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Basic Rheological Properties of Virgin and Recycled LDPE-Modified Bitumen

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Abstract: Polymers have widely known in its capability in enhancing rheological properties of bitumen for various pavement applications. The polymer modified bitumen (PMB) properties are different depending on the used polymers. LDPE or Low-Density Polyethylene are one of widely studied polymers in bitumen modification that exhibit higher bitumen's viscosity, perform better in resisting deformation under heavy loads, and tend to show better integrity in high temperatures. LDPE-modified bitumen also believed to enhance elasticity, allowing a potentially better resistance to cracking due to ability to recover at low strain. Many studies also stated the improvement of LDPE-modified bitumen against thermal and mechanical stress, better adhesion to aggregates in asphalt mixtures, and various promising result for overall durability and longevity of pavement. This study investigates the basic rheological properties of virgin and recycled LDPE-modified bitumen, prepared using high-shear mixing at varying LDPE concentrations (2%, 4%, 6%, 8%, and 10%). Rheological changes were evaluated using penetration, ring and ball softening point, and rotating spindle viscometry tests. Results indicate noticeable differences between the modifications where recycled LDPE exhibits superior dispersion and swelling, leading to improved performance compared to virgin LDPE.

Keywords: polymer modified bitumen; low density polyethylene; bitumen

1. Introduction

Polymer modified bitumen's basic rheological characteristics are critical to its performance in asphalt mixtures application. PMB offers higher viscosity compared to normal bitumen which help to resist flow and deformation against loads, allowing a better performance for high loads and high volume of traffic in road pavements. Another feature of PMB is better elasticity that enables it to regain its shape after deformation and lowers the fracture susceptibility. The PMB's enhanced viscoelastic behaviour allows the material to absorb and release energy, increasing its resistance to temperature changes and traffic-related stresses. Additionally, PMB performs consistently across a range of regions and is less susceptible to temperature fluctuations [1].

Bitumen modification with low-density polyethylene (LDPE) has been widely studied and believed to improve the performance of its application in asphalt surfaces. LDPE enhances the bitumen's rheological characteristics especially in term of viscosity and improve the mixture's resistance to deformation. This benefit particularly in pavements or regions with high temperatures and large traffic volumes.

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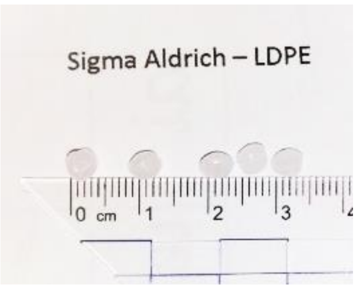
The LDPE properties modify the rheological properties of the final product (LDPE-based PMB), increasing the elasticity of pavement under traffic loads. This believed to produce more durable road pavement and prevent early damages. Furthermore, reusing LDPE or plastic waste in general for bitumen modification can be an environmentally beneficial because it prevents the negative impact on the environment while also improving the mechanical properties of asphalt pavements [2,3]. However, the addition of some type of polymers in the PMB increases storage stability problems and the risk of phase separation between bitumen and the polymers. Thus, careful handling pre-application are important to ensure successful application on PMB in general, including the LDPE-modified bitumen.

Some of basic and important properties in bitumen is its softening point, penetration number and viscosity. These parameters are important in understanding the general properties of the material for specified task such as handling of bitumen, especially pre-application in the mixtures. This study tends to measure basic rheological properties of LDPE modified bitumen, prepared by high shear mixer and specified mixing method, in term of penetration test, softening point and viscosity.

2. Method

2.1. Materials and equipment

This study used standard 50/70 penetration grade bitumen and low-density polyethylene (LDPE) plastic pellets as the modifier. Two type of LDPE plastics were used: freshly made or virgin LDPE (VL) and recycled LDPE (RL). The virgin LDPE (VL) was produced by Sigma Aldrich/Merck (Germany), in the forms of opaque round pellets of 3-4 mm. The RLs or recycled LDPE were supplied by BJ Parr recycling company, Mansfield, United Kingdom, in the forms of flat pellets with typical diameter of 4-5 mm. The RLs presented in a mixed colour of light to dark blue. Figure 1 presents the VLs and RLs. Standard distilled water was used in the ring and ball test for normal bitumen, while Glycerol was used for highly modified bitumen, i.e., when the bitumen’s softening point was expected to exceed 80°C.



3-4 mm opaque round pellets
(Sigma-Aldrich/Merck)

4-5 mm mixed light and dark blue flat pellets
(BJ Parr recycling company)

Silverson High Shear Mixer

Figure 1. LDPEs for bitumen modification and high-shear mixer

This study used Silversone high-shear mixer for bitumen modification, bitumen standard needle penetrometer, a ring and ball softening point apparatus, oven for various heating purposes, and rotary spindle viscometer.

2.2. Procedure

The study was started by testing the unmodified bitumen with standard test in penetration, softening point and viscosity. Following the standard test were the polymer-modification process using Silverson high-shear mixer. The final modified product then tested with the similar standard test for unmodified bitumen.

2.2.1. Details of Preparation and Modification Process

The modifications were conducted using Silverson high shear mixer. All bitumen with different percentage of modification used the similar procedure: 30 minutes mixing at 5000 rpm speed and controlled temperature of 165°C. This mixing procedure was selected based on previous study that stated successful modification result and insignificant improvements in terms of viscosity when a longer mixing duration were carried out [2]. This study used 2%, 4%, 6%, 8% and 10% virgin and recycled LDPE of bitumen weight, with the labelling of VL1, VL2, VL3, VL4, and VL5 for virgin LDPEs, and RL1, RL2, RL3, RL4 and RL5 for recycled LDPEs, respectively, while the control or unmodified bitumen was labelled R0.

To prepare the sample for the high shear mixing modification process, neat 50/70 penetration grade bitumen was oven-heated to 165°C until it become liquid. For every modification level, bitumen were added to a 2000 mL tin to the capacity of about 1700 grammes in order to guarantee that the high mixing shear head was completely immersed in the blends. Based on the actual poured bitumen, the weight of the VL and RL modifiers was also calculated and prepared.

At a lower rate of ±250 rpm and a maintained temperature of 165°C, ±1700 grammes of bitumen were shear mixed. LDPE was added to the mixes gradually at a rate of around 20 grammes per minute during this low shearing rate. After that, the speed was increased to 5000 rpm, and the blending process was carried out for an additional 30 minutes while keeping the temperature at 165±5°C. All ten of the modified bitumen samples went through the same procedure as shown in Figure 2.

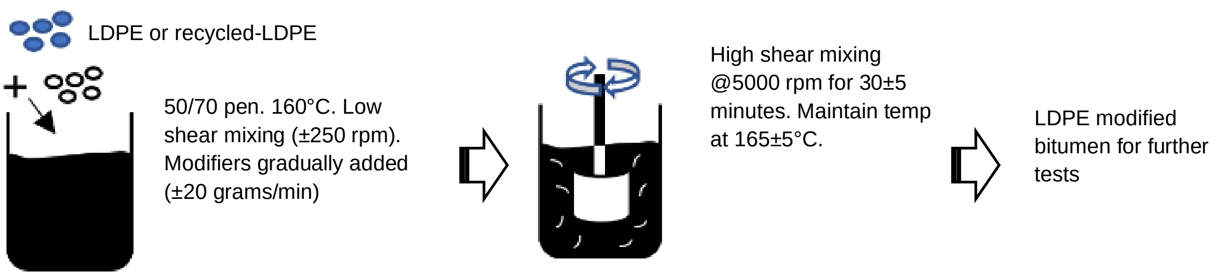


Figure 2. High Shear Mixing Method For LDPE-Bitumen Modification

2.2.2. Standard penetration and softening point test

The unmodified bitumen (R0), virgin LDPE-modified bitumen (VLs), and recycled LDPE-modified bitumen (RLs) were standard tested on the penetration number (BS EN 1426-2015), softening point (BS EN 1427-2015), and viscosity (BS EN 13302-2018). The outcomes were expected to distinguish between unmodified and modified bitumen samples. It has been established through several earlier research that LDPE-modified bitumen has a higher softening point and a lower penetration number [2,4,5].

Furthermore, it was believed that the R&B softening point data could offer a useful explanation for the improved bitumen modification process' success rate [6]. The results showed that bitumen treated by 2% and 4% had R&B t<80°C, while bitumen modified by higher amounts and using glycerol had t>80°C.

3. Result and Discussion

3.1. Penetration Number

There were discernible variations between the unmodified and both VL and RL modified bitumen, according to the penetration number test. Figure 3 demonstrates that at 2%, VL and RL produced roughly the same penetration number; however, at 4%, RL's value was somewhat lower than VL's, which had a greater modification effect. At greater rates, an additional effect was noted, with RL comparatively having a lower penetration number than VL at the same percentage of modification. According to its definition, penetration number is a straightforward test that can reveal early changes in the physical characteristics of modified bitumen. It was commonly known that LDPE was strong, resilient to impact, and could endure tensile strength of about 9 MPa at room temperature [7].

Based on the degree of compatibility between the two materials, it was found that the modification of bitumen caused the polymer particles to swell and disperse [8,9]. Lower penetration numbers of the modified bitumen at room temperature revealed the amounts of LDPE's physical qualities that altered the bitumen-polymer system's attributes. A higher concentration of LDPE led to higher changes of physical properties of the modified bitumen, or lower penetration numbers of the changed product. Furthermore, at the same percentage of bitumen weight, it was shown that RLs decreased the penetration number more than VLs. This suggested that, in comparison to VL, RL underwent superior alteration because of its superior bitumen dispersion and swelling.

However, it should be noted that the polymer's performance will be more evident at higher temperature, thus the whole modified bitumen system changes will be more obvious to observe [10]. At higher temperature, polymer's mechanical properties will perform dominantly than the bitumen itself. Therefore, softening point is believed to result in better understanding of this modification.

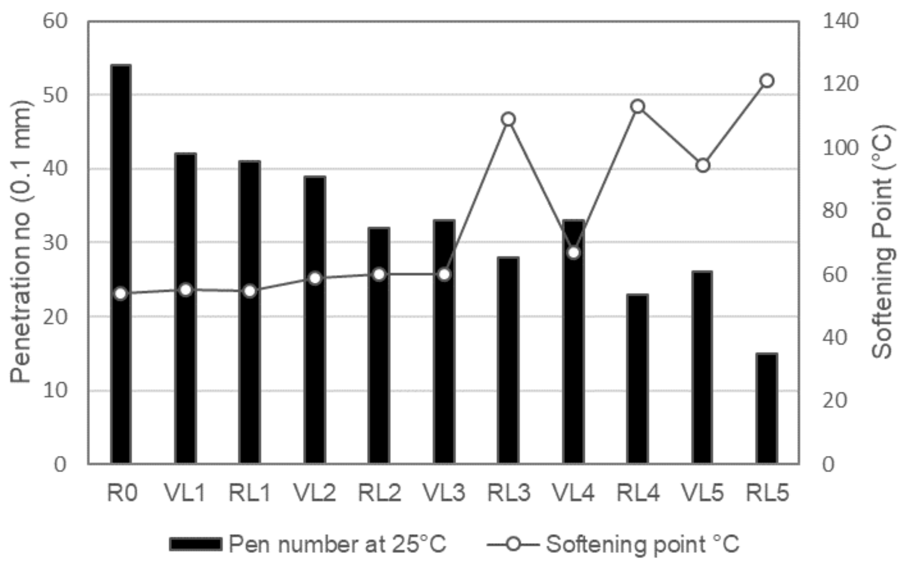


Figure 3. Penetration Number and Softening Point

3.2. Softening point

As was shown with the penetration number, the softening point test also revealed certain modifications by the presentation of polymer blend in the bitumen. Figure 3 showed that the softening points were rising, as an inverse trend of the decreasing penetration number. Studies have stated that in the case of PMB there are correlations between modification result and softening point. In other words, a higher number of modified bitumen’s softening points compared to normal bitumen indicated a better modification blend [6]. Based on this, the compatibility of polymer blends can be assessed from the trend result of ring and ball softening point. Higher softening points were reported in several investigations on materials treated with polyethylene, and this was also supported by changes in the high-temperature complex modulus as a crucial rheological feature [2,4,11–15]. The R&B test result for the changed bitumen displayed the typical outcomes of substantially modified bitumen, namely VL4, VL5, RL3, RL4 and RL5.

3.3. Viscosity

The test results clearly show that the LDPE modifier raises bitumen viscosity, which is consistent with the rising softening point and falling penetration number. In its application, bitumen is typically prepared at range of 160-170°C during the aggregate-mixing process of hot asphalt mixes. This is typical temperature for bitumen to have the viscosity of approximately 0.1-0.2 Pa.s. According to the test results, the highly modified bitumen remains have high viscosity at average hot mixing temperature. Figure 4 clearly shows the 165°C viscosity test produces approximately 0.8 Pas for 8% of VLs-modified bitumen, and 30 Pas for 8% of RLs-modified bitumen. The 10% modified bitumen produce even higher viscosity at this temperature. The very high viscosity in the case of 10% recycled LDPE modified bitumen at 120°C was beyond capacity of the spindle viscometer thus resulted in unreadable result.

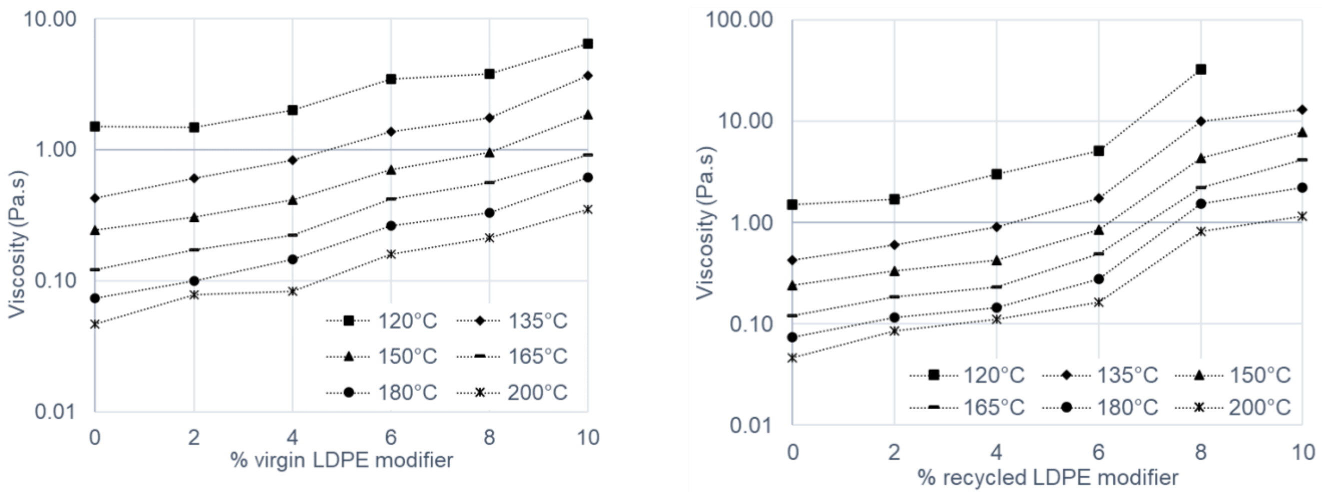


Figure 4. Viscosity test results

Based on this result, it is impossible to obtain the range of bitumen’s viscosity for satisfactory workability 0.17 – 0.28 Pa.s according to BS EN 12697-35 in the case of highly modified bitumen, i.e., 8% and 10% for both virgin LDPE and recycled LDPE modified bitumen. Therefore, it can be stated that 8% and higher bitumen weight modification of LDPE are unfeasible for PMB application.

4. Conclusion

The modification has been successfully carried out by high shear mixing at selected temperature and durations, with distinguishable result differences on each proportion of modification. Basic rheological tests have been carried out and several points can be concluded as follows:

- Modified bitumen product with a reduced penetration number and a noticeably greater softening point was successfully produced using LDPE polymers. This result served as additional confirmation shown in earlier studies, where the standard test particularly softening point is highly related to the rheological performance of modified bitumen. Further detailed performance-based rheological tests of the modified bitumen might be helpful to pinpoint the precise modification benefits.

- The RLs or recycled-LDPE modified bitumen have been modified more significantly than VLs or virgin-LDPE modified bitumen at the same percentage of modifications. This is because of different ability of dispersion between the modifiers to the bitumen.
- Standard penetration test was able to identify the modification through the decreasing number of penetrations. However, the R&B softening point is considered better in the modification confirmation because at higher temperature the polymer's mechanical properties will dominantly perform to the whole modified bitumen system compared to standard penetration test that only performed at room temperature.

Additionally, in both case of virgin and recycled LDPE modification, an 8% bitumen weight or higher will produce a stiff and too viscous modified bitumen that are unfeasible for application.

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