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Scientific paper

Studying the Effect of Adding Polymeric Wastes on the Rheological Properties of Asphalt

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Abstract

This research aims to develop various types of asphalt materials with enhanced rheological properties compared to unmodified asphalt. Three types of polymeric materials (PS), (PFR), and (PP)-were used to modify Al-Doura asphalt, with the goal of evaluating their impact on the rheological characteristics of the resulting asphalt systems. These modified materials were then compared with each other with both local and international standards to assess their suitability for specific applications. Polymeric waste materials were used instead of virgin polymers to reduce environmental pollution and lower modification costs. The modification process was carried out using two approaches: physical treatment and chemical treatment. The chemical method involved a catalytic reaction using 2% ($FeCl_3$) and 1% (S). Results showed that chemical treatment had a more significant positive impact on the rheological properties of the asphalt systems compared to physical treatment. In both approaches, the addition of polymers led to an increase in de-asphaltene %, with the highest values recorded for AsPS (44.5%), AsPFR (40%), and AsPP (40%). Furthermore, chemically modifying asphalt with PS produced the most notable improvements among the tested polymers. Based on key performance indicators such as softening point, penetration, ductility, penetration index (PI), and asphaltene %, the modified asphalt samples demonstrated suitability for use in producing mastic, which are widely applied as waterproofing material.

Keywords: Rheological properties, Polymeric wastes, Asphalt, Softening point, Penetration Index

1. Introduction

Pure asphalt is a complex structure chemical substance that can be obtained through the distillation process of crude oil and has many properties such as: little cost and widely spread, It also have associative viscoelastic, water-resistant properties, which can be used in various applications such as paving and others.[1,2] The chemical composition of asphalt consists mainly of hydrocarbon compounds (paraffinic, naphthenic, and aromatic) in which carbon atoms reach 88% and hydrogen about 11%. It also includes cyclic or non-cyclic compounds containing oxygen, nitrogen, and sulfur, which are called heterogeneous atoms, and these last atoms are responsible. About the polarity of bitumen.[3] Mineral elements that are polar in nature affect the physical and chemical properties in addition to increasing the interaction between molecules of asphalt. Asphalt have a chemical composition consisting of four parts called SARA (i.e. Saturates, Aromatics, Resins, and Asphaltene). These components differ in their properties such as solubility and polarity. And its molecular weight, as maltin consists of non-polar parts that are characterized by a low molecular weight (Aromatics, Saturates), which represent the dispersed part in the asphalt. As for the polar part, which have a higher molecular weight compared to the first two parts, it is the resin. These three parts have the ability to dissolve in n-heptane.[4] Asphaltene represents the part responsible for gaining asphalt stability and hardness properties.[5] Asphalt is known by several names around the world, In North America, the word asphalt is called bitumen, while abroad it is called mixtures of bitumen with a mixture of mineral materials.[6]

The chemical inertness that characterizes asphalt, coupled with its physical properties, is what makes it eligible for wide uses in construction and industry, and the physical properties is what determines the nature of the use more than the chemical ones.[7] Given the physical properties of asphalt its wide availability in nature, its different sources, and its diverse applications many researchers have conducted studies in order to improve and develop many of its characteristics, for example: softening, ductility, and penetration using different types of additives, in various ways and methods, and by referring to the literature, many studies in this field, including:

Awaeed et al.[8] was able to use polymeric waste such as poly (ethylene-terephthalate) taken from plastic water bottles in modifying the rheological specifications of asphalt. Different percentages of polymer were used, the best of which was (8%) by weight of the asphalt mixture. The Marshall test was conducted and it was found that these the mixtures give maximum stability and rigidity voids are filled with asphalt when using this type of modification.

Firyal and Mohanad[9] were able to improve the flow properties of asphalt by adding several different polymers, namely Poly (Acrylonitrile-Co-Maleic anhydride), Poly (Indene-Co-Maleic anhydride), and Poly (Dipentine-Co-Maleic anhydride), and using sulfur. The results are high properties of these mixtures when compared with original asphalt. All improvements include increased asphalt viscosity, thermal sensitivity, increased asphalt cohesion, increased resistance to permanent deformation, improved impact resistance at low temperatures, and improved binder adhesion (viscosity is higher than that of the binder).

Soultan[10] studied the addition of different percentages (1, 2, 3, 4, 5, 6, 7, 8%) of polypropylene to bitumen (60–70). It was able to improve the properties of asphalt in terms of increasing its resistance and tolerance to high temperatures under various climatic conditions. The study was conducted Tests on modified bitumen samples included penetration, ductility, softening, penetration index calculation, and using the RTFOT rotary thin-layer oven. Bitumen compounds were also identified by performing a structural diagnosis of its constituent groups. Results showed that the ideal percentage of polypropylene added was (7%).

Lin et al.[11] were able to improve the attributes of asphalt by using quick waste bags (WEBs), which are difficult to recycle. The results showed increase in viscosity and decrease in penetration and softening. Results of FT-IR spectroscopy showed that the modification was physical without a chemical reaction occurring. Khiavi et al.[12] modified the rheological properties at high temperature to bitumen by adding Polymer 2 hydroxyethyl methacrylate (PHEMA) in different proportions (3%, 5% and 7% by weight), the samples were in the form of homogeneous mixtures. The obtained results show that enhancement in the resistance of permanent deformation of the asphalt at high temperatures, from through multiple measurements light scanning, penetration, softening and viscosity. Fournier et al. [13]studied the possibility of using construction and demolition waste (CDW) to obtain recycled coarse aggregate suitable for manufacturing hot mix asphalt (HMA), which makes this mixture economically beneficial due to reducing the acquisition of aggregate from natural sources as well as maintaining a healthy and clean environment.

Hamedi et al. [14]were also able to modify asphalt with the polymer styrene-butadiene rubber (SBR), and the results obtained showed that the polymer added to the mixture produced a good improvement through the change observed in the moisture susceptibility of the axle asphalt, and this was confirmed by repeated loading tests under dry and wet conditions. Salih et al.[15] using solid waste represented by PVA in addition to spent lubricating oils to enhance the characteristics of the bitumen. The process was carried out at a temperature of (180 °C) in the presence of anhydrous aluminum chloride at one time and sulfur at other times. The results showed an enhancement in the properties of bitumen compared to original bitumen. The measurements were repeated again after 12 months. AL-Shabani and Obaid[16] were able to study the use of reclaimed asphalt paving (RAP) with a ratio of (15, 30, and 45%) and the polymer polystyrene butadiene styrene (SBS) with a ratio of 4% on the properties of the asphalt mixture. Mineral fillers made of Ordinary Portland Cement (OPC) were also used. It was concluded that the use of polymer in the asphalt mixture led to a significant improvement in its performance.

The process of obtaining good asphalt samples that can be used in different fields is a difficult process, especially since their use varies according to the weather conditions of the area of use. This research is focused on using waste industrial polymers PS, PFR, and PP for the purpose of modifying the rheological characteristics of asphalt to determine its suitability for use in a specific field. Waste polymeric materials used instead of virgin materials for purpose of reducing environmental pollution, reducing costs of modification. The treatment was carried out using two methods: physical treatment based on mixing thermally broken down polymeric materials with asphalt and Chemical treatment.

2. Experimental

2. 1. Material and Characterization

This section includes an explain of the initialization mechanism for carrying out the asphalt improvement process by mentioning the materials used, and the devices used to measure the properties of asphalt. It also mentions the initialization of the polymeric materials that will be used in the asphalt treatment process.

2. 1. 1. Raw Materials

Asphalt: AL-Doura asphalt was used as a raw material for treatment and was characterized by the properties shown below:

Table 1. Rheological properties of asphalt material

Properties	Experimental Value
Softening point (°C)	50
Penetration, mm (100g, 5sec, 25 °C)	45.5
Ductility (cm, 25 °C)	+100
Asphaltene %	18

n-Hexane (Obtained from Fluka company), and Polystyrene, Phenol-Formaldehyde Resin, Polypropylene Obtained from waste materials from which they are manufactured, Anhydrous Ferric Chloride (Obtained from Fluka company), Sulfur.

2. 1. 2. Characterization Methods

Ring and Ball Apparatus: The measurement was conducted using ASTM (D36-95), which are internationally dependent.[17] Penetrometer: The measurement was based on ASTM (D5/D5 M-13), which are internationally approved.[18] Ductility: The measurement was conducted using ASTM(D113-07) internationally dependent.[19]

Treatment apparatus asphalt by polymers: The device consists of the following parts:

1. A large glass round (200 ml) three necked flask
2. A mechanical motor mounted on the middle opening of the flask.
3. Electrical mental equipped with a regulator to control the temperature.
4. A thermometer installed in one of the side openings.
5. An iron stand equipped with a holder to fixed the flask.

2. 2. Preparing the Polymeric Materials for the Reaction

The polymeric waste was subjected to a mechanical and thermal crushing process before being mixed and reacted with asphalt to obtain polymeric materials that have a little molecular weight. This process was carried out based on thermo-gravimetric analysis.

The polystyrene sheets were crushed into small pieces, then placed in a ceramic crucible and heated for a full hour at a temperature of (350 °C). Then it was cooled and ground until it became a fine powder. The phenol-formaldehyde resin was prepared in the same way as the previous thermal cracking method, with the difference in heating time, which reached half an hour and at a temperature of (400 °C). By thermal cracking method, which was done on polystyrene sheets, polypropylene was broken.

2. 3. Asphalt Treatment

Asphalt was treated with polymeric materials through two paths:

2. 3. 1. The First Path: Physical Treatment Procedure

This treatment included physical mixing of polymeric materials in weight ratios (3%, 6%, 9%, 12%, 15%) with specific weights of asphalt that were weighed accurately and using the processing device described as above. The mixing continues for an hour at a temperature (160)°C, and after completing the treatment, the necessary rheological measurements were carried out for the prepared asphalt samples.

2. 3. 2. The Second Path: Chemical Treatment Procedure

This treatment was carried out by conducting a chemical reaction between certain quantities of accurately weighed asphalt and weight percentages (3%, 6%, 9%, 12%, 15%) of the polymeric materials, using anhydrous ferric chloride as a catalyst, and in the presence of sulfur, as the asphalt is mixed well with the polymer. And also, using the treatment device referred as above, then 2% by weight of the catalyst and 1% sulfur were added, and the reaction continued for an hour at a temperature of (160 °C). After the end of the treatment, rheological measurements were carried out on the prepared asphalt samples.

2. 3. 3. De-Asphaltene

Placed a (2) g of asphalt material in a glass flask and weigh it accurately, add (80) ml of n-hexane at a ratio of (1:40) (g/ml), and shake the mixture using an electric shaker for two hours at zero degrees Celsius, and then leave the solution for Half an hour at laboratory temperature, then the precipitate was filtered and washed with sufficient amounts of n-hexane until the wash drops became colorless. The precipitate was then dried at laboratory temperature, then the percentage of the precipitate (asphaltenes) was weighed and calculated. Here we chose this ration of n-hexane according to research.[20]

3. Results and Discussion

Obtaining asphalt with excellent rheological specifications to suit the purposes for which it is used is extremely important. From this standpoint, this research focused on the use of three types of different polymers in terms of their compositional forms. The polymers (polystyrene, phenol-formaldehyde resin, polypropylene) were treated as described in the method of work, as the temperature used in these polymeric materials was inferred from the results of thermo-gravimetric analysis (TGA), which gives information about the temperatures at which the polymeric materials begin to break down. The amount of loss in polymer weight at those temperatures. (Table 2–4) and (Figure 1–3) show the curve of the results obtained.

The reason to use polymeric waste instead of commercial virgin materials is to reduce the cost of modification as well as the many environmental and economic benefits.

Table 2. TGA results for polystyrene

Temperature (°C)	Loss in Weight (gm)
0	*0.5006
100	0.4963
150	0.4932
200	0.4908
250	0.4271
300	0.3753
350	0.2506
400	0.1011
450	0.0664
500	0.0035

* Original weight

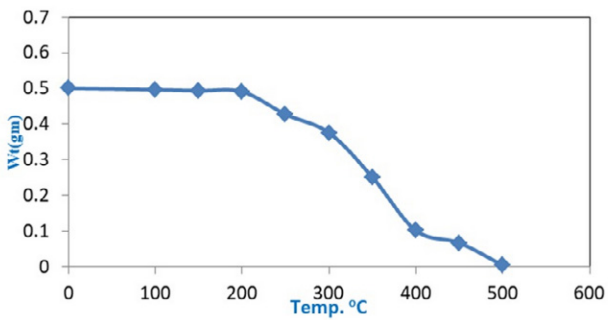

Figure 1. TGA curve for polystyrene

Table 3. TGA results for phenol-formaldehyde resin

Temperature (°C)	Loss in Weight (gm)
0	*1.0673
100	1.0412
150	0.9763
200	0.8345
250	0.5674
300	0.5210
350	0.4833
400	0.3075
450	0.2013
500	0.1909

* Original weight

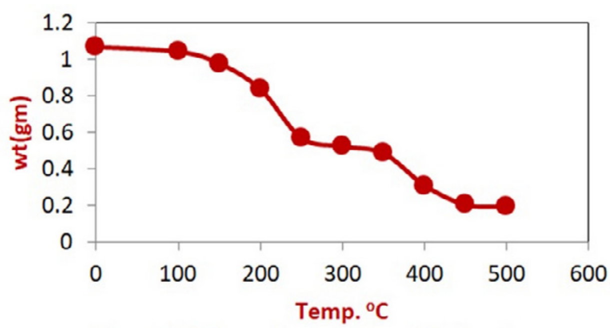

Figure 2. TGA curve for phenol-formaldehyde resin

Table 4. TGA results for polypropylene

Temperature (°C)	Loss in Weight (gm)
0	*1
100	0.9995
150	0.9975
200	0.9944
250	0.9424
300	0.8794
350	0.7478
400	0.5103
450	0.250
500	0.0001

* Original weight

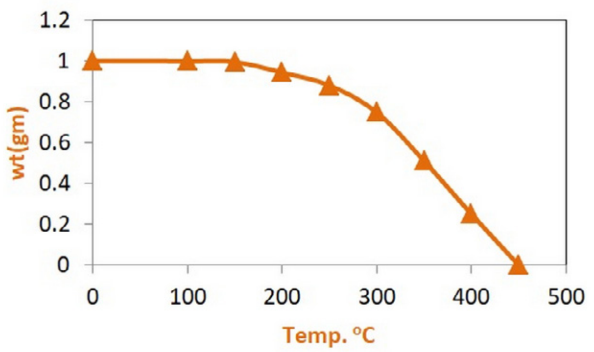

Figure 3. TGA curve for polypropylene

3. 1. Modifying Rheological Attributes of Asphalt by Physical Treatment

3.1.1. Asphalt Treatment with Polystyrene (AsPS)

Asphalt was treated with different percentages ranging between (3, 6, 9, 12, 15%) of polystyrene waste under the conditions shown below at a temperature of (160 °C) for one hour. The rheological properties of the treated asphalt were measured, including softening point, penetration, ductility, and the percentage of separated asphaltene, and the penetration index was calculated. These character-

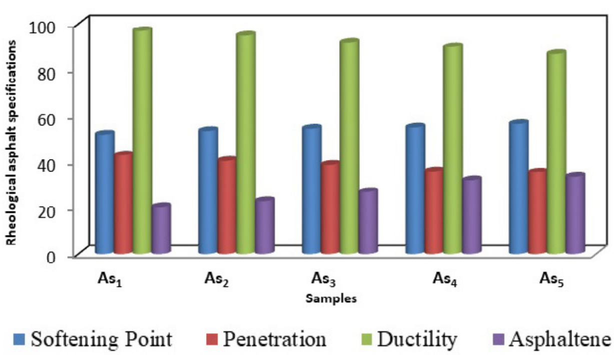

Figure 4. Rheological asphalt specifications mixed with various proportions of polystyrene

Table 5. Rheological asphalt specifications mixed with various proportions of polystyrene (PS) at temperature (160°C) for 1 hr.

Sample	%PS	Softening Point (°C)	Penetration, (100 g, 5 sec, 25 °C)	Ductility (cm, 25 °C)	Asphaltene %	Penetration Index (PI)
As_0	0	50	45.5	+100	18	–1.404
As_1	3	52	42.9	97	20.5	–1.052
As_2	6	53.5	40.5	95	23	–1.198
As_3	9	54.5	38.8	92	27	–1.415
As_4	12	55	36	90	32	–0.755
As_5	15	56.5	35.5	87	33.5	–0.567

As_0: Asphalt AL-Doura without treatment.

istics determine the suitability of the modified asphalt for use and the success of the treatment process. (Table 5) and (Figure 4) show the results of this treatment.

It is clear to us from Table 5 that the asphalt physically treated with polystyrene waste (AsPS) differed in its rheological properties from the original asphalt (As) by changing the degree of softening point, penetration and ductility. When the percentage of added polymer increased, it was observed that values of softening point increased, and values of penetration and ductility decreased. That is, the relationship between percentage of added polymer and softening point is a direct relationship, while the relationship is inverse with both penetration and ductility.

As for the Penetration Index (PI), it is a developed relationship linking the softening point of the sample and its penetration. The PI is considered a function of the extent of the sensitivity of the asphalt material and its effect on temperatures, and it can be calculated from the following mathematical relationship:[21]

$$\frac{20-\mathrm{PI}}{10+\mathrm{PI}} = 50\left[\frac{\log 800-\log pen.}{T_{RB}-T}\right] \quad (1)$$

T_{RB} = softening point
T = temperature at which the penetration was measured 25 °C

3. 1. 2. Asphalt Treatment with Phenol-Formaldehyde Resin (AsPFR)

Mixing asphalt with different weight ratio of phenol-formaldehyde resin waste for the purpose of studying this type of additives on the resulting asphalt systems, (Table 6) and (Figure 5) shows the treatment results.

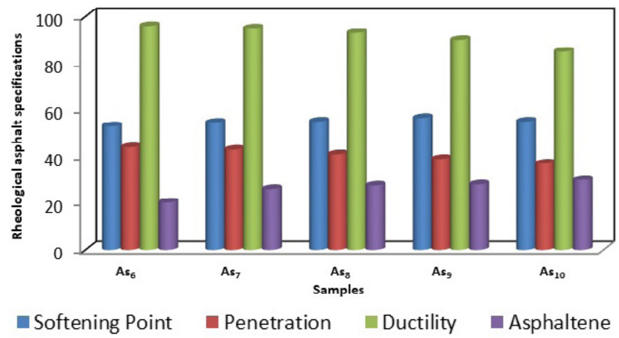

Figure 5. Rheological asphalt specifications mixed with various proportions of phenol-formaldehyde resin

It was observed from the table above a clear update in rheological asphalt specifications physically treatment by phenol-formaldehyde resin waste (AsPFR) comparison with source asphalt (As), where values of the softening point of the treated asphalt changed and increased with the increase in the ratio of added polymer, with the exception of (As_{10}) due to heterogeneity. The values of penetration and ductility decreased with increasing polymer ratio.

3. 1. 3. Asphalt Treatment with Polypropylene (AsPP)

Physically mixing asphalt with different ratio of polypropylene (AsPP), (Table 7) and (Figure 6) shows the treatment results.

It was noted from (Table 7) that asphalt physically treated with different ratio of AsPP generally led to product asphalt systems by rheological characteristics different

Table 6. Rheological asphalt specifications mixed with various proportions of phenol-formaldehyde resin (PFR) at temperature (160 °C) for 1 hr.

Sample	%PFR	Softening Point (°C)	Penetration, (100 g, 5 sec, 25 °C)	Ductility (cm, 25 °C)	Asphaltene %	Penetration Index (PI)
As_0	0	50	45.5	+100	18	–1.404
As_6	3	53	44	96	20.3	–0.769
As_7	6	54.5	43	95	26	–0.482
As_8	9	55	41	93	27.5	–0.479
As_9	12	56.5	39	90	28	–0.266
As_{10}	15	55	37	85	30	–0.697

Table 7. Rheological asphalt specifications mixed with various proportions of polypropylene (PP) at temperature (160°C) for 1 hr.

Sample	%PP	Softening Point (°C)	Penetration, mm (100 g, 5 sec, 25 °C)	Ductility (cm, 25 °C)	Asphaltene %	Penetration Index (PI)
As_0	0	50	45.5	+100	18	−1.404
As_{11}	3	52	41.9	95	21	−1.103
As_{12}	6	54.2	40.5	90	22	−0.680
As_{13}	9	55	39.4	81	28	−0.566
As_{14}	12	55.5	37.5	79	30	−0.560
As_{15}	15	57	36.8	75	32	−0.275

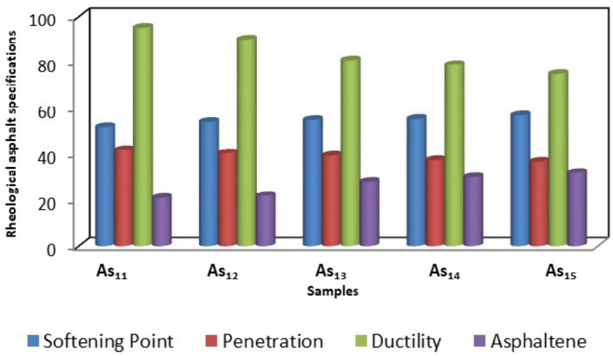

Figure 6. Rheological asphalt specifications mixed with various proportions of polypropylene

from original (As). Also note that the softening point is directly proportional to the ratio of PP added and inversely proportional to both penetration and ductility.

It was observed from the (Tables 5–7) shown previously that most of the asphalt samples (AsPP, AsPFR, AsPS) were characterized by good resistance to thermal sensitivity. This was demonstrated by calculating the PI values for these samples, as they generally increase with the increase in the ratio of polymer added.

It was also observed that there was a clear increase in the ratio of asphaltene for the three asphalt systems compared to the original (As), accompanied by an increase in the ratio of added polymer. This is due to the fact that the addition of polymers led to a change in the nature of the existing balances within the components of the asphalt system due to the relatively high molecular weight of these polymers.

When comparing the rheological properties of the three physically treated asphalt systems, it becomes clear to us that in terms of the softening point they were close, as the effect of physical mixing on the softening point is very similar despite the difference in the polymers used. The reason may be the lack of complete mixing with the asphalt.

As for the penetration point, it was observed that its values were similar for all the prepared asphalt systems. As for the ductility values, it was noted that the ductility values of the asphalt samples modified with polystyrene with a linear composition were higher than the ductility values of the asphalt modified with polypropylene. As for the asphalt modified with phenol-formaldehyde resin, the prepared samples appeared with higher values. Average between the rest of the other modified samples.

As for the ratio of asphaltene for the three asphaltene systems, it was noted that it was higher compared to the original asphalt. It is believed that the reason for this is due to the interference of some of the polymeric molecules with asphaltene-like materials, and thus they will precipitate and the ratio of asphaltene will increase.

3. 2. Modifying the Rheological Properties of Asphalt Through Chemical Treatment

Asphalt was treated by conducting a chemical reaction between the asphalt and the polymeric material, using anhydrous ferric chloride as a catalyst and in the presence of sulfur. This catalyst was chosen based on what was indicated in the scientific literature, and the choice of the sulfur percentage of 1% was based on a previous study.[22]

3. 2. 1. Asphalt Treatment with Polystyrene (AsPS)

This treatment depends on linking the polystyrene molecule with the asphalt molecule with existence sulfur, anhydrous ferric chloride as a catalyst for this process, (Table 8) and (Figure 7) shows the results of this treatment.

It was noted from the table above that the chemical treatment of asphalt with polystyrene (AsPS) led to a change in its rheological properties from the original (As), and a clear increase in softening values was also observed

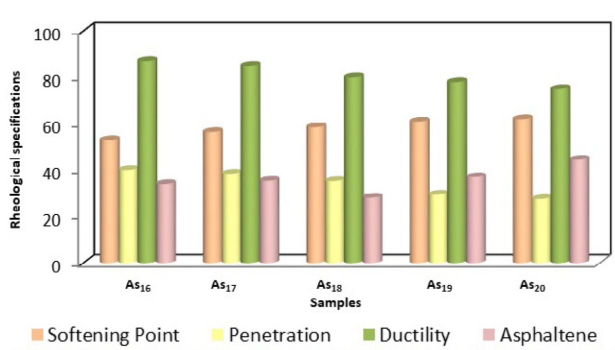

Figure 7. Rheological specifications of chemically treated asphalt with various ratio of polystyrene

Table 8. Rheological specifications of chemically treated asphalt with various ratio of polystyrene (PS) at temperature (160 °C), catalyst ratio (2% $FeCl_3$) and (1%) sulfur for an hour

Sample	%PP	Softening Point (°C)	Penetration, mm (100 g, 5 sec, 25 °C)	Ductility (cm, 25 °C)	Asphaltene %	Penetration Index (PI)
As_0	0	50	45.5	+100	18	−1.404
As_{16}	3	53	40.1	87	34	−0.966
As_{17}	6	56.5	38.5	85	35.4	−0.297
As_{18}	9	58.5	35.3	80	28.2	−0.076
As_{19}	12	61	29.5	78	37	+0.045
As_{20}	15	62	27.6	75	44.5	+0.077

with an increase in the ratio of added polymer in the prepared asphalt samples, accompanied by a decrease in the values of penetration and ductility.

3. 2. 2. Asphalt Treatment with Phenol-Formaldehyde resin (AsPFR)

This treatment depends on linking the phenol-formaldehyde resin (PFR) molecule with the asphalt molecule with existence sulfur and anhydrous ferric chloride as a catalyst for this process. (Table 9) and (Figure 8) shows the results of this treatment.

Looking at the results recorded in (Table 9), it was noted that treating asphalt with this polymeric material led to increase softening point of modified asphalt samples (AsPFR), while remaining constant at (58 °C) despite the increase in the ratio of polymer, while the values of the penetration point and ductility decreased. It also led to this is due to the increase in the ratio of asphaltene, which increases with the increase in the ratio of polymer.

3. 2. 3. Asphalt Treatment with Polypropylene (AsPP)

This treatment depends on linking the polypropylene molecule with the asphalt molecule with existence sulfur, anhydrous ferric chloride as a catalyst for this process. (Table 10) and (Figure 9) shows the results of this treatment.

Following the samples shown in (Table 10), it was observed that there was a clear increase in the softening values of the modified asphalt samples (AsPP) with an increase in the ratio of added polymer, accompanied by a decrease in the values of penetration and ductility.

Table 9. Rheological specifications of chemically treatment asphalt with various ratio of phenol-formaldehyde resin (PFR) at temperature (160 °C), catalyst ratio (2% $FeCl_3$) and (1%) sulfur for an hour

Sample	%PFR	Softening Point (°C)	Penetration, mm (100 g, 5 sec, 25 °C)	Ductility (cm, 25 °C)	Asphaltene %	Penetration Index (PI)
As_0	0	50	45.5	+100	18	−1.404
As_{21}	3	55.5	38	90	27	−0.430
As_{22}	6	56	35	86	30	−0.598
As_{23}	9	57	33.5	83	32.5	−0.485
As_{24}	12	58	31	73	33	−0.442
As_{25}	15	58	29.5	70	40	−0.542

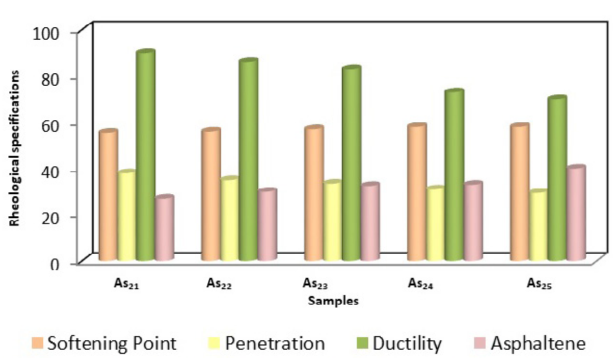

Figure 8. Rheological specifications of chemically treatment asphalt with various ratio of phenol-formaldehyde resin

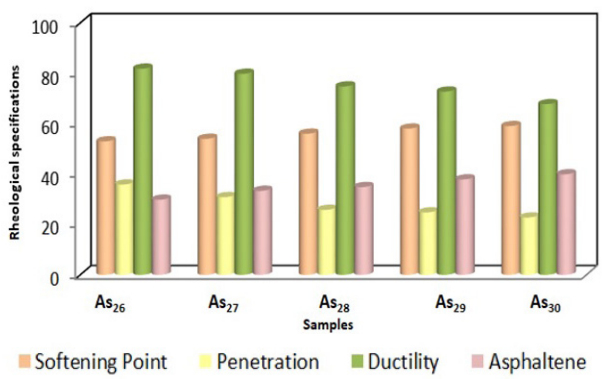

Figure 9. Rheological specifications of chemically treated asphalt with various ratio of polypropylene

Table 10. Rheological specifications of chemically treated asphalt with various ratio of polypropylene (PP) at temperature (160 °C), catalyst ratio (2% $FeCl_3$), and (1%) sulfur for an hour.

Sample	%PP	Softening Point (°C)	Penetration, mm (100 g, 5 sec, 25 °C)	Ductility (cm, 25 °C)	Asphaltene %	Penetration Index (PI)
As_0	0	50	45.5	+100	18	−1.404
As_{26}	3	53	36	82	30	−1.189
As_{27}	6	54	31	80	33.5	−1.263
As_{28}	9	56	26	75	35	−1.179
As_{29}	12	58	25	73	38	−0.856
As_{30}	15	59	23	68	40	−0.817

When comparing the rheological specifications of chemically treated asphalt systems (AsPP, AsPFR, AsPS), it was noted that there is a clear discrepancy in terms of the values of the softening point. It was found that the asphalt modified with polystyrene has the highest values of softening, the lowest than that treated with polypropylene, and the least than both treated with phenol-formaldehyde resin. It is believed The reason for this is that thermally broken polystyrene has more active sites, which makes the possibility of chemical bonding (chemical reaction in the presence of $FeCl_3$, sulfur) of the polystyrene molecule to the asphalt molecule to a greater degree than the other two polymers. This is clear from the rise in asphaltene values and also reflected in the decrease penetration values.

The increase in the polymer ratio led to an increase in the amount of non-reactive polymeric materials, which affected the ductility and penetration values and made them lower than the original, and this may also be reflected in the penetration index (PI) values.

As for the ductility values of asphalt treated with polystyrene (AsPS), we find that they are higher than the ductility values of polypropylene (AsPP), despite the lower penetration values and higher softening point of the (AsPS) system compared to the (AsPFR) system. The reason for this may be attributed to the association of the linear polystyrene molecule with asphalt chemical compositions, it contributed to imparting ductility properties to a higher degree than asphalt linked to PP.

After looking at the results obtained, it was found that part of these samples, especially those resulting from chemical treatment were characterized by high softening points and low penetration and ductility values that qualify them for use in the production of Mastic, which is used as water proofing material. It has many uses and in wide fields, such as its use for the purposes of roofing, surfacing, and covering pipes for transporting liquids and gases under the surface of the earth to prevent their corrosion and collapse, based on the standard specifications shown in (Table 11–13).

Table 11. American standard specifications ASTMD (D491-41) for asphalt used to produce mastic[23]

Rheological Measurements	Minimum	Maximum
Softening point (°C)	54	65
Penetration, mm (100g, 5sec, 25 °C)	20	40
Ductility (cm, 25 °C)	15	---

Table 12. Specifications of American standards ASTM (D491-41) for mastic asphalt used as a moisture insulating material[24]

Rheological Measurements	Minimum	Maximum
Softening point (°C)	50	70
Penetration, mm (100g, 5sec, 25°C)	15	40
Ductility (cm, 25 °C)	15	---

Table 13. Iraqi standard specifications for asphalt used in surfacing[25]

Rheological Measurements	Minimum	Maximum
Softening point (°C)	57	66
Penetration, mm (100g, 5sec, 25°C)	18	40
Ductility (cm, 25°C)	10	---

4. Conclusions

Chemical treatment yields more favorable effects on the rheological properties of the asphalt systems compared to physical treatment methods. Both treatment approaches-chemical and physical-led to an increase in the separated asphaltene percentage within the modified asphalt, with the highest values recorded for AsPS (44.5%), AsPFR (40%), and AsPP (40%). Among the tested polymers, chemically modifying asphalt with polystyrene had the most significant impact on enhancing rheological characteristics. Notably, some of the modified asphalt samples demonstrated rheological properties that make them suitable for applications as moisture and leakage-resistant materials (mastic), particularly when evaluated against both local and international performance standards.

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Povzetek

Namen raziskave je bil razvoj različnih vrst asfaltnih materialov z izboljšanimi reološkimi lastnostmi v primerjavi z nespremenjenim asfaltom. Uporabljene so bile tri vrste polimernih materialov (PS), (PFR) in (PP) za modifikacijo asfalta Al-Doura, s ciljem oceniti njihov vpliv na reološke lastnosti nastalih asfaltnih sistemov. Ti spremenjeni materiali so bili nato primerjani med seboj s tako lokalnimi kot mednarodnimi standardi za oceno njihove primernosti za specifične aplikacije. Uporabljeni so bili polimerni odpadni materiali namesto deviških polimerov za zmanjšanje okoljske onesnaženosti in znižanje stroškov modifikacije. Postopek modifikacije je bil izveden z uporabo dveh pristopov: fizikale in kemijske obdelave. Kemijska metoda je vključevala katalizirano reakcijo z uporabo 2% ($FeCl_3$) in 1% (S). Rezultati so pokazali, da je imela kemijska obdelava pomembnejši pozitiven učinek na reološke lastnosti asfaltnih sistemov v primerjavi s fizikalno obdelavo. V obeh pristopih je dodatek polimera pripeljal do povečanja % de-asfaltena, pri čemer so najvišje vrednosti beležili za AsPS (44,5%), AsPFR (40%) in AsPP (40%). Poleg tega je kemijsko modificiranje asfalta s PS prineslo najbolj opazne izboljšave med preizkušenimi polimeri. Na podlagi ključnih kazalnikov uspešnosti, kot so točka mehčanja, penetracija, duktilnost, indeks penetracije (PI) in odstotek asfaltenov, so modificirani vzorci asfalta pokazali primernost za uporabo pri proizvodnji mastik, ki se široko uporabljajo kot vodoodporen material.