The Copolymers and their Effect on the Rheological Properties of Sulfureted Asphalt

Mohammed Ahmad Alwan[1*], Ammar Ahmed Hamdoon[2], Nabeel Jamal Ayed[3]

Abstract

Due to the harsh climatic conditions and the maximum loads on the original unmodified asphalt used in paving process, some defects appear over time such as cracks and deformation of roads. This calls for work to improve the rheological properties of asphalt to produce asphalt paving more resistant to the factors above.

This study focuses on the use of polymeric mixtures of consumed copolymers in asphalt modification processes. These polymers were thermally treated to find out the temperature at which they could be used in the modification process. Asphalt was treated with different percentages of sulfur as a catalyst under specific conditions of temperature and reaction time, during which the optimum catalyst ratio that can be used in the modification processes was determined. Asphalt was treated with a polymer mixture consisting of (ASA and SBS) (1:1) in different weight ratios with the presence of the optimum catalyst ratio and under the above reaction conditions. Several samples were obtained and the rheological properties of the original and modified asphalt were measured by penetration, softening point, ductility and penetration index calculation as well as calculating the weight percentage of asphaltene. The best sample obtained from the above modification process was determined, and reactions were performed on it again to determine the optimal temperature and reaction time, as well as to determine the optimal percentage of sulfur as a catalyst by measuring the rheological properties of the best sample. The best sample obtained in this study was (AS9), and to find out the suitability of this sample that was selected for paving process, the Marshall, chemical immersion and aging test as well as the field emission scanning electron microscope were performed. The modified sample gave better rheological properties and a resistance greater by 56% than the original asphalt when compared with the standard specifications approved in the field of paving.

Key Words: Polymeric Mixtures, Copolymers, Compound Polymers, Rheological Modification.

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Introduction

Asphalt is the heaviest component that is produced from the distillation process of crude oil under high pressure and temperature (Al-Dabouni, and Ali, 1986). It is black to dark brown in color and has a high molecular weight when compared with other petroleum products, has a high density ranging between (1.1-1.0 g / cm3) and has a strong smell when heated (Introduction to asphalt, 2001). Asphalt can be defined in general as a material that has a black to dark brown color and is semi-solid and has a high viscosity at room temperature and is produced through the different distillation processes that take place on crude oil (Parkash, 2010; Zhang, and Greenfield, 2008). Asphalt is characterized by its chemical inertness associated with its physical properties, which enabled it to have wide uses in industries and construction processes since ancient times, and the nature of its use is determined by knowing its physical properties (Lesueur, 2009).

Corresponding author: Mohammed Ahmad Alwan

Address: [1*]Ministry of Oil, North Refineries Company, Iraq; [2]Department of Chemistry, College of Education for Pure Science, University of Mosul, Iraq; [3]Department of Chemistry, College of Education for Pure Science, University of Tikrit, Iraq.

[1*]E-mail: mohammed.a.alwan@st.tu.edu.iq

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The largest use is concentrated in the field of road paving in general and other uses in other fields because it has a high adhesion characteristic and a suitable viscosity with various solid because it is relatively inexpensive. Therefore, many studies were conducted on it, which showed that it is possible to improve the rheological properties of asphalt by using various additives and chemical modifications (Vargas, and Manero, 2011; Hussein, and Al–Abdul- Wahhab, 2005). Upon going back to previous studies, we find a large number of studies that included asphalt modification process that were carried out by many researchers, including (Can, 2008) who treated the asphalt with consumed oil at different rates ranging between (1-12%) as a modified material at low temperatures and the study gave a remarkable improvement in the rheological properties of the asphalt towards the scraping and stripping process. (Arslin, and Toque, 2008) studied the treatment of asphalt with lubricant oil by heating and in different proportions and showed improvement in the rheological properties by conducting the following tests (Penetration test, Ductility test, Softening point, TFOT). (Mohammed and Hussein, 2014) treated the asphalt with (PET) polyethylene terephthalate to improve the performance of the asphalt properties. As this study included the rheological tests for asphalt and the storage stability test was calculated at high temperatures this study proved that when adding polymer to asphalt leads to low results in the penetration and Ductility test and an increase in testing the softening point and the optimum percentage of the added polymer is at (4%). The addition of the polymer leads to a decrease in the thermal sensitivity of asphalt. (Gama, 2016) and his group also studied the rheological properties of asphalt modified polymeric mixtures type of (EMA-GMA) Ethylene Methyl Acrylate - Glycidyl Methyl Acrylate. This polymer is an elastic elastomer. As the use of high-density polyethylene (HDPE), the addition of polymers showed a clear improvement in the elastic properties of asphalt modified, which is subject to maximum traffic loads. (Sherini and Imansap, 2016) studied the rheological properties of rubber-modified porous asphalt in comparison with a modified porous asphalt mixture using poly styrene butadiene styrene (SBS). It was found that when adding (10%) from rubber crumbs improves the performance of porous asphalt in resistance to mold compared to asphalt modified using copolymer (SBS). (Thakre, 2016) and his group treated the asphalt with the polymer additive ethylene vinyl acetate (EVA) and rubber crumbs to modify the rheological properties of the asphalt where the study showed good asphalt samples that are more resistant to fatigue, thermal cracks, rotting and thermal sensitivity, and can be used in the field of paving. (Hussein, and Hamdoon, 2019) also treated the asphalt with damaged oils and by using aerobic oxidation where the study showed asphalt samples that can be used in the field of paving and others that can be used in surfacing process as anti-moisture depending on the tests performed on samples such as penetration, ductility, softening point, asphaltene ratio, and penetration index calculation.

Experimental

First - Used Materials

1. Asphalt

It was obtained from the North Refineries Company.

2. Sulfur

Prepared from British company called Judex Chemicals.

3. n-hexane

Prepared from a FERAK company.

4. Sodium Carbonate

Prepared from Judex Chemicals.

5. Copolymer (acrylonitrile styrene acrylonitrile) (ASA)

Obtained from consumables manufactured from it.

6. Copolymer (Styrene Butadiene Styrene) (SBS)

Prepared from consumables manufactured from it.

Second - The Devices Used

1. Penetration Testing Device

Penetration is a measure of the hardness of asphalt, as this device measures the penetration of solid and semi-solid asphalt materials. The device is of British origin from Cooper technology company, model 2017.

2. Ductility Testing Machine

This device measures the distance that asphalt materials can be stretched when exposed to the impact of clouds at a constant speed (5 cm/min),

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until the asphalt sample is cut off, and the total distance of this device reaches (150 cm) this device is of British origin prepared with Cooper company, model 2017.

3. Softening Point Device

This device measures the softening point of bituminous materials whose softening ranges between (30 - 200) C°, the softening point is known as the temperature at which the asphalt sample descends a distance of (2.54) cm when heated at a speed of (5) C°/min. The device is of British origin prepared with Cooper technology company, model 2017.

4. Thin Film Oven Tester (TFOT)

When conducting this test, it becomes clear to what extent the original and modified asphalt paving is affected by the aging conditions for a period of (5) hours, and at a temperature of (163) C°. The device name MARENO is of Japanese origin.

5. Marshall Testing Apparatus

This device performs a Marshall test on the prepared asphalt mixtures to determine the suitability of asphalt for paving. The device type WYKEHAM FARRANCE is of English origin.

6. Field Emission Scanning Electron Microscopy (FESEM)

It is a type of modern electron microscope that produces images by scanning the sample using focused beams of electrons. The type of device is Tescan Mira 3 France.

Third - Experimental Methods

1. Heat Treatment of Co_polymers

Polymers used in this study were treated at a temperature ranging between (25 - 400) C°. To find out the optimum temperature that can be used to crack it in order to obtain polymers of lower molecular weight to facilitate its entry into the chain of reactions that was used during the rheological modification process.

2. Sulfurization of Asphalt

The asphalt was treated with different weight ratios of sulfur at a temperature of (180) C° for a period of one hour for the purpose of determining the optimum percentage of sulfur used.

3. Rheological Modification of Asphalt

The asphalt was treated with a polymeric mixture of (ASA: SBS) (1:1) with different weight ratios that ranged between (0.5 - 5)% by weight, and with presence (1%) by weight of sulfur at a temperature of (180) C° for a period of one hour.

4. Measurement of the Rheological Properties of the Original and Modified Asphalt

The rheological properties of both the parent and modified asphalt were measured, which include (Ductility, Softening point, Penetration, and Penetration Index) as well as calculating the weight ratio of the separated asphaltene. (ASTM D113 – 07, 2008; ASTM, D 36, BS2000; ASTM, D5, 2013; AL-Frakh and Abu Shihada, A., 1981; Ali, and Al-Ghannam 1981) Straight.

5. Determine the Optimal Conditions for the Modified Reaction

Taking the best sample obtained from paragraphs two and three several reactions were carried out on it for the purpose of knowing the optimum sulfur weight percentage as well as determining the optimum reaction time and the optimum temperature.

6. Marshall Test, Chemical Immersion, TFOT and FESEM

The best sample obtained from this study was taken and tests were performed on it, such as the Marshall test (ASTM D1559, 2004), and chemical immersion (ASTM D-1664, 1986), as well as studying the effect of TFOT, (ASTM D1754-97R, 2002) and FESEM (Stokes, 2008).

Results and Discussion

The use of modified asphalt with polymeric additives is one of the methods widely used to obtain asphalt with better rheological properties than the original asphalt, in addition, this modification process is useful in disposing of even a small fraction of the materials that are polluting to the environment, which are polymeric wastes.

The copolymers used in this study where treated as described in paragraph(3_1) of the experimental part.

It is clear from the treatment that the optimum temperature for copolymers crushing (SBS&SAS) were 180 centigrade. The purpose of the heat treatment is to convert the copolymer into a powder and reduce its reaction with other components. (Flanagan, 1969).

Then the asphalt was treated with different percentages of sulfur, ranging between (0.25 - 4%) by weight for the purpose of sulfurizing the asphalt and determining the optimal ratio that is used in the modification process with a temperature of (180) C° and the reaction time is one hour. Table (1) shows the results obtained.

Table 1. The rheological properties of the original and modified asphalt with different percentages of sulfur, at (180C°) for one hour.

samples	sulfur %	Penetration mm	Softening point C°	Ductility cm	Asphaltenes %	Penetration Index
AS_0	___	48	49	+150	17.0	-1.539
AS_1	0.25	47	49	+150	17.5	-1.584
AS_2	0.5	46	50	+150	18.4	-1.384
AS_3	1.0	44	51	+150	19.7	-1.236
AS_4	2.0	39	53	140	24.3	-1.026
AS_5	3.0	42	48	+150	21.8	-2.069
AS_6	4.0	44	46	+150	20.6	-2.501

AS_0 Original Asphalt Sample

We note from the table above that the best catalyst percentage that can be selected in Modification the rheological properties of asphalt is (1%) by weight of sulfur in the catalytic modification process. It is evident from table (1) that the best conditions for the asphalt modification process take place at a temperature (180 C°), a reaction time (60 minutes), and the percentage of sulfur as a catalyst (1%) by weight. As we can see from the table, the percentage of asphaltene increases in general with the increase in the catalyst percentage when time and temperature are constant except for the samples (AS_5 and AS_6). They differ from the base above because of the increase in the percentage of asphaltene is due to the occurrence of condensation reactions more than the disintegration reactions that lead to a decrease in the percentage of asphaltene. That is, the percentage of the dissociation reactions in the two above samples is more than the percentage of condensation reactions. After that, these conditions were used in treating asphalt with different proportions of a mixture consisting of equal proportions of (Styrene-Butadiene-Styrene) and (Acrylonitrile-Styrene-Acrylonitrile) [ASA: SBS] with a ratio of (1:1) and in the presence of (1%) by weight of sulfur and at a temperature (180) C° and reaction time (1 hour). Table (2) illustrate the results obtained.

Table 2. Rheological properties of asphalt treated with different percentages of (ASA: SBS) mixture (1:1) and (1%) and at (180) C° and for one hour.

samples	Mix. %	Penetration mm	Softening point C°	Ductility cm	Asphaltenes %	Penetration Index
AS_7	0.5	43	51	+150	20.1	-1.285
AS_8	1.0	42	52	+150	21.2	-1.099
AS_9	2.0	41	54	+150	22.7	-0.700
AS_{10}	3.0	38	55	135	23.9	-0.645
AS_{11}	4.0	36	56	100	26.1	-0.544
AS_{12}	5.0	33	58	65	29.7	-0.318
AS_{13}	6.0	28	60	35	33.8	-0.260

It is evident from table (2) that the use of this polymer mixture (ASA: SBS) gave good rheological properties to the extent of (4%) with respect to the values of ductility and softening point, as for the penetration values, they are outside the range of permissible specifications shown in the tables (1,9,15). The percentage (3%), but it is still within the values that can be used in various fields. As for the asphaltene values, they, as expected, increase with the increase of the additive percentage until it reaches a percentage (33.8%) at the ratio (6%) by weight of the polymer mixture this indicates that condensation reactions occurred significantly between the polymeric additives and the asphalt with an increase in the proportion of the polymeric additive. Sulfur plays an important role in the rheological modification processes, as it turns into free radicals at the temperature range (180 C°), which facilitates its bonding process with asphalt and has a positive effect on the rheological properties of asphalt. And that the best sample obtained under the above conditions is the sample (AS_9), which represents a percentage (2%) of the mixture used in the modification process that was within the limits of the standard specifications for the asphalt of the paving. After determining the best sample through which the optimum time for this process is determined, and table (3) illustrate the results obtained.

Table 3. The rheological properties of asphalt treated with (2%) of the mixture (ASA: SBS) (1:1), (1%) of sulfur and at(180) C° for one hour

samples	Time	Penetration mm	Softening point C°	Ductility cm	Asphaltenes %	Penetration Index
AS_{14}	30	42	52	+150	21.9	-1.099
AS_9	60	41	54	+150	22.7	-0.700
AS_{15}	90	39	55	+150	24.3	-0.586
AS_{16}	120	35	56	150	25.1	-0.601

It is evident from table (3) that the best samples obtained are (AS_9 and AS_{14}), which were in conformity with the standard specifications for asphalt paving. As we note that the softening point and the ratio of asphaltene in general is increasing and the penetration and ductility are constantly declining under the above reaction conditions at different times and at constant temperature. After determining the optimal time for the reaction, it is through him the optimum temperature for this process is determined. Table (4) illustrate the results obtained.

Table 4. The rheological properties of the asphalt treated with a (2%) of the mixture (ASA: SBS) (1:1), (1%) of sulfur with different temperatures and for one hour

samples	Temperature C°	Penetration Mm	Softening point C°	Ductility cm	Asphaltenes %	Penetration Index
AS_{17}	150	43	51	+150	21.7	-1.285
AS_9	180	41	54	+150	22.7	-0.700
AS_{18}	200	37	55	+150	25.3	-0.698
AS_{19}	230	34	57	140	27.1	-0.457

It is evident from table (4) that the best samples obtained are (AS_9 and AS_{17}), which were in conformity with the standard specifications for asphalt paving. As we note that the softening point and the ratio of asphaltene in general is increasing and the penetration and ductility are constantly decreasing under the above reaction conditions at different temperature and reaction time (60 minutes). After determining the optimum temperature and time for the catalytic modification of the asphalt through these conditions, the optimum catalyst ratio for the best sample is determined. Table (5) illustrate the results obtained.

Table 5. The rheological properties of asphalt treated with a (2%) of the mixture (ASA: SBS) (1:1) and in the presence of different percentages of sulfur at (180) C° for one hour.

samples	Sulfur %	Penetration mm	Softening point C°	Ductility cm	Asphaltenes %	Penetration Index
AS_{20}	0.25	44	50	+150	19.8	-1.477
AS_{21}	0.5	43	52	+150	20.7	-1.050
AS_9	1.0	41	54	+150	22.7	-0.700
AS_{22}	2.0	42	53	+150	23.1	-0.870
AS_{23}	3.0	44	51	+150	21.0	-1.236
AS_{24}	4.0	46	48	+150	20.1	-1.887

It is evident from table (5) that the selected catalyst percentage (1%) by weight represents the best catalyst ratio that can be used in the process of modifying the rheological properties of asphalt. Most of the samples were in conformity with the asphalt standard specifications by increasing the percentage of catalyst except for the sample (AS_{24}) that does not conform to the specifications in the softening point test. As we can see in the samples (AS_{23} and AS_{24}) there is an increase in the values of penetration and a decrease in the values of the softening point and the ratio of asphaltene and the reason for the decrease in the ratio of asphaltene is due to the occurrence of dissociation reactions more than the condensation reactions that lead to an increase in the ratio asphaltene. That is, the rate of dissociation reactions in the two samples above is more than the condensation reactions, the decrease and rise in the ratio of asphaltene is due to the competition between the two reactions above. And the ductility values were not affected by the increase in the percentage of the catalyst used to a limit of (4%).

The last field in all the tables above shows penetration index (PI) and it is a developed relationship between the softening point and the degree of penetration of the asphalt sample at 25 Cº. Through it, the sensitivity of the asphalt material and its impact by temperature are identified, and it can be calculated from the following mathematical relationship (Al- Frakh, and Abu Shihada, 1982).

$$\frac{20-PI}{10+PI}=50\left[\frac{log\ log\ 800-log\ log\ Pent.}{T.R.B-T}\right]$$

PI: penetration index.

Pent: Penetration degree of the asphalt sample.

T: The temperature at which penetration is measured is 25 Cº.

T.R.B: The softening point measured by the Ring and Ball method.

Asphalt samples with standard specifications suitable for use in the field of paving have penetration index values ranging from (-2 _ +2) (Hobson, 1973). Our study showed that all the values of the penetration index (PI) were within the limits and ranging between (+2 _ -2). This indicates that the asphalt system is of the type (Sol-Gel-Asphalt), meaning that the thermal stability of the product increases.

Table 6. The rheological properties of paving asphalt according to the specifications of the Iraqi Roads and Bridges Authority (S.C.B.R) (2003)

NO.	Rheological specifications	minimum	maximum
1	Penetration@25C°(100g,5sec,0.1mm)	40	50
2	Softening Point (R & B) C°	54	60
3	Ductility@25C° cm	100	---

Table 7. American standard specifications for asphalt used to produce mastic (ASTM D491-88, 2006)

NO.	Rheological specifications	minimum	maximum
1	Penetration@25C°(100g,5sec,0.1mm)	20	40
2	Softening Point (R & B) C°	54	65
3	Ductility@25C° cm	15	---

Table 8. Iraqi standard specifications used in the field of flattening (Standard Specifications, 1988)

NO.	Rheological specifications	minimum	maximum
1	Penetration@25C°(100g,5sec,0.1mm)	18	40
2	Softening Point (R & B) C°	57	66
3	Ductility@25C° cm	10	---

To know the suitability of asphalt samples for paving purposes, a Marshall test was performed. This test gives an indication of the suitability of the asphalt for the paving by applying pressure on the sample to be tested and when the sample starts to deform, the stability and crawling measurement is taken simultaneously through the reading recorder in the device. Stability is defined as the ability of the asphalt mixture to resist the deformation resulting from the exposure of roads to excessive and repeated loads of the means of transport and stability depends on internal friction and cohesion. Crawling is defined as the amount of vertical deformation in the Marshal sample during the moment of failure. The higher values of the crawling rate give an indication that the asphalt mixture is more substandard in which the failure of what is known as permanent deformations. The low values of crawling give an indication that the mixture contains few voids that lead to the emergence of primary cracks (Taylor, 2006). The measurement was carried out according to the internationally approved American standard specifications (ASTM D1559_2004).

In this study, the Marshall test was performed on the best modified and original asphalt samples that the modified asphalt sample was in conformity with the specifications of the Iraqi Roads and Bridges Authority (S.C.R.B), unlike the original asphalt sample that did not conform to the crawling. According to Marshall Quotient (MQ), the permanent deformations that occur in flexible paving are predicted by calculating the marshal's stiffness especially since increasing the hardness of the asphalt mixture is required when the asphalt pavement is exposed to high temperatures during service(more than 60 Cº) to avoid rutting, while reducing stiffness is desirable at low temperatures during service to avoid shrinkage cracks. The value of Marshall stiffness is calculated from the product of Marshall stability divided by the value of crawling (Zoorob, and Suparma, 2000). Table (9) shows the results obtained.

Table 9. Shows the stability and crawling values of the original and modified asphalt and the specifications of the Roads and Bridges Authority (S.C.R.B)

samples	Asphalt %	Stability (KN)	Crawling (mm)	MQ
AS_0	**4.7**	**11.1**	**5.0**	**2.22**
AS_9	**4.7**	**16.0**	**3.1**	**5.16**
AS*	**---**	**7 min**	**2 - 4**	**3.5 min**

AS_0: The Original Asphalt

AS: Iraqi Roads and Bridges Authority Specifications*

We note from the table above that the values of (stability and crawling) of asphalt modified with polymeric mixtures are better than the original asphalt. That is, modified asphalt is better than original asphalt if it is used in paving. This is considered an excellent indicator of the ability of the paving to resist deformation and is more stable and resistant to crawling resulting from the exposure of the roads to the maximum and repeated loads of the transportation means. This indicates that the mixture of modified asphalt contains a small percentage of voids. As we note that the value of (MQ) for modified asphalt is higher than the value of (MQ) for the original asphalt, and this indicates that the modified asphalt is more resistant to permanent deformation than the original asphalt. The chemical immersion test was also performed, which is a measure or number that shows the extent of adhesion of aggregates to asphalt. This type of test shows the resistance of asphalt after mixing it with aggregate to acid rain and high temperatures. Table (10) shows the results obtained.

Table 10. Shows the separation values of asphalt from aggregate for modified and original asphalt

samples	Na_2CO_3 (g)	R & W NO.	R&W NO. Original asphalt	R&W NO. Modified asphalt
---	0.025	1	---	---
---	0.041	2	---	---
AS_0	0.082	3	**3**	---
---	0.164	4	---	---
---	0.328	5	---	---
AS_9	0.656	6	---	**6**
---	1.312	7	---	---
---	2.624	8	---	---

We note from the table above that the value of the modified asphalt sample is more resistant to acid rain and high temperatures than the original asphalt. As the numbers from (0-8) refer to (R&W) Riedel and Weber number, No. (1) indicates the amount of sodium carbonate (Na_2CO_3) (0.025 g) in (50 ml) of distilled water and the number (8) indicates the highest concentration of sodium carbonate, which is (2.624 g).

To know the degree to which the asphalt samples, the original and the modified, are affected by the polymeric additives by the aging conditions, furnace test was performed a for thin Asphalt Films (TFOT) for sample modified (AS_9) and original asphalt (AS_0) and table (11) shows the results obtained.

Table 11. The rheological properties of modified and original asphalt before and after subjecting it to a furnace test for Thin Asphalt Films (TFOT)

samples	Rheological properties	Before the test	After the test	Difference
AS_0	Penetration@25C°(100g, 5sec, 0.1mm)	48	43	5
	Softening Point (R & B) C°	49	52	3
	Ductility@25C° cm	+150	+150	--
	Penetration Index (PI)	-1.539	-1.050	--
	Loss on Heating %Wt (5HRS,163C°)	--	0.048	--
AS_9	Penetration@25C°(100g,5sec,0.1mm)	41	40	1
	Softening Point (R & B) C°	54	56	2
	Ductility@25C° cm	+150	+150	--
	Penetration Index (PI)	-0.700	-0.318	--
	Loss on Heating %Wt (5HRS,163C°)	--	0.025	--

We note from the table above that the degree of vulnerability of modified asphalt to the aging conditions of temperature and oxygen in general is low, and this is a positive indicator and we infer from this that the asphalt modified sample is more resistant to stress and less cracks, as well as a longer operational life and the references indicate that the modified asphalt sample is not affected by the aging conditions due to its polymeric additive composition and which works to improve the mechanical properties of asphalt which represents an increase in the strength of the asphalt sample and its susceptibility to stress, reducing thermal cracking and increasing its resistance to grooves formation (Becker, and Rodriguez, 2001; Navarro, 2004). The field emission scanning electron microscope (FESEM) is one of the types of modern electron microscopes that give images by scanning the sample using focused radiation of electrons which interact with the sample atoms to produce different signals that contain information about the topography and composition of the surface. This FESEM is characterized by high magnification power (McMullan, 2006; Scimeca, 2018). The modern electron microscope (FESEM) contains an X-ray detection and analysis unit and the main technology used in this unit is known as energy dispersive X-ray (EDX) and means the analysis of the discharged energy of X-rays as the technique (DEX) gives the type of elements contained in the material as well as their proportion. Through this unit, all elements can be identified to be analyzed except hydrogen, lithium and helium (Suzuki, 2002; Lyman, 2012; Behnood, and Gharehveran, 2019). The field emission scanning electron microscope (FESEM) test was performed on the best sample obtained from the process of modifying asphalt with polymeric additives in this study is (AS_9). The addition of polymeric mixtures to the asphalt system increases the complexity of studying the internal structure of modified asphalt and its effect on the rheological properties of asphalt. As we note through (FESEM) images that the role of adding the polymeric mixture is clear in changing the structure of asphalt and its effect on the rheological properties of polymer modified asphalt. (EDX) was also measured, and the measurement gave the percentage of the main elements in the composition of modified asphalt, which are carbon, sulfur and oxygen.

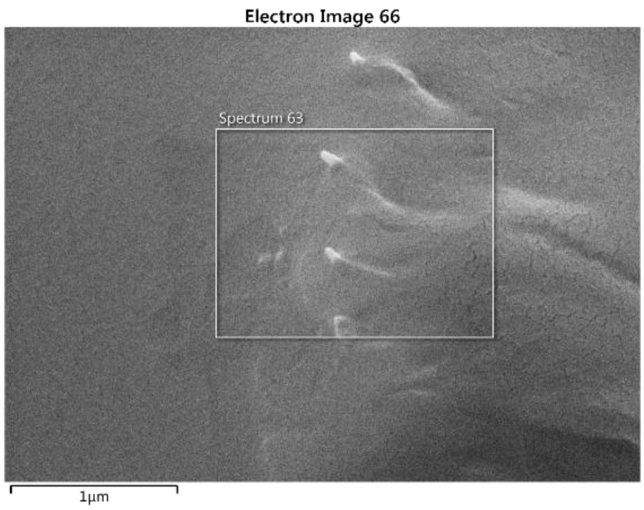

Image 1. Field emission analysis by scanning electron microscopy of modified asphalt with polymeric additives

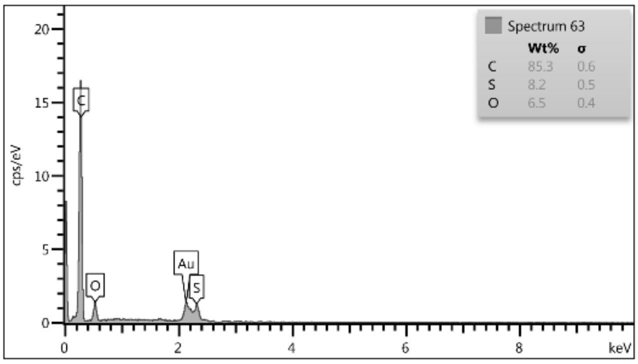

Figure 1. Energy dispersive X-rays (EDX) and the main components of modified asphalt

Conclusions

After completing this study, we conclude the following:

1. The use of polymeric mixtures has had an effective effect in the field of rheological modification.
2. Sulfur has an important role in improving the rheological properties from time to time with the polymeric additive.

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