Optimization of mixing time for polymer modified asphalt

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Abstract. Asphalt pavement made with neat binder is not sufficient to resist heavy traffic loads as well as harsh environmental condition. Therefore, there is a need to modify the binder with polymers in order to improve its properties. From literature, it was indicated that various blending process parameters, namely, blade shape, temperature, shear rate and mixing time influenced the properties of the produced polymer modified asphalt. In this study, the influence of mixing time on six different types of polymer with 60/70 asphalt binder was focused. The polymers were blended with asphalt binder and inspected at 30 minutes intervals during the mixing process. Then, all the samples were tested through Dynamic Shear Rheometer at 58ºC, 64ºC and 70ºC. It was shown that the complex modulus (G*) values at these temperature levels for all polymers modified asphalt indicated proper particles dispersion within the binder. The optimal blending time, which produces the best rheological properties of all modified asphalt is 30 minutes except for asphalt modified with Lucolast7010 and Anglomak2144, which is 60 minutes. In conclusion, mixing time has significant influence on the particle distribution of polymer within the binder to ensure the quality of asphalt-polymer blend.

1. Introduction

Since asphalt binder and polymers are of non-homogeneous nature, polymer is required to disperse and not to dissolve in the asphalt binder. Polymer modifiers are usually supplied indifferent forms. They are mainly supplied as a powder (fillers), pellets (granules), fibers, and liquid form. Each modifier has its own way of mixing and handling. It depends on the modifier type and the purpose of usage. For each modifier, the method of mixing and handling is known either from experience or from supplier recommendations [1]. The quality of asphalt-polymer blend is affected by the type of the asphalt, type and concentration of polymer and the shear rate applied by the mixer[2].

There are several ways of blending polymers with asphalt. In the field, one of the very useful techniques is in-line blending of the polymer into the asphalt feed line. Another technique is pre-blending polymer at the asphalt terminal, refinery, batch plant and drum plant operations[3, 4]. In laboratory, it is recommended that the blending machine is capable of providing high shear rate. The configuration of the blender head (i.e., the blade) and the speed of blending define the level of shear rate that the blender induces into the asphalt binder. The recommended speed should not be less than 2500 Rotation Per Minute (RPM)[5-8]. Optimum blending time is evaluated during the blending process at an interval of 30 minutes [7, 8],20 minutes [5], starting from zero until two hours. If a low shear mixer is used, longer mixing time is needed [9, 10].

Al-Dubabe et al.[5] modified Arab asphalt binders by different polymers to satisfy the performance requirements of the Gulf countries, in terms of rutting, fatigue, and low-temperature cracking. For identification of potential polymers, the polymers were blended with asphalt binder from Riyadh Refinery, which is the main supplier for asphalt binder in the Gulf countries. The polymers were blended at concentrations (2%, 4%, 6% and 8% by total binder weight) with 500 grams of asphalt binder to produce the Polymer Modified Asphalt (PMA). Visual inspection using an optical microscope and softening point testing were used to evaluate the homogeneity of the blend at 20-minute intervals from the beginning of the blending operation until 120 minutes.

Al-Abdul Wahhab et al.[7] studied the performance modification of Saudi-asphalt binders using five polymers produced by Saudi Basic Industries Company (SABIC). Polymers were blended with asphalt from Riyadh Refinery at various polymer concentrations (3%, 4% and 5% by total binder weight). Each polymer type was blended with 800 grams of asphalt binder to produce the PMA binder. A high shear mixer with maximum speed of 2500 RPM was used in the study. Optimum blending time was determined by means of complex shear modulus per sine phase angle ($G^*/\sin \delta$) at 76 ºC and evaluated during the blending process at an interval of 30 minutes. The assumed maximum blending time was two hours.

Al-Soliman [8] studied the effect of using polymers for asphalt binder modification. Five grades of low-density polyethylene polymers (LDPE)(120W, 218W, M200024, R50035 and 2022J) and three grades of high- density polyethylene polymers (HDPE) (B4660, M200056, and F00952) were used. The polymer grades were blended at various polymer concentrations (3%, 5% and 7% by total binder weight) and visually inspected at 30 minutes intervals until 120 minutes in order to examine blend consistency and appearance of any unparsed particles. For each blend, a constant quantity of asphalt binder of 950 grams was mixed at a temperature of 180ºC. A high shear mixer with maximum speed of 2500 RPM was used in the study.

The objectives of this study are, (1) to investigate appropriate mixing time for different polymer modified asphalt type, (2) to evaluate the effect of mixing time on binder rheological properties for different polymer modified asphalt type and (3) to propose optimum mixing time which satisfies the dispersion and consistency requirement of polymer modified asphalt.

2. Materials

The asphalt binder used in this study was a 60/70 penetration grade. The properties of the neat asphalt binder are tabulated in Table 1 [11, 12]. Six different polymers, namely, Lucolast7010, Anglomak2144, SBS KTR401, EE-2, Crumb Rubber and Pavflex140 were used in this study as shown in Figure 1. The physical and chemical properties of those polymers are tabulated in Table 2

Table 1: Properties of 60/70 asphalt binder[11, 12].

Properties	Reference	Value
Penetration @ 25°C (0.1mm)	ASTM D0005-05	68
Softening Point (°C)	ASTM D0036-95	48
Penetration Index	-------	- 0.99
Ductility (cm)	ASTM D0113-99	+ 100
Rotational Viscosity @ 135 °C, 20 rpm, (cps)	ASTM D4402-02	487
Specific Gravity	ASTM D0070-03	1.025
RTFO @ 163°C, for 85 minutes, (% wt loss)	ASTM D2872-04	0.07
High Temperature Grade (°C)	ASTM D7175-00	64
Low Temperature Grade (°C)	ASTM D6648-01	- 22

EE-2 Lucolast7010 Anglomak2144

Crumb Rubber Pavflex140 SBS- KTR401

Figure 1. Different polymers used in this study

Table 2: The physical and chemical properties of polymers

Polymers	Physical Form	Density (g/cm^3)	Melting Point (°C)	Melt Flow Index (g/10min)	Components
Lucolast7010	Pellet	0.924	95	3.9	Ethyllene and Butyl Acrylate with low crystallinity.
Anglomak2144	Pellet	0.930	96	3.5	Oxidised Polyethylene Homopolymer.
Paveflex140	Powder	-	212	-	Ethylene Vinyl Acetate Resins.
SBS KTR 401	Pellet	0.94	270	< 1	Styrene Butadiene Styrene.
EE-2	Pellet	0.96	-	-	Medium Density Oxidized Polyethylene.
Crumb Rubber	Pellet	1.2	200	-	Synthetic Rubber, Natural Rubber, Carbon Black, Anti-Oxidants, Fillers.

3. Preparation of polymer-modified asphalt

Polymer-modified asphalts were prepared in the laboratory by blending neat asphalt with polymers without curing. The blending procedure usually defines how the polymer particles disperse within asphalt particles. To get the required performance, the polymer particles should be properly dispersed within asphalt to produce a homogeneous blend. As shown in Figure 2, a Ross blender with a high shear blade was used to blend the polymers with the asphalt. The blending speed was controlled with a direct current motor which capable of producing up to 3000 RPM.

Figure 2. The Ross blending machine and its components

The temperature was controlled through an oil bath heating system. The blending temperature was determined based on asphalt plant blending temperature, as shown in Table 3. The asphalt binder was blended with different percentages of polymers in order to achieve high Performance Grade (PG), which was adopted by the Ministry of Transportation.PG76was selected since it represents the highest performance grading requirements in Saudi Arabia [5, 12]. The samples were tested using the Dynamic Shear Rheometer (DSR) test at 58 ºC, 64 ºC and 70 ºC. 30 minutes intervals were taken during the blending process to examine blend consistency.

Table 3. Temperature and speed of blending

Polymers	Polymer (%)	Temperature (°C)	Speed (RPM)
Lucolast7010	3.6	170	2500
Anglomak 2144	3.2	170	2500
Pavflex140	5	245	2500
SBS KTR 401	3	180	2500
EE-2	4	170	1800
Crumb Rubber	8	180	2500

4. Result and Discussion

In this part, the process of polymer blending with asphalt binder was analyzed and discussed. The effect of mixing time was investigated in order to select the proper mixing time. Polymers were blended with asphalt binder and tested at 30 minutes intervals during the blending process to examine blend consistency and appearance. The samples were tested on dynamic shear rheological properties at different temperatures of 58 ºC, 64 ºC and 70 ºC.

Dynamic shear rheometer test was conducted at various temperatures to evaluate the effect of mixing time on binder rheological properties. Dynamic complex moduli versus time at different temperatures are graphically presented in Figure 3 to Figure 8. It was indicated that there is variation in complex modulus (G*) for all PMA blends at 30 minutes of mixing time. The values of G* increased by increment of mixing time due to dispersion of polymer particles. The G* increment will continue until the polymer particles are completely dispersed. At that point, the G* is expected to stabilize at a certain limiting value. An example of this behavior is shown in Figure 3for asphalt modified with SBS KTR 401. It can be seen that G* values were increased by mixing time increment until 30 minutes. Then, the G* values were leveled off until 120 minutes of mixing time. This means that the minimum blending time to produce a homogeneous blend for the polymer SBS KTR 401 at a concentration of 3.0 % is 30 minutes. This concept was also used to identify the minimum blending times for polymer-modified asphalt binders as shown in Figure 4 to Figure 6.

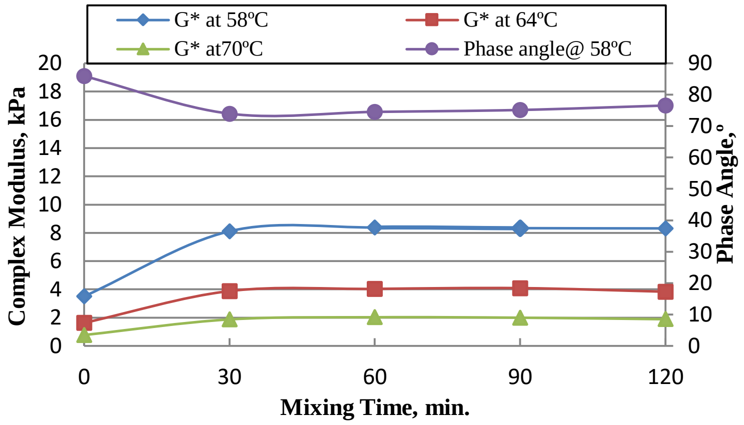

Figure 3. Dynamic modulus and phase angle with mixing time of SBS KTR 401

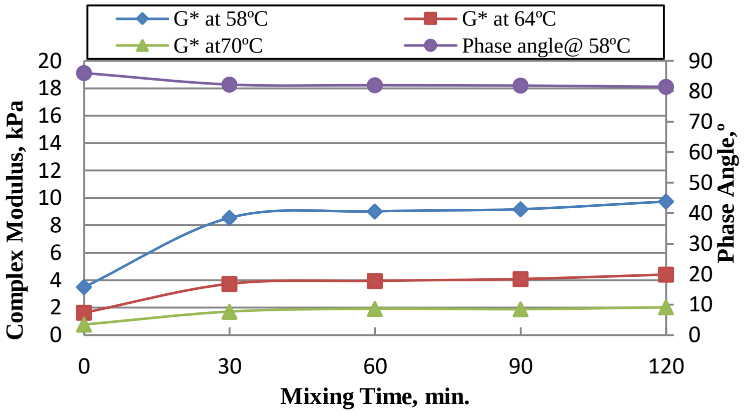

Figure 4. Dynamic modulus and phase angle with mixing time of Pavflex140

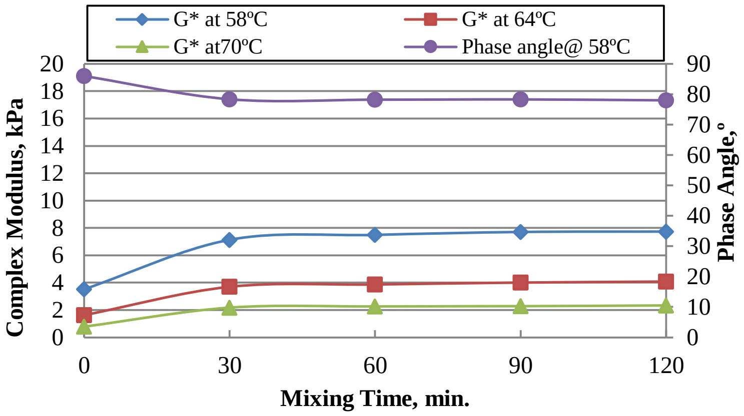

Figure 5. Dynamic modulus and phase angle with mixing time of EE-2

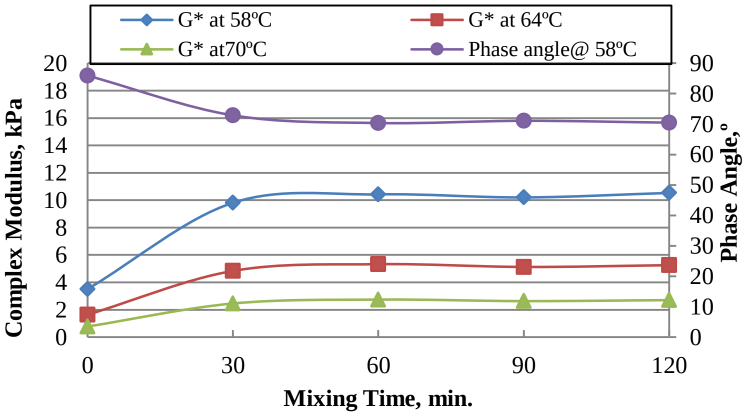

Figure 6. Dynamic modulus and phase angle with mixing time of Crumb Rubber

Lucolast7010 and Anglomak2144 show different trends, as shown in Figure 7 and Figure 8, respectively. Figure 7shows G* values versus mixing time behavior. In general, G* values increased with mixing time to a certain value, decreased slightly and then increased again. However, the amount of increment or decrement were depending on testing temperature. This behavior is probably due to the changes in the degree of polymer particle distribution within the binder as mixing time increases.

Figure 8displays that the value of G* increases with increasing mixing time due to more dispersion of polymer particles until the particle starts to become finely and completely dispersed. At that point, it starts to decrease until the end of fine dispersion. The same behavior was observed in the previous study which was conducted by Al-Soliman [8].

The variation of G* with temperature at specific mixing time can be considered as an indication of temperature sensitivity of the PMA blends. The G* at low temperature (58ºC) showed higher variation with mixing time than at high temperature (70ºC). The same phenomena can be seen for the phase angle, which is a measure of the elasticity part. As the mixing time increased, phase angle decreased due to polymer dispersion. When the dispersion starts to complete and fine, the phase angle stabilizes to a certain limiting value.

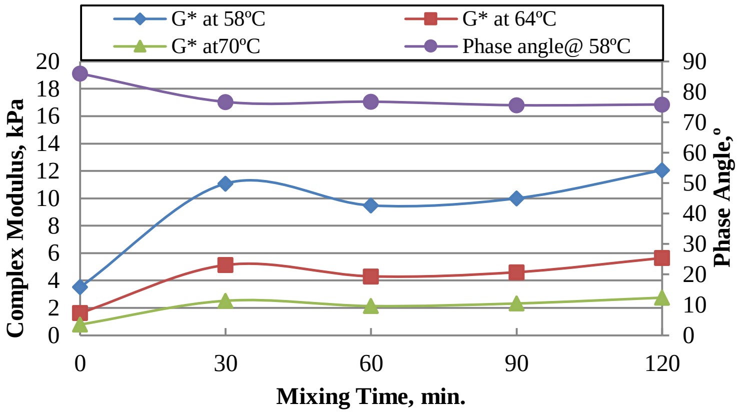

Figure 7. Dynamic modulus and phase angle with mixing time of Lucolast7010

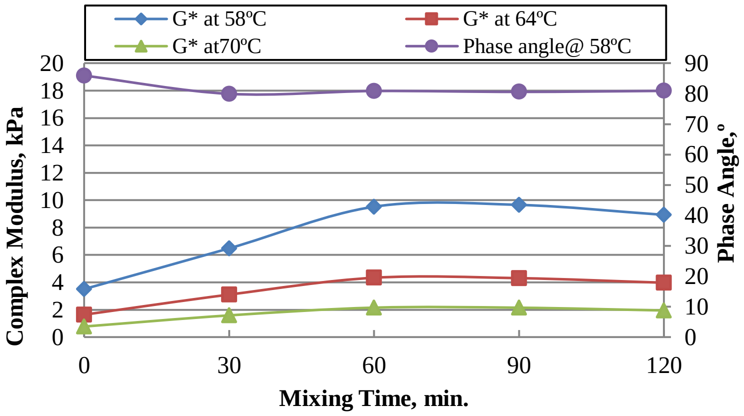

Figure 8. Dynamic modulus and phase angle with mixing time of Anglomak2144

5. Conclusion

Based on the results and analysis of this study, the following conclusions and recommendations can be obtained.

- Determination of mixing time for blending processes can best be made by measuring the changes in complex modulus at 30 minutes intervals during the blending process. Complex modulus at 58°C, 64°C, and 70°C were found to be good measures of proper dispersion and indicated the same trend.
- During the blending process of all polymers except Lucolast7010 and Anglomak2144, complex moduli tends to increase with mixing time until 30 minutes and then were leveled off until 120 minutes mixing time, indicating full dispersion of polymer particles and no change in consistency of blend.
- In this study, one shape of the mixer blade and shear rate were used to blend polymers with asphalt binder. For future work, it is recommended to study the effect of other shapes of mixer blade and different shear rates on blending time.
- 60-70 penetration grade asphalt binder was used in this study. It is recommended to investigate the effect of other asphalt binder grades on properties of polymer-modified asphalt.

6. References

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