The Use of Plastic Waste in Bituminous Mixture for the Road Pavement

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Abstract. The increase of plastic waste generation leads the serious problems, it will easily dispose to landfill, urban and commercial areas. When the unsafe plastic waste secretes the toxic chemicals that leach out into the soil and under-ground water and then pollutes the water bodies. 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 our environment but also able to help the road construction industry. The aims of this research are to determine the physical and chemical properties of modified bitumen containing different percentages of plastic waste and also to determine the optimum percentage of plastic waste in modified bitumen. Modified bitumen was prepared by using blending techniques. Bitumen was heated and plastic waste was slowly added. Physical and chemical of bitumen were analyzed by conducting the laboratory tests such as penetration, softening point, viscosity and also direct shear. As the content of plastic waste increase, the penetration grade, softening point and viscosity of bitumen increase. Plastic waste improves the performance of bitumen when it was added into bitumen. The usage helps to improve the performance of the road pavement which also reduces the rutting effect.

Introduction

Plastics is a material that contains one or more organic polymer of large molecular weight, solid in its finished stated and it also can flow under specific state. It is durable and has very slow process of degradation. Plastic can be divided into two major categories which are thermoses and thermoplastics. Thermos 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. 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 bio-decomposition. 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 help to well manage this waste plastic. Road pavement that uses plastic waste as one of it material is called plastic road [1].

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 [1].

The use of plastic waste in road construction can be one of the solutions. 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. However, often incinerators used are not recommended standards and guidelines.

It is particularly significant to use plastic waste because it can minimize the landfilling. It was translates that 1.125 tons of plastic wastes are used per km of single lane road. In addition, the dry process does not result in the burning of plastics because they are only heated. In the process of

making this plastic road, plastic wastes are not burnt and no carbon dioxide liberated into the atmosphere. In India, 2500 km of plastic road has been laid and save over 2500 tons of plastic waste and give 7500 tons less of CO2 that has escaped into atmosphere which can reduce global warming.

The objective of this research is to investigate the effect of using different percentages of plastic waste on penetration, viscosity and 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. Therefore, the specific objectives of this study are to study the physical and chemical properties of modified bitumen containing different percentages of plastic waste and also to determine the optimum percentage of plastic waste in modified bitumen.

Bitumen grade of 60-70 was used in this research. Physical tests for the viscosity, penetration and also softening points for both unmodified and modified bitumen of 60-70 penetration grades were included in this study. In addition, the rheological properties of modified binders will able to help for the identification of the importance of using the modifiers in pavement industries. The test for rheological will be conducted by using a Direct Shear Rheometer (DSR) apparatus based on the fundamental of dynamic mechanical analysis. All the procedures used for the laboratory works are referred to American Society for Testing and Material (ASTM) specifications.

Previous Studies

Plastic waste can act as binder and also modifier[2]. When this materials was heating soften at 130°C, the result indicates no gas evolution occur in the range of 130°C-180°C and the binding property of the softened plastics have appear. Several types of materials such as granite stone and ceramics can be coated with molten plastics waste and give the increase in the values of the compression and also bending strength. Therefore, waste plastics have a high potential to enhance the road characteristics

Plastic road give better resistance towards rain water and water stagnation, no stripping and no potholes, increase binding and better bonding of the mix, reduction in pores in aggregate and hence less rutting and raveling, no leaching of plastics, no effect of radiation like UV, the strength of the road is increased by 100%, the load withstanding property increases. It also helps to satisfy today's need of increased road transport, for 1km x 3.75m road, 1 ton of plastic waste is used and 1 ton of bitumen is saved, cost of road construction is also decreased, disposal of waste plastic will no longer be a problem, the use of waste plastics on the road has helped to provide better place for burying the plastic waste without causing disposal problem.

Centre for Transportation Engineering of Bangalore University have discuss about the possibility use of the processed plastic bags as an additives in bituminous mix[5]. The properties of the modified bitumen are compared with normal bitumen and it shows that the penetration and ductility values of the modified bitumen decreased as the proportion of plastic addictive increased. This can be shows that the life of the pavement surfacing course that used modified bitumen can be increased substantially compared with normal bitumen.

The 25 km plastic road was laid in Bangalore and it shows superior smoothness, uniformity and less rutting compared with normal road which began developing "crocodile cracks" soon after. The process of plastic road construction was improved in 2003 by Central Road Research Institute Delhi (CRRI). This construction of plastic road has proved that the road life improves through the improved tackiness and viscosity of the bituminous mix.

Plastic road also has better strength and performance of road, does not need to use the anti-stripping agent, can avoid disposal of plastic waste by incineration and land filling and ultimately develop a technology, which is eco-friendly. The increasing of traffic load will make life span of the road become short but plastic roads are means of prevention and ultimately will be the cure. It will save millions of dollars in future and reduce the amount of resources used for construction.

The polymer bitumen blend is a better binder compared to normal bitumen[6]. Polymer bitumen blend has increased softening point and decreased penetration value with a suitable ductility. When it used for road construction it can resist higher temperature and load. Hence the use of waste

plastics for flexible pavement is one of the best methods for easy disposal of waste plastics. Used of plastic waste in road help in many ways like easy disposal of waste, better road and prevention of pollution.

We can conclude that by adding waste plastic as a modifier in bitumen it can improve properties of the bitumen itself. This modified bitumen exhibit good results when it is compared to ordinary bitumen. Normally, the optimum moisture content of waste plastic to be used is between the ranges of 5% to 10%. In the same time, problems like bleeding in hot temperature can be reduced. The waste plastics thus can be put to use and it ultimately improves the quality and performance of road.

Methodology

Study was be carried out by using experimental methods to mix the plastic waste in bitumen. The sample testing on BRHA that was conduct is show in Figure 1.

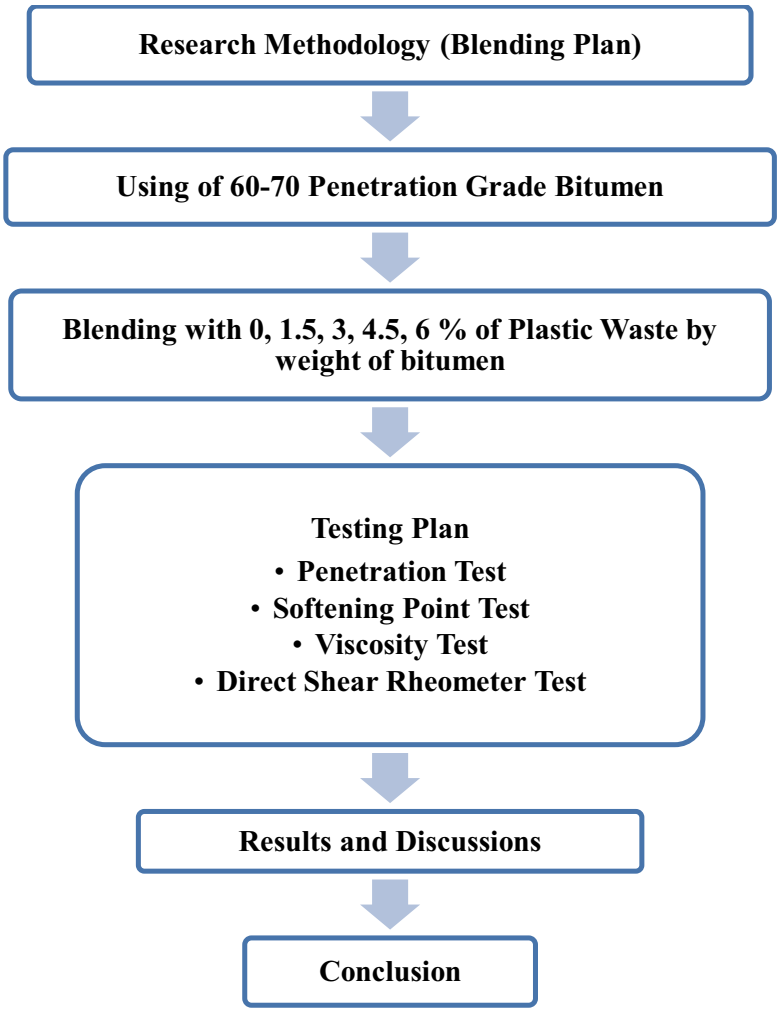

Figure 1: Flow chart of laboratory process

Material and Testing Method

Materials UsedBitumen with 60/70 PEN grade was used in this study as recommended in new JKR Standard Specification for Road Works (2007) based on tropical climate. The properties of asphalt binder are presented in Table 3.1. Plastic waste is obtained from used plastic.

Table 3.1: Properties of original bitumen

Properties	Results
Penetration at 25˚C (d-mm)	65
Softening Point (˚C)	51
Specific Gravity (g/cm^3)	1.03
Viscosity at 135˚C (cP)	600
G*/sinδat 64 ˚C (kPa)	2.14

Materials PreparationModified bitumen was prepared by using blending techniques. 500g 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, 4.5 and 6 % by weight of the blend. 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. Figure 3.2 and Figure 3.3 shows the plastic bag that will be used in this research and shredded plastic bags.

Figure 3.2 Plastic Bags **Figure 3.3** Shredded Plastic Bags

Binder TestingBinders were characterized by using a number of standard physical tests such as penetration test is based on ASTMD5-97 (temperature, load and time are 25˚C, 100g and 5 secs respectively), softening point test follow ASTM D36-95, viscosity is based on Brookfield viscometer ASTDM D4402 (temperature range from 135˚C to 165˚C, spindle No. 27 and rotating speed of 20 rpm) while the test for rheological properties of bitumen was performed by using direct shear test (DSR) (test conducted by using a temperature sweep starting from 46˚C to 94˚C and the frequency is 1.159Hz with 1 mm gap).

Penetration TestPenetration Test(ASTMD5-97) is simple and easy to perform but it does not measure any fundamental parameter and with one temperature 25˚C (77˚F). This test is used for evaluating the consistency of bitumen before and after heating. The penetration of bituminous material defined as the distance in tenth of millimeter that a standard needle vertically penetrates a sample of the material under known conditions of loading, time, and temperature. The penetration test is used for evaluating the consistency of bituminous material The apparatus used in this test are penetration apparatus, penetration needle, penetration cup, water bath, transfer dish, thermometer, timing device, heater and also balance. Figure 3.4 shows the penetration test apparatus.

Figure 3.4 Penetration Test Apparatus

Softening Point TestSoftening point (ASTMD36-95) is the temperature at which a substance attains a particular degree of softness under specified conditions of test. As temperature increases, asphalt cement changes from solid to liquid, and the stiffness of asphalt cement will reduce accordingly. Before mixing with aggregates to form a road pavement work, asphalt cement must be soft enough in order for it to be handled easily during pavement work. The most common method to soften the asphalt cement is by heating it. Higher grade asphalt cement has higher softening temperature compare to lower grade asphalt cement. The ring and ball test is commonly used to determine the softening temperature of asphalt cement. Figure 3.5 shows the softening point test apparatus.

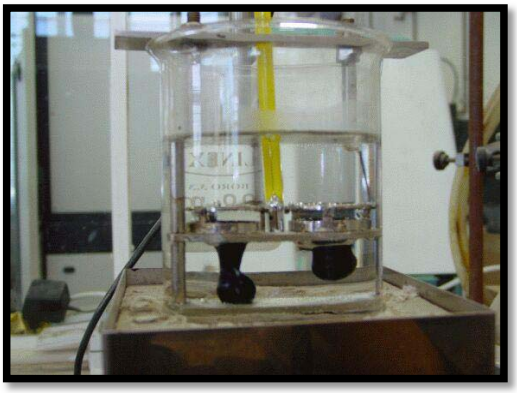

Figure 3.5 Softening Point test apparatus

Viscosity TestViscosity can be defined as a resistance to flow. This resistance to flow is important characteristic of asphalt binder as it able to determine the behavior of the material at a given temperature and over a range of temperatures. Viscosity is used to indicate the viscosity of asphalt binder in the high range of temperature of mixing and paving. This measurement is used in the Superpave PG asphalt binder specification. The RV test can be conducted at various temperatures but since manufacturing and construction temperatures are quite similar, the test for Superpave PG asphalt specification is always conducted at 135˚C.

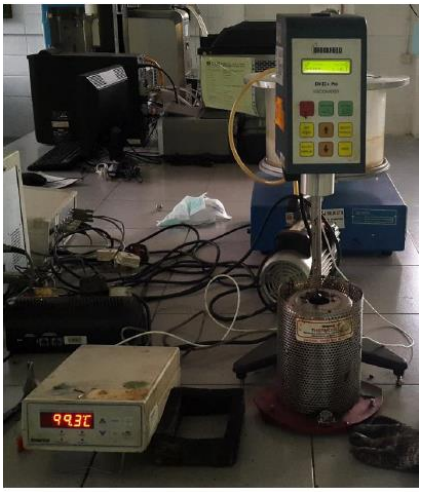

Figure 3.6 Brookfield Viscometer

(DSR) Dynamic Shear Rheometer TestThe Direct Shear Rheometer (DSR) is used to classify the viscous and elastic behavior of asphalt binder at high and intermediate service temperature and estimate its rutting and fatigue cracking potential. The behaviors of the asphalt binder can be captured by measuring the complex shear modulus (G*) can be considered the total resistance of the sample to deformation when repeatedly sheared while phase angle (δ), is the lag between the applied shear stress and will result to shear strain. The temperature of the test, size of the specimen and diameter of plate are depends on the type of asphalt binder that is being tested.

Figure 3.7 Direct Shear Test (DSR)

Data Analysis

Penetration Penetration values for original and modified bitumen 60-70 shown in Table 4.1.

Table 4.1: Penetration values for original and modified bitumen 60-70

% Plastic waste by weight	Penetration (dmm)
0	66.0
1.5	55.3
3.0	47.1
4.5	31.9
6.0	24.1

Figure 4.1 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. From the table, it can be proved that when the content of plastic waste is increased from 1.5% to 6 %, the penetration number 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 bitumen binder. Make the binder less susceptible and will result to resist the deformation like rutting.

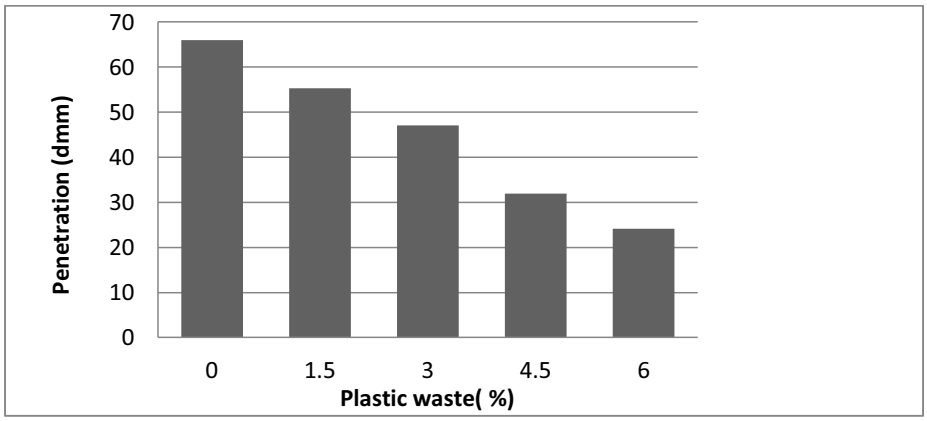

Figure 4.1 Penetration results for bitumen grade 60-70 added with plastic waste

Softening Point Results Table 4.2 shows the softening point values for original and modified bitumen 60-70.

Table 4.2: Softening point values for original and modified bitumen 60-70

% Plastic waste by weight	Softening Point (ºC)
0	52
1.5	53
3.0	54
4.5	55
6.0	56

Figure 4.2 shows that the increases of softening point as the percentage of plastic waste increase. For bitumen 60-70 penetration grade, it can be seen that when plastic waste content is 1.5% by weight of bitumen, the softening point is 53ºC and when plastic waste is added 6% by weight of bitumen the softening point reaches until 56ºC. Based on the chart of softening point, it can be illustrated that when the softening point is increasing there will be the reduction of susceptibility at high temperature.

This type of phenomenon shows that the resistance of the binder to the effect of heat is increased and will reduce its tendency to soften in the hot weather. 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.

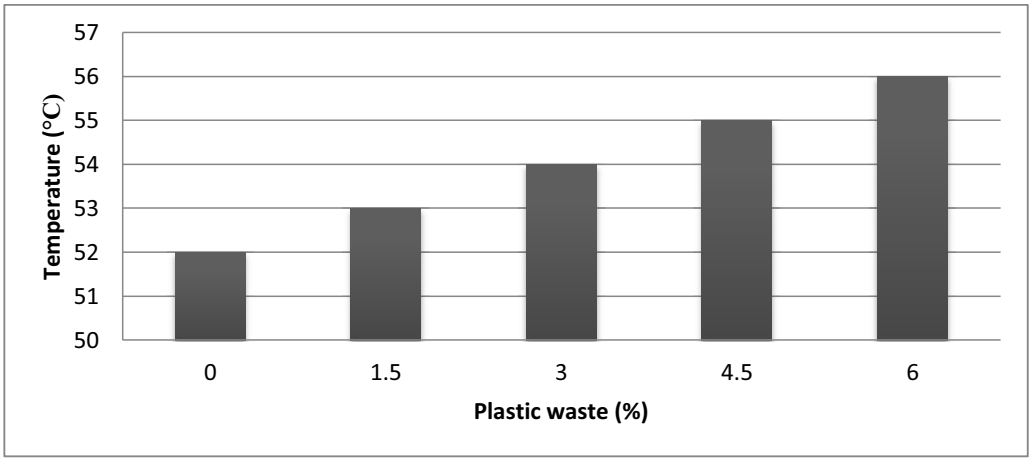

Figure 4.2 Softening point results for original and modified bitumen 60-70

Viscosity ResultsThe 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. It is important to apply this viscosity test because it investigates the effect of plastic waste on the binder workability. The characteristics of viscosity in the asphalt binder were examined at two temperatures which are 135ºC and 165ºC. Table 4.3 shows the result of viscosity for original and modified binder 60-70.

Table 4.3 Viscosity values for original and modified binder 60-70

% Plastic waste by weight	cP at 135 ºC	cP at 165 ºC
0	500	200
1.5	600	200
3.0	700	200
4.5	1100	200
6.0	1600	200

Figure 4.3 illustrates the modified binder with plastic waste additive at 135ºC has greater viscosity compared to original 60-70 penetration grade bitumen. As the percentage of plastic waste increase, the viscosity increased which means that the binder is getting more viscous. From the chart, it can be seen that the viscosity of original bitumen 60-70 is 500cP at 135ºC which is less viscous compared to the addition of 6% plastic waste which has viscosity of 1600cP at the same temperature. At 165ºC the original and modified binder maintained constant 200cP.

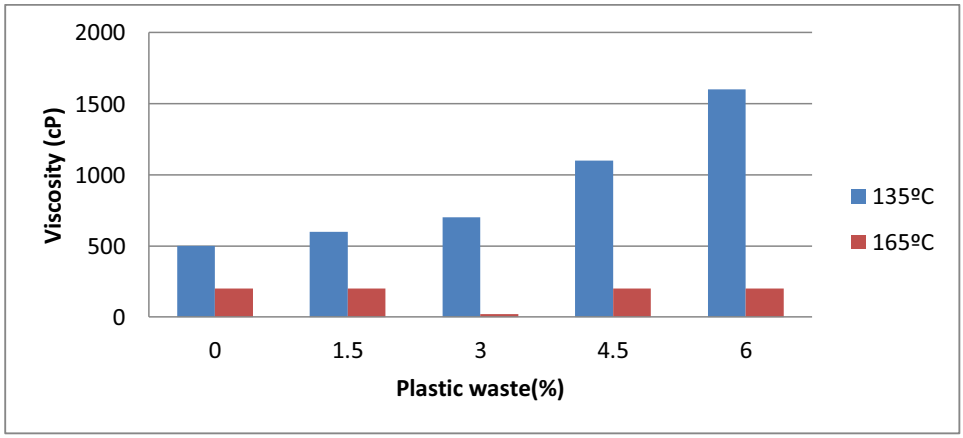

Figure 4.3 Viscosity values for original and modified binder 60-70

Penetration Index (PI)The penetration index (PI) represents the quantitative measureof the response of bitumen to variation in temperature. The information of 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 asphaltbinders with low penetration numbers that known as hard are used for warm climates.

Table 4.4 lists the value of PI for original and modified bitumen at different percentage of plastic waste. As we can see from the table, Penetration Index values are inconsistent for all of the 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 by weight of bitumen. 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. These results show that the resistance of modified bitumen to resists the low temperature cracking and permanent deformation is inconsistent.

Table 4.4 Results of penetration index of original and modified bitumen

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

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. Table 4.5 illustrates the PVN values for the original and modified bitumen that containing plastic waste at different percentage by weight. The result shows that the increases of the plastic waste percentage by weight increase the PVN values. Based on the table, 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 also can be indicated that the addition of plastic waste in bitumen can enhance the rutting resistance of the bitumen at high temperatures.

Table 4.5 Results of PVN values of original and modified bitumen.

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

Direct Shear Rheometer (DSR) ResultsThe Dynamic Shear Rheometer (DSR) is used to characterize the viscous and elastic behavior of asphalt binder at high and intermediate service temperatures. DSR also evaluate rutting and fatigue cracking potential. Table 4.6 shows the DSR results for original and modified bitumen 60-70.

Table 4.6 DSR results for original and modified bitumen 60-70

% Plastic waste by weight	Temperature of bitumen failure (ºC)
0	75
1.5	76
3.0	82
4.5	88
6.0	94

Figure 4.6 shows the G*/sin (δ) trend for original and modified bitumen 60-70 in a temperature ranging from 46ºC to 94ºC and at the constant frequency of 1.59 Hz. From the figure also it can be seen that higher the percentage of plastic waste higher the G*/sin (δ). Also it is shown that at 6% of plastic waste addition, the G*/sin (δ) still met the condition even the temperature reached 94ºC. This shows that the use of plastic waste will improve the performance of binder against permanent deformation (rutting) at high temperature. However G*/sin (δ) of 6% is lower than 4% of plastic waste which indicate that the 4% of plastic waste is the optimum percentage.

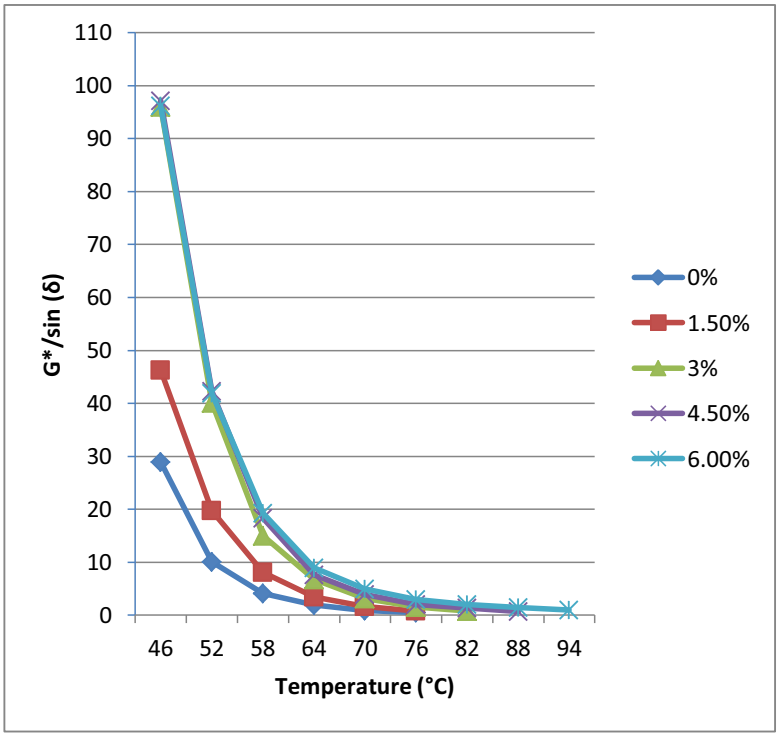

Figure 4.4 G*/sin (δ) trend for original and modified bitumen 60-70

Conclusion

This research is to investigate the physical and chemical properties of the modified bitumen containing different percentages of plastic waste.

1. The result clearly illustrates the 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.

2. 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. However it also resist the compactive effort and there will be low stability values at low temperature. The constant viscosity at 165°C shows there is no effect when different percentage of plastic waste was added in bitumen.

3. Plastic waste improves the performance of bitumen when it was added into bitumen. The higher plastic waste percentage give the higher G*/sin δ which is rutting factor. So the modified bitumen able to reduce the rutting effect.

4. As the plastic waste increased, the G*/sin δ value is also increased but in the country like Malaysia, the usage of 4% of plastic waste by the weight of bitumen which 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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