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RHEOLOGICAL CHARACTERIZATION OF INDUSTRIAL WASTE MODIFIED BITUMEN

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Abstract. The aim of this research is to evaluate the rheological properties of industrial waste modified bitumen. The varying proportion of polypropylene ranging from 0% to 20% of the weight of bitumen at 5% interval with 60/70 penetration grade was used. The asphalt binder modification was prepared by using high-speed mixer at temperature from 150 °C to 190 °C. The conventional test like softening point, penetration, ductility, flash and fire point test were carried out to assess the physical characteristics of polypropylene modified and unmodified bitumen, thereafter dynamic shear rheometer and rotational viscosity test were conducted to determine the rheological properties of bitumen. The result indicated that polypropylene has ability to improve the conventional properties of bitumen by increased penetration and ductility, decrease softening point and flash and fire point. Polypropylene modified bitumen provides better resistance against permanent deformation due to their increase in complex modulus and rotational viscosity and decrease in phase angle. It can be concluded that polypropylene modified bitumen could improve the level of performance and service life of the road.

Keywords: *industrial waste, modified bitumen, performance, polypropylene, rheology.*

Rezumat. Scopul acestei cercetări este de a evalua proprietățile reologice ale deșeurilor industriale de bitum modificat. A fost utilizată proporția variată de polipropilenă, variind de la 0% la 20% din greutatea bitumului la interval de 5% cu grad de penetrare 60/70. Modificarea liantului asfaltic a fost preparată utilizând un malaxor de mare viteză la o temperatură de la 150 °C la 190 °C. Testele convenționale cum ar fi punctul de înmuiere, penetrarea, ductilitatea, punctul de aprindere și punctul de foc au fost efectuate pentru a evalua caracteristicile fizice ale bitumului modificat și nemodificat cu polipropilenă, apoi au fost efectuate reometrul de forfecare dinamică și testul de vâscozitate rotațională pentru a determina proprietățile reologice ale bitumului. Rezultatul a indicat că polipropilena are capacitatea de a îmbunătăți proprietățile convenționale ale bitumului prin creșterea pătrunderii și ductilității, scăderea punctului de înmuiere și a punctului de aprindere și de foc. Bitumul modificat cu polipropilenă oferă o rezistență mai bună împotriva deformării permanente datorită creșterii modulului complex și a vâscozității de rotație și scăderii unghiului de fază. Se poate concluziona că bitumul modificat cu polipropilenă ar putea îmbunătăți nivelul de performanță și durata de viață a drumului.

Cuvinte cheie: *deșeuri industriale, bitum modificat, performanță, polipropilenă, reologie.*

1. Introduction

The asphalt binders are considered as one of necessary materials of construction in flexible pavement, and the performance of flexible pavement is related to asphalt binders. Asphalt pavement with its superior quality has become one of necessary pavement type demanded in Nigeria. It is achievable to increase the service life of asphalt pavement and decrease the maintenance activities by using modifies. The bitumen characteristics can be enhanced using modifies and the toughness of asphalt concrete mixture at high temperature can be reduced which will help in lay down and compaction during constructions.

Waste plastic have been enormously utilized in different area of their significant benefit in term of durability, availability, light and cost effectiveness [1]. The worldwide production of waste plastic attained 368 million metric tons in year 2019 [2], and Nigeria is one of largest producers, accounting for 25%. The diffused use of waste plastic contributes outstanding comfort to everyday life and improves social and economic development. However, large quantity of waste plastic consumed has caused stresses on our environment. Presently, various nations have different waste management strategies for plastic waste. Landfill and incineration have been adopted as a simple way of disposing waste in United State of America, China and other countries. United Stated of America received 27 million tons of plastic by municipal solid waste (MSW) stream in landfill [2]. Landfill has been the natural plastic disposal method that demanded high land resource which also becomes problem facing plastic waste disposal in different countries [2]. The environmental threat created by chemical leaching from plastic into soils and waters could many decades which are disadvantage of using landfill method of disposal of waste plastic. But then, incineration is method of reducing mass and volume of waste in which air pollution results from the high temperature process in the incinerator producing dioxin, CO_2 and other toxic emission [3]. The heavy metals such as lead (Pb) and Cadmium (Cd) released from waste plastic during incineration process is dangerous to the human health [4]. Additionally, micro plastic gotten from degradation of plastic waste created intensive worry for waste management sector, as micro plastic were able to find their way through filtration system and become hard to take way [5]. Accordingly, plastic pollution is one most urgent environmental threat to the modern world [6].

Asphalt binder plays an essential role in pavement performance because it demonstrates the viscoelastic characteristics under pavement operative condition [7]. In other to enhance the reliability of flexible pavement to satisfy the traffic, climatic and other requirements, the use of modified binder rather than unmodified binder has been commended approach [8].

It is established facts that polymer can improve flexible pavement performance in term of high temperature stability [9]. High costs of construction combined with environmental problem created by plastic waste have promoted the utilization of plastic waste in flexible pavement.

Many researchers have investigated the suitable application of utilizing waste plastic in asphalt binder, environmental concern, modified morphology, the properties of waste plastic modified binder and modified mechanism [10]. The utilization of packaging waste polymer and organic montmorillonite was researched by [11] studied and they concluded that waste polymer content resulted increased in viscosity and decrease in penetration while organic montmorillonite decrease the viscosity and improved cracking resistance. The use PET as partial replacement for fine aggregate and result indicated the highest resistance to permanent deformation was recorded at 20 % PET was studied by [12]. The polymer modified asphalt depend on test temperature, asphalt source and polymer type in a study concluded by [13]. They further concluded that polypylene-maleic anhydride and oxidized PE required lower compaction and temperature. A crumb rubber (CR) modified decreased susceptibility to cracking at low temperature and increased the toughness of asphalt concrete in investigation carried out by [14]. The use of rubber tire (scrapped) as a replacement to bitumen was studied by [15] and concluded that scrap rubber modified asphalt binder increased softening point and had 55% elastic recovery which is higher than 35% of unmodified. The utilization of low density polyethylene (carry bag waste) in asphalt concrete was studied by [16], they obtained 10% waste content by weight of bitumen as optimum content and concluded that low density polyethylene improved resistance to fatigue, provide better blending between asphalt binder and aggregate and as well decreased the permanent deformation. Another studied on polymer waste aggregate (PCA) modified blended using polypropylene by [17] reported reduction in water absorption and decrease abrasion of aggregate in asphalt concrete.

Present curiosity in recycling waste plastic indicate substantive gain of utilizing it as a sustainable polymer in enhancing bituminous characteristics, achieving environmental stability and advancing economic-industrial growth. Several type of industrial waste such as modifier were tried globally to improve the rheological characterization of bitumen, such as nano-materials [18], waste plastic [19], crumb rubbers [20] and geopolymers [21]. Waste plastic based polypropylene could be used to enhance the rheological characteristics of bitumen. Polypropylene modified bitumen for road construction can improve the permanent deformation and thermal cracking resistance at high and lower temperature. These possible enhancements can improve the pavement life [22].

The main commonly utilized polymer worldwide includes 75% elastomeric modified binder, 15% plastometric and remaining 10% belongs to either rubber or other modification. The elastomers often use to increase the bitumen at low and high temperature. Nevertheless plastomers are well known efficient additive that can increase high service temperature [23]. Polypropylene belongs to plastomers family which provides rigidity to the bitumen and decrease the deformation under load and effect is more profound when the concentration of polypropylene is high by weight of the base bitumen. Different researchers have examined the possibility of using modifiers in polymer form on the bitumen and asphalt concrete mixture characteristics. The result of these research indicated that modifying using polymers could alter bitumen properties by increasing viscosity [24], increasing softening point [25], improving the performance of grade [26] and decreasing the penetration [27].

Polypropylene is one of the most effective polymer modifiers which are generated from polymer industry. It is semi-crystalline material with excellent chemical resistance, wears resistance, good fatigue and has wide range of properties. Polypropylene is a simple structure that has a long chain of carbon atom with hydrogen atoms attached to each carbon atom. It provides good resistance to organic solvent with low moisture absorption rates.

Polypropylene is commonly use in sweet wrapping, straws, textile, furniture and automobile industrial. These qualities have made polypropylene efficient enough to be used as modifier of bitumen.

2. Materials and Method

2.1. Materials

The bitumen utilized in the present research is 60/70 penetration grade bitumen obtained from K.K Hassan Construction Company in Akure, Nigeria. As shown (Plate 1 and 2) local waste plastic in form of polypropylene were collected at dumping site, washed and grounded to 0.5 to 0.05 mm to be utilized as efficient polypropylene modifier in 60/70 bitumen penetration grade.

Figure 1. Dumping site of waste plastics.

Figure 2. Grounded waste plastic.

2.2 Sample preparation

Samples were prepared using melt blending method. The 200 mg of bitumen was filled inside steel bowel and pre-heated in oven at 130 °C. The grounded polypropylene was replaced at varying proportion of 5%, 10%, 15% and 20% by weight of bitumen. The modified bitumen was thoroughly blended at mixing temperature of 185 °C. Mixing was continued for 45 minute to produce homogenous mixtures. Empirical tests such as softening point, penetration, ductility, flash and fire point were carried out on the samples and thereafter dynamic shear rheometer and rotational viscosity test were conducted to determine the rheological properties of modified bitumen.

2.3 Test Method

The physical test performed on the bitumen and modified bitumen to determine its suitability was flash and fire point test [28], softening point [29], viscosity test [30], ductility test [31] and penetration test [32]. The rheological test conducted in the bitumen and modified bitumen were dynamic shear rheometer test [33] at temperature of 60, 70, 80 and 90 °C and rotational viscosity tests [34] at 135 and 165 °C.

3. Results and Discussion

3.1 Conventional test result of modified and unmodified bitumen mixture

The experimental results of conventional physical properties of modified bitumen with varying percentages of polypropylene are indicated in Figure 3, 4, 5 and 6. It is showed that penetration values continued to decrease as percentage of polypropylene increased as indicate in Figure 3. They decreased resulted to hardness of modified bitumen because polypropylene has higher molecular weight thereby increase viscosity of the bitumen [35].

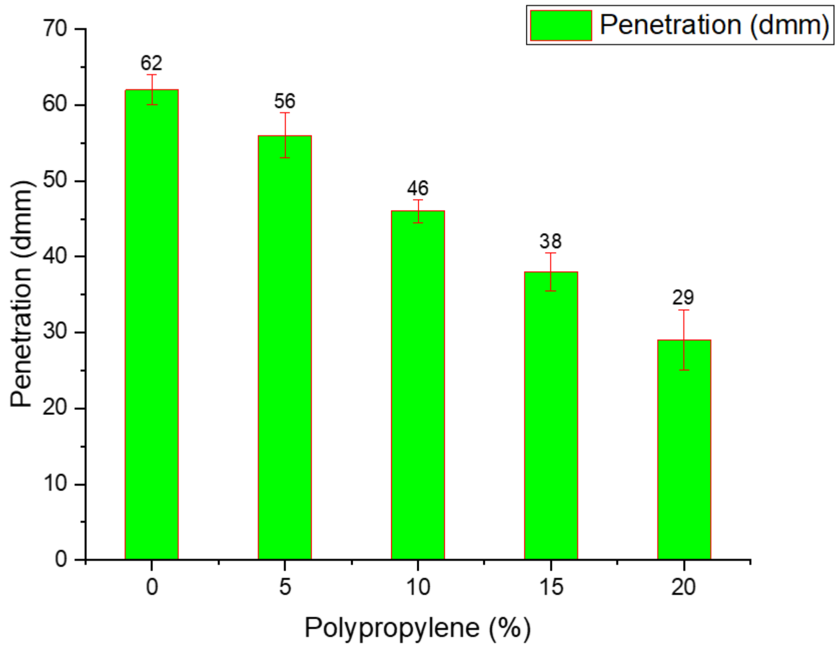

Figure 3. Penetration of Polypropylene.

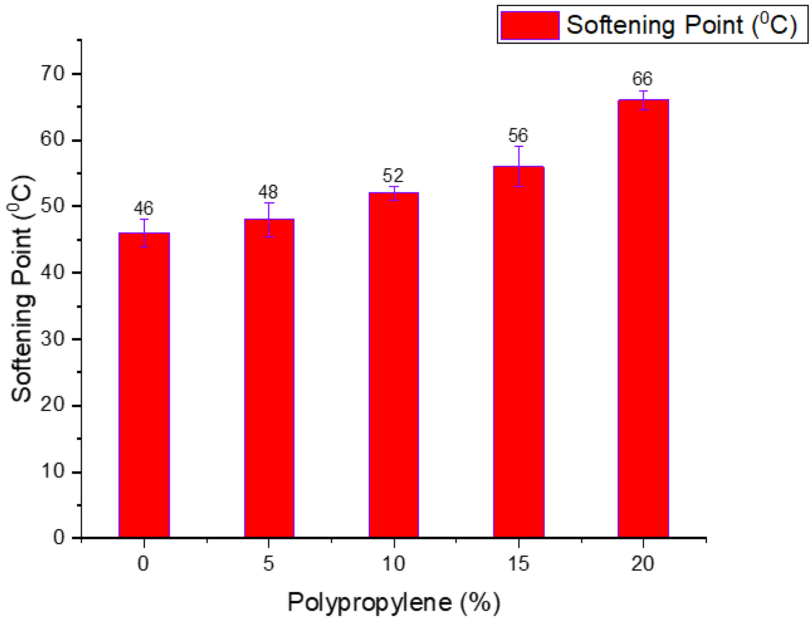

Figure 4. Softening Point of Polypropylene.

Softening point result increased as percentage of polypropylene increased as shown in Figure 4, the result clearly indicated that addition of polypropylene to bitumen increased softening point values. This could be as result of bitumen resistance to the essence of temperature and this shall decrease asphalt pavement to soften in hot weather, thus polypropylene modified bitumen will be less affected to temperature changes [35]. Flash and fire point increased continuously as various proportion of polypropylene increases as indicated in Figure 5. This can be attributed to the different in temperature of the polypropylene and bitumen blended together at increase in temperature. This also showed that addition of polypropylene content into asphalt mixture will like to decrease fire hazard in asphalt pavement [36].

The result of ductility obtained showed that ductility trend to decrease continuously as proportion of polypropylene increases as shown in Figure 6. As the polypropylene modified bitumen get harder and stiffer, it could resist anti-cracking performance of asphalt concrete at low temperature [37].

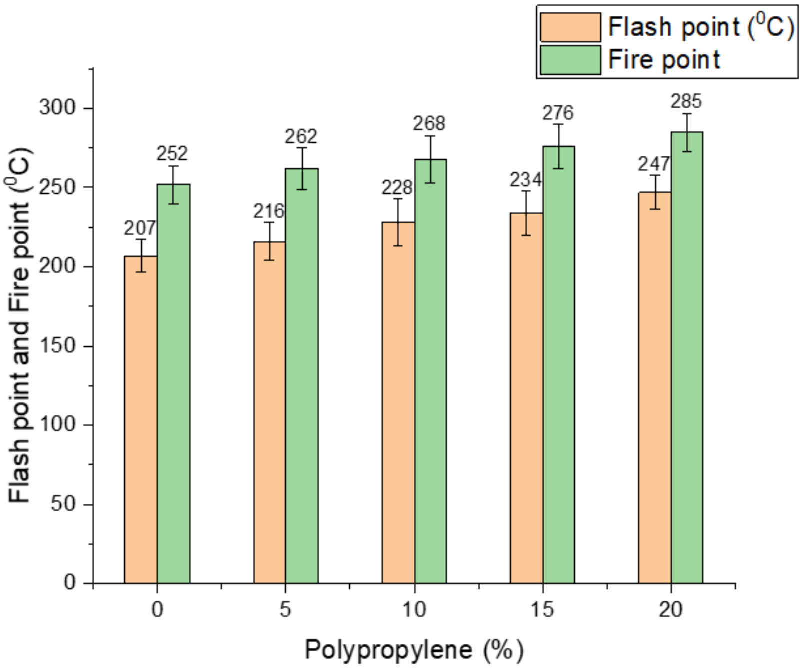

Figure 5. Flash and Fire Point of Polypropylene.

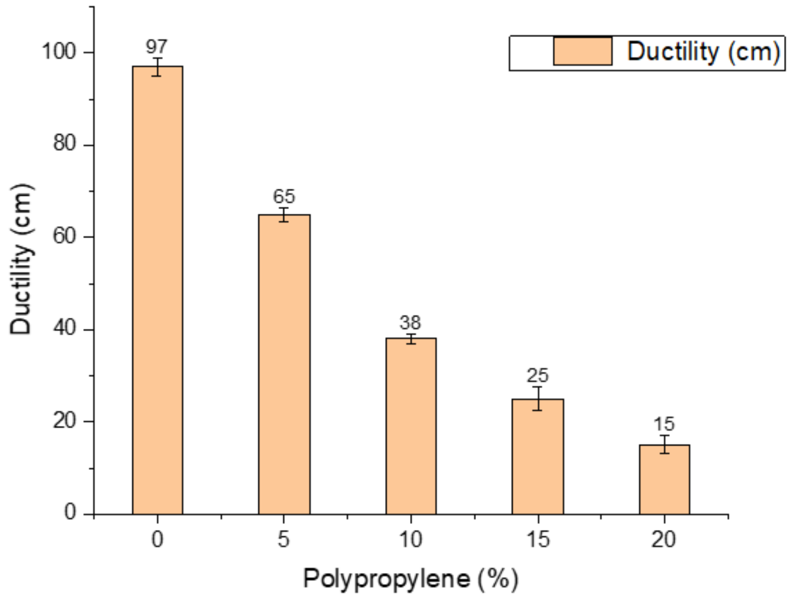

Figure 6. Ductility of Polypropylene.

3.2 Rheological result of modified and unmodified bitumen

The viscoelastic behavior of asphalt binders was characterized at temperature of 60℃, 70℃, 80 ℃, and 90 ℃ using dynamic shear rheometer (DSR). The test results are shown in Figures 7 and 8 which illustrate the complex modulus and phase angle respectively against different temperature in the binder. The values of complex modulus obtained at 0% (385.9 kPa, 392.5 kPa, 419.8 kPa, 425.7 kPa, 452.9 kPa); 5% (369.5 kPa, 388 kPa, 418 kPa, 421 kPa, 441.8 kPa); 10% (396 kPa, 407.7 kPa, 411.5 kPa, 431.2 kPa, 435.8 kPa); 15% (379.6 kPa, 385 kPa, 379.6 kPa, 401.5 kPa, 415 kPa), 20% (344 kPa, 368 kPa, 385.3 kPa, 400.5 kPa, 408 kPa) and the values of phase angle at 0% (89.2 δ, 86.5 δ, 82 δ, 78.2 δ, 75 δ); 5%(80 δ, 79.5 δ, 77.8 δ, 75 δ, 72.5 δ); 10%(82.5 δ, 77.6 δ, 71.9 δ, 73 δ, 70 δ) δ, 15%(82 δ, 80 δ, 78.6 δ, 77 δ, 60.4 δ); 20% (70.1 δ, 65.2 δ, 60 δ, 58 δ, 52.6 δ). From the result, it can observe that, all samples indicated decrease in phase angle and increase in complex modulus values as the temperature increases. These could be as result of higher shear blending of polypropylene modified bitumen mixture and its synergistic process, which might resist changes in polypropylene asphalt binder particle size and arrangement. The engineering properties of modified was enhanced as seen Figure 7 and 8.

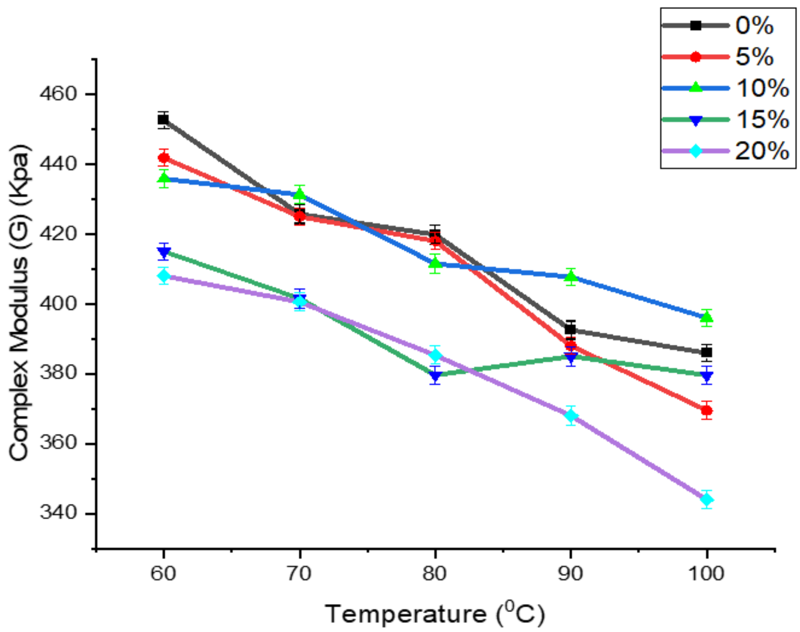

Figure 7. Complex Modulus of Polypropylene.

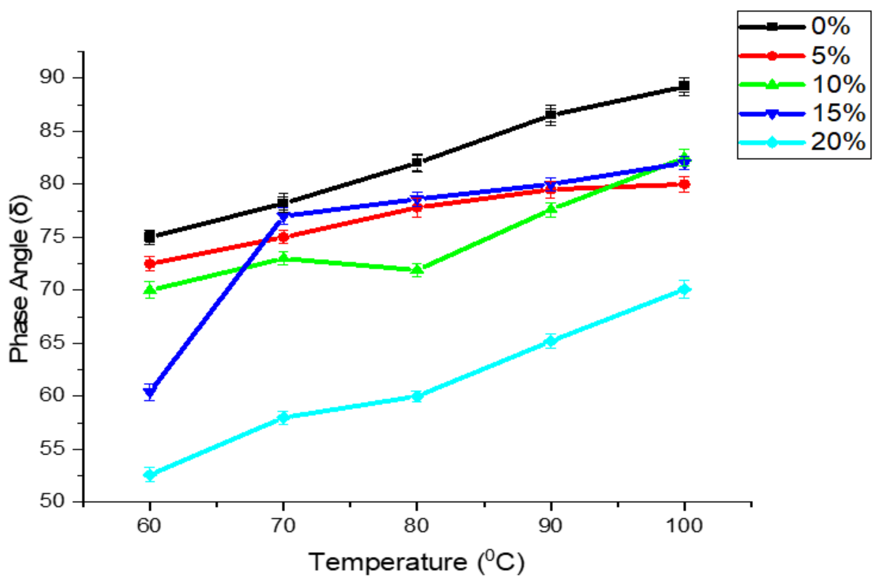

Figure 8. Phase Angle of Polypropylene.

The increase in elasticity is because of the position arrangement of molecule and bonding system with each other which made it more elastic and tough and therefore more resistant to rutting and permanent deformation [38]. Moreover when temperature to the existence to each other increased, it will have higher improvement. The lower phase angle δ means that asphalt concrete mixture is more elastic than viscous and will recover to its original condition without break up [39]. Also, at high temperatures, the lower phase angle is desirable since this will decrease permanent deformation. The addition of Polypropylene had a significant effect on the rotational viscosity of the asphalt as shown in Figure 9. By increasing the Polypropylene content, the rotational viscosity of the asphalt increased rapidly. According to the laboratory test results, Polypropylene contents at 135 °C have high rotational viscosity values while Polypropylene content at 165 °C has low rotational viscosity values because polypropylene decrease molecular weight due to higher temperature was applied [40].

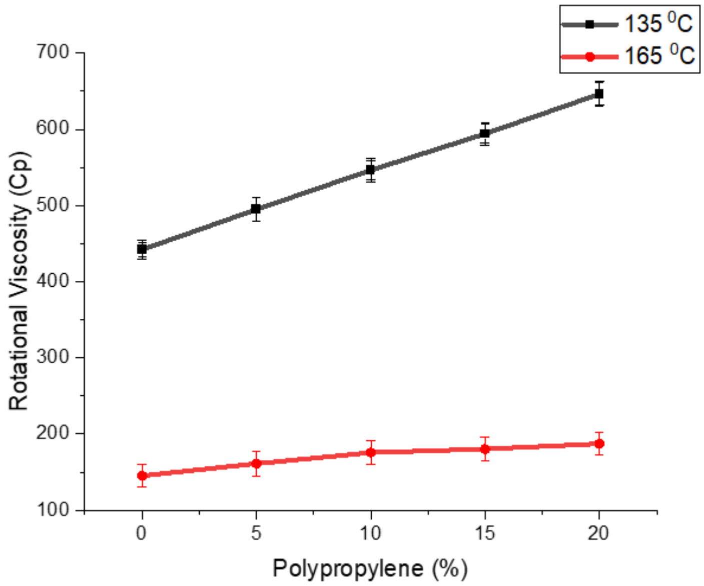

Figure 9. Rotational Viscosity of Polypropylene.

4. Conclusions

The modification of bitumen using polypropylene improves conventional and rheological properties of the modified bitumen produced. Based on the experimental results, the asphalt binder containing polypropylene resulted decrease in penetration, increase in softening point, decrease in ductility and increase in flash and fire point. These results demonstrated that polypropylene modified bitumen improve resistance against permanent deformation and also more advantage when compared to unmodified bitumen used in pavement industry. The rheological property of bitumen was highly affected by addition of polypropylene as indicated by result of dynamic shear rheometer and rotational viscosity. This indicated that polypropylene used as a modifier showed better performance in term of enhancing the rutting deformation and decrease the bitumen susceptibility to crack and deformation at higher temperature.

Conflicts of Interest. The authors declare no conflict of interest.

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