Evaluation and Comparison of Rheological Properties of Bituminous Binders Using Different types of Additive Materials

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Abstract- The purpose of this study is to examine the impact and potential of bitumen binders modified with waste plastic as a sustainable and affordable polymer. Several waste plastic kinds, such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polyethylene terephthalate (PET), have been employed in this modification. The physical attributes, rheological qualities, and age resistance of the binders are the areas of alteration. Pressure ageing vessels (PAVs) and rolling thin film oven tests (RTFOT) are used to evaluate both short- and long-term ageing in order to assess the modified binder's ageing resistance and durability. The complex shear modulus, stiffness, elasticity, and viscous characteristics were investigated and assessed using penetration tests and dynamic shear rheometer (DSR) testing.

Keywords— *Waste Plastic, PET, HDPE, LDPE, Penetration, DSR, Ageing, RTFOT, Pressure Ageing Vessels (PAVs).*

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INTRODUCTION

The increasing significance of pavement and geotechnical concerns has spurred study in these domains, which has led to the resolution of recyclable materials incorporation in civil engineering projects. On the aggregate problems, the use of numerical tools and laboratory testing is well-documented. However, garbage is being produced on a daily basis. Due to this, the cost of disposing of trash has increased significantly, preventing the development of new landfill sites. There are a number of benefits to using waste materials instead of fresh ones in the road building sector. The first is a significant reduction in expenses, and the second is a decrease in the amount of garbage dumped in landfills. Therefore, improving the qualities of pavement construction must be the main goal of using waste plastic in asphalt modification. The application of polyethylene polymers to enhance the engineering qualities of asphalt mixes was the subject of a joint study by Awwad and Shbeeb. They studied which kind of polyethylene would work best and how much of it should be used in an asphalt mixture to get the greatest results. Thus, they coated the aggregate with two different kinds of polyethylenes: high-density polyethylene (HDPE) and low-density polyethylene (LDPE). There were two ways that the polymers were added to the mixture: ground and unground. The mixed samples demonstrated that the ground HDPE contributed superior engineering qualities to the final mixture. It was discovered that 12% of the bitumen weight should be the most suitable proportion of the modifier applied to the mixture. The experiment's findings further support the idea that adding HDPE can lessen the density of the asphalt mixture, increase the amount of air voids (VIM) and voids of mineral aggregate (VMA) in the mixture, and enhance mixture stabilit. Al-Hadidy and Tan Yi-qiu collaborated to carry out a second research that examined the engineering characteristics of LDPE as a modifier that may be utilised to enhance and modify asphalt mixes. This indicates a significant improvement in the overall durability of the original SMA. Furthermore, the results revealed that the LDPE-modified SMA mixture could be the optimal mixture for pavement construction and coating in regions with extreme temperature fluctuations and excessive moisture.

LITERATURE REVIEW

Hinishoglu and Agar used other kinds of waste plastic materials with HDPE to modify binders at various blending temperatures, times lengths, and HDPE percentages. For this experiment, they used the Marshall stability, Marshall quotient, and Marshall flow. It was concluded that 4% of HDPE at 165 °C blended continuously for 30 min provided the best Marshall stability, Marshall flow, and Marshall quotient (MQ). As a result, as a new condition applied to this experiment, the percentage of the Marshall quotient was raised by 50% in comparison to that of the control mixture. Furthermore, researchers noted that the resistance of the HDPE-modified bituminous mix against severe deterioration and deformation was significantly increased (Hinishoglu and Agar 2004). A study by Zoorob and Suparma revealed that using LDPE waste plastic in bituminous mixtures could result in a significant enhancement of their stability of approximately 2.5 times greater than the stability of the control mixtures and durability while decreasing its density. In addition, the outcomes of the study showed that the plastiphalt fatigue life of the modified mixtures was longer than that of the control ones. Based on the results of these experiments, adding the polymer significantly increased the rutting resistance of the asphalt-modified mixture. Moreover, using polyethylene as a polymer for asphalt mixtures results in improvements to the fatigue resistance, workability, and efficiency of the modified mixture. According to previous reports, using waste plastic for asphalt modification could help reduce environmental contamination and reduce additional costs. Further, introducing waste plastic into asphalt will also improve the temperature susceptibility and stiffness. Thus, waste plastic-modified bitumen results in an enhancement in the rutting and fatigue resistance. Modifying and improving the properties of the bitumen and asphalt mix by using certain additives, such as plastic polymers, is one way of increasing the service life of road surfaces. In 2018, the plastic ban by China, Malaysia, and India put significant pressure on the Australian recycling industry, and researchers have worked to find an effective solution to manage this issue. One significant proposal involved using Australian waste plastic in asphalt and pavement engineering. In 2019, there were some trial sections in Sydney that incorporated waste glass, crumb rubber, and waste plastic bags in asphalt mixtures using the dry mix method; however, these trials did not investigate the mechanical characteristics, rheological properties, durability, and engineering prospects of bitumen plastic modifiers using wet mix methods. Currently, at Curtin University, Perth, scientific research on using waste/by-product in geotechnical and pavement projects is being conducted. The plastic inclusion as a bitumen modifier is being conducted to improve the benefits of using waste plastic to produce asphalt mixtures modified with cost-effective waste polymers, which also have a high resistance to permanent deformation. At Curtin University's laboratory, Mashaan et al. investigated the possibility of using waste PET to improve the engineering properties of the C320 bitumen binder, finding promising results. However, more investigation is required to examine the impact of other types of waste plastic on the engineering properties of modified binders in Australia. The aforementioned literature indicates that there is a lack of research on the impact of waste HDPE and LDPE on C320 bitumen binders, which are most commonly used for road design in Australia. Therefore, it is imperative to conduct more research into this.

MATERIALS AND TESTING METHODS

(i) Bituminous Material- In this study asphalt binder 80/100 penetration grade bitumen was used. The properties of asphalt binder are presented in Table 1. These properties are within the specification of penetrated bitumen grade 80/100.

Test	Test result
Ductility (cm)	< 100
Penetration (0.1 mm)	84-100
Softening point (°C)	46
Specific Gravity (g/cm ^{3})	1.03

Table 1- Tests results performed on original bitumen

(ii) Polyethylene- In this research work waste PET in powder form was prepared by grinding the waste plastic bottles using the crusher machine and sieved according to sieve size given in table 2. The density and melting point of the used waste PET are 1370 kg/m 3 and 260°C, respectively.

Sieve size	Percent passing
701 µm	100
450 µm	0

Table 2- Gradation of PET

(iii) Sample Preparation- Modified binders were prepared by mixing 80/100 penetration grade bitumen with various percentages of waste PET, namely 2%, 4%, 6% and 8% by mass of bitumen. Blending the bitumen and waste PET was done using high speed shear mixer at temperature of 130ºC for a period of time of 3 min.

(iv) Binder Testing- Binders were characterised by using a number of standard physical tests such as penetration test (temperature, load and time are 25ºC, 100g and 5sec respectively), softening point test, viscosity test using Brookfield viscometer (temperature range from 90 to 170ºC, spindle No.27, and a rotating speed of 20rpm), and including rheological measurements by using a Dynamic Shear Rheometer (tests conducted by using a temperature sweep starting from 30ºC to 80ºC, and the frequency is 1.159Hz).

MATERIALS AND METHODOLOGY

(i) Sample Production- Three different types of waste plastic PET, HDPE, and LDPE were used to prepare the modified binder using the wet-mixing method in different percentages: 0%, 2%, 4%, 6%, and 8%. The blending parameters were 45 min of blending time, a temperature of 180 °C, and a 2000 rpm shear velocity; this selection was based on numerous trial blends. The mixing commenced at a low shear rate of 700–800 rpm for the first 15 min to ensure fewer air voids; subsequently, the speed was increased to 2000 rpm for 30 min. DSR tests were conducted to assess and verify the viscoelastic performance and examine the rutting and fatigue resistance of the modified bitumen binders.

Figure 1-Apparatus of the RTFOT test

(ii) Penetration Test- The penetration test was conducted following the specifications laid out in AS 2341.12. The penetration test measures the distance, in millimetres, of a standard needle that is perpendicularly diffused in the bitumen sample under specific conditions: 5 s of time, 25 °C temperature, and 100 g for loading. The main purpose of this test is to establish the stability of the bitumen and, thus, the ability to resist rutting failure and cracking deformation.

(iii) Dynamic Shear Rheometer (DSR) Test- To examine the viscoelastic behaviour at high temperatures and the bitumen's resistance to rutting and fatigue, both treated and nontreated binder samples were subjected to the dynamic shear rheometer (DSR) test following the AASHTO 315 standard. This test focuses on determining the shear stress and linear viscoelastic properties of bitumen tested in oscillatory shear using parallel plates. The main aim of the test is to measure the complex shear modulus, which is known as the stiffness indicator G*, and measure the phase angle, which is known as the elasticity indicator.

(iv) Rolling Thin Film Oven Test (RTFOT)- To simulate the ageing conditions during pavement construction and under traffic loads, the rolling thin film oven test (RTFOT) is conducted. Figure 1 shows the apparatus at Curtin University. This test was carried out in the Curtin laboratory following the procedure and specification standards as AS/NZS 2341.10:2015 (Standards Australia 2015).

(v) Pressure Ageing Vessel (PAV) Test- To simulate the long-term and in-service ageing of the bitumen binder after five to ten years of traffic service, the pressure ageing vessel (PAV) test is conducted, where the bitumen binders are subjected to a high pressure of 2.1 MPa for a period of 20 h under a high temperature of 110 °C.

RESULTS AND DISCUSSION

(i) Penetration test- Penetration measures the bitumen consistency. The depth of penetration is measured in units of 0.1 mm and reported in penetration units (e.g., if the needle penetrates 8 mm, the asphalt penetration number is 80). Penetration Grading is based on the penetration test. Figure 2 shows the variation of penetration value with the various percentages of bitumen modified PET decreases with the addition of PET. The figure indicates that the consistency of the PET modified bitumen decrease as the PET content increases in the mix. Reduction of 14%, 21%, 30% and 35% in penetration values with the addition of 2%, 4 %, 6% and 8% of PET, respectively, as compared to the original bitumen. This means that the addition of PET makes the modified bitumen harder and more consistent. This is good in one sense since it might improve the rutting resistance of the mix, but on the other hand this may affect flexibility of the bitumen by making the asphalt much stiffer, thus the resistance to fatigue cracking can be affected.

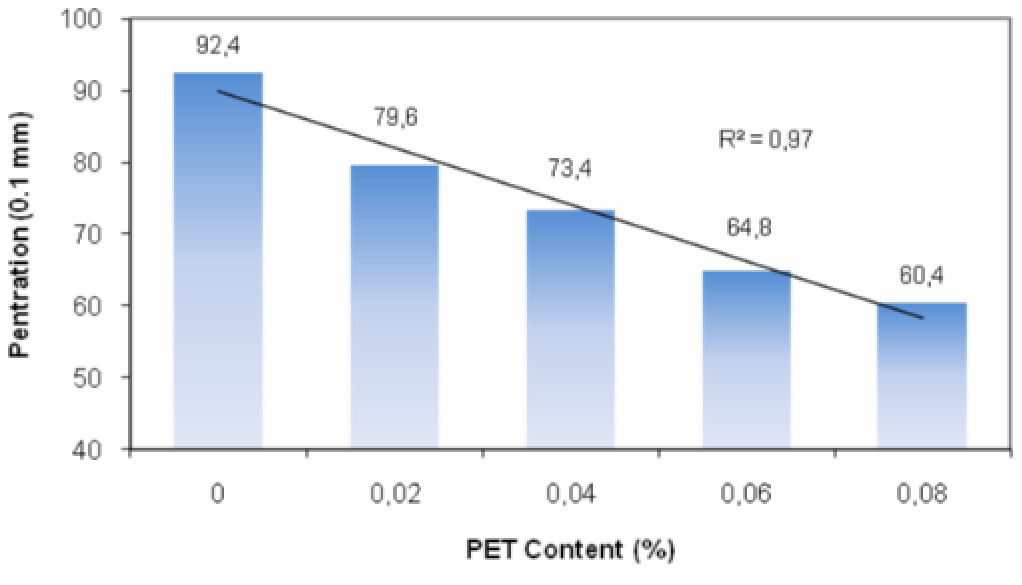

Figure 2- Penetration grade vs. different percentage of PET

(ii) Softening point- The softening point is defined as the temperature at which a bitumen sample can no longer support the weight of a 3.5-g steel ball. Basically, two horizontal disks of bitumen, cast in shouldered brass rings are heated at a controlled rate in a liquid bath while each supports a steel ball. The softening point is reported as the mean of the temperatures at which the two disks soften enough to allow each ball, enveloped in bitumen, to fall a distance of 25 mm (1.0 inch). Figure 3 show that softening point increases with increasing PET content.

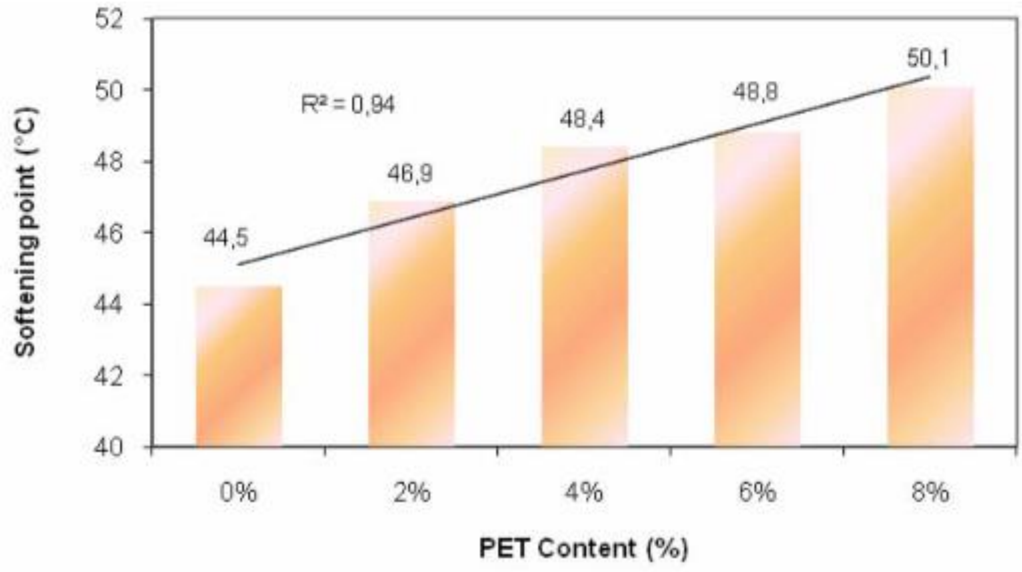

Figure 3- Softening point vs. different percentage of PET

It appears clearly from the results that the addition of PET to bitumen increases the softening point value, and as the PET content increase the softening point also increases. This increase ranges from 5% to 13% with the addition of 2% to 8% PET contents. This phenomenon indicates that the resistance of the binder to the effect of heat is increased and it will reduce its tendency to soften in hot weather. Thus, with the addition of PET the modified binder will be less susceptible to temperature changes. The effect of softening point of a binder on resistance to permanent deformation of bituminous pavement mixes has been studied by various researchers. An example is hot rolled asphalt where it was found that the rate of rutting in the wheel tracking test at 45°C, was halved by increasing softening point by approximately 5ºC. Therefore it is expected that by using the PET in the bituminous mix the rate of rutting will decrease due to the increase in softening point.

CONCLUSION

This paper's primary goal was to identify the best kind and amount of waste plastic to add to C320 bitumen in order to change its properties and prevent it from permanently deforming. The following is a summary of the conclusions. It was investigated if discarded plastic may be used as an eco-friendly bitumen modifier in Australia. The findings demonstrate the potential for altering C320 bitumen with waste plastic. According to penetration tests conducted both before and after ageing, two and four percent of HDPE and LDPE, respectively, are suggested contents that function well. Regarding the DSR tests, a comparable pattern revealed that stiffness and elasticity are not considerably improved by larger amounts of 6–8%. The samples are more prone to permanent deformation because the changed binder has ageing qualities that make it more prone to ageing. Long-term ageing data indicate that, when compared to C320 bitumen, almost all waste PET samples had a longer fatigue life, reduced ageing, and a stronger resilience to fatigue and cracking. The resistance to permanent deformation improves significantly by using up to 8% more waste PET plastic. The results indicate that PET waste plastic with a concentration of 6% and 8% is the optimal kind, as it exhibits superior resistance to permanent deformation.

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