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Influence of Controlled Heat and Pressure on the Properties of Modified Asphalt Cement

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Abstract

The asphalt cement is obtained as a byproduct through the distillation process of crude oil, it requires further processing to control its constituents and quality. In Iraq, the processing units are out of order due to aging and lack of maintenance, and the produced asphalt cement does not match the standard specification required for paving work. One of the existing remedy process is to go for modified asphalt cement, which can be prepared by the addition of certain additives. The preparation method of modified asphalt cement has a great influence on its quality. In this work, asphalt cement of 44 penetration grade was obtained from Dora refinery, south of Baghdad, the asphalt cement had experienced physical and rheological properties determination. Asphalt cement was then digested with three types of modifiers, scrap tire rubber, Styrene-butadiene-styrene (SBS) and low density Polyethylene (LDPE). A cooking pressure vessel of 6 liters capacity was implemented throughout the preparation process of modified asphalt cement. The mixture was subjected to four mixing periods (10, 20, 30 and 50) minutes and a temperature of 130°C and the pressure applied by the vessel was maintained to 1bar (15 Psi). The modified asphalt cement obtained was subjected to physical and rheological properties determination, and the test results have been analyzed and compared. It was concluded that the controlled heat and pressure and mixing period have a various positive or negative impacts on the overall properties of modified asphalt cement.

Keywords

Modified Asphalt Cement, Mixing Temperature, Pressure, Rheology, SBS, LDPE, Scrap Tire Rubber

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1. Introduction

Modified asphalt cement was developed to support the required physical and rheological characteristics of asphalt cement under extreme loading, and environment conditions. Asphalt cement modifiers have proved acceptable performance when subjected to moisture damage, and have controlled the impact of temperature susceptibility of the binder, [1].

Methods of mixing such modifiers with asphalt cement can enhance the future performance and durability. The mixing procedure should accommodate the physical homogeneity and chemical reaction so that the final modified asphalt cement can withstand the repeated loading stresses and provide the required durability for the design life of the pavement structure, [2]. [3] Used crumb to modify asphalt binder and the short-term aging effects on the properties of modified asphalts were evaluated. Penetration, softening points, ductility, viscosity, elastic recovery, low temperature creep, and rutting susceptibility were tested and analysed before and after thin film oven test. The results indicated that the softening point, viscosity, elastic recovery, creep

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stiffness, are all linearly increased with increasing age, while the penetration and ductility are linearly decreased with increasing age. The temperature susceptibility behavior of virgin and polymer modified asphalt was evaluated by [4] and suggests some practical implication considering local industry use. Six polymer modified asphalt samples were prepared in the laboratory and tested with two virgin grades and one factory polymer modified sample using Dynamic Shear Rheometer (DSR). The testing results revealed that polymer modification has significant impact on rheological properties of asphalt binder.

[5] Had prepared the modified Asphalt cement for pavement construction in the laboratory by digesting each of the two penetration grade Asphalt cement (40-50 and 60-70) with sulphur, fly ash, silica fumes. Three different percentages of each of the above mentioned additives have been tried using continuous stirring and heating at 150ºC for 30 minutes. The prepared modified Asphalt specimens were subjected to physical properties determination; the penetration, softening point, ductility before and after laboratory aging. It was concluded that all percentage of additives has reduced the penetration value of asphalt cement. Softening point was increased with the addition of all percentage of additives.

The effect of adding several types of polymers on asphalt cement was evaluated by [6]. Experimental program involved modifying the asphalt using six types of polymers then evaluating the properties of the modified asphalt. It was found that the optimum percentage of PVC, plastic bags and novolac was 4%, and the optimum percentage of high density polyethylene HDPE was 5% by weight of asphalt. These percentages caused increase in kinematic viscosity, and caused reduction in penetration.

A paper was presented by [7] which deals with the procedure for modification of 80/100 -paving grade asphalt cement using reclaimed polyethylene (PE) derived from low-density polyethylene carry bags collected from domestic waste. The details of the preparation of the PE-modified binder and the results on variation of binder properties with blending temperature and blending time were presented. Results of various tests carried out on the different PE blends indicated enhanced binder properties like improved storage stability, resistance to aging, degradation, and temperature susceptibility. It was observed that viscosity at a given temperature increases with the addition of PE in the binder. It was found that 5% PE content in modified asphalt by weight is adequate in terms of enhanced binder properties studied.

Laboratory investigations was carried out by [8] to determine the various engineering properties such as physical properties of asphalt cement and (polymer modified asphalt binder) PMAB with (styrene-butadiene-styrene triblock copolymer) SBS. The temperature susceptibility of PMAB-SBS is lower than asphalt cement. Moisture susceptibility of PMAC mixes is low when compared to AC mixes.

It was stated by [9] that a styrene-butadiene-styrene (SBS) modified asphalt cement was characterized by empirical tests such as ring and ball softening point, penetration and elastic recovery. After aging in the rolling thin-film oven, the polymer-modified asphalt presented structural changes relating to oxidation of the material. The physical characterization showed modified asphalt with greater penetration than the unmodified asphalt cement. Its thermal susceptibility and elastic recovery were also improved.

The aim of this investigation was to verify the capability of using controlled mixing period, heat and pressure in the production of modified asphalt cement for pavement construction.

2. Materials and Methods

2.1. Asphalt Cement

Asphalt cement of (40-50) penetration grade was implemented in this study. It was obtained from Dora Refinery. Test procedures have been conducted according to ASTM [10] on asphalt cement to determine its physical and rheological properties. The test results are demonstrated in Table 1.

Table 1. Physical and rheological properties of asphalt cement.

Physical properties				Rheological properties			
Penetration	Softening point (°C)	Ductility (Cm)	Specific gravity	Penetration index (PI)	Kinematic Viscosity (CSt.)	PVN	Stiffness modulus (N/m^2)
44	48	150	1.04	- 1.7	365	1.2	8×10^6

2.2. Polymer Modifiers

Three types of polymer modifiers have been implemented, their properties as obtained from the manufacturers are presented in Table 2, while Figure 1 shows the polymers type implemented.

Table 2. Properties of polymer additives.

Polymer type	Density (gm/cm^3)	Melting temperature (°C)	Tensile strength (MPa)	Tensile elongation at yield (%)	Melt flow index (g/10min)
LDPE	0.92	110	20	600	2.0
SBS	0.85	180	16.5	660	0.3
Tire rubber	1.3	210	18	565	0.5

2.3. Mixing of Asphalt Cement with Polymer Modifiers

A cooking pressure vessel of 6 liters capacity was implemented throughout the preparation process of modified asphalt cement. Three percentages of each type of polymer additives have been implemented based on the literature survey conducted so that the variation in the physical and rheological properties among these additive percentages could be clearly detected. The mixture was subjected to four mixing periods (10, 20, 30 and 50) minutes and a temperature of 130°C and the pressure applied by the vessel was maintained to 1bar (15 Psi).

Figure 1. Type of polymer additives implemented.

Heating of the pressure vessel was applied through electric hot plate with a thermostat control. Figure 2 demonstrates the cooking pressure vessel implemented. After each mixing period, the pressure was released through the safety valve, and the vessel cover was removed as shown in Figure 3. Figure 4 shows the swelling and formation of bubbles that could be observed after each mixing period indicating the chemical reaction occurred due to temperature and pressure.

Figure 2. Pressure vessel.

Figure 3. Temperature check.

Figure 4. Modified binder.

3. Results and Discussion

3.1. Physical Properties of Modified Asphalt Cement

As demonstrated in Figure 5, the polymer modifiers causes reduction in the ductility which represent the flexibility of modified asphalt as compared to that of virgin asphalt. The scrap tire rubber exhibit the lowest ductility values among other additives, the reduction in ductility which is a measure of flexibility was in the range of (88-91)%, (77-83)%, and (86-66)% for scrap tire rubber, SBS and LDPE respectively for various mixing periods. Similar findings were reported by [11].

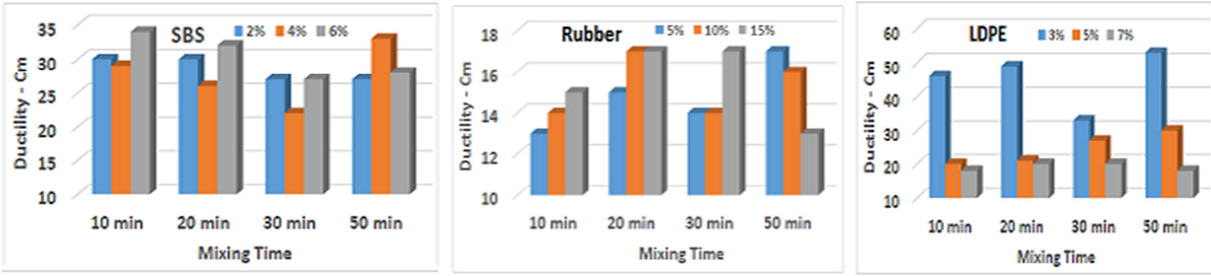

Figure 5. Influence of polymer additives on Ductility of asphalt cement.

It can also be observed that 10 and 20 minutes of mixing period could not provide a significant variation in ductility between various percentages of SBS modifier. On the other hand, the influence of mixing period is considered effective for rubber and LDPE polymers additive. 3% of LDPE is proved to be sufficient at various mixing periods.

Figure 6 exhibit the influence of polymer modifiers on softening point of asphalt cement which represent the susceptibility of asphalt cement to the temperature. The polymer modifiers exhibit an increment in the softening point in a range of (25-8)%, (12-4)%, (18-4)% for rubber, SBS, and LDPE respectively at various mixing periods. It can be observed that (10, 6, and 7)% of rubber, SBS, and LDPE respectively shows the higher softening point among other percentages of additives regardless of the mixing time. On the other hand, 50 minutes of mixing period provides a suitable softening point for rubber modified asphalt, while the effect of mixing period was not significant changing the softening point for SBS and LDPE polymer additives. Similar findings have been reported by [1] and [12].

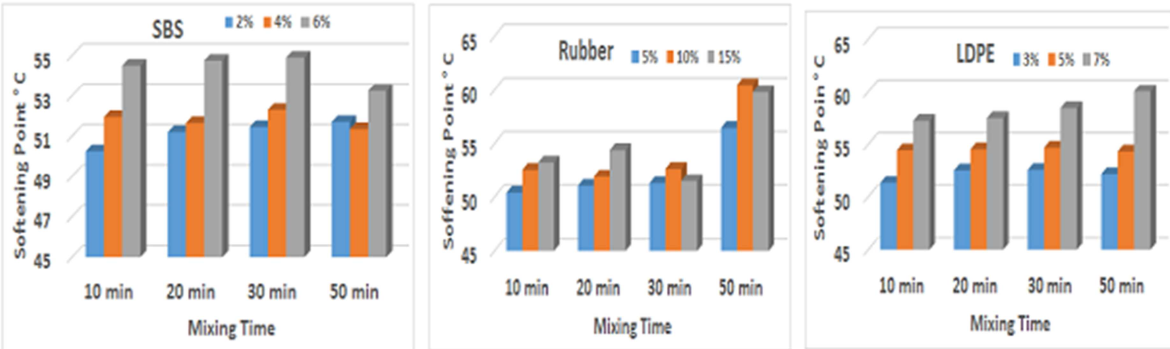

Figure 6. Influence of polymer additives on Ductility of asphalt cement.

Figure 7 present the impact of polymer additives on penetration of asphalt cement, penetration is a measure of consistency. It can be observed that penetration decreases after digestion of asphalt cement with polymer additives at all of the mixing periods. Penetration decreases in a range of (65-4)%, (66-23)% and (84-34)% for rubber, SBS, and LDPE respectively at various mixing periods. It can be observed that at 50 minutes of mixing period, the variation of SBS percentage was not significant, this may be attributed to the possibility of good chemical reaction taken place. On the other hand, stiffer mixture was obtained after 50 minutes mixing period when LDPE was implemented.

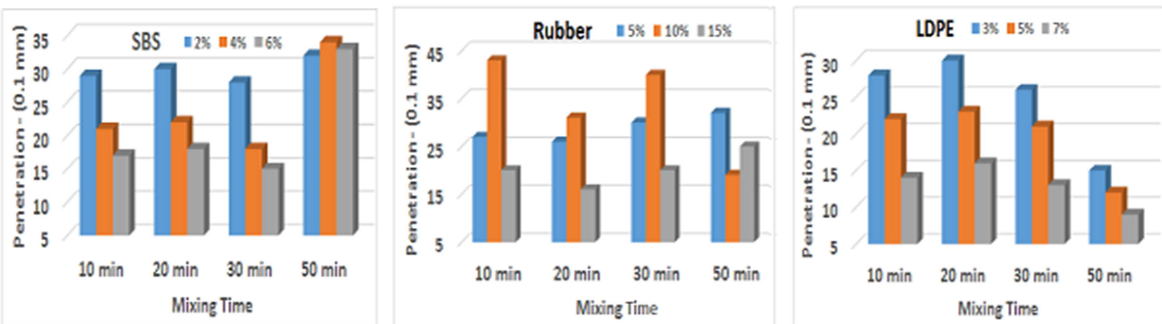

Figure 7. Influence of polymer additives on Penetration of asphalt cement.

3.2. Rheological Properties of Modified Asphalt Cement

The penetration index (P.I) which is a theoretical measure of temperature susceptibility of the binder's viscosity and gives a measure of its deviation from Newtonian behavior is presented in Figure 8. Such index was proposed to characterize asphalt cement according to its rheological behavior. Asphalt binder with (P.I) between +1 and -1 are suitable for pavement construction, [2]. On the other hand, (P.I) values below -2 are of brittle asphalt binder at low temperature while values above +2 indicates asphalt that have a flow behavior at large strain and marked time-depended elastic properties, [4]. It can be noticed that penetration index increases in a range of (25-30)%, (11-30)% and (12-3)% at lower mixing time for rubber, SBS, and LDPE respectively at various additive percentages as indicated in Figure 8. It can also be noted that 50 minutes of mixing time is sufficient to control the penetration index within the required specification of ±2 for SBS and Rubber additives and improves its resistance to temperature susceptibility. On the other hand, 30 minutes of mixing time is suitable to control the penetration index when implementing LDPE additive regardless of its content.

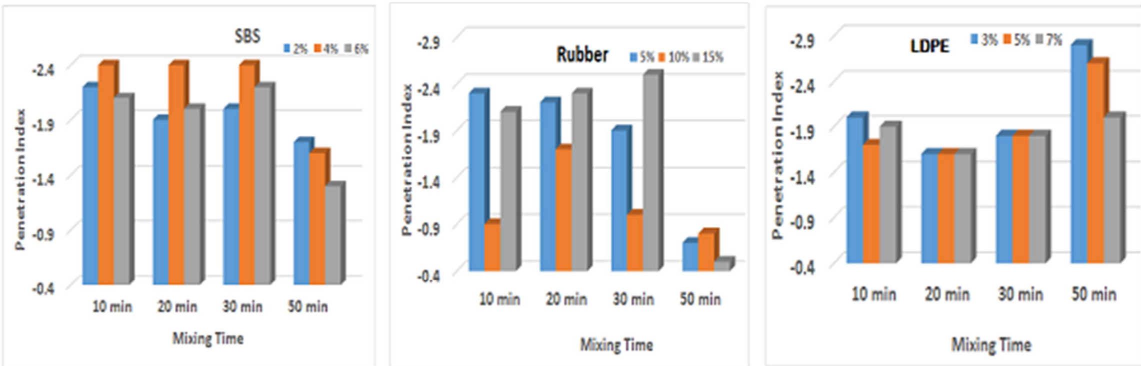

Figure 8. Influence of polymer additives on Penetration Index of asphalt cement.

The kinematic viscosity is currently the main asphalt property used to grade asphalts. Figure 9 exhibit the influence of polymer additives on the kinematic viscosity of asphalt cement. At lower mixing time, the viscosity increases, this may be attributed to the fact that the chemical reaction that is proposed to occur needs more time, however, at higher mixing time the viscosity decreased. Such changes in viscosity is hard to explain by classical models but could be explained by a model on a micro- and Nano-scale. One could imagine that a rearrangement of the particles in such mixes could take place by producing larger gaps (by making others smaller). The addition of polymer modifiers has a marked effect on the viscosity of asphalt cement, the increase in viscosity was rapid at 10% 2% and 3% rubber, SBS and LDPE content, while it was moderate at other percentages of polymers. 50 minutes of mixing time seems to be suitable for SBS to maintain the viscosity at various additive percentages.

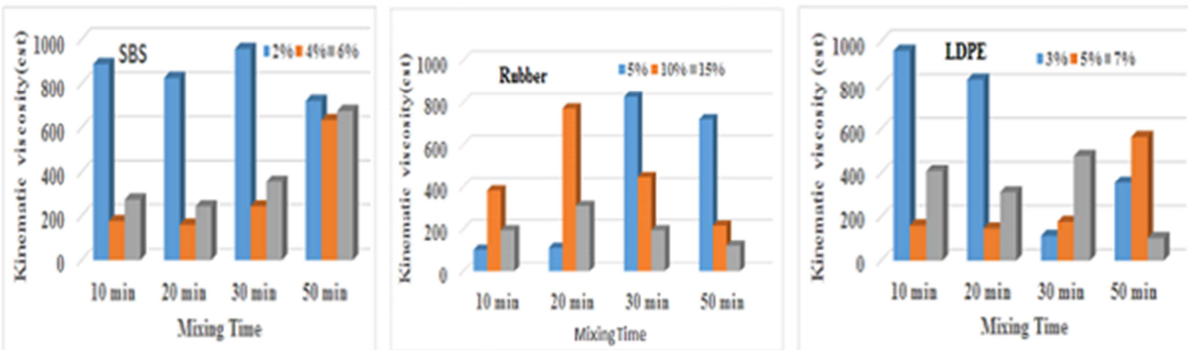

Figure 9. Influence of polymer additives on Kinematic viscosity of asphalt cement.

The penetration viscosity number (PVN) is based on an empirical correlation between penetration at 25°C and viscosity at 60°C. Figure 10 shows the influence of polymer modifiers on (PVN) of asphalt cement. The addition of SBS polymers had reduced the PVN value at 50 minutes mixing time regardless of its percentage. Similar behavior could be noticed for LDPE polymer, while rubber increases the PVN value. Such finding was in agreement with [11] work.

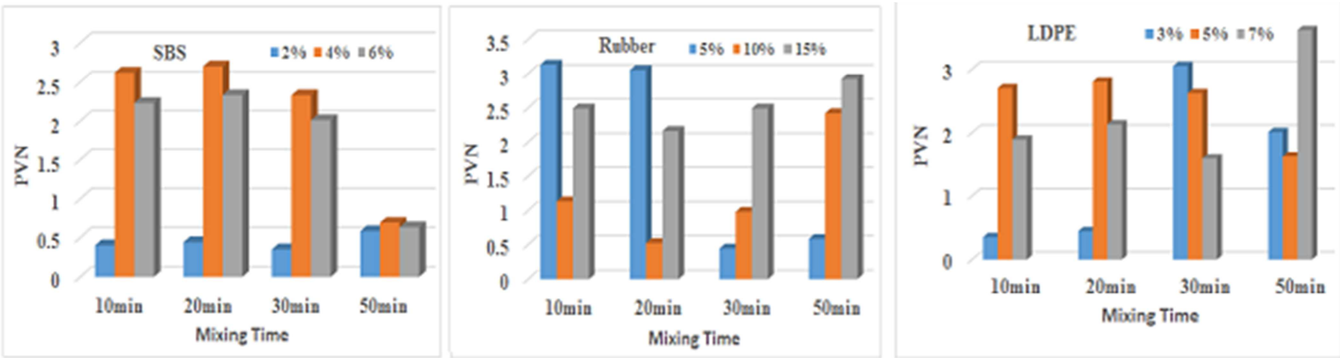

Figure 10. Influence of polymer additives on Penetration Viscosity Number of asphalt cement.

Asphalt stiffness modulus is a simple means of characterizing asphalt consistency over a wide temperature range. Figure 11 shows that the stiffness modulus of asphalt cement had increased by ten folds after digestion with polymer additives. This may be attributed to the increase in viscosity. The Stiffness Modules which is defined as the ratio of stress to strain was obtained from shell Nomo graph at [TR&B 75°C], and temperature of asphalt at [25°C] with a loading frequency of [10 Hz].

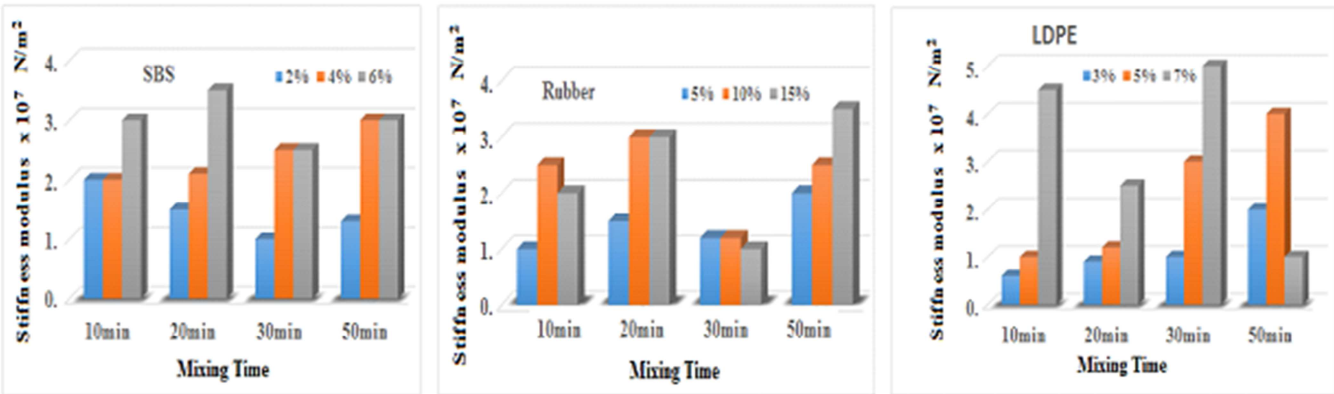

Figure 11. Influence of polymer additives on Stiffness modulus of asphalt cement.

4. Conclusions

1- The reduction in ductility of asphalt cement was in the range of (88- 91) %, (77- 83) %, and (86- 66) % for scrap tire rubber, SBS and LDPE respectively for various mixing periods.

2- The polymer modifiers exhibit an increment in the softening point in a range of (25-8)%, (12-4)%, (18-4)% for rubber, SBS, and LDPE respectively at various mixing periods.

3- Penetration decreases in a range of (65- 4)%, (66- 23)% and (84-34)% for rubber, SBS, and LDPE respectively at various mixing periods.

4- Penetration index increases in a range of (25-30)%, (11-30)% and (12-3)% at lower mixing time for rubber, SBS, and LDPE respectively at various additive percentages.

5- The addition of polymer modifiers has a marked effect on the viscosity of asphalt cement, the increase in viscosity was rapid at 10% 2% and 3% rubber, SBS and LDPE content, while it was moderate at other percentages of polymers.

6- The stiffness modulus of asphalt cement had increased by ten folds after digestion with polymer additives.

7- Implementation of controlled heat and pressure is capable for production of modified asphalt cement at an optimum mixing period of 50 minutes.

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