

# Effects of Waste Plastic on the Physical and Rheological Properties of Bitumen

**Mohd Ezree Abdullah<sup>1</sup>, Nurul Asyiqin Ahmad<sup>2</sup>, Ramadhansyah Putra Jaya<sup>2,3</sup>, Norhidayah Abdul Hassan<sup>2</sup>, Haryati Yaacob<sup>2</sup>, Mohd Rosli Hainin<sup>2</sup>**

<sup>1</sup>Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

<sup>2</sup>Faculty of Civil Engineering, Department of Geotechnics and Transportation, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia.

<sup>3</sup>Faculty of Engineering, Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak Darul Ridzuan, Malaysia

E-mail: rsyahputrajaya@gmail.com; ramadhansyah@utm.my; ezree@uthm.edu.my; hnorhidayah@utm.my; haryatiyaacob@utm.my; syiqin.pmc@gmail.com; mrosli@utm.my

**Abstract.** Plastic disposal is one of the major problems for developing countries like Malaysia, at the same time Malaysia needs a large network of roads for its smooth economic and social development. The limited source of bitumen needs a deep thinking to ensure fast road construction. Therefore, the use of plastic waste in road construction not only can help to protect environment but also able to help the road construction industry. The aims of this research are to study the effects of waste plastic on rheological properties of bitumen. Modified bitumen was prepared by using blending techniques. Bitumen was heated and plastic waste was slowly added. Rheological properties of bitumen were performance by penetration, softening point, viscosity and direct shear rheometer test. The results showed that when content of plastic waste increase, the penetration value, softening point and viscosity of bitumen also increase. Generally, plastic waste improves the performance of bitumen when it was added into bitumen. It can be said that the usage helps to improve the performance of the road pavement which also reduces the rutting effect.

## 1. Introduction

Plastics is a material that contains one or more organic polymer of large molecular weight, solid in its finished state and it also can flow under specific state [1]. It is durable and has very slow process of degradation [2]. Plastic can be divided into two major categories which are thermosets and thermoplastics. Thermoset is a condition of plastic when it is in solid form. This type of plastic is very useful in their durability and strength. Nowadays, the use of the plastic bag with several of sizes has been growing day by day [3]. This development led to an increase in the amount of waste. This hazardous waste is disposed by land filling or incineration. Waste plastic does not undergo biodecomposition. Therefore, whether it is land filled or incinerated, it still pollutes the land and the atmosphere. However, the discovery of the binding property of plastic in its molten state which can be used in road laying has helped to well manage this waste plastic [4]. Road pavement that uses plastic waste as one of its material is called plastic road [5]. Plastic bag is non-biodegradable but most of it is



recyclable. The recycled products are more environmentally harmful than the first time manufactured ones because every time plastic is recycled it is subject to high intensity heat. This can make it to deteriorate and lead to environmental pollution. That is why, it is necessary to determine the effective way to deal with this non-biodegradable waste [6]. The use of plastic waste in road construction can be one of the solutions [7]. This type of construction gives benefit to environment because it uses plastics that would otherwise be disposed through environmentally harmful means. Other type of methods that has been used to deal with plastic waste is by incineration [8]. However, often incinerators used are not recommended standards and guidelines. It is particularly significant to use plastic waste because it can minimize the landfilling [9]. It was translates that 1.125 tons of plastic wastes are used per km of single lane road. Based on review of literature, the objective of this research is to investigate the effect of using different percentages of plastic waste on rheological properties of bitumen. The main problems of asphalt pavement material is rutting and also cracking which is resulted from its main property of being high temperature susceptibility.

## 2. Material and Methods

### 2.1. Materials

In this study, bitumen 60/70 penetration grade was used. The properties of bitumen based on laboratory test are 65 dmm (penetration), 51 °C (softening point), 1.03 (relative density), and 600 cp (viscosity at 135°C).

### 2.2. Sample preparations

Modified bitumen was prepared by using blending techniques. 500 g of bitumen was heated in oven until it turns to fluid condition and plastic waste that was shredded to size of 2 mm was slowly added, while the speed of mixer was maintained at 1200-1500 rpm and the temperature was kept between 170 °C and 175 °C. The concentrations of plastic waste used were 1.5, 3.0, 4.5 and 6.0 % by weight of the bitumen. Mixing was continued for 1 hour to produce homogenous mixtures. Rheological tests such as penetration, softening point, viscosity and also direct shear test were then conducted on the prepared sample.

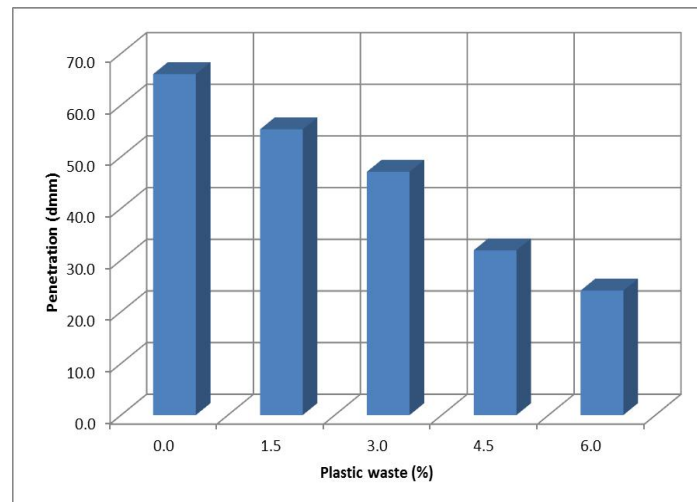
### 2.3. Bitumen test

The tests to determine rheological properties such as penetration, softening point, viscosity, and direct shear test are performed in the following study. Binders are characterized by using a number of standard physical tests such as penetration test [10] (temperature, load and time at 25 °C, 100 g and 5 sec, respectively), softening point test [11], viscosity test using Brookfield viscometer [12] (temperature ranging from 135 to 165 °C, spindle No. 27, and a rotating speed of about 20 rpm). The short-term aging test of the binder is conducted using RTFOT [13] at 163 °C for 85min; the long-term aging is performed using PAV [14] at 100 °C for 20hrs with 2.1 Mpa. The aged samples are evaluated by measuring their rheological properties. Furthermore, the bitumen rheological properties are evaluated using dynamic shear rheometer (DSR) (tests conducted by using a temperature sweep starting from 22 °C to 84 °C and the frequency of 1.59 Hz with 1mm gap [15]).

## 3. Results and Discussions

### 3.1. Penetration

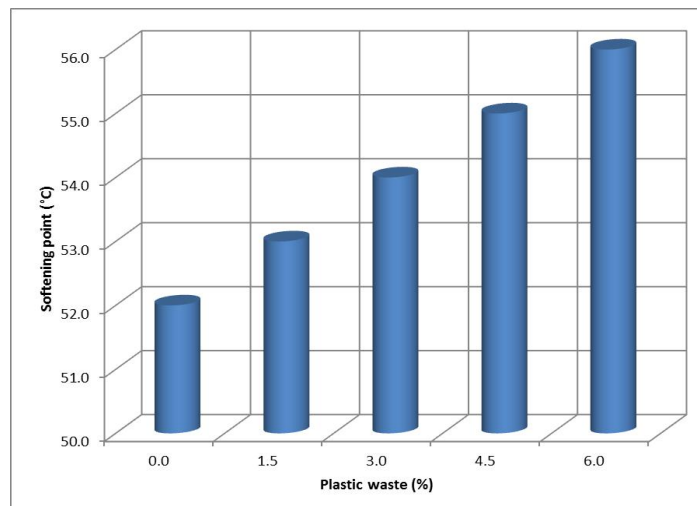
Fig. 1 illustrates the effect of plastic waste concentration on penetration. The penetration depth decreased as the amount of plastic waste increases up to 6%. This shows that plastic waste content has a significant effect on the penetration value. The results also found that when the content of plastic waste is increased from 1.5% to 6 %, the penetration value decreases gradually from 55.3 to 24.1. It means that plastic waste has a great effect on reducing the penetration value by increasing the stiffness of plastic waste in binder. Make the binder less susceptible and will result to resist the deformation like rutting [16].



**Figure 1.** Penetration Values

### 3.2. Softening Point

Fig. 2 shows that the increases of softening point as the percentage of plastic waste increase. It can be seen that when plastic waste content is 1.5% by weight of bitumen, the softening point is 53 °C and when plastic waste is added up to 6%, the softening point reaches up to 56 °C. It can be said that when the softening point is increasing there will be the reduction of susceptibility at high temperature. This phenomenon shows that the resistance of the binder to the effect of heat is increased and was reduce its tendency to soften in the hot weather [17]. With the addition of plastic waste, the modified binder will be less susceptible to the changes of temperature. Therefore by using plastic waste in bituminous mix, the rate of rutting will decrease due to the increase in softening point.



**Figure 2.** Softening Point Values

### 3.3. Penetration Index (PI)

The penetration index (PI) represents the quantitative measure of the response of bitumen to variation in temperature. Tables 1 summarized the value of PI for virgin and modified bitumen at different percentage of plastic waste. It can be seen that the penetration index values are inconsistent at all addition percentages. The PI value for original binder is -0.02 and decrease to -0.23 when it was

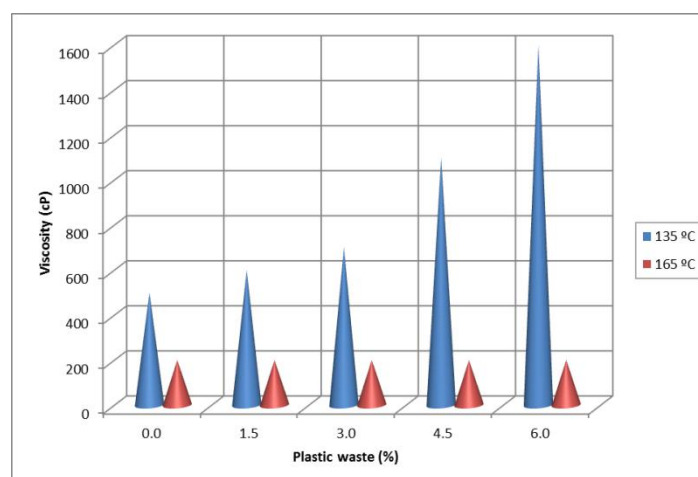
modified with 1.5% of plastic waste. However, PI values were increase from -0.39 to -0.10 for 3% and 4.5% respectively. Then it decrease again from -0.10 to -1.31 at 4.5% and 6% respectively. The results show that the resistance of modified bitumen to resists the low temperature cracking and permanent deformation is inconsistent. Yaacob et al. [1] reported that the penetration index of particular bitumen can be used to predict its behavior in an application. Therefore, bitumen with high penetration numbers that can be called as soft are used for cold climates while asphalt binders with low penetration numbers that known as hard are used for warm climates [18].

**Table 1.** PI at different percent plastic waste

Plastic waste (%)	PI
0	-0.02
1.5	-0.23
3.0	-0.39
4.5	-0.10
6.0	-1.31

### 3.4. Viscosity

The viscosity of bitumen at high temperature is assumed as an important factor to have great road pavement work. This is because viscosity represents the ability of bitumen to be pumped through an asphalt plant and coating aggregates in asphalt concrete mix. The characteristics of viscosity in the asphalt binder were examined at two temperatures which are 135 °C and 165 °C. Fig. 3 illustrated the modified binder with plastic waste additive at 135 °C has greater viscosity compared to virgin bitumen. It is showed that as the percentage of plastic waste increase, the viscosity increased which means the binder is getting more viscous. Based on figure, it can be seen that the viscosity of original bitumen 60-70 is 500 cP at 135 °C which is less viscous compared to the addition of 6% plastic waste which has viscosity of 1600 cP at the same temperature. However, at temperature 165 °C the original and modified binder maintained constant 200 cP.

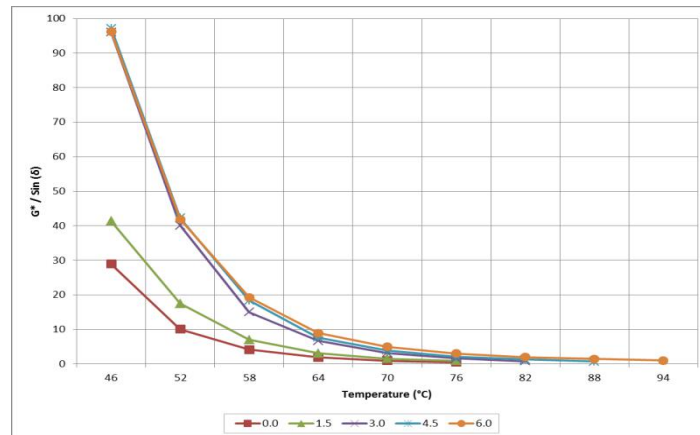


**Figure 3.** Viscosity value

### 3.5. Direct Shear Rheometer

Fig. 4 shows the  $G^*/\sin(\delta)$  trend for original and modified bitumen at temperature ranging from 46°C to 94°C and at the constant frequency of 1.59 Hz. The results indicated that higher the percentage of

plastic waste will result in higher the  $G^*/\sin(\delta)$ . It also shown that at 6% of plastic waste, the  $G^*/\sin(\delta)$  still met the condition even the temperature reached up to 94°C. It can be said that the use of plastic waste as modifier will improve the performance of binder against permanent deformation (rutting) at high temperature. However,  $G^*/\sin(\delta)$  at 6% plastic is lower than 4%. Indicate that a 4% of plastic waste is the optimum percentage.



**Figure 4.**  $G^*/\sin(\delta)$  trend

### 3.6. Penetration-Viscosity Number (PVN)

The PVN must be based on penetration at 25 °C and viscosity at 135 °C which are standard specifications for paving the asphalt. Base on Table 2, the increases of plastic waste was increasing the PVN values. The PVN value is increases from -0.36 to 0.13 which have the percentage of 0% and 6% respectively. This increases of PVN values shows the significantly of the plastic waste addition in the bitumen to improve the temperature susceptibility of bitumen. It is indicated that the addition of plastic waste in bitumen can enhance the rutting resistance of the bitumen at high temperatures.

**Table 2.** PVN at different percent plastic waste

Plastic waste (%)	PVN values
0	-0.36
1.5	-0.29
3.0	-0.25
4.5	-0.05
6.0	0.13

## 4. Conclusions

- Additive of plastic waste at different content gives effect on the temperature susceptibility of the bitumen. As the content of plastic waste increase from 1.5% to 6%, the penetration number decreases gradually and softening point of modified bitumen increase.
- The addition of plastic waste content increases the viscosity of the bitumen at high temperature i.e. 135 °C. High viscosity means less chances of rutting.

- c) Plastic waste improves the performance of bitumen when it was added into bitumen. The higher plastic waste percentage give the higher  $G^*/\sin \delta$  which is rutting factor. Thus, the modified bitumen able to reduce the rutting effect.
- d) The usage of 6% of plastic waste is found to be the optimum percentage for modification of bitumen. This percentage could make the pavement able to resist the heavy vehicles and hot climate.

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## References

- [1] H. Yaacob, M. Ali Mughal, R.P. Jaya, M.R. Hainin, D.S. Jayanti, C.N. Che Wan, Rheological properties of styrene butadiene rubber modified bitumen binder. *J. Teknologi*. **78** (2016) pp 121–126.
- [2] A.I.B. Farouk, N.A. Hassan, M.Z.H. Mahmud, J. Mirza, R.P. Jaya, M.R. Hainin, H. Yaacob, N.I.M. Yusoff, Effects of mixture design variables on rubber–bitumen interaction: properties of dry mixed rubberized asphalt mixture. *Mater. Struct.* **50** (2017) pp 1–10.
- [3] S. Köfteci, P. Ahmedzade, B. Kultayev, Performance evaluation of bitumen modified by various types of waste plastics. *Constr. Build. Mater.* **73** (2014) pp 592–602.
- [4] M. Garcia-Morales, P. Partal, F.J. Navarro, C. Gallegos, Effect of waste polymer addition on the rheology of modified bitumen. *Fuel* **85** (2006) pp 936–943.
- [5] X. Lu, U. Isacson, Modification of road bitumens with thermoplastic polymers. *Polym. Testing* **20** (2001) pp77–86.
- [6] M. Naskar, T.K. Chaki, K.S. Reddy, Effect of waste plastic as modifier on thermal stability and degradation kinetics of bitumen/waste plastics blend. *Thermochim. Acta* **509** (2010) pp 128–134.
- [7] C. Fang, J. Hun, S. Zhou, H. Wang, M. Zhang, Y. Zhang, Comparative study of asphalts modified by packaging waste EPS and waste PE. *Polym-Plast. Technol. Eng* **50** (2011) pp 220–224.
- [8] L.M.B. Costa, H.M.R.D. Silva, J.R.M. Oliveiran, S.R.M. Fernandes, Incorporation of waste plastic in asphalt binders to improve their performance in the pavement. *Int. J. Pavement Res. Technol.* **6** (2013) pp 457–464.
- [9] Y. Yildirim, D. Hazlett, R. Davio, Toner-modified asphalt demonstration projects. *Resour. Conserv. Recycl.* **42** (2004) pp 295–308.
- [10] ASTM D5/D5M–13. Standard Test Method for Penetration of Bituminous Materials. ASTM International, West Conshohocken, PA, USA.
- [11] ASTM D36/D36M–14e1. Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus). ASTM International, West Conshohocken, PA, USA.
- [12] ASTM D4402/D4402M–15. Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer. ASTM International, West Conshohocken, PA, USA.
- [13] ASTM D2872–12e1. Standard Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test). ASTM International, West Conshohocken, PA, USA.
- [14] ASTM D6521–13. Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV). ASTM International, West Conshohocken, PA, USA.
- [15] W.N.A.W. Azahar, R.P. Jaya, M.R. Hainin, M. Bujang, N. Ngadi, Chemical modification of waste cooking oil to improve the physical and rheological properties of asphalt binder, *Constr. Build. Mater.* **126** (2016) pp 218–226.

- [16] W.N.A.W. Azahar, M. Bujang, R.P. Jaya, M.R. Hainin, A. Mohamed, N. Ngadi, D.S. Jayanti, The potential of waste cooking oil as bio-asphalt for alternative binder—an overview, *J. Teknologi*. **78** (2016) pp 111–116.
- [17] W.N.A.W. Azahar, M. Bujang, R.P. Jaya, M.R. Hainin, N. Ngadi, M.M.A.B. Abdullah, Performance of waste cooking oil in asphalt binder modification. *Key Eng. Mater.* **700** (2016) pp 216-226.
- [18] M.R. Hainin, M.M.A. Aziz, A.M. Adnan, N.A. Hassan, R.P. Jaya, H.Y. Liu, Performance of modified asphalt binder with tire rubber powder. *J. Teknologi* **73** (2015) pp 55-60.