



## EVALUATING THE PERFORMANCE PROPERTIES OF ASPHALT PRODUCED FROM BITUMEN MODIFIED WITH THERMOPLASTIC POLYMER

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### ABSTRACT

Flexible pavements, particularly in urban areas, deteriorate rapidly after construction due to poor workmanship and inadequate drainage facilities. The demand for roads continues to increase. Engineers of the highway system are concentrating on alternative solutions to meet this expanding challenge. Highway system engineers are currently focused on developing alternative solutions in order to address this growing challenge. To prevent the premature deterioration of the road system, the performance of flexible pavements must be enhanced. The addition of waste polymers to asphalt mixtures is one method that can significantly enhance the quality of the pavements. This study examined the mechanical properties of asphalt produced from waste plastic polymer-modified bitumen. The addition of thermoplastic polymer (0 to 12%) increased the softening point, viscosity, flash and fire points of bitumen, but decreased its penetration and ductility for the production of hot mix asphalt. The Marshall stability and flow of all asphalt concrete formulations were greater than 9 kN and within 2 - 6 mm of the General Specifications of Nigerian for Road and Bridges, Federal Ministry of Works and Housing, 2016 and the Asphalt Institute, 1991. Modification of asphalt with thermoplastic polymer is suitable for enhancing the performance properties of the asphalt. Additional research is required for the development of recyclable additives that do not significantly increase the final cost of bitumen

### 1.0 Introduction

Asphalt is widely used as a material in highway construction. Continuous increment in industrialization and urbanization increases the demand for highway networks. Akinleye *et al.* (2020a) reported that global highway networks consist of numerous track miles and facilitate countless vehicle miles annually. Mantzos and Capros (2006) predicted that this demand will continue to rise significantly over the next ten years as the volume of goods and people traveling by road continues to rise globally. An evaluation of the quality of asphalt concrete used in road construction in Nigeria suggested that asphalt quality should be enhanced due to the early failure of road pavements in the country. Modification of hot mix asphalt (HMA) pavements is essential for resolving the quality of surface materials. It improves performance, extends service life, and reduces maintenance costs (Arslan *et al.*, 2012; Akinleye and Tijani, 2017; Salami *et al.*, 2023). There are two primary ways to incorporate polymers into asphalt mixtures, namely the moist process and the dry process (Salami and Bello, 2021). Nevertheless, the modification of bitumen has been the method most frequently used for this purpose (Kalantar *et al.*, 2012).

Plastic is widely used in contemporary society, and its disposal poses a significant problem. Plastic is an inorganic substance; therefore, it pollutes the environment and causes problems. Now, the greatest challenge is to reduce plastic pollution by converting it into something useful (Akinleye *et al.*, 2020a, 2020b). According to Mohd *et al.* (2017), given that the waste consists of Polyethylene Terephthalate (PET) plastic bottles, disposable glasses, purses, and various appliance covers that become moist at 160°C, one solution is to use waste plastic in such a way that it becomes coated by an aggregate via heating (140–160°C). Every year, following the monsoon season, almost all of the main roads in urban areas of Nigeria require immediate and extensive rehabilitation due to the country's traditional construction methods and harsh climate. This maintenance work is not only costly, but it also disrupts normal traffic flow, causing drivers inconvenience and delay. Utilizing waste plastic (polymer) in the construction and maintenance of pavements could reduce the frequency of rehabilitation work and provide a cost-effective solution. The second benefit of plastic recycling is the enhancement of the problem of solid waste disposal.

Additives used to modify or enhance the quality of virgin materials are referred to as its modifiers. To enhance the properties of asphalt concrete, modifiers are either blended directly with the binder or added during production. The recent trend in the pavement industry is to use polymer as a bitumen modifier, as polymer is analogous in nature to certain bitumen constituents. Bitumen is a complex mixture of various compounds. Asphaltenes and malthenes are the principal components of bitumen. The amount of aromatic malthenes and asphaltenes (Baker, 1998) is crucial to the suitability of bitumen modification. Polymer and copolymer of distinct category and grade are used to improve the overall quality of bitumen due to their similar composition. Polymer increases the viscosity of bitumen and the thickness of the coating surrounding aggregates (Murphy *et al.*, 2001; Salami *et al.*, 2023). Thus, the adhesive and cohesive properties of bitumen are improved. Another potential bitumen modifier is natural rubber (granules or latex) or reprocessed rubber dust (Kakar *et al.*, 2021). The waste plastic (Scrap Polythene) can also be used to modify binder (Kakar *et al.*, 2021).

As asphalt binder is responsible for the thermos-rheological properties of asphalt mixtures, it plays a crucial role in determining a variety of factors, such as permanent deformation and fatigue cracks. A portion of asphalt's induced strain is attributable to non-recoverable viscous flow, which progressively increases with loading time and temperature. The variation in strain with time is caused by the material's viscous behavior. When the burden is removed, the elastic strain recovers, and some additional recovery takes place over time; this phenomenon is known as delayed elasticity. Due to the viscosity of the binder, there is a permanent residual strain that cannot be recovered. Review of literature revealed that thermoplastic polymer is viscous in a nature. Hence, this study modified the bitumen with thermoplastic polymer in a bid to enhance the viscosity of the binder. Thus, this study examined the mechanical properties of asphalt produced from waste plastic polymer-modified bitumen.

## **2. Materials and Methods**

### **2.1 Materials**

Wastes of metals and high-density polymer (broken buckets, bowls, overhead water tanks and plastic chairs) were obtained within at waste generation point of Adeleke University, Ede, Nigeria. metropolis, Osun State, Nigeria, the polymers were shredded into small sizes and melted and allowed to cool. The polymers were melted using a gas cooker at the Highway and Transportation Laboratory of the Department of Civil Engineering, Adeleke University, Ede, Nigeria. Asphalt thermometer was used to check the temperature. The polymers have a melting point of 160°C. The polymers' very high melting temperature and readiness of compatibility with the asphalt prompted its addition at varied weight proportions of bitumen in the proportions 0, 2, 4, 6, 8, 10 and 12% for the preparation of modified asphalt mixture. The plastic pieces were melted with bitumen at temperature between 160 -170°C and the mixture was stirred thoroughly for about 15 to 20 minutes to attain a uniform blend in

accordance with ASTM standard specification. Different compositions (broken buckets, bowls, overhead water tanks and plastic chairs) of polymer-bitumen mixtures (blends) were prepared and utilized for the experiments. The purpose of bitumen modification includes softening blends at low temperatures to reduce fractures, increasing the stability and strength of mixtures, enhancing the asphalt cohesive strength in pavements, preventing oxidation and aging, and lowering the construction costs of asphalt roads. The waste plastics were burnt using a portable gas cooker. The fine (stone dust) and coarse aggregate was gotten from crushed igneous rock at Ayofe Quarry, Ede, Nigeria. Figure 1 (a – d) depicts the breakable plastic wastes, modified bitumen sample (showing the melting process), fine aggregate sample and coarse aggregate sample, respectively.



**Figure 1a:** Breakable Plastic Wastes



**Figure 1b:** Modified Bitumen Sample



**Figure 1c:** Fine Aggregate Sample



**Figure 1d:** Coarse Aggregate Sample

## 2.2 Determination of Penetration Values

This is used to measure the vertical depth of bitumen to ascertain its rigidity or pliability. Penetrometer was used to determine the penetration of the bitumen in accordance with ASTM D5-06. (2006) standard specification. The bitumen mixture was liquefied to a pourable consistency, thoroughly mixed, and poured into containers. The test was conducted at 250°C. The bitumen temperature was achieved and maintained using a water bath. Figure 2 depicts a diagram of a penetration test configuration.



**Figure 2:** Penetration test Set-up

### 2.3 Determination of Ductility Values

Bitumen is ductile, allowing it to withstand significant deformation or elongation. Mold-containing bitumen compositions were cooled in the air and then in a 27°C water bath in accordance with ASTM D113-86. (1986) standard specification. The surface was leveled of excess bitumen was removed with a heated knife. The sample-containing mold was then deposited in the ductility machine's water reservoir for approximately 90 minutes. The model of the ductility machine is TO-565-DG-03 and it is electrically operated at 220V, 50Hz. The sides of the molds were removed, clamps were affixed to the machine, and the machine was activated. Ductility values were obtained at the point of rupture of the bitumen. The ductility values were taken at the point at which the bitumen breaks after elongation in accordance with ASTM D113-86. (1986) standard specification. The laboratory configuration for the ductility machine is depicted in Figure 3.



**Figure 3:** Ductility test Apparatus

### 2.4 Determination of Softening Point

The softening point is the temperature at which bitumen softens to a specific degree under the specified test conditions. The bitumen mixture sample was covered with a 3.5g steel ball, and the liquid medium was heated to 50°C per minute using an electric hot plate. When the bitumen reaches a depth of 25 millimeters below the ring, the temperature was recorded. Softening point test was conducted in accordance with ASTM D36-2002. (2002) standard specification. Figure 4 depicts the test setup for the study's evaluation of the softening point.



**Figure 4:** Ring and Ball Softening Point Apparatus



**Figure 5:** Flash and Fire Point Test Apparatus

## 2.5 Determination of Flash and Fire Point

Depending on the condition of the bituminous material, volatiles should be eliminated at high temperatures. The flash point is the temperature at which bituminous vapour ignites when exposed to a small flame. The fire point is the lowest temperature at which a fuel's vapour continues to ignite for at least five seconds. The experiment was conducted in compliance with ASTM D92 – 02 (2002) standard specification. Figure 5 depicts the setup for the test.

## 2.6 Determination of Viscosity (IS: 1206-1978)

Viscosity denotes the fluid property of bituminous material and it is a measure of the material resistance to flow. The bitumen was heated to a temperature not exceeding 60°C, which is slightly above the softening point of bitumen. The bitumen was heated until it became fluid enough to be readily poured. The viscometer container was filled to a maximum of 25 ml and placed gingerly beneath the spindle section of the viscometer. The spindle was then meticulously positioned within the sample. The opening beneath the test apparatus was then sealed. Afterward, the viscometer was activated. The viscometer rotated at 200 revolutions per minute until the temperature of the bitumen reached 135 degrees Celsius. When the viscometer attained the required temperature and the viscosity was stable, the viscosity values were recorded. According to ASTM D445-06 (2006) standard specification, the testing apparatus was used to measure the viscosity of the bitumen. Figure 6 displays the viscosity testing apparatus.



**Figure 6:** Viscosity Test Apparatus

## 2.7 Marshall Stability Test

The Marshall stability test is used for assessing two crucial features of flexible characteristics and strength. The Marshall stability of a mixture measures its tensile strength, while the Flow value quantifies its pliability. The machine's upper dial gauge displays the stability value, while the lower dial gauge displays the flow value. The Marshall Stability test was successfully carried out in accordance with the specifications of ASTM D2487 (2011). Figure 7a depicts thermostatically controlled water reservoir in which the test samples were immersed for 30 to 40 minutes at a temperature of 60°C. Probably, the Marshall stability of the mixture is a greater load carried by a compacted specimen at a standard temperature of 60°C. The flow value is the distortion in millimeters that the test specimen experiences during loading up to the maximum load. The thermostatically controlled water reservoir in which the test samples were immersed for 30 to 40 minutes at a temperature of 60°C is presented in Figure 7a. The Figures 7b and 7c show the Marshall stability test set-up and Marshall stability sample, respectively.



**Figure 7a:** Marshall Samples in Thermostatically Controlled Water Bath



**Figure 7b:** Marshall Stability test set up



**Figure 7c:** Marshall Stability Sample

## 3. Results and Discussion

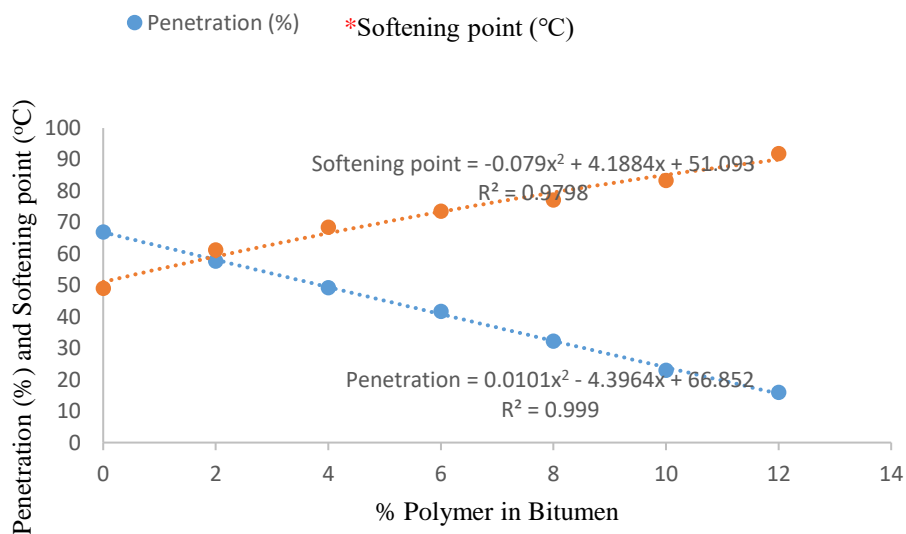
### 3.1 Penetration and Softening Points

The results of penetration and softening values of plastic polymer modified bitumen are presented in Table 1. The values of penetration points for the 0 – 12% of polymer addition ranges from 16 to 67 percentage. It was observed that the penetration value decreased as the percentage polymer addition increased (Figure 8) which could attribute to the addition of the polymers. The coefficient of prediction of 99.9% implies that the polynomial model shows a good relationship between penetration value and polymer addition level. Also, the softening point values of the asphalt produced from bitumen modified with plastic polymer ranged from 49.05 to 91.9°C. It was deduced that the softening point value increased as the percentage polymer addition increased as surfaced in Figure 8. The increment in the softening point could

attributed to the addition of the polymers. This is corroborated by the findings of Ajagbe et al. (2018); Ajagbe et al., 2020; Akinleye et al., 2020a; Akinleye et al., 2020b; Salami et al., 2023a; Salami et al., 2023b. The coefficient of prediction of 97.98% implies that the model shows a good relationship between softening point and polymer addition level. It demonstrates that the temperature sensitivity of the binder decreased significantly as the amount of modifier increased. This is in line with Mohammad (2012); Murana et al. (2020); Akinleye et al. (2020a); Salami and Bello (2021); Salami et al. (2023a) where it was discovered that the softening point increased from 50 to 70°C when 10% of the plastic waste was present. It implies that a greater amount of heat will be required to soften the improved binder because polymer increased the binder's consistency.

**Table I:** Penetration and softening properties of plastic polymer modified asphalt

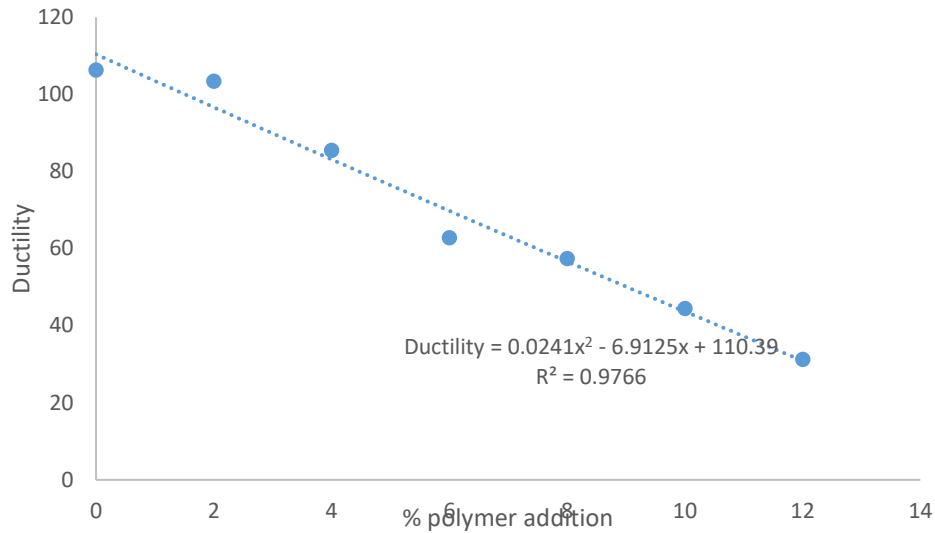
% Polymer in Bitumen	Penetration (%)	Softening point (°C)
0	67.0	49.05
2	57.7	61.25
4	49.3	68.50
6	41.7	73.55
8	32.3	77.20
10	23.0	83.35
12	16.0	91.90



**Figure 8:** Penetration and Softening points

### 3.2 Ductility

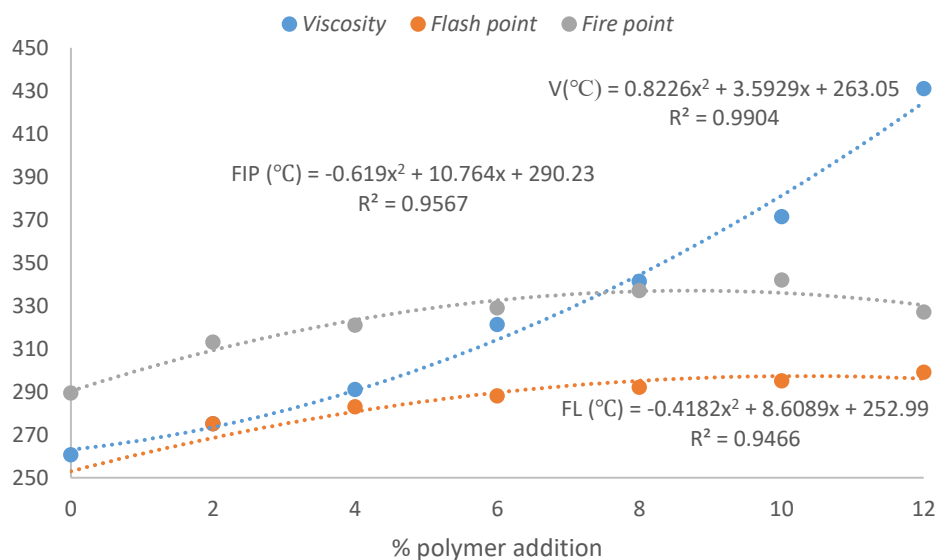
Ductility test results of the asphalt produced from bitumen modified with plastic polymers are presented in Figure 9. The average values ranged from 31.3 to 106.3 which also signifies that ductility declined with surge in the content of modifier in the bitumen. The decrement in the ductility could attributed to the addition of the polymers. This is corroborated by the findings of Ajagbe et al. (2018); Ajagbe et al., 2020; Akinleye et al., 2020b; Salami et al., 2023a; Salami et al., 2023b. The polynomial model representing the ductility at a known percent polymer addition showed 97.66% coefficient of prediction which showed an adequate representation.



**Figure 9:** Ductility values of the plastic polymer modified asphalt

### 3.3 Viscosity, Flash and Fire Points

The Viscosity (V) values of plastic polymer modified bitumen ranged from 260.7 to 431.0°C and it increased with an upsurge in the percent polymer addition level as shown in Figure 10. The viscosity values obtained increases with an increase in the percent polymer addition. The increment can be attributed to the addition of polymer. Polymer is known to be viscous in nature. The result is in consonance with the findings of Ajagbe *et al.* (2018); Ajagbe *et al.* (2020); Akinleye *et al.*, (2020b); Salami *et al.*, (2023a); Salami *et al.*, (2023b). The polynomial model generated to predict the relationship has a 99.04% agreement as shown in Figure 10. In the same vein, the Flash Point (FL) value obtained for the bitumen modified with plastic polymer ranged from 248.3 to 299.0°C. The increment in the values obtained for flash and fire point is as a result of the addition of polymer. Polymer and bitumen are known to be flammable in nature (Salami *et al.*, 2023a; Salami *et al.*, 2023b) The values obtained increases with an increase in the percent polymer addition and the polynomial model generated to predict the relationship has a 94.66% agreement. The Fire Point (FIP) value obtained for the bitumen modified with plastic polymer ranged from 289.4 to 327.0°C. The flash and fire point values obtained increases with an increase in the percent polymer addition and the polynomial model generated to predict the relationship has a 95.67% agreement as shown in Figure 10.



**Figure 10:** Viscosity, Flash and Fire Point of the plastic polymer modified asphalt



### 3.6 Optimum Bitumen Content

The results of Marshall Stability and flow varying plastic content are presented in Figure 11 below for the determination of Optimum Bitumen Content (OBC) at various addition level (0-12% by weight of bitumen). Figure 11 shows the result for Stability, while Figure 12 presents the result for Flow. These results were obtained to determine the optimum bitumen used to produce the asphalt sample for the determination of Stability and flow for the final mix. The OBC indicate the quantity of bitumen needed to produce the asphaltic concrete. All the OBC values obtained satisfy the requirement specified for binder and wearing courses by the FMW (2016). Furthermore, Figure 11 indicated the results of OBC for at 0, 2, 4, 6, 8, 10, and 12% modification were 5.80, 6.20, 5.80, 5.90, 5.90, 6.20, 6.10, 6.20, 5.90 and 5.60% respectively. The OBC values obtained satisfy the requirement specified for binder and wearing courses by the FMW (2016). Moreover, all values obtained for stability satisfy the FMW (2016) standard specification.

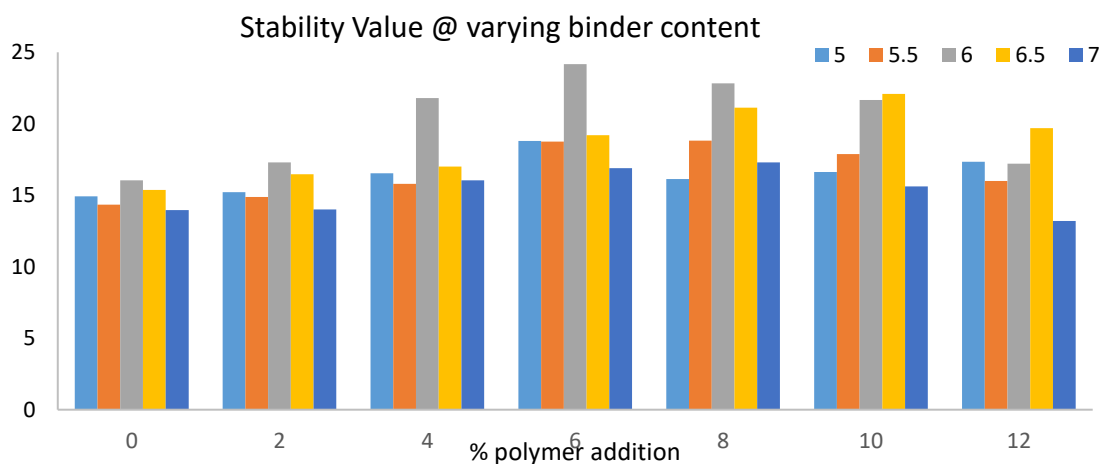


Figure 11: Marshall Stability Values for OBC Determination

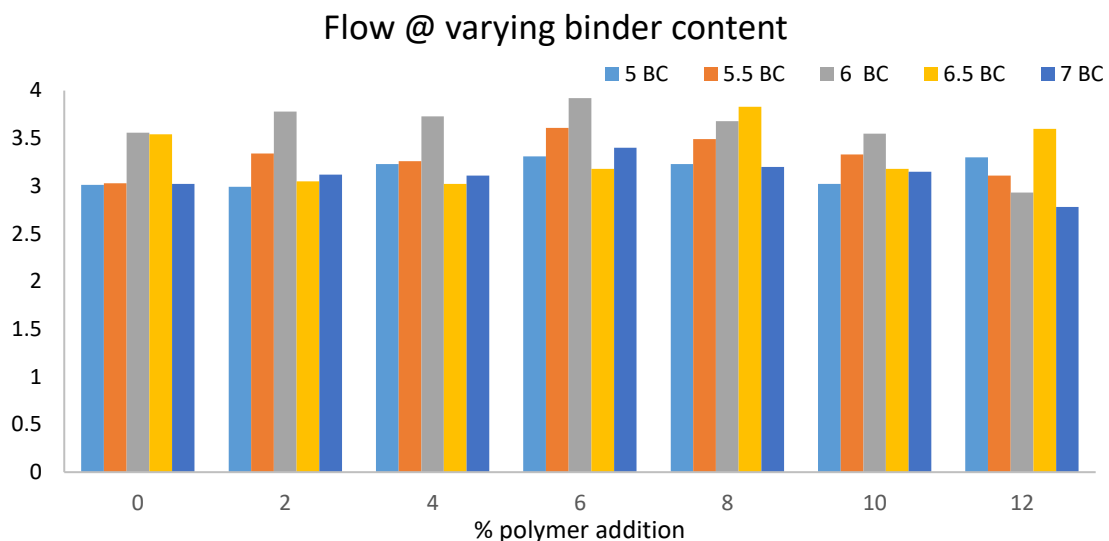
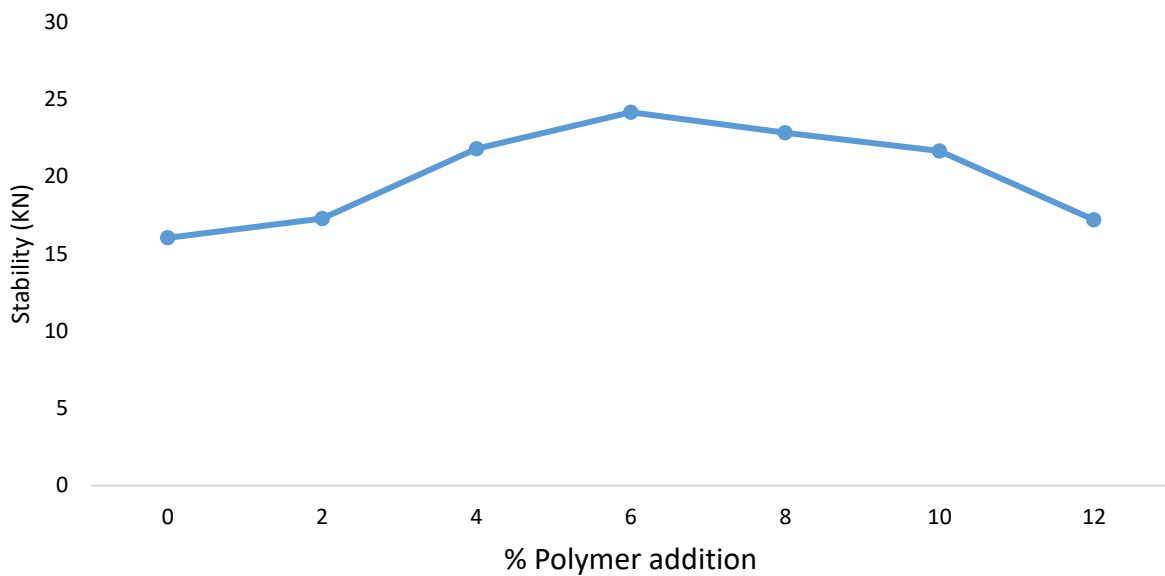


Figure 12: Marshall Flow Values for OBC Determination

### 3.7 Marshall Stability

Variation of stability with percentage polymer addition with bitumen test is presented in Figure 13. Stability values increased as the content of the polymer increased which could be attributed to the polymer's addition. The result is in consonance with the findings of Ajagbe et al. (2018); Ajagbe et al. (2020); Akinleye et al., (2020b); Salami et al., (2023a); Salami et al., (2023b). The upsurge in the stability values of the blend is attributable to the enhancement of the modified binders to aid adhesiveness and cohesiveness of the asphalt blend, which is a result of the

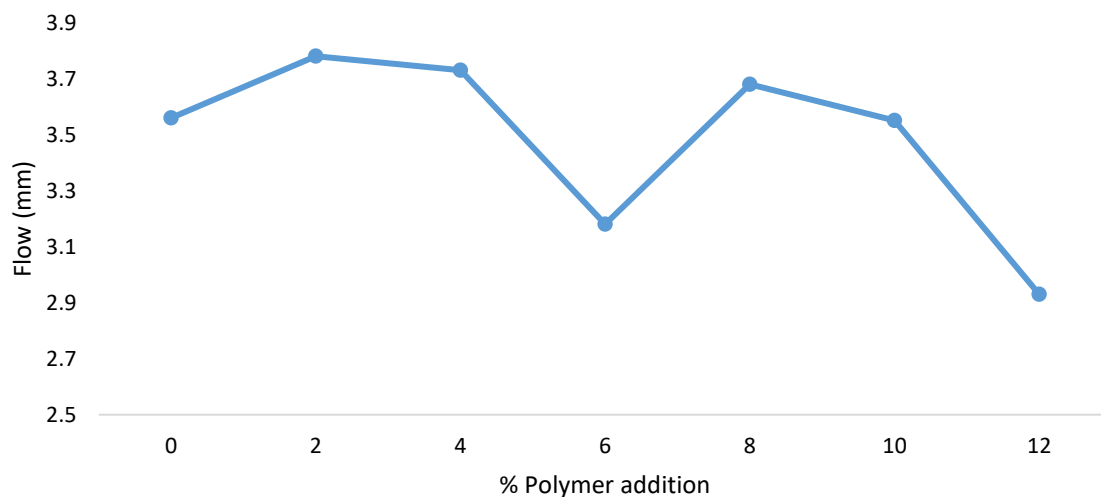
hardening and decrease in penetration of the modified bitumen blend in the mixture. The result is in consonance with the findings of Ajagbe *et al.* (2020); Akinleye *et al.*, (2020b) and Salami *et al.*, (2023a). This result concurs with the findings of Taih (2011), who investigated the influence of additives in hot asphalt mixtures and determined that the stability was 18.5 kN at a modifier content of 6%.



**Figure 13:** Variation of stability with percentage polymer addition with bitumen test

### 3.8 Marshall Flow

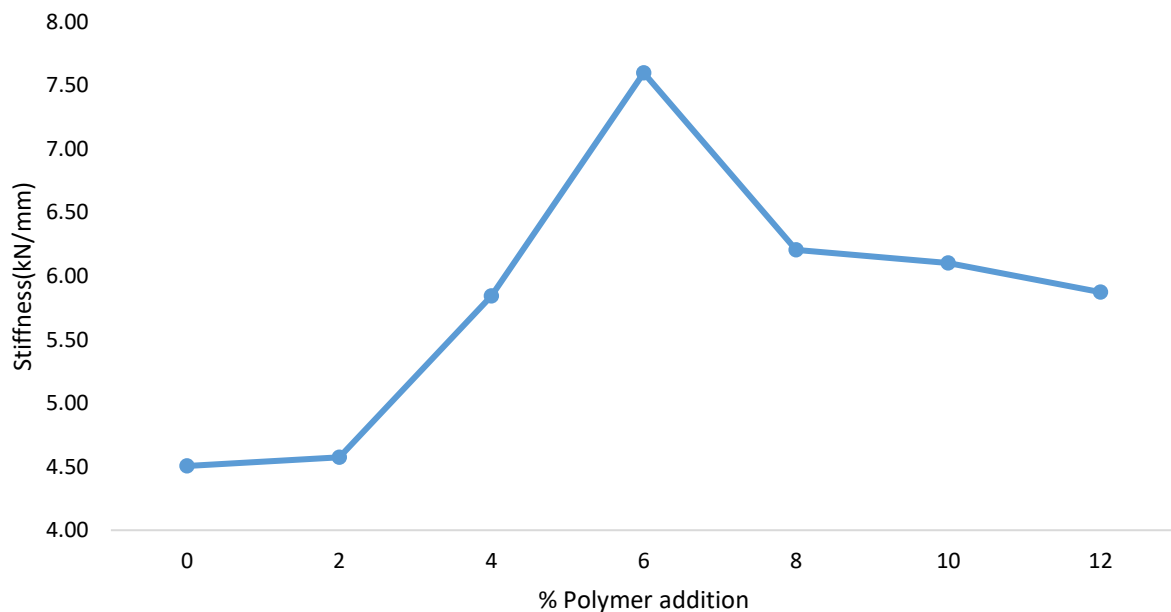
Figure 14 illustrates the variation of flow with percentage polymer addition content for all percentages. A reduction in the values of Marshall flow was observed from 6 to 8% in this study which may be attributed to the addition of the thermoplastic polymer in the asphalt which makes the asphalt to be more viscous thereby reducing the flow. A gradual reduction and increment were observed in the trend of result obtained for the Marshall flow. Similar trend was obtained by Akinleye *et al.*, (2020b); Salami *et al.*, (2023a); Salami *et al.*, (2023b). Hence, 6% is the optimum thermoplastic content in the mix in accordance with the FMW (2016) standard specification. This is consistent with the findings of Aliyu *et al.* (2015), who concluded that a decrease in flow indicates that polymer content has a greater influence on the internal friction of the mixture. This implies that the asphaltic concrete is less permeable. Hence, the lower the flow value, the higher the stability/strength of the asphaltic concrete.



**Figure 14:** Variation of flow with percentage polymer addition content

### 3.9 Marshall Stiffness

Figure 15 Figure 4.15 presents the results of stiffness of produced asphalt concrete. The stiffness values obtained at 0, 2, 4, 6, 8, 10 and 12% plastic addition doses were 4.51, 4.57, 5.84, 7.60, 6.21, 6.10 and 5.87 kN/mm respectively. The highest stiffness was obtained at 6% addition level (Figure 15). This implies that thermoplastic enhanced asphalt can counterattack deformation in response against wheel load induced to an optimum level of 6%. The result is in consonance with the findings of Ajagbe et al. (2018); Ajagbe et al. (2020); Akinleye et al., (2020b); Salami et al., (2023a); Salami et al., (2023b).



**Figure 15: Marshall Stiffness Values**

### 4. Conclusions

It was established that the addition of thermoplastic polymer (0 – 12%) enhanced the softening, viscosity, flash and fire points of bitumen. However, it decreased the penetration and ductility for hot mix asphalt (HMA) production. Indeed, the high polynomial model  $R^2$  values obtained from the quantitative statistical polynomial models for the breakable Plastic polymer modification for these characteristics means high degree of prediction of the mathematical relations. Likewise, addition of breakable Plastic polymer also improved the stability, flow and stiffness up to 12% dosage level for HMA for the required specifications for pavement works. The Marshall Stability and flow of all asphalt concrete mixtures were all greater than 3.5 kN and 9 kN for (stability) and within 2 – 6 mm (flow) specifications of both Nigerian General Specification for Road and Bridges, Federal Ministry of Works and Housing, 2016 and the Asphalt Institutes, 1991 respectively. From the study, it can be recommended that the use of breakable Plastic polymer is promising due to their effect on the bitumen and consequently the asphalt Produced. However, additional research is required to establish more uniform mixing conditions (mixing durations, temperatures, and mixer type). Similarly, additional research is required for the development of recyclable additives that do not significantly increase the final cost of bitumen.

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