# DEVELOPMENT OF MELTED EXPANDED POLYSTYRENE AS BITUMEN MODIFIER FOR PAVEMENT CONSTRUCTION

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**Abstract:** This study was designed to investigate the Performance of melted Expanded Polystrene (EPS) wastes on the quality of bitumen used in asphaltic concrete. The EPS materials were ground and then melted (200-400 ºC) to form a slurry. Specific gravity of the EPS and chemical composition were determined by AAS analyses. The melted EPS was used as a modifier in mix proportions of 0, 2.5, 5, 7.5 and 10% by weight of bitumen. The 5% unmodified bitumen content obtained from the Marshall mix design was used to prepare asphalt concrete samples with 0 to 10% contents of melted EPS. The products were tested for Marshall stability, specific gravity, penetration, softening point, ductility, loss on heating, viscosity, flash and fire points and the melting point tests using standard methods. The ground EPS was uniform and well-graded (4.750-0.010 mm) with a specific gravity of 0.012, having a styrene structure with methanol on the ring. The specimen prepared with the specified mix proportion of EPS produced results that ranged between 5598.71-16937.70 N for Marshal stability; 2.02-3.54 for specific gravity; 129-152 mm for penetration; 42.80-47.50 ºC for softening point; 75.00-32.90 cm for ductility; 0-3.48% for loss on heating; 208-2204 sec.STV for viscosity; 243.3-269.0 ºC for flash point; 196.1-211.0 ºC for melting point. The results also showed that with correlation coefficients ranging from r = 0.658-0.999, there is a strong positive correlation between the improvement exhibited in the specimen tested properties and melted EPS used in bitumen. At the 5% bitumen with 5% EPS by weight of asphalt concrete, the results of stability, flow and optimum bitumen content satisfied the British Standard Specification framework for polymer-modified bitumen and it is therefore suitable for flexible pavement construction.

**Keywords:** expanded polystyrene, modified bitumen, marshal tests, asphaltic concrete, softening point, viscosity

## 1. INTRODUCTION

Asphalt road surfacing is the popular method employed in the construction of modern roads. The soil solid on which the roads are constructed is usually not stable enough to carry the vehicular loads when water is allowed to reach the solids. Apart from the need to stabilize this soil, it is usually imperative to surface dress the road to prevent penetration of water which easily undermines the strength of the soil. Asphalt road surfacing constitutes an economic means of surface dressing flexible pavements.

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Bitumen used in asphalt concrete is either obtained naturally by mining or as a waste product in crude oil refineries. Less attention is paid to the quality of bitumen in both methods of extraction of the bitumen. When this bitumen of low quality is used in asphalt pavement construction, the pavement fails within a short time and huge amounts of scarce resources are expended for maintenance and rehabilitation. This challenge has led to many studies on how to improve the quality of bitumen. Researchers such as [1–4] indicated in their research that modified bitumen performs significantly better than conventional bitumen in asphaltic concrete. Polymer is the modifier that is most commonly used [5–7].

The challenge to improve the quality of bitumen led to studies on polymer-modified asphalts (PMAs) by [8–11]. Among the few researchers who studied the use of EPS for the modifications of bitumen are [12–13]. Both researchers observed that the EPS improved the mechanical performance of the asphalt concrete mixture. Nassar et. al. [12] observed the addition of EPS to the asphalt increased the viscosity at temperatures 60 ºC and 135 ºC, increased the softening point, decreased the penetration, increased the stability values, increased the air voids and reduced the flow of the asphalt concrete. Similarly, Al-Haydari and Masued, [13] observed the addition of EPS to asphalt decreased the penetration and ductility, increased the viscosity, increased the softening point, reduced the stability values, reduced the flow, reduced the air void and increased the indirect tensile strength.

Expanded polystyrene wastes that result from discarded electrical electronic appliances packages, Cases of CDs, trays, cutlery, empty cartons, disposable cups and other disposable receptacles are very difficult to dispose of. No microorganism has yet been known to biodegrade polystyrene. Because of its low-density cellular form, it is easily carried by air and water which makes it a great pollutant in the outdoor environment, especially along shores, waterways and city centres.

Baker et al. [14], observed that increasing the expanded polystyrene content in asphalt decreased the penetration ductility and increased softening point, flash and fire points. This makes the modified material useful in hot climates. The modified asphalt could also be used for pavements for heavy traffic roads. Listiani et al. [15] in a study in which EPS plastic waste was added as a partial substitute in asphalt concrete wearing course mixture observed that the addition of EPS to the asphalt concrete reduced the penetration value, increased the softening point, increased the stability and reduced the costs of procuring the asphalt. The reduced penetration value increased the durability of the pavement and resistance to deformation. The increase in the softening point makes the asphalt less sensitive to temperature changes and the increased stability makes the asphalt pavement very suitable for receiving heavy traffic without deformation, rutting or bleeding.

Akbar et al. [16], observed that the optimum amount of Expanded Polystyrene to achieve the maximum strength of asphalt is 5% by weight giving a stability value of 10.41 kN and flow of 3.46 mm. He observed that a decrease in the strength of the asphalt occurred beyond 5% by weight of EPS.

Ramadan et al. [17], in a study on styrofoam to modify asphalt binder observed that the rotational viscosity (RV) and the complex shear modulus ($G^*$) value in the styrofoam/asphalt percentage thereby producing rutting resistant asphalt pavements at high service temperatures that can reach 64 ºC.

Murana et al. [18], used disposable food pack, a form of polystyrene to modify bitumen in hot mix asphalt and observed that with the increase in percentage by weight of the disposable food pack in bitumen there was a decrease in the penetration, ductility, flow and specific gravity while there was an increase in softening point and stability value. An optimum disposable food pack content of 6.7% by weight of the optimum bitumen content was obtained in the study. Nciri et al. [19], established in their study that waste EPS could be used as a bitumen modifier in asphalt concrete. Kumar et al. [20] observed in a study that for both wet and dry methods of mixing polystyrene with bitumen, the addition of polystyrene increased the stability and flow but, decreased the volume of voids and voids filled bitumen.

Abdul-Mawjoud and Thanoo [21], observed in a study that the addition of SBR and PS to modify asphalt binder decreased the penetration and ductility and increased the softening point and Marshall Quotient values showing that the performance of SBR and PS modified asphalt mixtures is superior to that of conventional asphalt mixtures. Abinaya et al., [22] carried out a study using extruded polystyrene waste polymer to modify bitumen in asphalt concrete and observed that the addition of the polystyrene beyond 10% by weight decreased the penetration value, the density and ductility and increased the flow, viscosity and the softening point and showed that the modified binder could be best used in hot arid regions for the construction of flexible pavements. The effects of the source of the bitumen on how the addition of polystyrene affects the performance of the bitumen were studied by [23]. They observed in the study that the addition of polystyrene to bitumen obtained from two different sources has different effects on the rheological properties of the modified blends as measured by changes in the phase angle (a measure of elasticity) and the complex modulus, $G^*$ (a measure of the degree of stiffness). Lu et al. [24], investigated the sustainable benefits of using polymer-modified bitumen (PMBs) by constructing a test road on a highway in Sweden. They observed that PMBs, especially with SBS polymers have better rheological properties, good ageing resistance and better enhancement of fatigue behaviour.

Research on the use of EPS for polymer-modified asphalts (PMAs) encountered the problems of a non-uniform mixture of the blended PMA and incomplete dissolution of the EPS. This could be due to the lightweight of the EPS. Nassar et. al. [12], observed the white EPS particles randomly dispersed in the asphalt matrix in a morphological study using an optical microscope. This partial dissolution and non-uniform mixture deserve further studies.

## 2. EXPERIMENTAL SETUP

### 2.1. Materials

The major materials used in this study are expanded polystyrene and bitumen.

*2.1.1. Expanded polystyrene (EPS)*

The Expanded Polystyrene (EPS) used for this study was found in large quantities at the refuse collection points at the University of Ibadan. The EPS was separated from other waste materials, washed thoroughly with lukewarm water and allowed to dry naturally. The EPS was reduced to sizes small enough to pass through 2 to 3 mm sieves by a milling machine to increase the surface area to improve dissolution, and the average density was determined to be 12 $kg/m^3$.

*2.1.2. Bitumen*

The sample of bitumen was obtained from Total Asphalt Depot in Epe, Lagos. The bitumen was normal (uncut) bitumen.

### 2.2. Methods

*2.2.1. Chemical analysis of the EPS*

The chemical analysis is carried out using the Atomic Absorption Spectrophotometer (AAS) and the Fourier Transform Infrared (FTIR) analysis to determine the inorganic and organic constituents of the EPS respectively.

*2.2.2. Preparation of EPS modified bitumen*

The EPS-modified bitumen is obtained by partially replacing the weight of bitumen with the shredded EPS directly at 0 % (control), 2.5 %, 5 %, 7.5 % and 10 %. The mixtures were heated and manually stirred at a constant rpm on a temperature-regulated electric hot plate (as shown in Figure 1) at a temperature range of 300-400 $^0$C for 20-30 minutes until a uniform blend was obtained. Each sample was approximately labelled with the inscription percentage modified. The samples were brought down from the hot plate and allowed to cool at room temperature and hardened for 24 hours.

Fig. 1. Melting of ground EPS in bitumen.

*2.2.3. Standard tests on EPS-modified bitumen*
As a means of assessing the influence of melted EPS on each specimen, the following tests were carried out in line with ASTM standard procedure: Marshall test, specific gravity tests [25], penetration tests [26], softening point tests [27], ductility tests [28], loss on heating [29], viscosity tests [30], flash and fire point tests [31] and melting point tests [31].

## 3. RESULTS AND DISCUSSION

### 3.1. Marshal test characteristics
The asphalt concrete mix used for this study is prepared with 5 % bitumen content, this is also used as the control specimen throughout this study. The test result of the Marshal and flow characteristic tests of the control and modified specimen are summarized in Table 1.

Table 1. Marshal and flow tests characteristics of the control and melted EPS modified asphalt mixes.

| S/N | Test | Specification | Expanded Polystyrene Content (%) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 0 | 2.5 | 5.0 | 7.5 | 10 |
| 1 | Marshal Stability (N) | 350 (Min) | 12783.27 | 5598.71 | 15092.06 | 16937.70 | 16937.51 |
| 2 | Air Void (%) | 3-5 (Min-Max) | 2.16 | 1.22 | 1.98 | 7.55 | 7.46 |
| 3 | Marshal Flow (mm) | 2-4 (Min-Max) | 8.46 | 7.81 | 4.12 | 13.82 | 13.75 |
| 4 | Density (g/cm$^3$) | Nil | 2.05 | 2.09 | 2.16 | 2.10 | 2.08 |
| 5 | Specific Gravity | Nil | 2.02 | 2.69 | 4.32 | 3.54 | 3.51 |

### 3.2. Penetration test
Figures 2 and 3 showed the chart of a penetration test and correlation between penetration test results and percentage EPS in bitumen respectively. The results in Figure 2 showed penetration of melted EPS ranging from 129-152 mm for mix proportions of 0 to 10 % with a decrease in penetration after the initial rise at 2.5%, this indicates increased stability for the EPS modified bitumen. This decrease in penetration could lead to cracking of the pavement at low temperatures, but suitable in a hot climate. The low penetration asphalt resulting from melted EPS is useful for constructing pavement for roads where there are very high stresses or high traffic volume.

From Figure 3, the Coefficient of Determination, $R^2 = 0.9819$, implies that the polynomial (3rd order) correlation coefficient, $r = \sqrt{0.9819}$. It showed that, at correlation, r = 0.991, the penetration displayed a very strong positive correlation of the melted EPS in bitumen. Melted EPS forms dry coatings slightly immiscible with bitumen at room temperature of the penetration test. This could be responsible for the decrease in penetration with the increase in the melted EPS content in the bitumen. This result agrees with the observations of [14, 15, 18] in which the penetration also decreased with the addition of EPS plastic wastes in ground form.

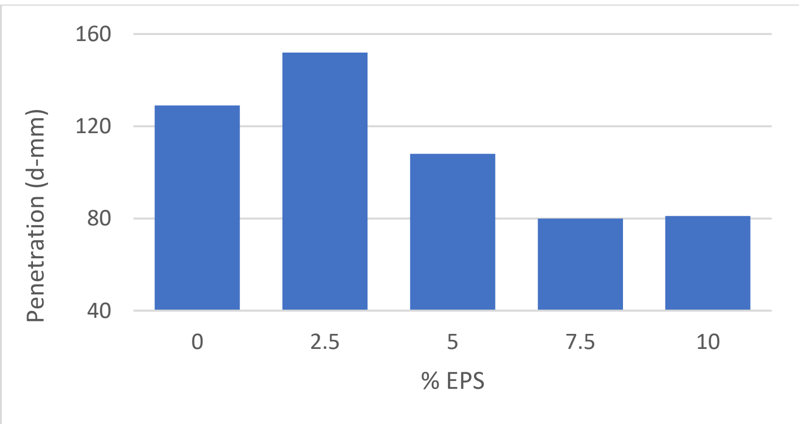


Fig. 2. Penetration test results for EPS melted in bitumen.

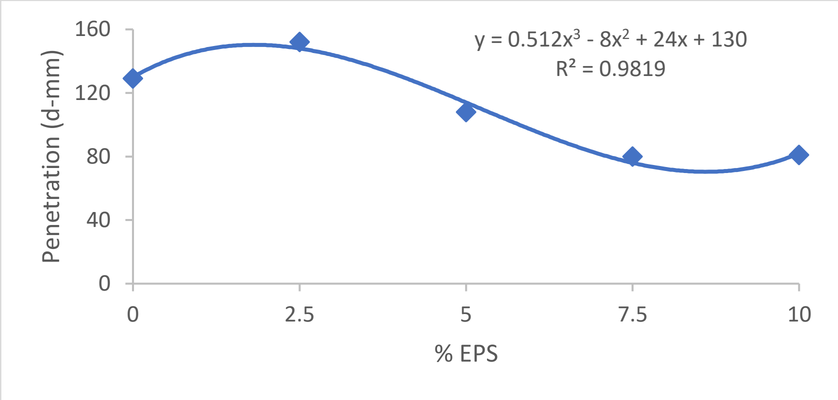


Fig. 3. Correlation between penetration test results and percentage EPS in bitumen.

### 3.3. Penetration index

The temperature vulnerability of the modified bitumen was studied through the measurement of the penetration index. As shown in Figure 4, the results for the penetration index for melted EPS in bitumen showed a general increase from -0.71 at control to 0.22 at 5% EPS content before declining to -1.61 at 10% EPS content. The increase in the penetration index signifies less temperature vulnerability; the modified specimen gives greater resistance to cracking at low temperature and rutting or permanent deformation at high temperature, exhibiting elastic and rubbery characteristics.

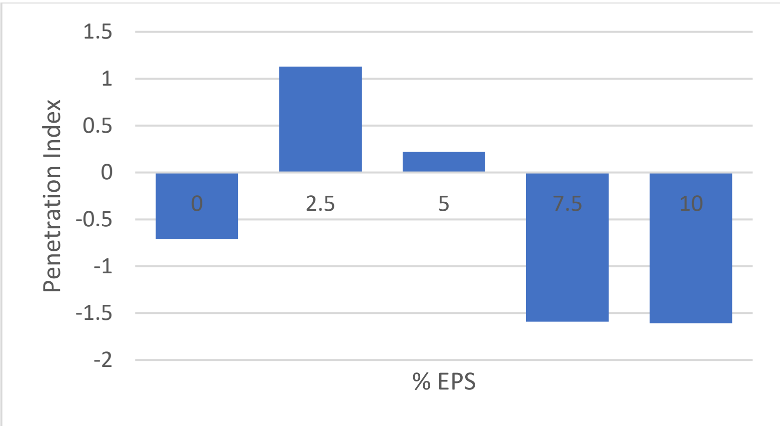


Fig. 4. Penetration index results for melted EPS in bitumen.

### 3.4. Softening point

Figures 5 and 6 showed the chart of the softening point test and correlation between softening point test results and percentage EPS in bitumen respectively. As shown in Figure 5, the softening point increased from 42.80 ºC at control to 47.50 ºC at 5.0% EPS content and then dropped to 44.70 ºC at 10% EPS content. The increase in softening point up to 5% EPS content further buttresses the suitability of the modified bitumen in a hot climate [14]. The physico-mechanical interaction occurring between the polar molecules of asphaltenes and those of polymer modifiers increases with an increase in EPS content. This could be the cause for the increase in the pliability of the modified bitumen with the increase in EPS content. From Figure 5, the coefficient of determination, $R^2 = 0.9049$, implies that the polynomial (3rd order) correlation coefficient, $r = \sqrt{0.9049}$. It showed that, at correlation, r = 0.951, the softening point displayed a strong positive correlation of the melted EPS in bitumen.

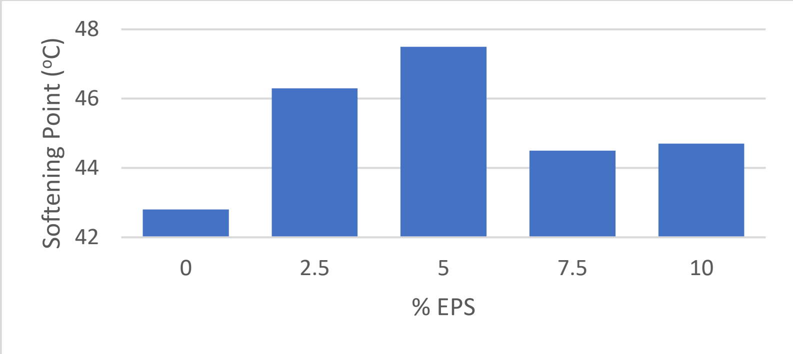


Fig. 5. Softening point test results for melted EPS in bitumen.

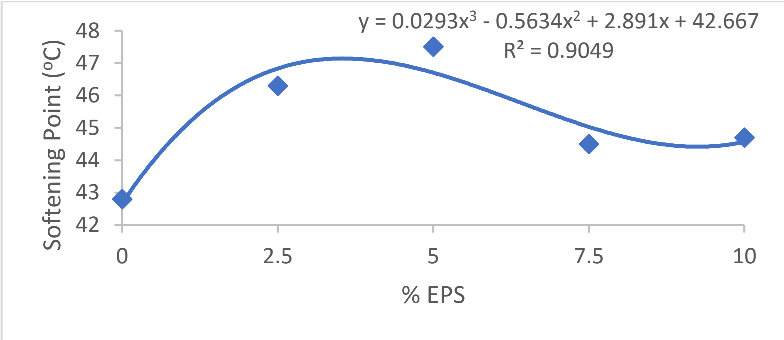


Fig. 6. Correlation between softening point test results and percentage EPS in bitumen.

### 3.5. Ductility test

Figures 7 and 8 showed the chart of ductility test and correlation between ductility test results and percentage EPS in bitumen respectively. The ductility of the bitumen decreases continuously with an increase in melted EPS content as revealed in Figure 7. This could be due to an increase in the forces of adhesion (forces between unlike molecules) over the forces of cohesion (forces between like molecules) which makes materials easier to pull apart. From Figure 8, the coefficient of determination, $R^2 = 0.9665$, implies that the polynomial (3rd order) correlation coefficient, $r = \sqrt{0.9665}$. It showed that, at correlation, $r = 0.983$, the ductility displayed a very strong positive correlation of the melted EPS in bitumen.

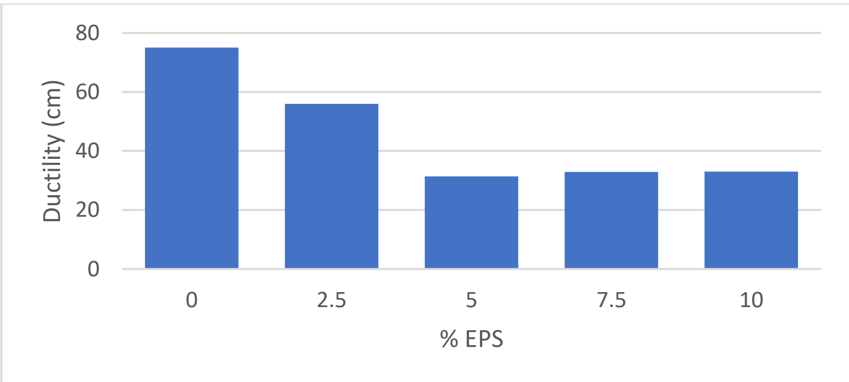


Fig. 7. Ductility test results for melted EPS in bitumen.

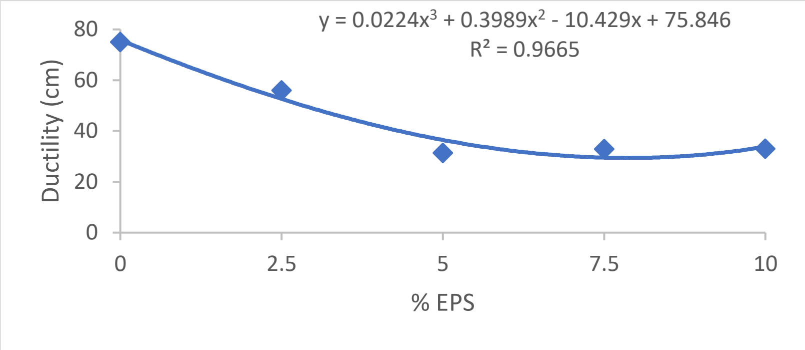


Fig. 8. Correlation between ductility test results and percentage EPS in bitumen.

### 3.6. Loss on heating

Figures 9 and 10 showed the chart of loss on heating test and correlation between loss on heating test results percentage EPS in bitumen respectively. The initial addition of % EPS (as shown in Figure 9) has a stabilizing effect on the loss on heating of the bitumen until a saturation point is reached at 7.5% where loss on heating begins to manifest. The increase in loss on heat could be due to the combustible nature of the EPS. From Figure 10, the coefficient of determination, $R^2$ = 0.9447, implies that the polynomial (3rd order) correlation coefficient, r = √0.9447. It showed that, at correlation, r = 0.972, the loss on heating displayed a very strong correlation of the melted EPS in bitumen.

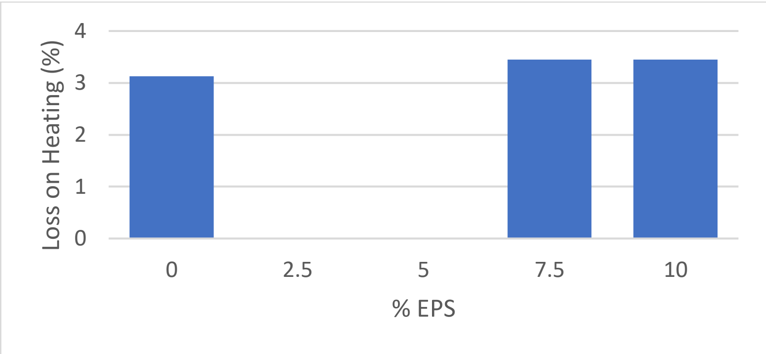


Fig. 9. Loss on heating test results for melted EPS in bitumen.

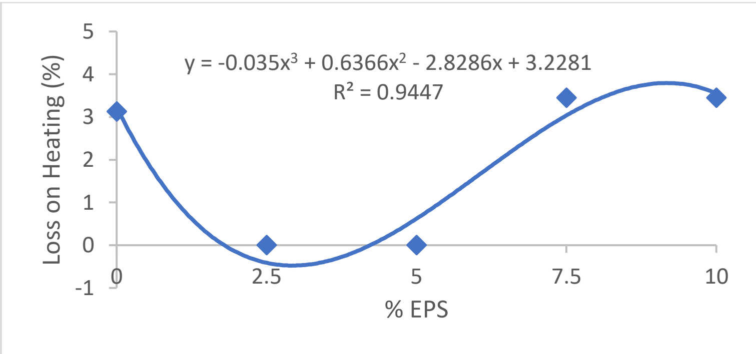


Fig. 10. Correlation between loss on heating test results and percentage EPS in bitumen.

### 3.7. Viscosity

Figures 11, 12, 13, and 14 showed the graphs of viscosity, kinematic viscosity tests and correlation between viscosity, kinematic viscosity test results and percentage EPS in bitumenrespectively. The drop in the viscosity and kinematic viscosity at 5% melted EPS in bitumen could be due to the easy miscibility of the molten EPS with bitumen. At 5 % melted EPS content, the phase difference is minimal, and the bitumen mixture flows readily.

From Figure 13 the Coefficient of Determination, $R^2$ = 0.4499, this implies that the polynomial (3rd order) correlation coefficient, r = √0.4499. It showed that, at correlation, r = 0.671, the viscosity displayed positive correlation with the melted EPS in bitumen. From the Figure 14, the coefficient of determination, $R^2$ = 0.4325, this implies that the polynomial (3rd order)correlation coefficient, r = √0.4325. It showed that, at correlation, r = 0.658, the kinematic viscosity displayed positive correlation with the melted EPS in bitumen.

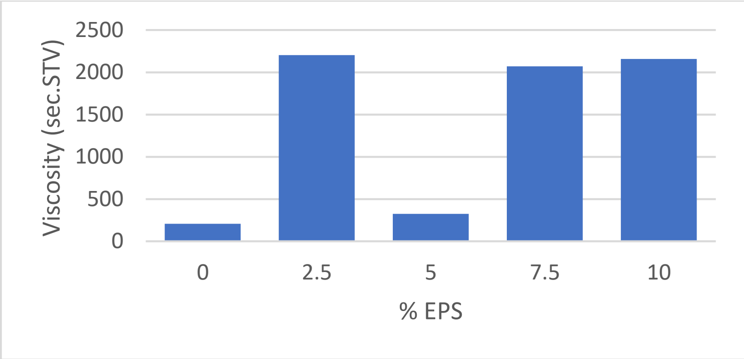


Fig. 11. Viscosity test results for melted EPS in bitumen.

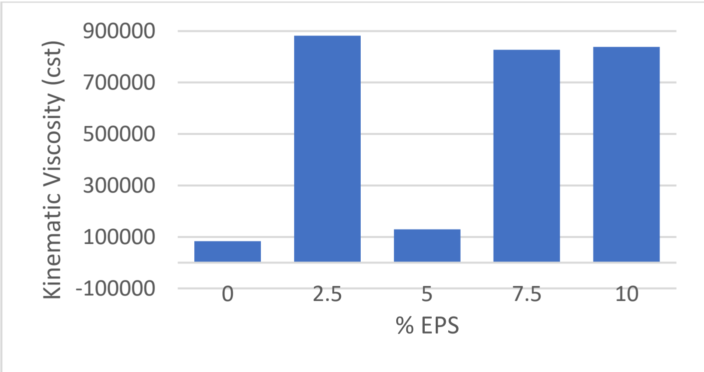


Fig. 12. Kinematic viscosity test results for melted EPS in bitumen.

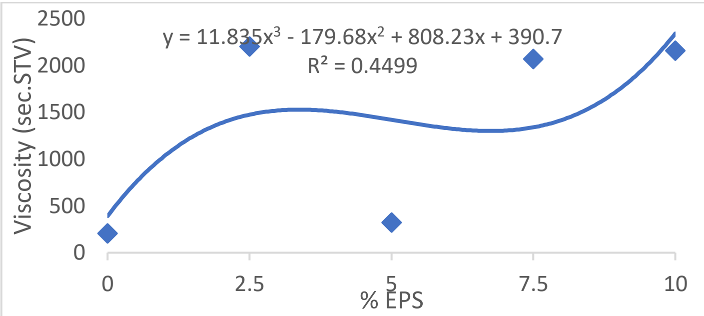


Fig. 13. Correlation between viscosity test results percentage EPS in bitumen.

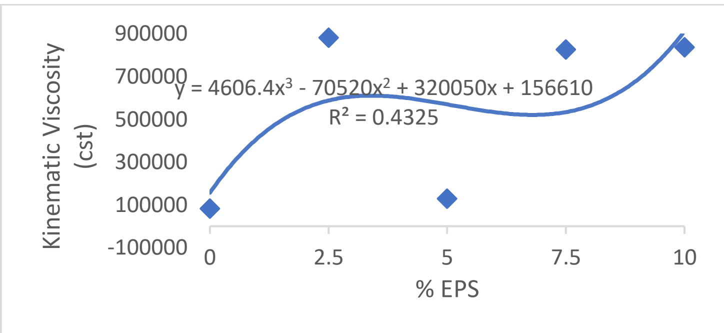


Fig. 14. Correlation between kinematic viscosity test results and percentage EPS in bitumen.

### 3.8. Flash and fire point

Figures 15 and 16 showed the charts of flash and fire point tests and correlation between flash and fire point test results and percentage EPS in bitumen respectively. There is a general increase in the flash and fire point with increase in the EPS content as shown in Figure 14, the flash and fire points of the specimen ranged from 243.3-269.0 ºC and 243.3-284.4 ºC respectively, indicating more flammability with melted EPS. This shows that the EPS reduces the tendency of the modified bitumen to ignite and increases the temperature to which the bitumen can be safely heated. From Figure 15 the coefficients of determination for flash and fire points are $R^2$ = 0.9768 and 0.9998 respectively, these imply that their polynomial (3rd order) correlation coefficients, r = √0.9768 and √0.9998. At correlations, r = 0.988 and 0.999, the flash and fire points displayed a very strong positive correlation with the melted EPS in bitumen.

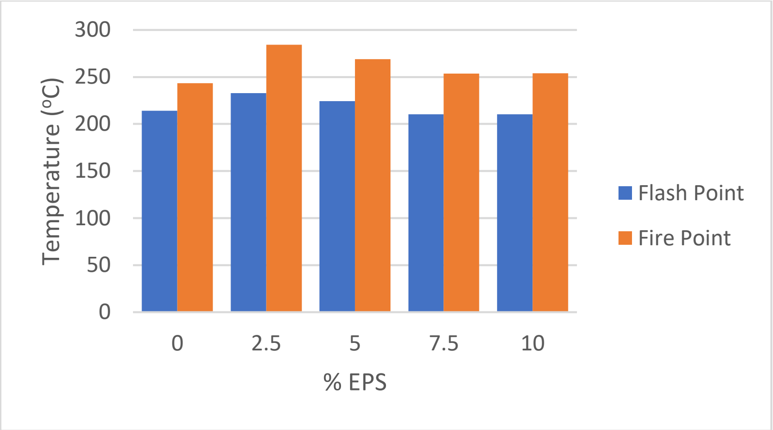


Fig. 15. Fire and flash point results for EPS melted in bitumen.

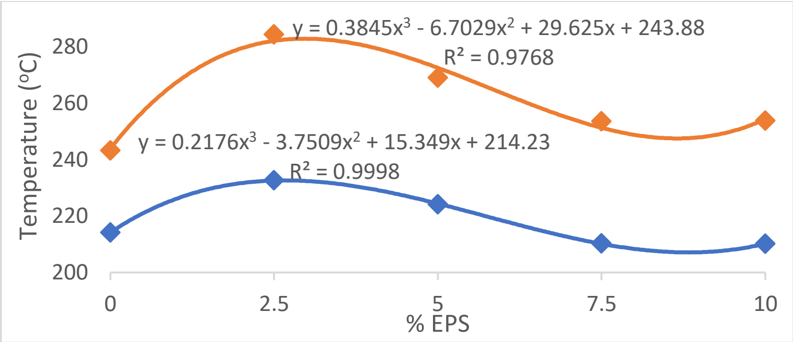


Fig. 16. Correlation between fire and flash point results and percentage EPS in bitumen.

### 3.9. Melting point

Figures 17 and 18 showed the charts of melting point test and correlation between melting point test results and percentage EPS in bitumen. There is a general increase in melting point as the EPS content increases as shown in Figure 17, the melting point of the specimen ranged from 196.1-211.0 ºC. This could be because the EPS acts as an impurity which usually has the effects of increasing melting point. The higher melting point is especially useful in hot climates. From Figure 18 the coefficient of determination for melting point, $R^2$ = 0.9783, this implies that the polynomial (3rd order) correlation coefficient, r = √0.9783. At correlation, r = 0.989, the melting point displayed a very strong positive correlation with the melted EPS in bitumen.

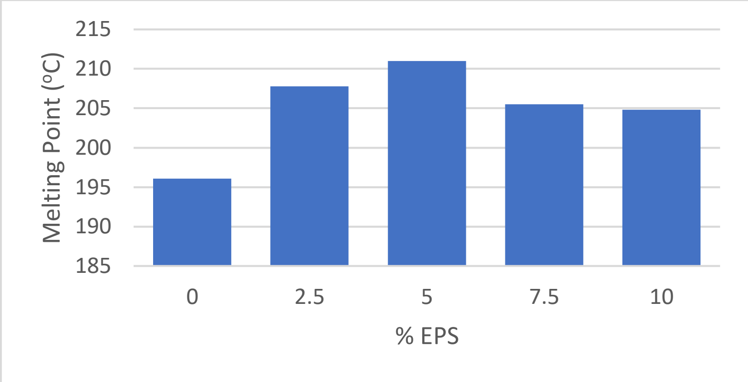

Fig. 17. Melting point results for EPS melted in bitumen.

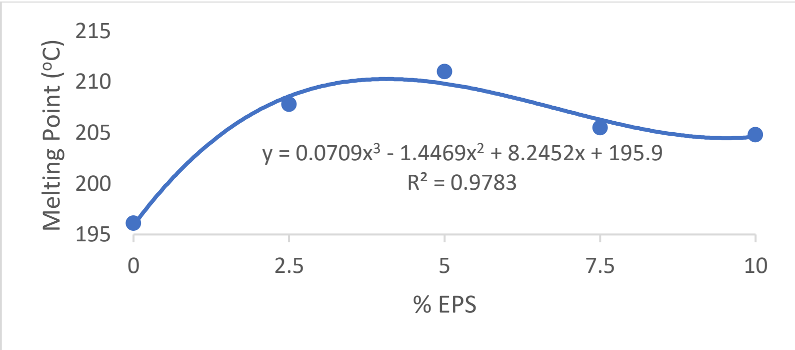

Fig. 18. Correlation between melting point results and percentage EPS in bitumen.

## 4. CONCLUSIONS

The effect of melted expanded polystyrene waste modified bitumen on properties such as Marshal stability, specific gravity, penetration, softening point, ductility, viscosity, kinematic viscosity, flash and fire points, melting point and flow on bitumen have been evaluated. Optimum bitumen content (OBC) of 5% was obtained from the Marshall mixed design for the unmodified bitumen asphalt concrete. The Marshal stability of the modified asphalt concrete ranged between 5598.71-16937.70 N, with specific gravity of the range 2.02-3.54, indicating the effect of EPS on specific gravity. The penetration ranged from 129-152 mm for mix proportions of 0 to 10% melted EPS, it decreases with an increase in the percentage of melted EPS in the modified bitumen indicating increased stability. The softening point ranged from 42.80-47.50 °C indicating better temperature tolerance and gave an optimum of 5 % melted EPS in bitumen. The ductility of specimen treated with melted EPS decreased from 75.00–32.90 cm with increase in EPS, indicating increased brittleness. The viscosity tests gave a continuous increase in viscosity of the bitumen with the increase in the percentage of melted EPS but has an optimum of 2.5% EPS content. Flash points of the specimen ranged from 243.3-269.0 °C indicating more flammability with melted EPS. The melting point of specimens treated with melted EPS ranged from 196.1-211.0 °C indicating more temperature vulnerability with melted EPS. The Marshall stability and flow tests for the asphalt concrete gave an optimum of 5% melted EPS in bitumen. The results showed that with correlation coefficients ranging from r = 0.658-0.999, there is a strong positive correlation between the improvement exhibited in the specimen tested properties and melted EPS used in bitumen. The results were satisfactory for the [32] specifications in asphalt concrete for stability, flow and optimum bitumen content except for the air voids. Based on these experimental results, it is concluded that the asphalt concrete mixes with waste EPS of 5% melted in bitumen are suitable for flexible pavement construction from the standpoint of stability and stiffness. However, further study on the performance of waste EPS as a bitumen modifier in asphalt concrete at very low temperatures should be carried out because of regions where temperatures usually fall below zero.

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