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Article

Assessing the rheological properties of bio modified asphalt cement

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Abstract: The production of asphalt cement binder in Iraq is conducted through the distillation of crude oil. The byproduct of such distillation is asphalt cement, which does not practice any further processing. Further processing of the binder is considered vital to controlling its physical properties and chemical composition. The implementation of bio-modifiers before using such asphalt cement binder for paving work is a sound practice to enhance its sustainability and reserve the required rheological properties. In the present study, the asphalt cement binder was modified by the implementation of extender oil (used diesel engine oil) and scrap tire rubber. The aim of this work is to improve and provide a sustainable and proper rheological quality of the binder for paving work. Various percentages of scrap tire rubber and extender oil have been tried to optimize the modifiers that can exhibit a suitable control on the required rheological properties of the asphalt binder, such as the stiffness modulus, its temperature susceptibility in terms of penetration index, and penetration viscosity number, and the temperature of the equivalent stiffness of the binder. The stiffness of asphalt cement binder was digested in hot, moderate, and cold environments. It was observed that the implementation of extender oil was able to reduce the penetration index (PI) by 36.3%, 54.5%, and 27.2% when 15%, 10%, and 5% of extender oil by weight of the mixture were added, respectively, to the control binder. The addition of scrap tire rubber to the binder-oil mixture was able to reduce the PI by up to 10% of the rubber content and exhibited further control over the temperature susceptibility of the binder. It can be revealed that the extender oil increases the negative values of penetration viscosity number (PVN), while the scrap tire rubber can improve the PVN of the binder. When a high percentage of extender oil (15%) is implemented, the stiffness of the binder declines by 50%, 90%, and 75% when the testing temperature changes from 4 to 25, and 60 °C, respectively. It was concluded that the inclusion of 15% scrap tire rubber and 15% extender oil in the asphalt cement binder produced by Qayarah oil refinery is recommended to provide a sustainable binder for pavement, control its temperature susceptibility, and provide a binder that is less susceptible to pavement distress.

Keywords: extender oil; scrap rubber; asphalt cement; rheological properties; sustainability; stiffness

1. Introduction

The feasibility of using high-density polyethylene (HDPE) waste as an asphalt binder modifier was evaluated by Mainieri et al. [1]. It was revealed that the waste HDPE could increase the binder's stiffness and slightly improve its ductility and elasticity. It was concluded that using a waste HDPE-modified binder is recommended for improving resistance to moisture-induced damage and adhesion. Sarsam [2] assessed the possibility of implementing extender oil (used oil) and scrap tire rubber to improve the physical qualities of the asphalt cement. It was revealed that a combination of 15% scrap rubber and 10% extender oil provided a suitable control on the softening point, ductility, penetration, and viscosity of the binder. However, the stiffness of the asphalt concrete mixture provides a suitable resistance to deformation in hot, moderate, and cold environments. It was concluded that the implication of such a combination of additives in asphalt cement can create a sustainable green binder for pavement. Al-Harbi [3] investigated the influence of implementing crumb rubber on the physical properties of asphalt binder. It was concluded that 12% of crumb rubber has the best content and exhibits higher fatigue resistance, lower rutting depth, and higher stability as compared with the control asphalt mixtures. Sarsam [4] studied the impact of polymer-based additives on the quality of asphalt binder using the surface-free energy concept. It was revealed that crumb rubber can provide higher surface free energy and contact angle as compared with the control binder when the sessile drop technique is implemented, regardless of the additive content. Lyu et al. [5] assessed the implications of extender oil (bio-oil made from biomass waste) and scrap tire rubber to create bio-modified rubberized asphalt for roadway paving construction. It was revealed that this technique can promote a clean and sustainable manufacturing process when turning two waste streams (rubber and biomass waste) into a product that supports resource conservation and sustainability. Nanjegowda and Biligiri [6] used scrap tire rubber to develop the modified asphalt-rush green paving mixture, which is considered superior to conventional asphalt-rubber mixtures. The modified asphalt concrete mixture was verified under the stiffness modulus test. It was revealed that the developed mixture exhibits an insignificant rate of change in viscosity with increasing temperatures; however, the rubber particles can provide the additional resilience required to endure the mix performance for the entire design life. The rheological properties and adhesion characteristics of modified asphalt cement binder were investigated by He et al. [7]. The modification was conducted using various crumb rubber powder contents and foamed binder. The temperature sensitivity and the viscoelastic characteristics of each asphalt binder sample were studied. The results showed that it was difficult to foam successfully when the rubber powder content was higher than 15%. Nassar et al. [8] investigated eco-friendly alternative asphalt binders for pavement construction. Green bio-additives were prepared using waste cooking oil and waste polystyrene and styrene-butadiene rubber and mixed with asphalt binder to prepare a green alternative binder. The physical properties of the modified binder, including softening point, penetration index, penetration temperature susceptibility, and penetration, were investigated. Mashaan et al. [9] assessed the impact of waste polyethylene terephthalate plastic on paving asphalt binder. Test results revealed that waste plastic can improve aging and rutting resistance. It was concluded that the application of plastic waste on pavements can reduce costs, conserve natural resources, and improve sustainability despite environmental impact. Pasetto et al. [10] stated that synthetic binders may be implemented in place of conventional and sustainable binders. A rheological study was conducted to characterize such materials. It was revealed that using non-linear data, the functions of temperature and strain rate can be modeled to evaluate the rheological response of the modified binders, which can exhibit complex behaviors. Wang et al. [11] investigated the possibility of using waste polyethylene as an additive to the asphalt cement binder. A positive impact could be noticed by such an additive on the rheological properties of asphalt binder. It was noted that the use of plastic modifiers leads to an overall higher softening point and complex shear modulus. It was stated that uneven dispersion of plastic material at high temperatures could exhibit scatter in the data. The modified binder, neat rubber, and complex modified binder were visually identified based on different rheological behaviors. Sarsam [12] assessed the changes in the aging index of asphalt cement binder after modification with polymeric additives such as polyethylene and crumb rubber. The aging index was evaluated through various physical testing procedures. It was revealed that the aging index declined after the addition of crumb rubber. However, the aging index increases after implementing polyethylene into the asphalt binder. It was stated that the implication of crumb rubber in the asphalt binder is beneficial from the point of view of resistance to oxidative aging.

The aim of the present assessment is to evaluate, improve, and provide a sustainable and proper rheological quality of the binder for paving work by enhancing the rheological properties of bio-modified asphalt cement. Asphalt cement binder will be digested with various percentages of extender oil and scrap tire rubber. The variations in the rheological properties of the modified asphalt cement binder will be evaluated.

2. Materials properties and testing methods

2.1. Scrap tire rubber

The scrap tire rubber in powder form was obtained from the Diwaniya tire plant, south of Baghdad. The specific gravity of the powder is 0.421 gram/cm^3. The grain size distribution of the rubber powder is demonstrated in **Figure 1**.

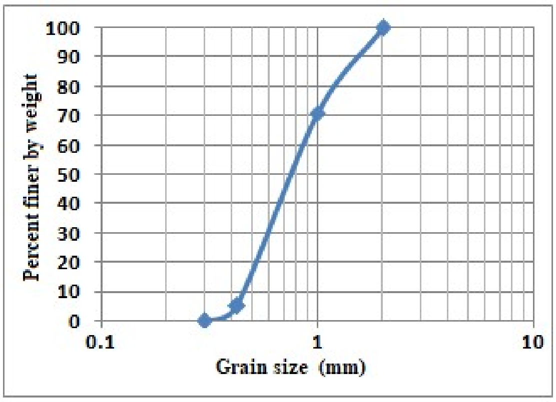

Figure 1. Grain size distribution of the rubber powder.

2.2. Extender oil (used oil)

The implemented extender oil was obtained from a diesel truck that used oil after a 1500 km run; the saybolt furol viscosity of the oil is 56 s at 60 °C.

2.3. Asphalt cement binder

The asphalt cement binder was obtained from Qayarah oil refinery, north of Baghdad, its softening point is 44 °C while the penetration value is 48. The chemical composition of the binder consists of 16.5% nitrogen base, 40% asphaltenes, 30% acidifies, and 13.5% paraffin. All of the testing procedures have been conducted according to ASTM [13].

2.4. Preparation of modified binder mixture

The preparation of the modified binder mixture was conducted using the wet process technique. The control asphalt cement binder was heated to 150 °C, and the pre-determined scrap tire rubber percentage was added with continuous stirring. Five percentages of rubber have been implemented: 3%, 5%, 7%, 10%, and 15% by weight of the asphalt binder. The blend was maintained at 150 °C for 30 min and subjected to stirring several times until a homogeneous mixture was achieved. Such preparation techniques for the modified binder in such an environment were conducted to promote the expected physical and possible chemical bonding between rubber and the binder. The extender oil was added to the blend with continuous stirring to promote the required workability and control the viscosity of the modified binder. Three percentages of extender oil were implemented: 15%, 10%, and 5% by weight of the binder. A control binder was reserved (with no extender oil or scrap tire rubber) for comparison. A similar preparation procedure was implemented by Sarsam and Lafta [14].

2.5. Testing for the rheological properties

The modified and control binders were tested for rheological properties such as stiffness of the binder, penetration viscosity number (PVN), penetration index (PI), and temperature of equivalent stiffness (TES). The shell nomograph [15] was utilized for evaluation of the test results.

3. Results and discussions

3.1. Influence of binder modification on penetration index (PI)

Norhidayah et al. [16] addressed the fact that the penetration index (PI) is considered a good measure of the temperature susceptibility of the viscosity of the asphalt binder. However, it can provide a measure of its deviation from Newtonian behavior, as stated by Bose and Jain [17]. The penetration index can be derived mathematically from the penetration and softening point test values. Asphalt binders with a PI value range between (−2) and (+2) exhibit normal susceptibility to the change in temperature. Asphalt binders with a PI below (−2) are brittle at low temperatures. Asphalt cement with PI between (+1 and −1) is normally used for pavement construction, as addressed by Button et al. [18]. In addition, the negative sign of PI can indicate that asphalt cement is highly susceptible to the change in temperature. **Figure 2** demonstrates the variation in the penetration index values after modification of the asphalt binder with extender oil and scrap tire rubber. It can be noticed that the asphalt-rubber mixture exhibits mostly negative values of PI. The negative values of the penetration index decline sharply as the rubber content rises. After reaching 0.075 of the rubber/asphalt ratio, the rate of variations in the PI values shows a gentle trend with further increments in the rubber content. When the extender oil is introduced, a further decline in the negative values of PI could be observed. It can be revealed that as the extender oil content increases, the temperature susceptibility of the rubber-treated asphalt binder declines regardless of the rubber content. It can be noticed from **Figure 2** that the control binder (without rubber or extender oil) exhibits high susceptibility to temperature, and the PI is −2.75. The addition of extender oil was able to reduce the PI by 36.3%, 54.5%, and 27.2% when 15%, 10%, and 5% of extender oil were added, respectively.

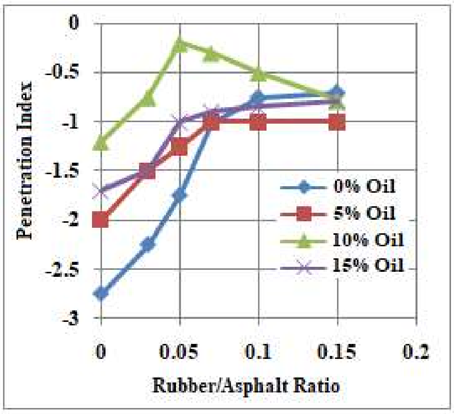

Figure 2. Influence of binder modification on penetration index.

However, the addition of scrap tire rubber exhibits further control of the temperature susceptibility and was able to reduce the PI up to 10% of rubber, further increments in the rubber content exhibit no significant impact on the PI regardless of the extender oil content. It can be concluded that the scrap tire rubber and extender oil additives can improve the resistance of the control asphalt cement binder to variations in temperature.

3.2. Influence of binder modification on temperature of equivalent stiffness (TES)

The temperature of equivalent stiffness TES is the temperature at which the stiffness of asphalt is 138 MPa at 2.77 h of loading time, as mentioned by the Shell Nomograph [15]. It can be noticed from **Figure 3** that the control binder (without rubber or oil) exhibits the lowest TES of (−21) among the modified binder mixtures. The implications of scrap tire rubber further decline the TES to (−29) at 15% rubber content. However, the implication of extender oil was able to significantly increase the negative values of TES, while the rubber content did not exhibit significant variation in TES. Such behavior agrees with Sarsam [19].

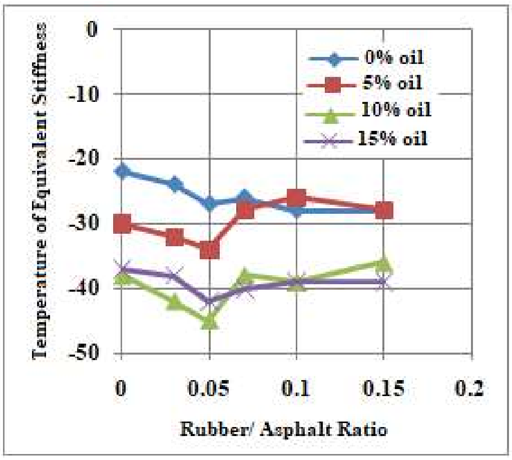

Figure 3. Influence of binder modification on temperature of equivalent stiffness.

3.3. Influence of binder modification on the penetration viscosity number (PVN)

The penetration viscosity number of asphalt binder PVN is calculated based on the empirical correlation between viscosity at 60 °C and penetration at 25 °C which are usually specified as a requirement for asphalt binders suitable for paving work, as stated by Beaty and Sunjaya [20]. The lower the PVN, the higher its temperature susceptibility. Most of the suitable paving asphalt binders have a PVN between +0.5 and −2, as reported by Rusbintardjo et al. [21]. It can be observed from **Figure 4** that the negative values of PVN decline after the implementation of scrap tire rubber, regardless of the rubber or oil content, while the negative values of PVN increase as the extender oil is implemented in the mixture. The control binder (without rubber or extender oil) exhibits a PVN value of (−0.6), and it declines by 33% after implementing 15% rubber into the mixture. When the extender oil is added to that combination, the negative PVN values increase by (1.6, 1.3, and 1) folds when 15%, 10%, and 5% of the extender oil are added, respectively. When 15% of scrap tire rubber was implicated in the binder, the negative PVN values increased by (2, 1.5, and 0.5) folds when 15%, 10%, and 5% of extender oil were added respectively. It can be revealed that the scrap tire rubber can decline the negative values of PVN in the binder, while the extender oil increases the negative values of VPN.

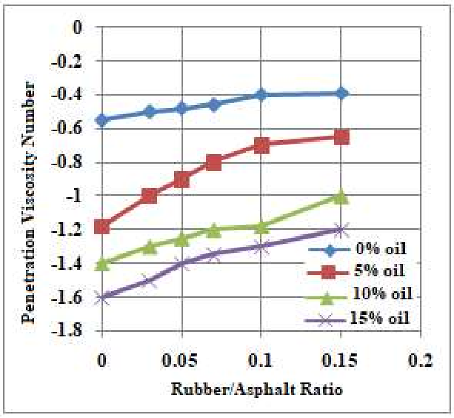

Figure 4. Influence of binder modification on the penetration viscosity number.

It can be concluded that lower negative values of both PI and PVN can show higher temperature susceptibility of the binder and are supposed to exhibit more imperviousness to breaking and rutting, as expressed by Fazaeli et al. [22]. One remarkable contrast between PI and PVN is that the PI changes because of the maturing process (during blending and in this manner in assistance), while the PVN esteem remains significantly similar.

3.4. Influence of binder modification on the stiffness of the binder

The stiffness of asphalt cement binder is considered a simple means for characterizing its consistency over a wide range of environmental conditions. **Figure 5** demonstrates the influence of binder modification on stiffness in a cold environment of 4 °C. It can be observed that the stiffness of the binder increases sharply as the rubber content rises. However, when the extender oil is implemented, the stiffness of the control binder declines by 50% while the stiffness of the rubber-binder mixture declines by 100%. This may be attributed to the change in the viscosity of the binder after digestion with rubber and oil. When the testing was conducted at a moderate environment temperature of 25 °C, a similar trend of change in stiffness could be detected, and the influence of extender oil was more pronounced at high rubber content, as exhibited in **Figure 6**.

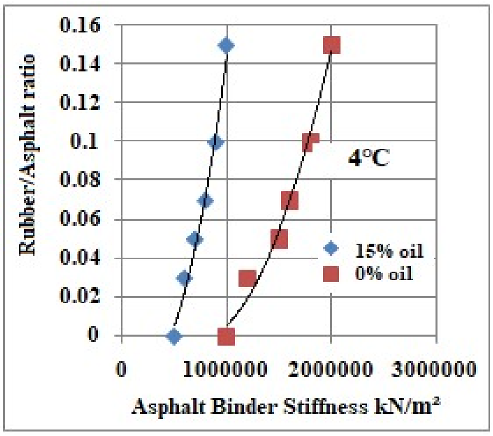

Figure 5. Influence of binder modification on the stiffness of a cold environment.

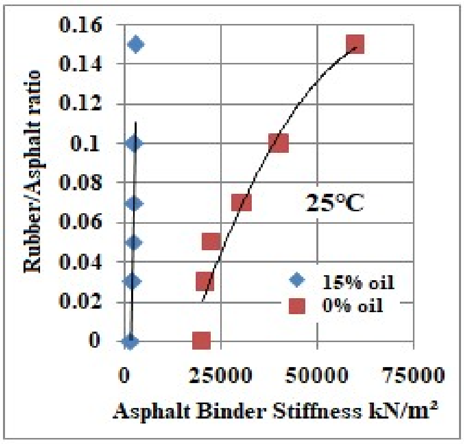

Figure 6. Influence of binder modification on the stiffness at moderate environment.

The stiffness of the control binder declines by 97% when the testing temperature rises from 4 to 25 °C, while it declines by 96% for a mixture of binder and 15% rubber as compared with the testing condition in a cold environment.

Figure 7 demonstrates the influence of binder modification on the stiffness in a hot environment. It can be observed that the implementation of scrap tire rubber exhibits a more pronounced influence on the stiffness of the binder at such a high testing temperature, while the addition of 15% of extender oil exhibits a significant change in the (rubber-asphalt) binder stiffness. It can be observed that for the control binder (no rubber and no oil), the stiffness increases by 99% and 500% when the testing temperature declines from 60 to 25, and 4 °C, respectively. However, when the 15% extender oil is implemented, the stiffness of the binder declines by 75%, 90%, and 50% when the testing temperature declines from 60 to 25, and 4 °C, respectively.

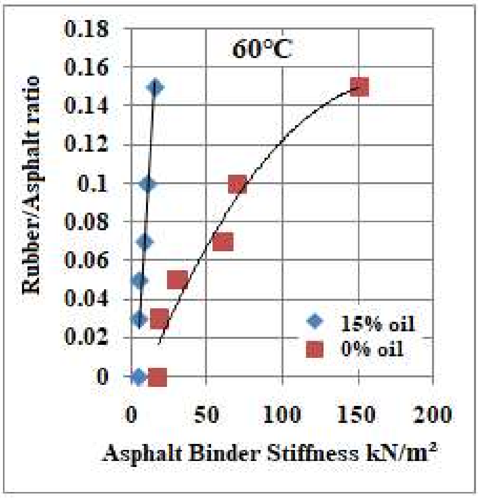

Figure 7. Influence of binder modification on the stiffness of a hot environment.

It can be observed that the testing temperature has a more detrimental impact on the asphalt cement binder mixture. This could be attributed to the possible scattering of rubber material due to stirring at high temperatures, which causes the dissipation of its impact. It can also be seen that the change in the testing environment does not affect the shape of the asphalt binder stiffness function but shifts it sharply along the y-axis after the implementation of extender oil and shifts it along the x-axis when scrap tire rubber was implemented. However, as the extender oil was introduced, the influence of variations in rubber content on the binder stiffness was not significant regardless of the testing environments. This may be attributed to the significant decline in the viscosity of the asphalt-rubber structure after the implementation of extender oil. Khairuddin et al. [23] and Gatoto et al. [24] reported similar behavior.

4. Conclusions

The following conclusions are addressed based on the limitations of testing and materials:

1) Implementation of extender oil declined the penetration index by 36%, 54%, and 27% when 15%, 10%, and 5% of extender oil were added to the control

binder, respectively. However, implementations of scrap tire rubber exhibit further control of the temperature susceptibility of the binder.

2) The implication of scrap tire rubber declines the temperature of equivalent stiffness to −29 at 15% rubber content. The implication of extender oil was able to increase the negative values of TES.
3) The penetration viscosity number of the binder declined by 33% after implementing 15% rubber. When the extender oil is added, the negative PVN values increase by (1.6, 1.3, and 1) fold when 15%, 10%, and 5% of the extender were added, respectively.
4) When 15% of extender oil is implemented, the stiffness of the binder declines by 75%, 90%, and 50% when the testing temperature declines from 60 to 25, and 4 °C, respectively.
5) The implication of 15% scrap tire rubber and 15% extender oil in the asphalt cement from Qayarah refinery is recommended to control temperature susceptibility and provide a sustainable binder for pavement.

Conflict of interest: The author declares no conflict of interest.

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