA at second half | 126 | 53 | 42.78 | -0.694 | 25.4 |
| AS₄₉    | EVA at first half hour and wood at second half | 150< | 56 | 42.99 | -0.138 | 24.2 |

AS₀ : Original Asphalt
It is evident from both tables that the addition of EVA in the first half hour and wood in the last half hour gives the best rheological properties of the modified asphalt.

As for the values of (PI), asphalt models have a penetration index value between (-2, + 2), which is fully achieved in all models on which the rheological modification process was performed in addition to the original model.

For the purpose of determining the suitability of the modified models for tiling work, the model (AS₅) was chosen and a Marshal examination and chemical immersion test were measured, as well as studying the effect of aging on this samples. Tables (12,13,14) illustrate the results obtained.

**Table (12): Marshall test**

| Samples | Asphalt% | Stability(KN) | Crawling (mm) | MQ   |
|---------|----------|---------------|---------------|------|
| AS₀     | 4.75     | 11.2          | 5.1           | 2.21 |
| AS₅     | 4.75     | 16.01         | 3.04          | 5.26 |
| AS*     | -------- | 7minimum      | 2-4           | 3.5 minimum |

**AS₀ : Original Asphalt**

**AS*: Iraqi Roads and Bridges Authority specifications**

It is noted from the table that the pivot model was better than the original model in terms of stability and creep and the (MQ) value which represents the stiffness of the marshal and is calculated by dividing the stability by creep (28) and thus the pivot asphalt becomes more resistant to deformation, so it can be used in the field of paving.

**Table (13): The chemical immersion**

| Samples | Na₂CO₃(g) | R&W NO. the origin Asphalt | R&W NO. for the modified Asphalt |
|---------|-----------|---------------------------|---------------------------------|
| --------| 0.025     | 1                         | ------                          |
| --------| 0.041     | 2                         | ------                          |
| AS₀     | 0.082     | 3                         | 3                               |
| --------| 0.164     | 4                         | ------                          |
| --------| 0.328     | 5                         | ------                          |
| AS₅     | 0.656     | 6                         | ------                          |
| --------| 1.312     | 7                         | ------                          |
| --------| 2.624     | 8                         | ------                          |

**AS₀ : Original Asphalt**

chemical immersion is considered to be the adhesion of asphalt to aggregates (29), as we note from the table that the axial model needed a greater amount of sodium carbonate than the original sample in order for the asphalt to separate from the aggregates, which indicates that the axis model is more resistant to acid rain and high temperatures. The numbers indicate (1 -9) To Riedel and Weber number (R&W) (24), where the number 1 is the lowest amount of sodium carbonate (0.025 g), while the number 8 indicates the highest amount of sodium carbonate (2.624 g).
Table (14): Rheological properties of the original and core asphalt before and after subjecting to a furnace test for Thin Asphalt Films (TFOT)

| Samples | Rheological properties | Before Aging | After Aging |
|---------|------------------------|--------------|-------------|
| AS₀     | Ductility (cm.25°C)    | 150<         | 150<        |
|         | Softening point (°C)   | 50           | 53          |
|         | Penetration (100gm.5sec.25°C) | 46.7    | 43.5       |
|         | Penetration Index (PI) | -1.349       | -0.793      |
|         | Weight loss%           | -----        | 0.05        |
| AS₃     | Ductility (cm.25°C)    | 101          | 96          |
|         | Softening point (°C)   | 57           | 59          |
|         | Penetration (100gm.5sec.25°C) | 42.61   | 41.55       |
|         | Penetration Index (PI) | +0.413       | +0.428      |
|         | Weight loss%           | -----        | 0.013       |

AS₀ : Original Asphalt

It is evident from Table (14) that the axial model was affected by the aging conditions of oxygen and the temperature were little compared to the original sample, which makes the axis sample characterized by greater resistance to stress and fewer cracks as well as a longer operational life. The previous studies indicated that the axis model is not affected by the conditions of time progression due to the added polymer composition, which improves mechanical properties in terms of increased durability, stress tolerance, reduces thermal breakage, and increases its resistance to grooving formation.<ref>(30)</ref>

After observing the results obtained through this study, we find that some models can be used for tiling, and there are other samples that can be used in the production of mastic, as it is considered a moisture-insulating material and is used in many uses, including for the purpose of roofing and flatness, etc. The tables (15, 16, 17) appear the properties of the standard asphalt used in the field of paving, mastic and flattening.

Table (15): Iraqi paving asphalt (S.C.B.R)<ref>(31)</ref>

| Rheological properties | Minimum | Maximum |
|------------------------|---------|---------|
| Softening point (°C)   | 54      | 60      |
| Penetration (100gm.5sec.25°C) | 40      | 50      |
| Ductility (cm.25°C)    | 100     | ----    |

Table (16) : Flattening asphalt properties<ref>(32)</ref>

| Rheological properties | Minimum | Maximum |
|------------------------|---------|---------|
### Softening point (°C)

| Softening point (°C) | Minimum | Maximum |
|----------------------|---------|---------|
| 57                   | 66      |         |

| Penetration (100gm,5sec,25°C) | Minimum | Maximum |
|-------------------------------|---------|---------|
| 18                            | 40      |         |

| Ductility(cm,25°C) | Minimum | Maximum |
|-------------------|---------|---------|
| 10                | ----    |         |

### Table (17) : American mastic properties (D491-41)

| Rheological properties | Minimum | Maximum |
|------------------------|---------|---------|
| Softening point (°C)   | 54      | 65      |
| Penetration (100gm,5sec,25°C) | 20      | 40      |
| Ductility(cm,25°C)     | 15      | ----    |

### Conclusions:

After completing this study, we can conclude:

1- The process of using the mixture improved the properties of the asphalt better than if the natural polymer was used alone.

2- Sulfur plays an important role in the field of rheological modification. Sulfur appeared to be widely used in rheological modulation.

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