RESEARCH PAPER

Enhancing Asphalt Performance with Polymer Blends: A Rheological Study

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ABSTRACT

This study investigates the use of polymer blends [polyvinyl acetate (PVA) and polyvinyl chloride (PVC)] to modify and improve the rheological properties of asphalt material and make it more resistant to environmental conditions such as acid rain and aging when used in road paving. Specific proportions of the polymer blend [polyvinyl acetate (PVA): polyvinyl chloride (PVC)] were added to the asphalt with the addition of 1% of (nano-sulfur) at a temperature ranging between (150-170) °C for one hour for each sample. Rheological measurements of the original and modified asphalt were performed, including penetration, ductility, softening point, and penetration index, in addition to measuring the Marshall coefficient, aging test, and scanning electron microscope (SEM) for some selected samples and comparing them with normal asphalt. The results indicate that the asphalt modified with the polymer blend and nano-sulfur resists environmental conditions of different temperatures, acid rain, and aging more than normal asphalt, making it a suitable candidate for road paving applications.

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INTRODUCTION

Asphalt's stability, durability, and water resistance make it the most popular material for paving roads [1]. Asphalt is produced from direct distillation of crude oil, as crude oil is the largest source of asphalt. Asphalt is characterized by its black or dark brown color and its high molecular weight when compared to other parts of crude oil and its high density [2,3]. It is characterized by its black color and viscous texture [4,5]. Asphalt is a heterogeneous hydrocarbon material composed of carbon, hydrogen, oxygen, sulfur, and nitrogen (N, S, O). It also contains cyclic and noncyclic compounds. In addition to being inexpensive, asphalt's good viscosity and excellent adherence to various metals make it a popular material for road paving [6-8]. Therefore, many researchers have been keen to improve the specifications of asphalt with different chemical and physical treatments and by using many additives, especially polymeric additives, because of their great impact on improving the rheological properties of asphalt and making it more suitable for various uses, especially In the field of paving, to improve performance at low and high temperatures, the use of asphalt with higher hardness improves the resistance of modified asphalt to corrosion in places with high temperatures. Polymer modification is the most effective alternative to conventional bitumen. For instance,, Fakhri et al. investigated the effect of

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two types of recycled polyvinyl chloride (recycled water pipes and recycled candy wrappers) [9] at three different percentages (2%, 3.5% and 5% by weight of bitumen) on enhancing the asphalt mixture’s mechanical qualities. Several asphalt tests, such as the deformation strength test and the static creep test, were employed. According to bitumen testing, recycled polyvinyl chloride components decrease bitumen’s ductility and penetration while raising its softening point and viscosity [10,11].

The effect of adding recycled polymer to bitumen and comparing it with pure polymer. The results showed that recycled polymers had similar improved pavement performance as compared to pure polymers [12]. A previous study examined the effects of three different polymers on asphalt characteristics. These polymers include polyvinyl chloride (PVC), poly tetra fluoro ethylene (PTFE), and styrene butadiene styrene (SBS). According to earlier research in this area, these polymers are plastomeric and flexible materials that are used to improve the mechanical qualities of blended asphalt while also boosting the hardness, flexibility, and stability of asphalt binders and decreasing the likelihood of cracks in the winter and ruts in the summer [13,14]. Arabani investigated the effects of 1%, 3%, and 5% weight ratios of polyvinyl chloride powder added to asphalt. The findings demonstrate that when PVC content rises, penetration and deformation fall proportionately. Thus, it may be said that PVC powder containing mixes have a higher corrosion resistance [15,16]. By adding 1 and 3% PVC to asphalt reinforced with 3% SBS, Estabraq was able to alter the characteristics of the asphalt using a combination of polymers. According to the findings, the addition of the polymer mixture considerably decreased the grooves’ ability to form at (60°C) by 98.08%) and (92.6%,) respectively. Therefore, it is advised to utilize these ratios in hotter areas where temperatures can rise above 60°C [17,18]. Ahmed and Hamdoun succeeded in raising the standards of asphalt by mixing different proportions of sulfur waste resulting from the purification of sulfur from the Mishraq mine using the thermal method and the nano-sulfur derived from it with asphalt. The results of the treatment showed through several tests that asphalt samples were obtained that were superior in their properties to the original asphalt. [19,20]. Evaluated the storage stability of asphalt binders by modifying the asphalt properties using waste ethylene and propylene rubber and waste thermoplastic oils (PPO). It was noted through rheological measurements that these additives led to improving the rheological properties, including the degree of ductility and stability of the modified asphalt. In this study, we used a polymeric mixture consisting of [polyvinyl acetate (PVA): polyvinyl chloride (PVC)][21] as a supplement to asphalt to enhance the qualities of Iraqi asphalt to accommodate the cold winters and scorching summers, as well as to withstand these environmental conditions with repetitive loads that cause the asphalt used to pave roadways to distort [22].

MATERIALS AND METHODS

Treating asphalt with a polymer mixture

A measured amount of asphalt was placed in the processing device, after which a mixture of [polyvinyl acetate (PVA): polyvinyl chloride (PVC)] was added at a fixed mixing ratio (1:1) with an increase in the percentage of the polymer mixture in each treatment and with 1% nano-sulfur serving as a binding agent, with the reactants mixed well and continuous stirring at a temperature of (150-170 degrees Celsius) for 60 minutes[23].

Determination of the asphalt rheological characteristics

After completing the treatment of asphalt with the polymer additive at different ratios, the process of determining the best samples obtained was carried out by measuring the rheological properties represented by examining the softening point [24], penetration [25], degree of ductility [26], and penetration index [27], and then measuring the Marshall test [28] and aging [29] for the modified asphalt samples.

RESULTS AND DISCUSSION

The chemical, mechanical, and physical properties of asphalt are altered when modified with polymers and other additives. “Modified asphalt” is a term used to describe asphalt whose characteristics have changed. Our study concentrated on the use of polymeric mixture (PVC: PVA) in modifying the properties of Iraqi Dora asphalt by improving its rheological properties with various additives [11], and to obtain asphalt with suitable specifications for paving roads. This was done by improving bitumen’s properties at low temperatures, moisture resistance, and at high temperatures, as well as its capacity to bear repeated, high loads. Nanotechnology has emerged as an essential tool for improving mechanical performance by customizing surface features, and this modification process is in line with the latest developments in material science. Numerous studies have examined the effects of nanoscale alterations on the rheology of asphalt. Studies suggest that nanoscale surface engineering significantly enhances adhesion, durability, and deformation resistance, among other material qualities [36, 37]. Furthermore, the COVID-19 pandemic intensified trash disposal problems, and the accumulation of plastic waste has become a serious environmental challenge. Studies on plastic waste management emphasize the importance of recycling plastic materials for infrastructure applications [38]. This lends credence to our strategy of enhancing the sustainability and longevity of asphalt by modifying it with polymeric waste materials. Moreover, the synthesis of hybrid nanomaterials has gained attention for its potential to revolutionize composite materials used in road construction [39].

The original asphalt and paving asphalt rheological characteristics

The original asphalt rheological characteristics, which were obtained from the Dora refinery, were measured and shown in Table 1.

The Iraqi standard standards for paving asphalt, which are displayed in Table 2, served as the basis for the asphalt modification procedure.

Treatment of asphalt with the polymer mixture

The asphalt was treated with the polymer mixture (PVC: PVA) as shown in the practical part at temperatures that range from (150-170) for (60 minutes) in the asphalt treatment device. It is worth noting that The Polyvinyl acetate is a polymer consisting of repeating units derived from the monomer vinyl acetate, and its overall chemical formula is $[-CH_2-CH(OCOCH_3)-]_n$ PVA is a thermoplastic polymer with good viscosity, and is

Table 1. Rheological Characteristics of Original Asphalt.

Properties	Value
Ductility (cm)	+150
Penetration (100gm.5sec.25°C)	45.3
Softening point (°C)	48
penetration index (PI)	1.915

Table 2. Rheological properties of paving asphalt according to Iraqi specifications [16].

Properties	Value
Ductility/ (cm)	+100
Penetration/ (100gm.5sec.25°C)	40-50
Softening point/(°C)	50-58
penetration index/ (PI)	2 _+2

Table 3. Details of asphalt altered using a polymer mixture (PVC: PVA).

Sample	Polymer mixture %	Ductility (cm, 25 ºC)	Penetration, mm (100 g, 5 sec, 25 ºC)	Softening point (ºC)	penetration index (PI)
AS_1	1	+150	44.6	54	0.510
AS_2	2	141	43.8	58	+0.304
AS_3	3	+150	43.6	56	0.124
AS_4	4	+150	41.7	58	+0.191
AS_5	5	95	41.2	59	+0.365
AS_6	6	74	37.2	66	+1.429
AS_7	7	48	29.7	76	+2.488

applicable in improving adhesion.Relatively stable at high temperatures

Polyvinyl Chloride (PVC)Molecular formula: (C_2H_3Cl) nIt consists of repeating units of vinyl chloride, produced by polymerization of vinyl chloride monomer (Vinyl Chloride). Chemical composition of the basic monomer unit:

[CH2=CHCl]. PVC is a thermosetting polymer characterized by hardness and strength.It begins to thermally decompose at temperatures ranging from 140-160 degrees Celsius[30].

The treatment was done using several asphalt samples, as 1% of the polymer mixture was mixed in the first sample (AS1) with a specific weight of asphalt, and in the second sample ((AS2) 2% of the polymer mixture was mixed with the same amount of asphalt in the first sample, and thus the percentage of 1% of the polymer mixture was

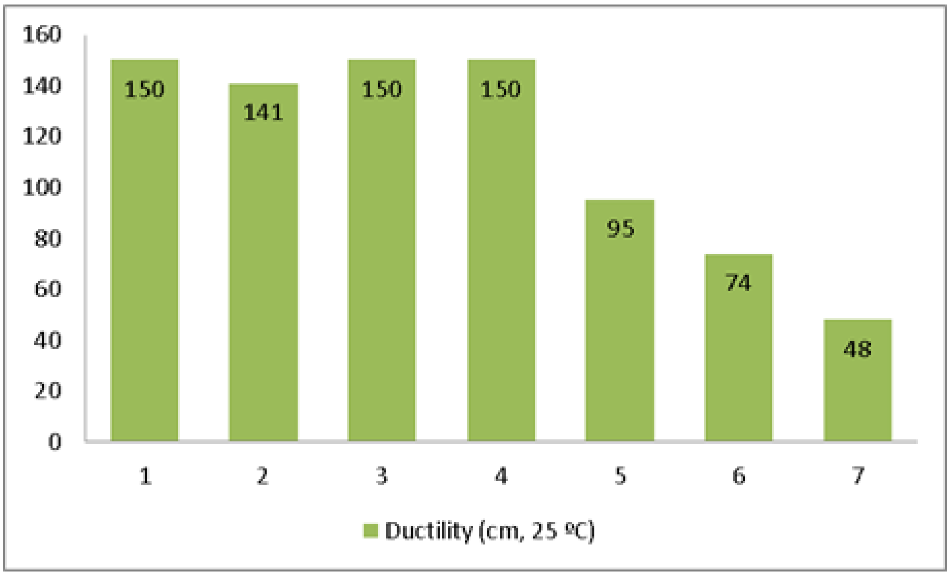

Fig. 1. Values of the degree of ductility of asphalt samples modified with polymeric mixture at different ratios.

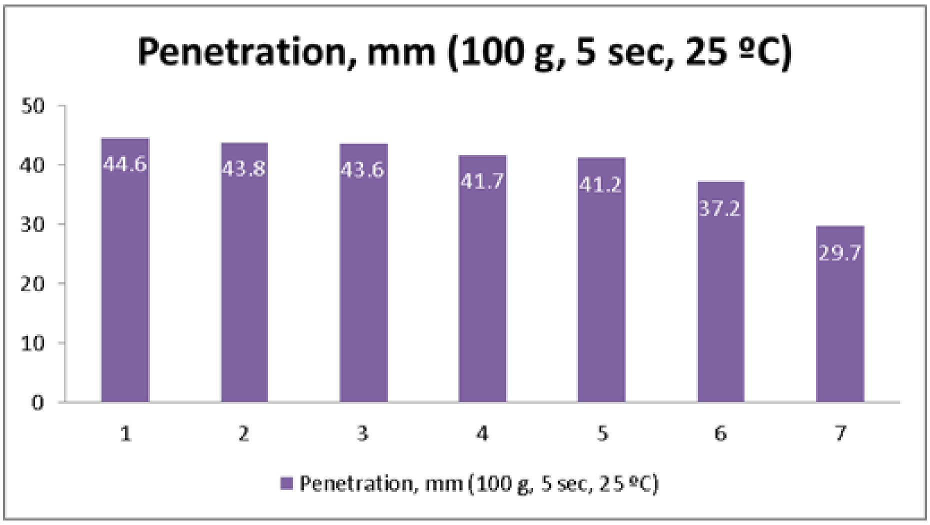

Fig. 2. Penetration values of asphalt samples modified with polymeric mixture at different ratios.

increased and then the rheological properties represented by the Ductility, penetration, softening point and penetration index of the modified Bitumen were measured and compared with the rheological properties of the original asphalt shown in Table 1. Table 3 and Figs. 2, 3, and 4 show the rheological properties of the modified asphalt polymer mixture (PVC: PVA).

We notice from Table 3, which displays the results of rheological measurements for asphalt samples modified with different percentages in the polymer mixture (PVC: PVA), that the percentages (1, 2, 3, 4) % are all better than the original asphalt based on the standard specifications for Iraqi paving asphalt, whose properties appear in Table 1. We also noticed a gradual decrease in penetration values with the increase in the percentage of the additive.. This suggests that the asphalt's hardness has increased for samples with increasing the percentage of the additive. As for the softening point values, they remained constant and within the standard specifications up to the percentage of 4%, and then at the percentage of 5% they began to decrease gradually, this implies that the hardness of the asphalt has grown for samples with raising the mixture's proportion, which is consistent with the penetration test. As for the degree of softness, it began to rise clearly at the percentage of 6% and became outside the standard specifications, The colloidal system was a hybrid of the type (Sol-Gel Asphalt) as the penetration index (PI) value for all results ranged between (2 _2 +) i.e. [12]. within

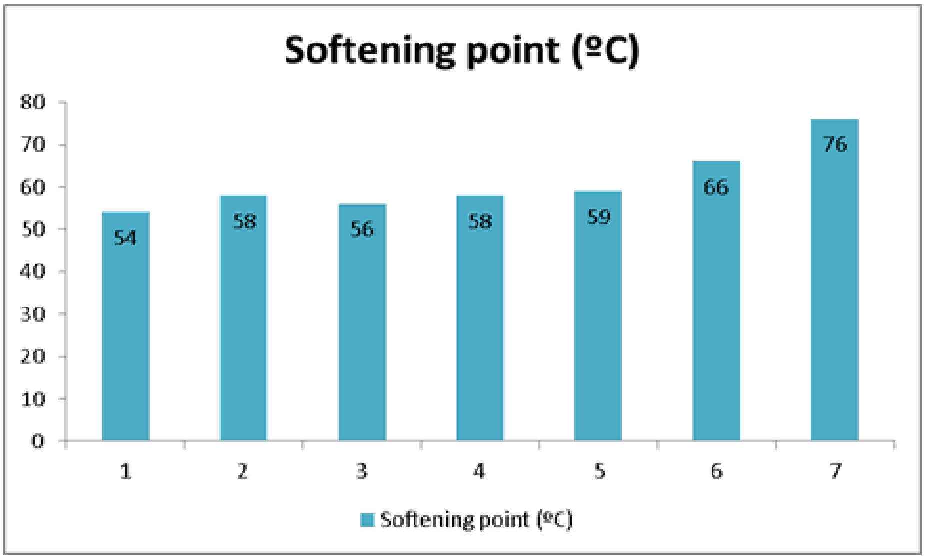

Fig. 3. Softening point values of asphalt samples modified with polymeric mixture at different ratios.

Table 4. Marshall test.

	Modified asphalt (best samples)			Percentage of asphalt added to aggregate (%)
Sample	Stability (KN)	Flow (mm)	[MQ]	
AS_0	10.2	5.3	1.92	4.5
AS_1	15.2	3.2	4.75	
AS_2	15.4	2.9	5.31	
AS_3	17.8	3.2	5.56	
AS_4	15.4	3.3	4.66	
AS_5	14.8	2.3	6.43	
AS_6	13.2	2.1	6.28	
AS_7	9.4	1.8	5.22	
AS*	7 Minimum	24	3.5 Minimum	

AS* Roads and Bridges Authority specifications the standard specifications except for the sample (AS7) which was outside this value. Figs. 1, 2, and 3 show the ductility, penetration and Softening point values in a clear graphical manner.

Marshall test

To understand the suitability of the modified bitumen samples with polymer mixture for road paving operations, the Marshall test (asphalt paving) was conducted. This test indicates the extent to which the asphalt can withstand repeated loads in the event that it is used as asphalt paving through the use of pressure on the sample to be examined[18]. When the sample begins to distort, the stability and creep measurements are taken through specific gradations available in the device. Table 4 shows Marshall test results for original bitumen (AS0) and samples whose specifications were improved using polymers (PVC: PVA).

We note from the results of the Marshall measurement shown in Table 4 that the stability and creep values of most samples modified with polymer are better than the original asphalt sample. This indicates the ability of the modified asphalt to withstand continuous wheel movement as well as repeated loads, and thus the possibility of using the modified asphalt in the road paving process. The stability and creep values were observed to have changed significantly for the better compared to their values in the original asphalt, especially in the samples (AS1, AS2, AS3, AS4). Then the creep values began to deteriorate in sample AS5 and continued to deteriorate to the extent of sample AS7. As for the stability values, they began to deteriorate in samples AS6, AS7. The Marshall stability quotient value (MQ) was also found, which we obtained by dividing the stability value by the creep values. It was noted that the MQ value for the modified sample is higher than the (MQ) value for the original asphalt [31].. Therefore, this explains that the use of the polymer mixture (PVC: PVA) used in modifying asphalt under certain conditions of temperature and time and at specified ratios increased the stability value significantly through (the stability) and (creep values) of the samples. These results indicate that the bitumen modified with the above-mentioned mixture can be used in the process of paving roads in a manner that is compatible with environmental conditions represented by high and low temperatures in addition to repeated loads.

Aging test

It is known that the rheologic properties of asphalt change when exposed to different weather conditions after some time, so we conducted a time aging test to determine the degree of influence of polymer modified asphalt by (aging) factors and compare it with the original asphalt, so the AS3 sample was selected, which represents the use of 3% of the polymer mixture (PVC: PVA) and subjected to the aging test and compared the effect of aging on the asphalt samples by measuring the rheologic properties before and after the aging test. The reason for choosing the sample AS3 as the best sample is due to the excellent stability and creep values that we obtained when testing it with the Marshall test. Table (5) shows the results obtained as a result of the aging test for the original asphalt (AS0) and the sample altered with the polymer mixture AS3.

We note from Table 5 The effect of modified bitumen sample with aging factors is very low compared to the original sample, as it was observed

Table 5. Time aging of asphalt samples

Samples	Rheological properties	Before Aging	After Aging
AS0	Ductility (cm,25◦c)	+150	145
	Softening point(◦c)	48	51
	Penetration (100gm,5sec,25◦c)	45.3	38.7
	Penetration Index (PI)	1.915	1.500
AS3	Ductility (cm,25◦c)	+150	+150
	Softening point(◦c)	56	57
	Penetration (100gm,5sec,25◦c)	43.6	43.4
	Penetration Index (PI)	0.124	+0.076

through the aging examination in general, this that the modified bitumen samples are distinguished by strong resistance to stresses and the noninfluence of the modified bitumen sample by the aging conditions is attributed to the improvement of the rheological properties represented by the increased durability of the asphalt sample and its tolerance to stresses and different temperatures, thus leading to a reduction in thermal cracking and an increase in its ability to withstand the development of grooves and Cracks are caused by harsh conditions [32]. The results of modifying the asphalt specifications using polymers and nano-sulfur qualify the modified asphalt sample for use in paving in a manner that is compatible with the unique weather conditions in Iraq, especially about the difference in temperatures in summer and winter, as well as the difference in the climate of the different regions of Iraq, and that the aging conditions do not affect its rheological properties.

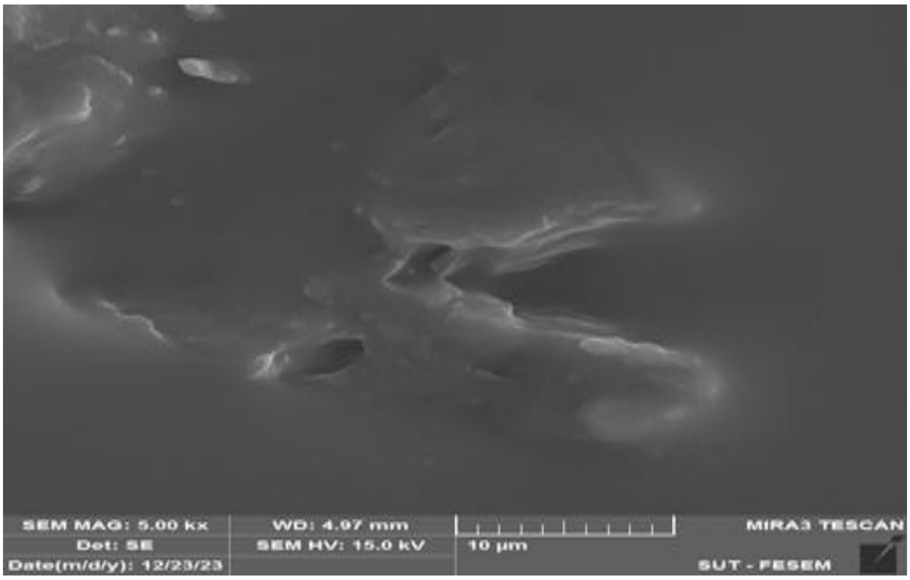

Fig. 5. Scanning electron microscope images of the modified sample. (AS3).

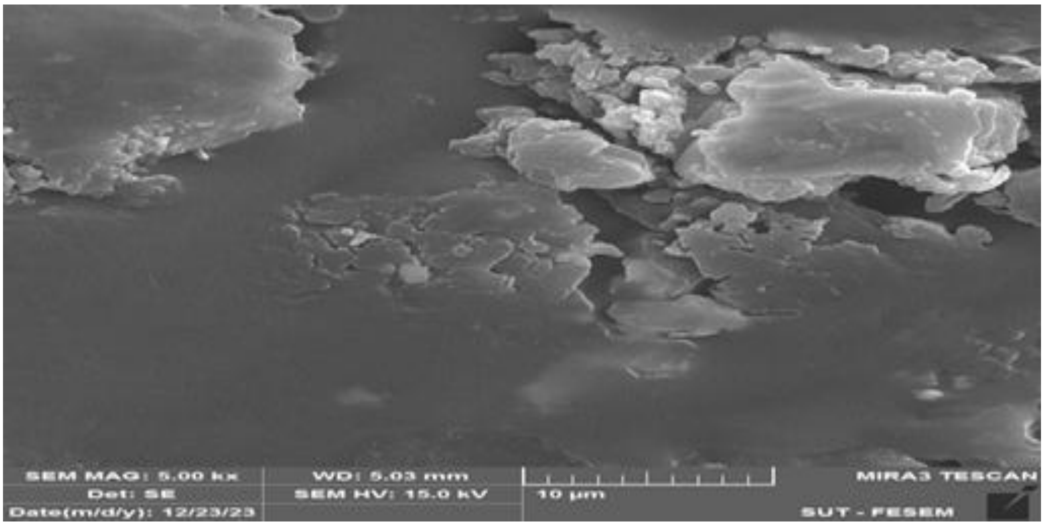

Fig. 4. Scanning electron microscope images of original asphalt (AS0).

Scanning Electron Microscope (SEM) examination of the asphalt samples.

The scanning electron microscope examination was conducted for field emissions (SEM) on a few chosen samples that we acquired from the asphalt modification with polymer blend. Adding the polymer mixture with Nano-sulfur to the asphalt material changes the chemical composition of the asphalt as well as changing the surface properties and morphological properties of the asphalt because the shape properties of the modified asphalt are the result of the mutual effects between the polymer and the asphalt [33-35]. Through the (FESEM) images, we notice that the role of adding the polymer at temperatures (150-170°C) is clear in changing the composition and surface shape of the asphalt (Figs. 4 and 5)..

Overall, the results obtained from this study confirm that polymer-modified asphalt exhibits improved rheological properties, making it a viable material for road construction. The approach of combining polymeric materials with nanotechnology-based modifications can contribute to sustainable infrastructure development while addressing environmental concerns related to plastic waste.

CONCLUSION

1-The possibility of improving the rheological specifications of asphalt and qualifying it as paving asphalt using the polymeric mixture (PVC: PVA) at a mixing ratio of (1:1) under specific conditions of temperature and reaction time.

2- Using nano sulfur as a binder for asphalt in the process of modifying asphalt with polymer mixtures.

3-As Marshall and aging experiments have demonstrated, asphalt samples with suitable rheological parameters can be used for road paving because they withstand a variety of environmental factors, including high and low temperatures, continuous loads, and aging.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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