Performance Evaluation of Dates Palm Ash (DPA) Modified Bitumen for Sustainable Pavement Construction

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Abstract

The purpose of this research is to investigate the suitability of using Dates Palm Ash (DPA) as binder modification. This study is probably the first attempt to investigate the possible use of Dates Palm Ash (DPA) in bitumen modification. The controlled bitumen of PG 64-10 was used as base binder and DPA of 4, 8 and 12 % by weight of bitumen were used in this study. The rheological tests using Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR) were conducted on un-aged binders. The experimental results showed an improved performance of Dates Palm Ash-Modified Binder (DPA-MB) in terms of resistance against rutting at various temperatures. Finally, it can be concluded that it is feasible to use DPA as bitumen modifier and it will contribute in reducing environmental problems by recycling Dates Palm waste for sustainable pavement construction.

Keywords: Rheology, Temperature, rutting, Dates Palm ash

1. Introduction

Asphalt is a viscoelastic material; hence its consistency and adhesion mechanism are affected by loading rate and temperature. At high temperature and under slow moving loads asphalt behaves as a viscous liquid; while at low temperature and under rapid loads it behaves like elastic solid. When improper binder is used in the mix or the mix is exposed to environmental or vehicular loading, not considered in the mix design, premature failure could occur; including fatigue, longitudinal, and block cracking, rutting, potholes, etc. The severe high temperature in the kingdom during the summer (up to 76°C) and the increased axle loading are the main reason for pavement distresses (cracking and rutting). Hence there is a need to modify/improve performance of bitumen as well as for sustainable pavement construction.The economic and social development of the nation depends on transportations infrastructure. The growth in any country's economy has a strong relationship with the development of its transportation sector. In kingdom of Saudi Arabia, the road network has received significant funding to build better highway. The kingdom has a total road length of 140,870 km; 61,376 km of which are paved road as estimated by Ministry of Transport in 2013 [1]. The Ministry of Transportation (MOT-2006) suggested the use of polymers as asphalt additive to meet such harsh environmental conditions. Different modifiers (e.g. low and high density polyethylene, sulfur, and crumb rubber) can be used to improve the performance of pavement against rutting and cracking. The rutting susceptibility of asphalt pavements can be significantly reduced by adding reclaimed asphalt pavement (RAP) to the mixes. The addition of RAP would stiffening the mixture [2]. The addition of sulfur to bitumen showed higher fatigue life significantly. The presence of gel-like type structure results in good bong with aggregates. The marshal stability and resistance to rutting can also be improved using sulfur-asphalt mix [3, 4]. The rheological properties of Polymers (an elastomer and a plastomer) Modified Bitumen (PMB) was highly effected by type and content of polymer. However the properties of bitumen are significantly improved when combined additives (two or more additives) are used in asphalt mixture as compared to individual modified bitumen [5, 6]. The rheological properties as well viscosity has very complicated behavior for field aged and laboratory aged binders. A research was carried out to compare the field and laboratory binder ageing and it was concluded that the viscosity of 9 days lab ageing had less value than 20 year field aged binder. Also the 5 days lab aged bitumen shows similar dynamic response with field aged binder [7]. Bone Glue modified binder may also be used as partial replacement of bitumen to reduce the cost and enhance the performance of pavement for long term. The rheological properties were significantly improved while adding Bone Glue to the neat binder, however there was no significant change in viscosities of Bone Glue modified bitumen as compared to neat binder [8]. Higher temperature susceptibility was observed for neat binder while as binder modified with 1.6 % Elvaloy polymer showed less temperature susceptibility at frequency range of 0.01 Hz to 100 Hz using Dynamic

Shear Rheometer [9]. The rheological properties of reclaimed PMB binder can be restored if mixed with fresh and soft PMB binder. However soft bitumen (without PMB) can change rheology and chemistry of reclaimed binder but are not consistent [10].

2. Materials and Methods

2.1 Materials

Bitumen "PG 64-10" was obtained from local Saudi refinery. Dates Palm Ash (DPA) is the by-product of fruit Dates palm, which has been disposed as waste and send to landfills thus polluting the environment. The DPA was grinded in ball mill and was sieved with # 200 to get uniform particle size of less than 0.075 mm.

2.2 Methods

The Performance Grade (PG) of base bitumen obtained from Saudi local refinery was determined in the laboratory by using SuperPave binder testing for grade determination according to ASTM D 7175-08, D 2872 – 04, D6521 – 08 and D6648 – 08 [11-14].

2.3 Sample preparation

DPA (4, 8 and 12% by weight of bitumen) was mixed with base bitumen using a laboratory mixer at 165℃ for two hours. Un-aged DPA-MB samples were used for rheological properties using DSR and BBR. These tests were conducted on virgin binder and binder modified with 4, 8 and 12% DPA to determine the resistance to permanent deformation, fatigue cracks and thermal cracking.

2.4 Rheology tests using Dynamic Shear Rheometer (DSR)

Dynamic Shear Rheometer (DSR) is an oscillatory type apparatus and a powerful tool to determine the rheological properties of binders. The elastic, viscous and viscoelastic behavior of binder can be investigated at various temperatures and frequencies to simulate the real field conditions. Virgin binder as well bitumen modified with 4, 8 and 12% DPA by weight of bitumen was tested using DSR. Frequency sweep test was conducted at frequency range of 0.1 Hz to 60 Hz using control stain at three temperatures 35 ℃, 45℃ and 55℃.

3. Results and Discussion

Following results are discussed based on laboratory testing evaluation.

3.1. Effect of temperature and DPA-MB on G/Sinδ*

Permanent deformation (rutting) normally occurs at high and intermediate temperature. The virgin binder and binder modified with DPA was tested in DSR at three temperatures 35 ℃, 45℃ and 55℃. Rutting perimeter G*/Sinδ which represent rutting resistance of binder was also computed for controlled sample as well as for DPA-MB. It can be seen from figure 1 that temperature has significant role to rut the pavement especially at high temperature. Virgin binder as well bitumen modified with 4, 8 and 12% DPA by weight of bitumen was tested using DSR. Frequency sweep test was conducted at frequency range of 0.1 Hz to 60 Hz using control stain at three temperatures 35 ℃, 45℃ and 55℃. The binder modified with DPA shows better performance as compared to controlled bitumen. The binder modified with 8 % and 12 % DPA showed better performance against rutting even at high temperature.

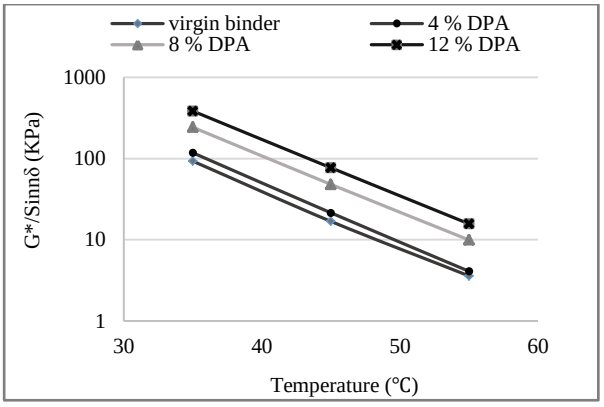

Figure 1. Effect of temperature and DPA-MB on Rutting Perimeter (G*/Sinnδ)

3.2. Effect of temperature and DPA-MB on visco-elastic behavior

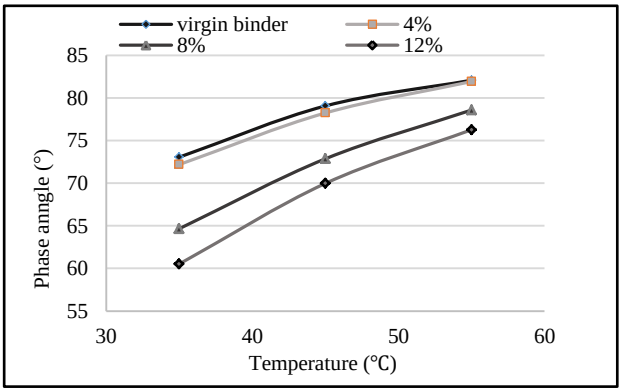

Figure 2. Effect of temperature and DPA-MB on Phase Angle

The visco-elastic behavior of binder can be investigated from phase angle (δ) obtained from dynamic shear rheometer. The lower value of phase angle (approaching to zero) indicate the elastic behavior of binder while as higher value (approaching to 90) shows its viscous behavior). At zero phase angle the binder is fully elastic and at 90 degree phase angle it behaves as fully viscous fluid. It can be observed from figure 2 that increase in temperature the phase angle also increases and the binder behavior changes from elastic behavior to viscous behavior which results in increase in rutting susceptibility. There is significant

decrease in phase angle at 8 and 12% DPA-MB and binder modified with dates palm ash shows more elastic behavior as compared to virgin binder and hence less susceptible to rutting.

3.3. Effect of frequency on binder behavior

There is significant correlation between temperature and speed of vehicle. The vehicle speed can be simulated in laboratory using frequency of Dynamic Shear Rheometer. At high temperature the binder behaves as viscous fluid and more susceptible to rutting and at low temperature it behaves as elastic solid. Similarly, low frequency represent slow moving and sustainable loads under which binder behaves as viscous fluid and is more vulnerable to rutting. At higher frequency (high speed vehicles) load is applied for less time period and binder behaves as elastic solid. It is clear from figure 3 and 4 that there is significant improvement in binder behavior (in terms of G*/Sinδ and phase angle) for binder modified with dates palm ash (DPA).

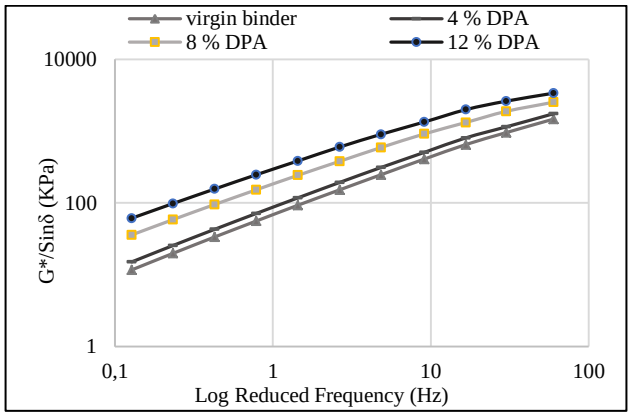

Figure 3. Stiffness master curves (Frequency vs G*/Sinδ) results obtained for a reference temperature of 35℃.

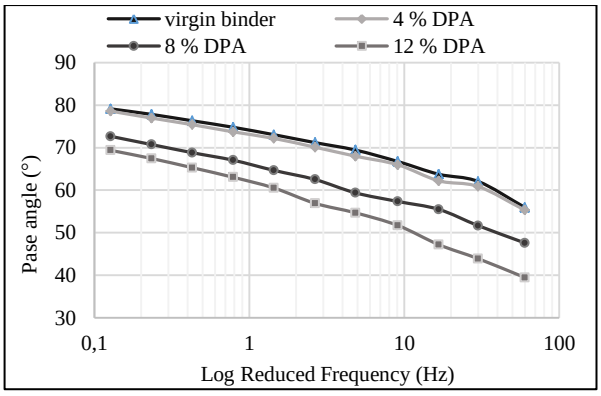

Figure 4. Stiffness master curves (Frequency vs Phase angle) at a reference temperature of 35℃.

4. Conclusion

Frequency sweep test was conducted using DSR on binder modified with dates palm ash (DPA) and following conclusions are made:

- Binder is more liable to rutting at high temperatures due to increase in phase angle.
- Binder modified with DPA especially at 8 and 12 % shows better performance at all temperatures.
- The elastic behavior of DPA-MB increases with increase in percentage of DPA at all temperatures.
- Using DPA in pavement construction will significantly in reduce the waste arising from huge amount of Dates Palms and helps in sustainable pavement construction.

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ASTM: D 2872 – 04 Standard Test Method for Effect of Heat and Air on a Moving Film of Asphalt.

ASTM D6521 – 08 Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel.

ASTM D6648 – 08 Standard Test Method for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer.