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INVESTIGATING THE EFFECT OF SHEAR RATE IN THE SHEAR THINNING BEHAVIOUR OF WASTE PLASTIC-MODIFIED ASPHALT BINDER

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Abstract- The major goal of this study was to determine how shear rate influences the shear-thinning properties of asphalt binder treated with waste plastic. The blending of asphalt and waste plastic was accomplished using a melting process. Asphalt binder is a non-Newtonian fluid that exhibits shear-thinning behavior, and the dependence of shear viscosity on shear rate is a key characteristic of its pseudo-plastic behavior. The addition of waste plastic as a modifier to asphalt binder at percentages of 16%, 18%, and 20% was found to increase the performance of the asphalt. The shear-thinning behavior of two types of bitumen grades, ARL 60/70, and ARL 80/100 was assessed through rotational viscometer testing. The experimental results demonstrated that shear rate and viscosity are inversely proportional, with an increase in the shear rate leading to a decrease in apparent viscosity. These findings indicated that waste plastic modification can impact the viscosity and shear-thinning behavior of asphalt binders.

Keywords- Brookfield Rotational Viscometer, Modified Asphalt, Shear thinning, Shear rate, Shear stress, Viscosity, Waste plastic.

1 Introduction

Asphalt binder is a crucial element in the construction of roads and highways, providing the required strength, stability, and durability to pavement [1]. However, asphalt binder's flow behaviour and viscosity undergo significant changes over time due to aging, oxidation, and weathering, which can negatively impact pavement performance[2]. To address this issue, researchers have investigated the utilization of waste plastic and waste cooking oil as a rejuvenator to improve asphalt binder's rheological properties, including stiffness and viscosity[3], [4]. According to Liu et al, [5], the flow behaviour of asphalt binder is influenced by several factors, including the shear rate. Shear rate is defined as the rate at which the material experiences shear stress or force. The relationship between shear rate and viscosity is critical for understanding the material's behaviour under different conditions.

Similar shear-thinning behavior has previously been reported in studies on waste plastic-modified asphalt binders. These studies have highlighted the influence of waste plastic content, polymer type, and processing conditions on the shear-thinning behavior. [6] The consistency of these findings across different studies further supports the understanding that waste plastic modification induces shear-thinning behavior in bitumen binders. The observed shear-thinning behavior and the associated decrease in viscosity have practical implications for asphalt applications. In road construction, for example, lower viscosity asphalt binders are desirable as they facilitate easier mixing, compaction, and coating of aggregates. [7] This characteristic can contribute to improved workability and overall performance of the asphalt mixtures. In this study, we evaluate the shear thinning behaviour of modified asphalt with waste plastic, focusing on the effect of shear rate. This study makes a novel contribution to the area by addressing a research gap on this specific topic. The relevance of this research is that it has the potential to improve our understanding of the rheological properties of modified asphalt and provide useful insights for the development of sustainable and high-performance road-building materials.

2 Problem Statement and Objectives

With the overproduction of plastic waste, recycling it for building materials and road construction is a promising solution. However, achieving the optimal shear thinning range (viscosity in Pa. s) is crucial for effective waste plastic modification of asphalt. Failure to do so can lead to further damage of the asphalt's properties. Therefore, investigating the impact of waste plastic modification on the shear-thinning behavior of asphalt using the Brookfield rotational viscometer is essential to ensure its suitability for road construction.

The main objective of this study was to determine the impact of waste plastic modification on the shear thinning behaviour of asphalt under various shear rates. The other objectives of the research are:

- To study the effect of varying waste plastic percentages on absolute viscosity of asphalt binder; and
- To quantify the effect of shear stress and torque on the viscosity of different binders with different waste plastic percentages.

3 Materials and Methodology

3.1 Bitumen

Bitumen samples of ARL 60/70 and ARL 80/100 grades have been obtained from the MKA Asphalt facility in Islamabad, near the Margalla stop. It is advised that bitumen be stored at ambient temperatures in 5kg canisters. The bitumen samples were subjected to standard testing like penetration, ductility, and softening point. Table 1 displays the assessment outcomes.

Table 1: Physical properties of Virgin bitumen

Properties	**Standard code**	**Unit**	**ARL 60/70**	**Specification limit (minimum)**
Penetration 0.1mm @ 25°C	ASTM D5	1/10 mm	61	60
Softening point (°C)	ASTM D36	°C	50	43
Ductility at 25°C	ASTM D36	Cm	103	100
Dynamic viscosity	ASTM D4402	Cp	343.5	300

3.2 Waste Plastic

The use of waste plastic shown in Figure 1(a) and (b) in road construction has gained increasing attention as a sustainable solution for plastic waste management. Adding scrap plastic into bitumen mixtures as a partial replacement for bitumen can improve asphalt durability, including its resistance to rutting, cracking, and moisture damage. This approach can also help to reduce demand for virgin bitumen, a finite resource, and boost the long-term viability of road infrastructure. [8]

a) https://www.google.com b) UET lab

Figure 1: a. waste plastic bottles, and b. Shredded Plastic for current study

4 Experimental work

Three samples were created for each waste plastic percentage (16%, 18%, and 20%) for all types of binders to evaluate the viability of waste plastic as a partial replacement for bitumen in the construction of roads. To guarantee appropriate mixing, the modified asphalt mixing temperature was kept between 180 and 200 °C. The waste plastic is added in shredded form, size ranges from 2.36mm to 4.75mm. Shredded waste plastic was added to the bitumen at the melting temperature of the appropriate bitumen grade, and the mixture was mechanically stirred to ensure uniform particle dispersal. The mixture was then tested with a rotational viscometer to see how it affected viscosity and shear thinning. Shredding at industrial level is done through shredding machines and then dried and heated at the shredded plastic in the drying chamber before mixing into asphalt biner.

4.1 *Brookfield Rotary Viscosity Test*

To measure the viscosity of asphalt modified with waste plastic, a Brookfield viscometer shown in figure 2 was utilized following the ASTM D4402 standard. The experiment involved recording various parameters such as temperature, rotational speed, shear stress, shear rate, and viscosity, as outlined in Table 2. The test aimed to evaluate the impact of waste plastic on the viscosity of asphalt, and the results could provide valuable insights into the feasibility of using waste plastic as a partial replacement for bitumen in road construction. Overall, the study provided a detailed methodology for assessing the rheological properties of bitumen modified with waste plastic.

Table 2: Test conditions for Brookfield rotary viscosity

Waste plastic (%)	Test temperature (°C)	Shear rate (1/s)
16%, 18%, 20%	135	1.7, 3.4, 6.8, 10.2, 13.6, 17, 20.4, 23.8, 27.2, 30.6, 34

Figure 2: Brookfield rotary viscometer

5 Results & Discussion

5.1 Discussion

Experimental work on asphalt grade 60/70 examined the impact of waste plastic modification on its behavior. The results revealed reduced viscosity and increased shear stress, indicating a thinning effect on the modified binder.[9] This behavior is attributed to the reorganization of the binder's internal structure, facilitating easier flow and lower resistance. Previous studies on waste plastic-modified asphalt binders have reported similar shear-thinning behavior, emphasizing the influence of plastic content, polymer type, and processing conditions. [10]. These consistent findings support the understanding that waste plastic modification induces shear-thinning behavior in bitumen binders. In conclusion, the experiments confirmed a clear relationship between viscosity and shear stress, demonstrating the shear-thinning behavior resulting from waste plastic modification of asphalt. The internal structure of asphalt plays a crucial role in determining its viscosity under different shear conditions. At low shear rates, the internal structure exhibits a higher resistance to deformation, leading to higher viscosity [11]. However, as the shear rate increases, the internal structure undergoes significant reorganization, promoting asphalt flow and deformation and resulting in a decrease in viscosity [12]. Understanding the shear rate-viscosity relationship and the underlying internal structure reorganization in asphalt has important implications for various applications. It allows for the optimization of asphalt mixtures, enabling the design of materials with specific flow characteristics that enhance workability and overall performance.[13] the findings presented in Figure 3 and supported by previous studies confirm the inverse connection between shear rate and viscosity in asphalt.

Figure 4 reveals a linear relationship between shear rate and shear stress for modified bitumen. The study investigated the influence of waste plastic content on shear stress at varying percentages. Notably, a significant increase in shear stress was observed at a waste plastic concentration of 20%. This implies that increasing waste plastic quantity in the binder notably affects shear stress. The observed relationship between shear rate and shear stress offers valuable insights into the rheological behavior of the modified bitumen binder, enabling the development of sustainable asphalt materials with enhanced structural and flow properties.

Figures 5 depicts the relationship between log shear rate and log viscosity for the modified binder, which shows an inverse relationship. As the log shear rate increases, the log viscosity values increase as well. This conclusion indicates that shear rate has a major impact on the shear-thinning behaviour of the asphalt binder. Higher shear rates result in lower viscosities, indicating a decrease in flow resistance. This finding emphasises the significance of shear rate in understanding the flow properties and behaviour of the modified binder, providing vital insights into its rheological features. In Figure 6, shear rate and torque display a consistent pattern: torque increases as shear rate rises. This suggests that higher rotation velocities correspond to greater shear rates unless significant shear-thinning behavior counteracts it. This relationship clarifies the rheological characteristics and informs the flow behavior of the binder under different shear conditions. Understanding this connection is crucial for developing enhanced and sustainable asphalt materials for road construction and maintenance, considering the influence of shear rate on torque.

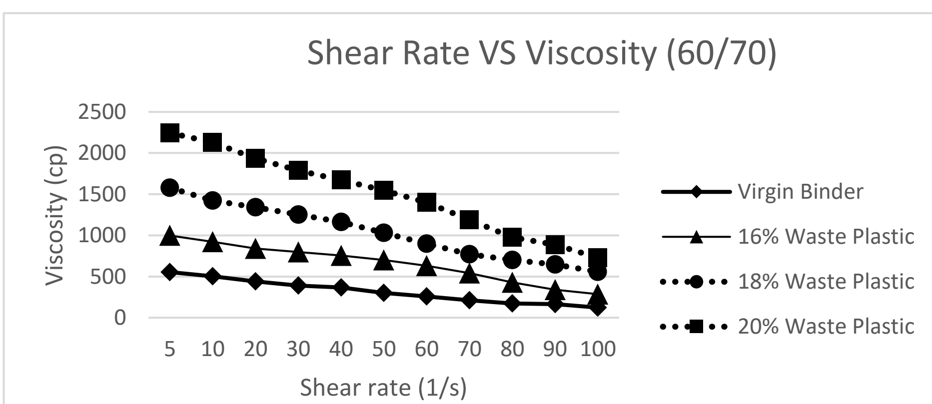

Figure 3 shear rate vs Viscosity of modified 60/70 bitumen binder.

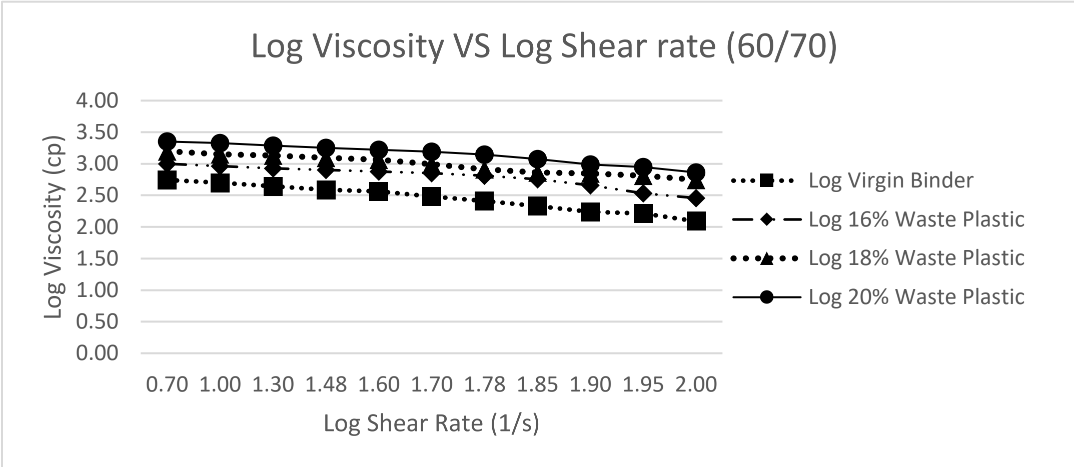

Figure 4: Shear rate vs Shear stress of modified 60/70 bitumen binder

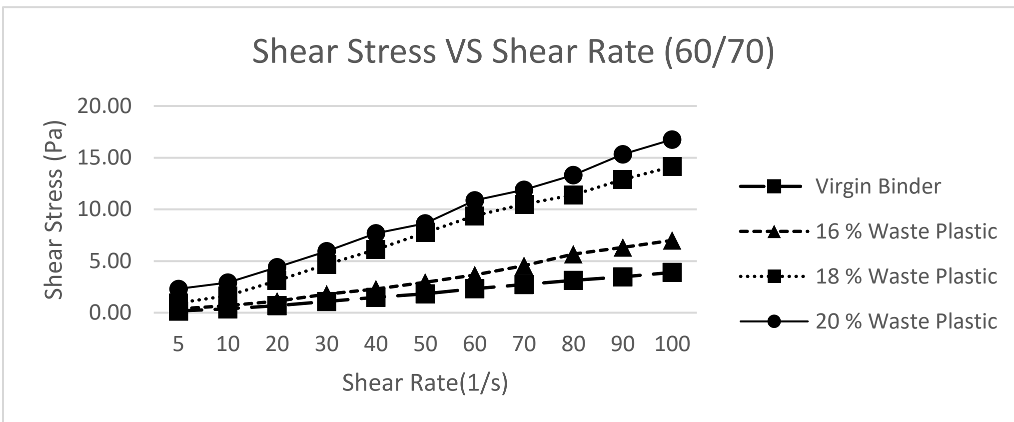

Figure 5: log Shear rate vs log viscosity of modified 60/70 bitumen binder

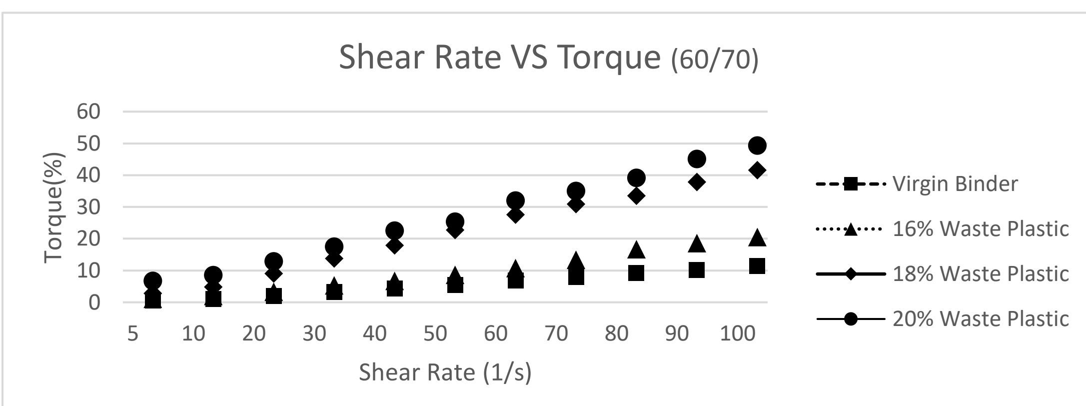

Figure 6: Shear rate vs Torque of modified 60/70 bitumen binder

5.2 Practical Implementation

The experimental work provided in the presented paper on waste plastic-modified bitumen has practical implications for asphalt binder and road building.[14] The research shows that incorporating waste plastic into bitumen reduces viscosity and increases shear stress, resulting in improved flow and workability during construction processes.[15] The research contributes to attempts to reduce environmental impact by diverting garbage from landfills and supporting the sustainable economy concept. The research findings have practical implications for facilitating the development of industry standards and guidelines for using waste plastic in asphalt binders.[16] To summarise, the research on waste plastic-modified bitumen has practical implications for improved workability, improved structural performance, customization, sustainability, and the development of industry standards in asphalt binder and road construction practises.

6 Conclusions

This study evaluated the properties of asphalt binder ARL 60/70 using a rotational viscometer, with a focus on apparent viscosity and shear-thinning behaviour. The outcomes indicated that:

1. When waste plastic was added to bitumen binders, it increased viscosity, especially at 20% concentration. On the other hand, a lowered amount of 16% approximately matched the viscosity of virgin bitumen, making it the best choice for a partial replacement.

2. However, the viscosity of all percentages i.e., 20%, 18% and 16% waste plastic-modified bitumen binders decreased as the shear rate increased. This behavior is characteristic of non-Newtonian fluids, demonstrating shear-thinning properties.

3. Increasing the shear rate resulted in higher shear stress i.e.., from 0.37 to 7.0 for 16% waste plastic and for 18% waste plastic the value goes from 0.95 to 14.4, while for 20% the values range from 2.31 to 16.76.

4. The torque values also increase with the increase of shear rate for waste plastic-modified asphalt binders i.e., for 16%, the value of torque goes from 1.1 to 20.6 and for 18%, torque values are 2.8 to 41.6, while for 20% its values range from 6.8 to 49.3.

Previous and contemporary research has demonstrated that waste plastic can cause shear-thinning in asphalt binders at medium and elevated temperatures. However, its usefulness in low-temperature environments is unknown. As a result, studying the influence of waste plastic on bitumen binder rheology at minimal temperatures would provide useful insights for its usage in cold climates.

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