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Study of Behavior of Plastic Modified Bitumen by Incorporating Carbon Black

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ABSTRACT

In recent years, the performance of polymer modified bitumen has been widely studied. This study reports a research carried out to investigate the properties of polymer modified bitumen (PMB) by using polypropylene as modifier, carbon black as additives, to examine the optimum ratio of polypropylene to carbon black. With this objective, sample preparation using wet mixing method combining high shear mix was firstly performed. Subsequently, 18 samples were developed for the study, of which the polypropylene (PP) contents 10%, 12%, 14%, 16%, 18% and 20% with 2%, 3%, 4% of carbon black content. Afterwards, samples were characterized by standard tests (Dynamic Shear Rheometer and Viscosity), and all the test results showed improved performance. Finally, the results concluded that the optimum binder-PP ratio PMB for applying is 14% PP with 3% carbon black.

1. INTRODUCTION

Bitumen is a common material that used in flexible pavement due to its properties, including economical, low melting point, adhesive etc. However, bitumen softens easily in warm environments and brittle in cold environments. Then, bitumen performance becomes one of the most important methods to deal with these problems to make better performance of the bitumen for pavement construction.

Among all attempted or investigation methods of bitumen, polymer modification of bitumen has been commonly performed since the 1980s in order to decrease bitumen

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(and pavement) susceptibility to high and low temperatures, allowing reduction in common failure mechanisms as rutting and cracking. And numerous studies have evidence to prove that the addition of polymer in bitumen can improve the properties of bitumen(Wang 2003)(Zhu 2014). The improved functional properties include permanent deformation (Khosla 1989) , fatigue and low temperature cracking (Valkering 1992), stripping (Beecken 1992), wear resistance, fatigue and rutting (Arabania 2016) and ageing (Harlin 1989) (Isacsson 2000). Therefore, using the plastic waste to become the modifier of the bitumen is a great idea to recycle the plastic waste and Improve asphalt performance.

Objectives of this study are: (1) To investigate the effect of polypropylene (PP) and carbon black (CB) in modified bitumen; (3) To evaluate the change in rheological properties of modified bitumen base on Dynamic Shear Rheometer (DSR) and Viscosity tests; (2) To determine the optimum content of PP and CB in modified bitumen and the ratio of PP and CB.

2. MATERIALS AND METHODS

2.1 Raw materials

(1) Bitumen

Bitumen is usually defined as a dark brown to black material, mainly obtained from crude oil distillation. It is widely used as a binder of mineral aggregates in road pavements. And Binder of 60/70 penetration grade obtained from the same company was used as the original bitumen in this study. The physical properties of this bitumen are given in Tab. 1.

Tab. 1 Properties of the original bitumen

Test	Method	Unit	Value
Penetration@25°C	ASTM D5	dmm	63.3
Softening Point	BS 2000-58	°C	47.9
Ductility	ASTM D113	cm	>150
Viscosity at 135	ASTM D4402	Pa.s	0.48
Viscosity at 175°C	ASTM D4402	Pa.s	0.1
Rutting Factor,G*/sinδ	AASHTO T315	kPa	1.40
Performance Graded	AASHTO R29	/	PG64

(2) Polypropylene

Polypropylene (PP), also known as polypropene, is a thermoplastic polymer used in a wide variety of applications. It is produced via chain-growth polymerization from the monomer propylene. PP is a linear hydrocarbon polymer, expressed as $(C_3H_6)_n$ and it is a polyolefin or saturated polymer. The physical and chemical properties of PP used in this study are shown in Tab. 2.

Tab. 2 Properties of PP

Physical state	Color	Melting point	Size	Density
Granular	White	170-176°C	~0.126mm	0.89g/cm3

(3) Carbon Black

Carbon black is a material produced by the incomplete combustion of heavy petroleum products such as FCC tar, coal tar, or ethylene cracking tar. Carbon black is a form of paracrystalline carbon that has a high surface-area-to-volume ratio, albeit lower than that of activated carbon. The physical and chemical properties of Carbon Black used in this study are shown in Tab. 3.

Tab. 3 Properties of Carbon Black

Physical state	Color	Melting point	Size	Density
Granular	Black	3827°C	~100 nm	0.89g/cm3

2.2 *Sample Preparations*

Samples were prepared using melt blending technique (High shear Mixing). The bitumen about 500g was heated in oven till fluid condition, carbon black and polypropylene were added simultaneously during mixing, while the speed of the mixer was maintained at 4000 rpm for 60 minutes and temperature was kept between 160°C and 180°C. Current rate of the progress indicates that the concentration of PP used were 10, 12, 14, 16, 18, and 20% by weight of the binder and the carbon black used were 2%,3% and 4% respectively.

3. RESULTS AND DISCUSSION

3.1 Dynamic Shear Rheometer (DSR)

DSR test is a method to determine the complex shear modulus (G*) and phase angle (δ) of the modified bitumen, then the rutting factor can be calculated. To determining the grading of PP modified bitumen (unaged) by Superpave Performance Grading System, the criteria is the rutting factor of the specimen should be larger than 1.0 kPa in the DSR test which means it passes the tested temperature. Rutting factor of PP modified bitumen for unaged specimens is shown in Tab. 4, Tab. 5 and Tab. 6.

Tab. 4 Rutting Factor of Modified Bitumen (10% to 20% PP, 2% CB, unaged)

PP Modified Bitumen		Rutting Factor (kPa) Testing Temperature		PG Grading
CB	PP	70℃	76℃	
2%	10%	1.98	0.87	70
2%	12%	0.94	0.48	64
2%	14%	2.05	0.98	70
2%	16%	2.20	1.05	76
2%	18%	2.45	1.22	76
2%	20%	2.73	1.34	76

Tab. 5 Rutting Factor of Modified Bitumen (10% to 20% PP, 3% CB, unaged)

PP Modified Bitumen		Rutting Factor (kPa) Testing Temperature		PG Grading
CB	PP	70℃	76℃	
3%	10%	1.30	0.71	70
3%	12%	2.38	1.10	76
3%	14%	2.42	1.18	76
3%	16%	2.50	1.21	76
3%	18%	2.81	1.35	76
3%	20%	2.84	1.38	76

Tab. 6 Rutting Factor of Modified Bitumen (10% to 20% PP, 4% CB, unaged)

PP Modified Bitumen		Rutting Factor (kPa) Testing Temperature		PG Grading
CB	PP	70℃	76℃	
4%	10%	2.28	1.10	76
4%	12%	2.22	0.70	70
4%	14%	1.01	0.51	70
4%	16%	2.20	1.15	76
4%	18%	2.51	1.22	76
4%	20%	2.57	1.28	76

According to the requirement of modified bitumen in Hong Kong, DSR test should be done again after the short-term aging of the modified bitumen which is the process of RTFOT. And the rutting factor of the aged specimen should be larger than 2.2 kPa which means it passed the tested temperature. Rutting factor of PP modified bitumen for aged specimens is shown in Tab. 7, Tab. 8 and Tab. 9.

Tab. 7 Rutting Factor of Modified Bitumen (10% to 20% PP, 2% CB, aged)

PP Modified Bitumen		Rutting Factor (kPa) Testing Temperature		PG Grading
CB	PP	70℃	76℃	
2%	10%	2.10	1.1	64
2%	12%	1.63	0.97	64
2%	14%	2.81	1.24	70
2%	16%	2.94	1.37	70
2%	18%	3.51	1.74	70
2%	20%	3.81	1.90	70

Tab. 8 Rutting Factor of Modified Bitumen (10% to 20% PP, 3% CB, aged)

PP Modified Bitumen		Rutting Factor (kPa) Testing Temperature		PG Grading
CB	PP	70℃	76℃	
3%	10%	2.05	1.00	64
3%	12%	3.10	1.51	70
3%	14%	3.20	1.67	70
3%	16%	3.38	1.75	70
3%	18%	3.56	1.80	70
3%	20%	3.94	1.96	70

Tab. 9 Rutting Factor of Modified Bitumen (10% to 20% PP, 4% CB, aged)

PP Modified Bitumen		Rutting Factor (kPa) Testing Temperature		PG Grading
CB	PP	70℃	76℃	
4%	10%	4.14	1.87	70
4%	12%	2.43	1.20	70
4%	14%	2.76	1.29	70
4%	16%	3.10	1.54	70
4%	18%	3.30	1.64	70
4%	20%	3.57	1.80	70

3.2 Viscosity

The original 60/70 bitumen has the viscosity of 0.48 Pa.s. Compare to 60/70 bitumen, plastic modified bitumen has overall increase in viscosity . It may due to the present of long PP chains within the bitumen . At 135℃, the temperature has not reached the melting point of PP (160-166℃). The bondings between PP chain are not totally broken. While the increase in PP concentration increases the amounts of PP chains within the bitumen. Thus, the viscosity increases by the percentage of PP.

Three trend lines show that the percentage of PP has a linear relationship with viscosity. Viscosity result at 135℃ of PP modified bitumen is illustrated in Fig. 1.

The standard requirement (AASHTO T316) of viscosity is smaller than 3 Pa.s. Although viscosity is increasing by the increase of PP, the viscosity values are still within the required range. The sample of 14% PP and 4% CB has the highest viscosity value of 1.44 Pa.s. Therefore, viscosity is not the control factor of the modified bitumen.

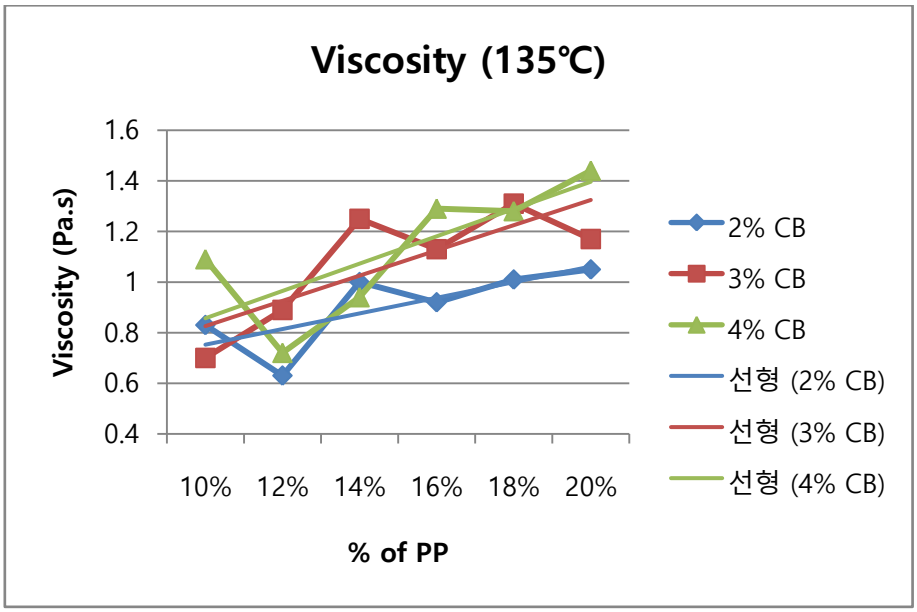

Fig. 1 Viscosity (135℃) against percentage of PP

For the viscosity at 175℃, the behavior of bitumen is similar to that at 135℃. The sample of 20% PP and 4% CB has the highest viscosity of 0.32 Pa.s.The original 60/70 bitumen has the viscosity of 0.1 Pa.s at 175℃. The addition of PP and CB increased the viscosity value. And similarly, the increase of PP increases the viscosity value. Samples with 2 to 4% CB has almost the same slope of trend lines, indicated that the increase ratio is similar by the increase of PP. Viscosity result at 175℃ of PP modified bitumen is shown in Fig. 2.

In the case of viscosity at 135℃ and 175℃, the lower the percentage of CB has the lower viscosity. It may due to the effect of CB. CB inside the bitumen reacts with PP particles and increases the molecular size of PP. With higher concentration of CB, more PP particles become larger in size which increases the viscosity. Hence, the viscosity value increases along with the percentage of CB.

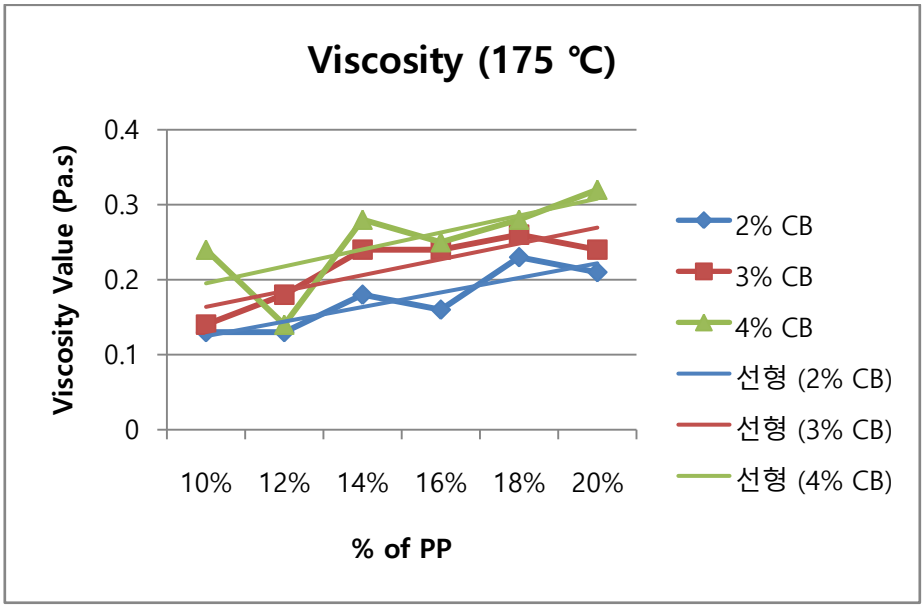

Fig. 2 Viscosity (175℃) against percentage of PP

3.3 Discussion

The tested result is similar to the expected result. The relationship of plastic (PP) content and the rheological properties are deduced. Moreover, the effect of CB has also been shown in the tests.

From DSR result, it can be seen that there are no polypropylene modified bitumen in this project can reach the PG 76 grading. But it can be saying that adding polypropylene to modified bitumen can increase the rutting factor of the bitumen. Thereby, improve the ability of resistance on rutting and higher the PG grading of the bitumen. And from viscosity result, it can seen that the test results of all samples meet the specifications

4. CONCLUSIONS

The following conclusions can be drawn in terms of polypropylene modified bitumen.

(1) PP in bitumen can increase the hardness and rigidity of the bitumen. It can make the bitumen less susceptible and higher resistant to deformation such as rutting. However, the results show that in high PP content, the bitumen cannot fully utilize and present in a solid particle form distributed in bitumen. With the aid of CB, it was observed CB can improve the cohesion between PP and bitumen.

(2) The value of rutting factor of polypropylene modified bitumen is proportional to the increase of polypropylene content. With higher polypropylene content, the

resistance on rutting of polypropylene modified bitumen is higher and it makes the modified bitumen easier to achieve a higher PG grading level.

(3) In a high polypropylene content modified bitumen, adding 3% carbon black may bring the highest value of rutting factor that improves the ability of resistance on rutting of PP modified bitumen and it makes the modified bitumen easier to achieve a higher PG grading level.

(4) 14% polypropylene modified bitumen with adding 3% carbon black is the optimum combination for polypropylene modified bitumen found in the research.

(5) Concerning the environmental pollution, the use of plastic in bituminous mix can reduce the plastic disposal to the environment. The addition of plastic can also improve the quality and strength to withstand heavy road and rutting which comes at a low cost.

REFERENCES

Wang, Shifeng & Zhang, Yong. (2003). SBS/Carbon Black Compounds Give Asphalts with Improved High-Temperature Storage Stability. Polymers and Polymer Composites. **11**, 477-485.

Zhu, J., Birgisson, B., Kringos, N. (2014) Polymer modification of bitumen: Advances and challenges. European Polymer Journal, **54**, 18-38

N.P. Khosla, S.Z. Zahran, A mechanistic evaluation of mixes containing conventional and polymer modified (styrelf) asphalts, Proc. Assoc. Asphalt Paving Technologists **58** (1989) 274–302.

C.P. Valkering, W.C. Vonk, C.D. Whiteoak, Improved asphalt properties using SBS modified bitumens, Shell Bitumen Rev. **66** (1992) 9–11.

G. Beecken, Ten years' experience with Caribit in Germany, Shell Bitumen Rev. **66** (1992) 12–15.

M. Arabania and M. (2016) Pedram, Laboratory investigation of rutting and fatigue in glassphalt containing waste plastic bottles, Constr. Build. Mater., **116**, 378–383

J.P. Harlin, J.L. Jariel, J.C. Blondel, Twelve years service life without specific maintenance for the bitumen Cariflex TR–1101 bound wearing course of the Saint–Quentin Bridge, Proc. 4th Eurobitume Symp. Madrid **1** (1989) 125–127.

X. Lu, U. Isacsson, J. Ekblad, Rheological properties of SEBS, EVA and EBA polymer modified bitumens, Mater. Struct. **32** (1999) 131–139