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Laboratory mechanical properties evaluation of the PP modified bituminous material and asphalt with different mixing method

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ABSTRACT

Polymer modified bituminous material and asphalt with different mixing method were studied to investigate the mechanical performance of polymer modified bitumen (PMB) in order to reach the sustainable pavement objective with good service life. The wet-mixed bitumen is modified with polymer before the blending with the aggregate, while the additives may add in order to compensate the decrease of the rheological properties of PMB. However, dry-mixed asphalt is adding certain polymer content to the aggregate before blending with the pure bitumen, which is similar to coating the aggregates with polymer to improve the adhesive interface between the aggregate and bitumen. The properties of wet mixed or the dry mixed asphalt were investigated by two standard tests (indirect tensile fatigue test and wheel tracking test) to ensure the compatibility to the pavement requirement. Before conducting these two tests, wet-mixed PMB conducted softening point, ductility, penetration and flash point tests to investigate the rheological properties. Finally, the mechanical properties of the polymer modified pavement with different mixed method were compared and possible application in the practical field can be proposed.

Keywords: polypropylene modified bituminous material, PMB, performance test, laboratory performance, dry mixing method, wet mixing method, indirect fatigue test, wheel tracking test

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1. INTRODUCTION

Bitumen is a material made from crude oil which is a hydrocarbon product combining different materials. It is commonly used as a construction material to provide a flexible pavement. In terms of the properties of bitumen, it will be affected by the temperature and form a solid or liquid state in different temperatures (Hunter, Self et al. 2015). The main components in bitumen are saturates (paraffins), aromatics, resins, and asphaltenes (SARA fractions) (Peralta 2009). Aggregate is the skeleton of construction material which provides the strength of asphalt or concrete. Aggregate can be defined as coarse and fine aggregate in the mixture. It controls the mechanical performance on the asphalt using different gradation and the portion ratio of coarse and fine aggregate. To standardize the gradation in asphalt mixture, there are three gradation including dense gradation, open gradation, and semi-open gradation for asphalt mixture, which showed the optimum range of gradation of asphalt to provide a suitable strength (Fang, Park et al. 2019). Asphalt is the construction material used for the pavement on the road which combines with around 4-7% of binder and 95-96% of aggregate (Hunter, Self et al. 2015). The material properties of asphalt, such as air void and bulk density, will affect its mechanical behaviour including durability, rutting deformation, and moisture damage. Besides, from the literature review, addition of plastic polymer in asphalt can improve several mechanical properties e.g. stiffness at high temperature. (Advanced Asphalt Technologies 2011)

PP and PE are the two main common plastic types in daily life. For the basic properties, melting point of PP is around 167°C and PE is around 125°C. They have similar adhesion properties, but PP has slightly higher adhesive strength than that of PE (Song, Bringuier et al. 2012). Both PE and PP had potential to make asphalt stiff and brittle, which were demonstrated by the improved fatigue performance of PE and PP modified asphalt in the experiment (Robinson 2005), (Arabani and Pedram 2016). The study aims to evaluate the influence of different types of mixing method with different content of polymer modified bitumen on the base of mechanical properties of asphalt binders in order to achieve the sustainable pavement application in Hong Kong.

2. MATERIAL AND SPECIMEN PREPARETION

2.1 Bitumen and Polymers

Bitumen, a by-product from the crude oil extraction or distillation process, is defined as the compound with long carbon chain hydrocarbon. The properties of the bitumen are different in terms of the region and manufacturing process, but also with respect to the extraction morphology and crude oil composition. The bitumen from local supplier is stated as in 50/60 grade, and the material properties examined with the experiments in laboratory were shown in Table 1.

To study the feasibility of wet mixed PMB to be used in Hong Kong, ductility, penetration, and softening point is conducted according to standard ASTM D113, ASTM D5, ASTM D36 and ASTM D4402, respectively. A standardized mixing and testing procedure are to ensure the accuracy and consistency of PMB. The samples were prepared using melt blending technique (High shear Mixing). The bitumen (about 500g) was heated in oven till liquidised texture. Afterwards, 0%, 5%, 10% and 15% by weight of the bitumen polypropylene (PP) is added and mixed, while the speed of the mixer is maintained at 4000 rpm and temperature needs to be kept between 160°C and 180°C. Details of the wet mixed PMB preparation procedure are illustrated in Fig. 1.

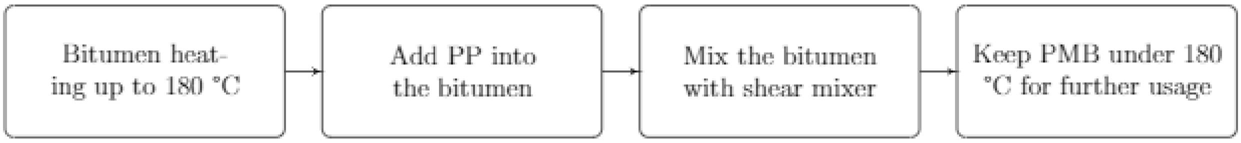

Fig. 1. Schematic Diagram of Binder Sample by Wet-mixing Preparation

PP CONTENT	PURE (0%)	5%	10%	15%	Unit	Method
Penetration@25°C	48.9	55.8	49.3	53.3	dmm	ASTM D5
Softening point	49.3	50.3	53.2	54.4	°C	ASTM D36
Ductility	>1500	531	401	220	mm	ASTM D113
Penetration index	-1.4	-0.9	-0.5	0.0	N/A	N/A
Viscosity at 135°C	0.48	0.566	0.714	0.744	Pa.s	ASTM D4402
Viscosity at 175°C	0.1	0.343	0.486	0.681	Pa.s	ASTM D4402

Table 1. Properties of Wet-mixed PMB with Different PP Content

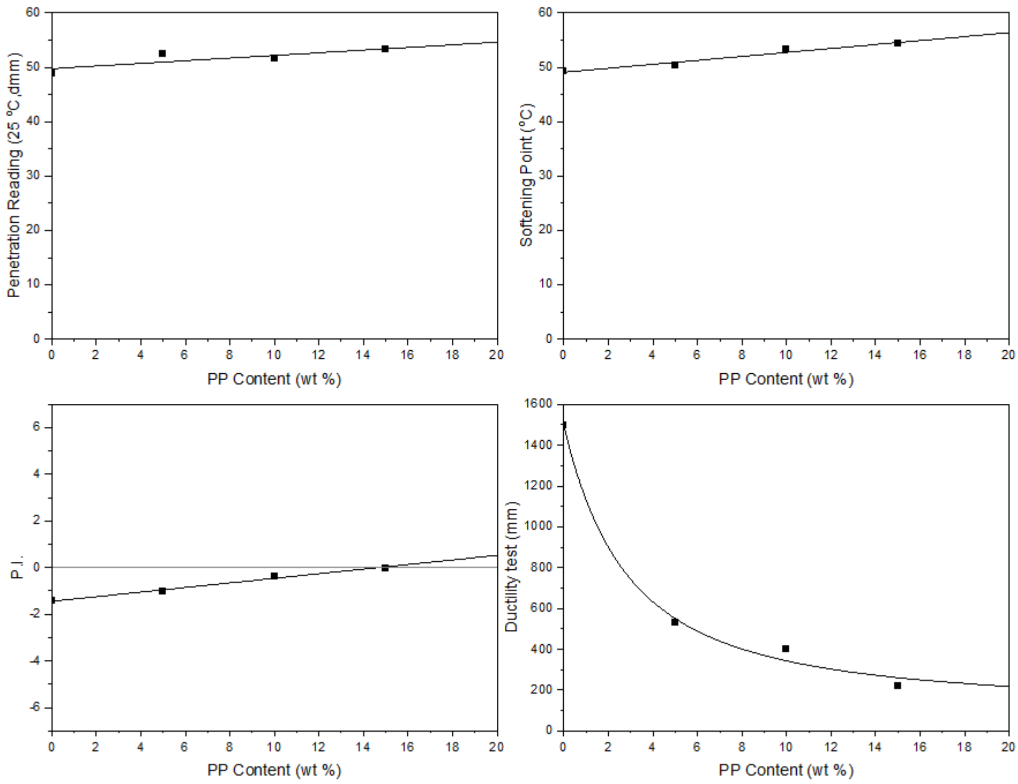

Fig. 2. Overall results for PMB with different PP content

2.2 Aggregate Preparation

Sieving test was performed before the specimen preparation. Aggregates were sieved to provide the suitable gradation of aggregate. 0mm to 14mm sized aggregates were used into the 0/14 open graded specimen preparation. There were 14mm, 10mm, 6.3mm, 3.35mm, 2mm, 1.18mm, 0.063mm and pan size of aggregate in the specimen preparation. As a result, there was a gradation curve provided in the experiment as shown in Fig. 3. The upper and lower limit of 0/14 mm open-graded pavement were included in the gradation curve.

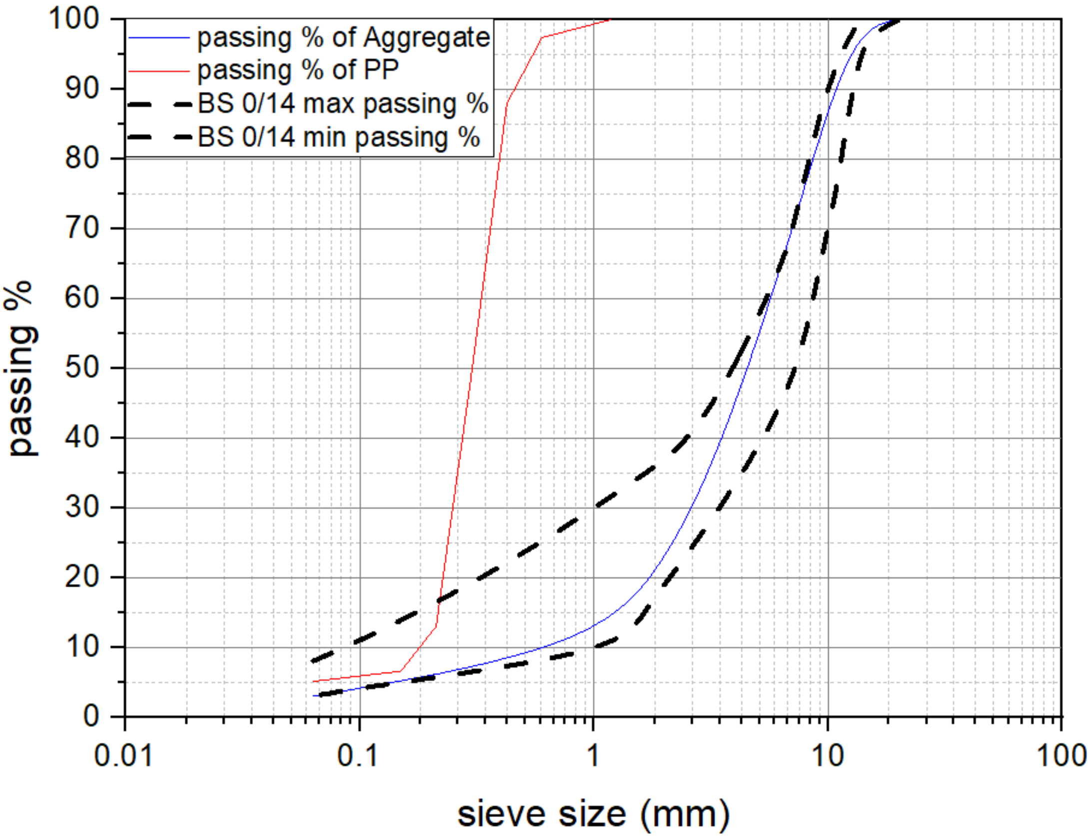

Fig. 3. Gradation curve of PP powder and aggregate in the experiment

2.3 Asphalt Preparation of Two Mixing Method

Two types of mixing methods were applied before the compaction of the specimens. 10kg of aggregate were prepared for every portion of specimen with 4.3% bitumen and corresponding amount of polymer. Coarse and fine aggregate after sieving was oven dried for more than 4 hours to ensure the dry state of aggregate and preheat the asphalt mixer to 180 °C. If dry method is selected, coarse aggregate will be put into the container of the mixer, then blended with the PP powder. Fine aggregate and pure bitumen (430g) were poured into the mixer and blended. Inversely, if wet method is selected, the bitumen required to be blended with the PP powder according to the steps described in Fig. 1 before mixing. Afterwards, coarse and fine aggregate were poured into the mixer and blended with wet mixed PMB.

3. METHODOLOGY

After the mixing process of the asphalt binder, there are two different compaction methods to adopt different experiments needs, where the gyratory compaction for indirect fatigue test and roller compaction for wheel tracking test.

3.2 Polymer Modified Asphalt (PMA) Specimen Preparation by Gyratory compactor for Indirect Fatigue Test

The BS EN standard on specimen preparation by gyratory compactor (BS EN 12697-31:2019) was used in the experiment, where 16 cylindrical specimens were prepared by using Gyrator compactor for one mixing. In terms of the procedure, 670g of specimens will be weighted and put into the 100mm diameter mould of the gyratory compactor. The specimens were required to have at least 40 mm in height to satisfy the indirect tensile fatigue test standard. Compaction procedures are also required to be completed within 8 minutes to maintain the temperature of the asphalt mix to increase the accuracy of the test. Specimens after compaction needed to be placed for 14 days before the indirect tensile fatigue test. In terms of the aging specimen, it is required to place not more than 20°C at a flat surface between 14 days and 42 days when it is produced.

3.3 Polymer Modified Asphalt (PMA) Specimen Preparation by Roller Compactor for Wheel Tracking Test

The BS EN standard of specimen preparation by roller compactor (BS EN 12697-33:2019) was used in the experiment. The roller compactor can simulate the compaction process on the real flexible pavement construction. 10.2kg of specimens was put into a 305 x 305 x 50mm mould and the compaction of specimens should be finished within 10 min. After putting the specimens into the mould, place the mould on the accurate position of the roller compactor. At least 2 specimens should be prepared in the test when using small size or large size devices because procedure B were selected. After mixing the specimens, they should be placed in the range between 48 hours and 42 days with not more than 25°C (BSI,2020).

3.4 Indirect Fatigue Test

The fatigue resistance of asphalt binder is determined by indirect fatigue test by applying a cyclic loading which is following BS EN 12697-24:2018 annex E. The horizontal displacement, total horizontal strain and number of cycles before failure were recorded during the test, which were analysed for different types of binders and asphalt. As bitumen were thermosensitive material, which showed that the temperature on different levels will produce different indirect tensile strength. The strength will be reduced when the temperature increases in the test. Therefore, 20°C were setup in the test to produce the consistent value for the analysis (Vasconcelos, Bernucci et al. 2012). Specimens were required to kept under 20°C for at least 4 hours in the temperature chamber with the accuracy of 1°C after 14 days air-conditioning time. During the indirect fatigue test, specimens were tested at different stress levels. 250kPa were selected as the reference stress level to determine the following stress testing level increment.

3.5 Wheel Tracking Test

The principle of the wheel tracking test or rutting test is determining the rutting resistance of the asphalt under practical application, where the specimen was put under the cyclic mobile loading with constant temperature. The BS EN standard of wheel tracking (BS EN 12697-22:2020) procedure B for specimens in air was applied in the experiment. 700 N mobile loading, 26.5 loading cycle per minutes, 230mm travel distance and 60°C testing temperature will be adopted in the experiment setting. The specimen was required to be kept for at least 4 hours before the beginning of test after the 2 days air-conditioning. During the experiment, there is a record for every 1000 cycles on the vertical displacement due to the loading. After the 10000 cycles, rutting slope and rutting depth would be determined.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Indirect Fatigue Test

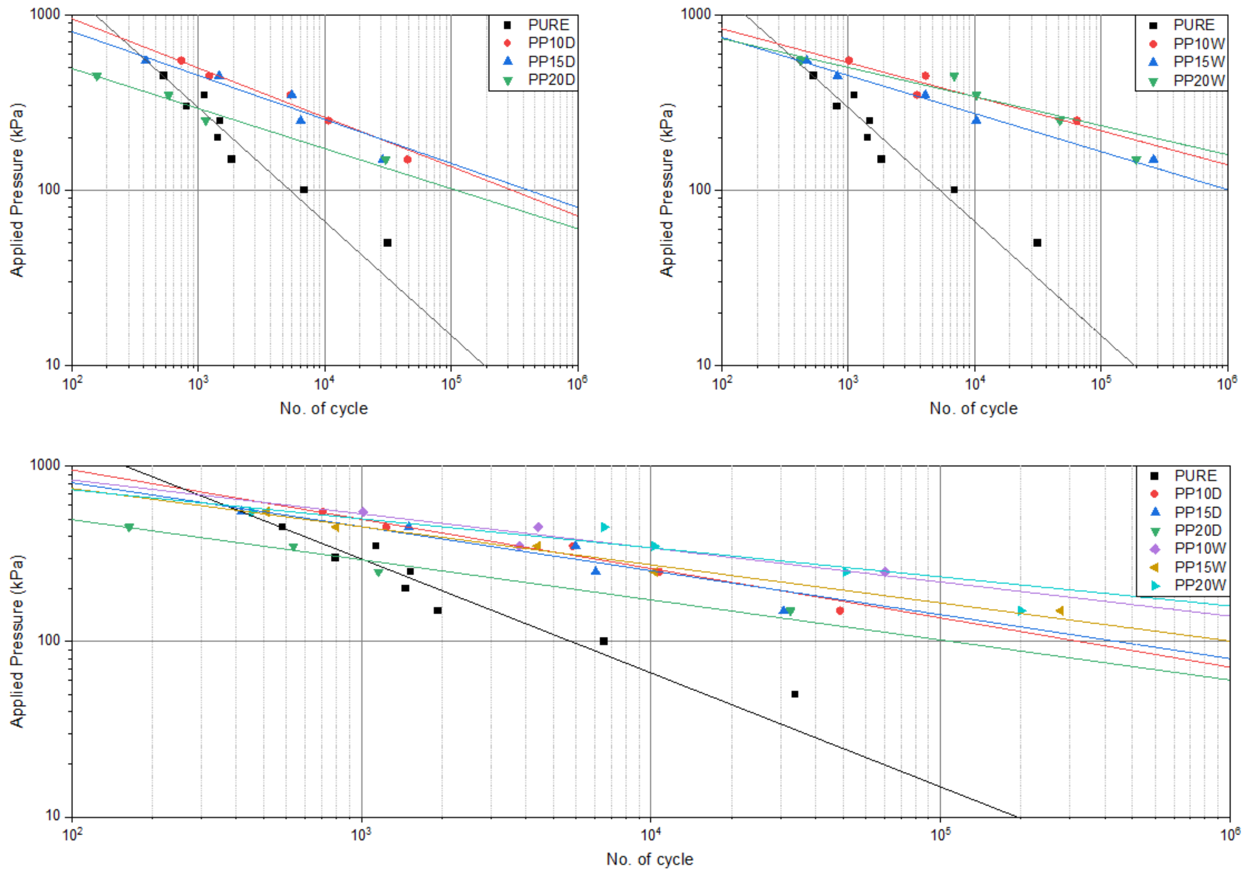

Fig. 4. Indirect Fatigue Test Result on Different Mixing Method (Applied Pressure Level against Number of Cycles)

When the specimens cracked completely in the experiment, the specimens reached a fatigue failure state. In the fatigue failure mode of the fatigue test, there is a local failure on the top of specimens caused by a load cell which is called node failure. Besides, the failure surface in the centre of specimens caused by the indirect tensile loading acting on the specimens. The indirect tensile cracking showed fatigue failure on the specimen.

Pure, 10%, 15% and 20% PP with dry mix or wet mixed asphalt were done. Fig. showed the overall result of the applied pressure level against the fatigue life of specimens. It showed that all the PP modified asphalt can provide a higher fatigue resistance on the asphalt compared to the control specimens. The fatigue performance of PMA with either dry or wet mixing were both significantly enhanced on high-cycle fatigue area (more than 10^4 cycles) which indicates the elastic strain of the PMA is increased with the existence of polymer modifier. 10% and 15% PP dry mixed PMA and 10% and 20% wet mixed PMA gave similar fatigue resistance lifetime respectively, while 20% dry mixed PMA and 15% wet mixed PMA gave a lower fatigue resistance. It shows that there are optimum PP content for PMA with different mixing methods, but the wet mixing PMA gave a better overall performance than that of dry mixing method. Although PMA provides a higher fatigue life of pavement, the strain level of the PMA was also investigated in the test. It shows that there is less changes of strain with dry mixing PMA, which indicates the PP polymer in dry mixing acts as filler more than a modifier to the bitumen. The PP in wet mixing acts as additive to the bitumen and changed the bonding strength of the PMA and the strain level decreases as polymer content from pure bitumen to 15%. However, over content of PP inside bitumen increases the brittleness of the PMA due to the dominant on heterozygous problem between bitumen molecules. As a result, 10% was the optimum ratio to dry mix PMA and 20% PP for wet mix PMA.

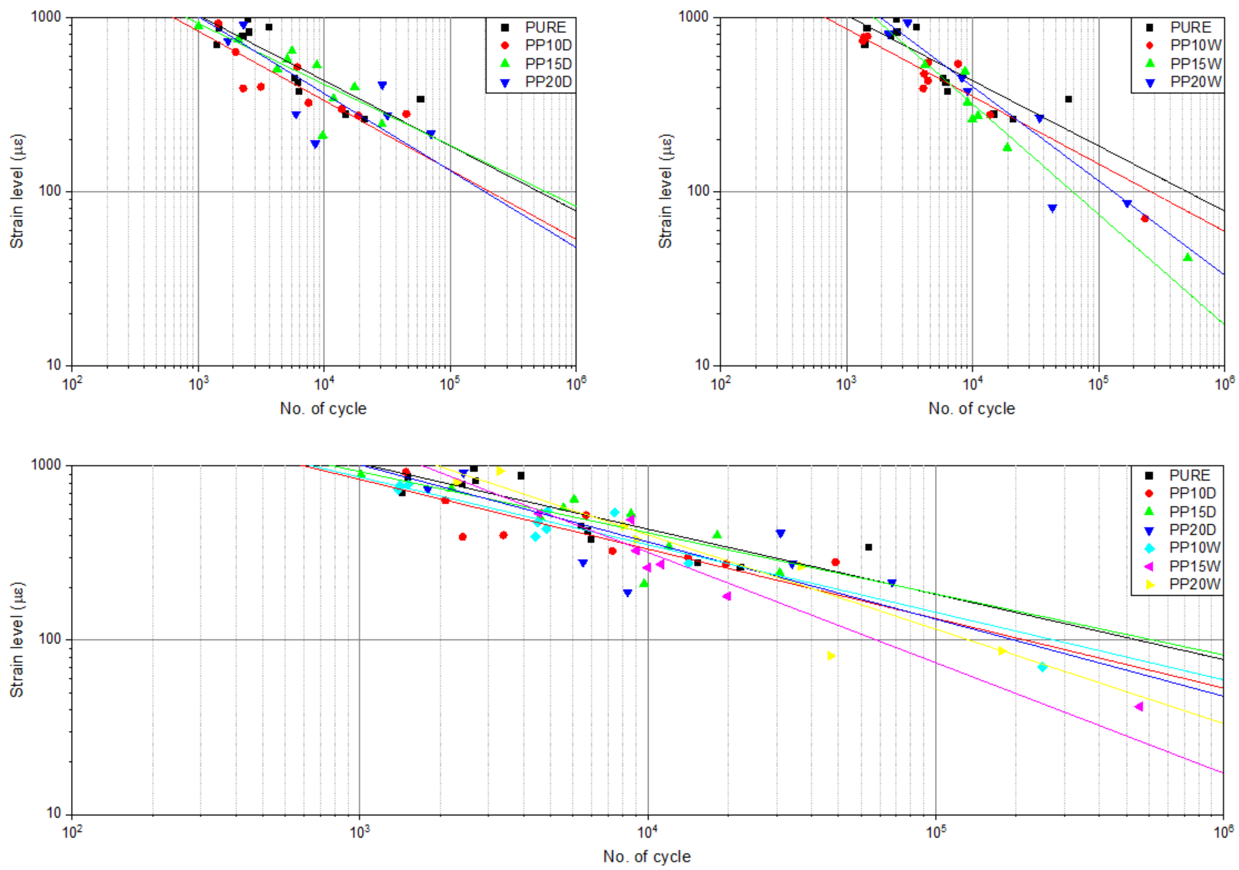

Fig. 5. Indirect Fatigue Test Result on Different Mixing Method (Strain Level against Number of Cycles)

4.1 Wheel Tracking Test

The rutting depth can be easily observed in the centre line of the specimens during the test with logarithmic increasing trend. Fig.

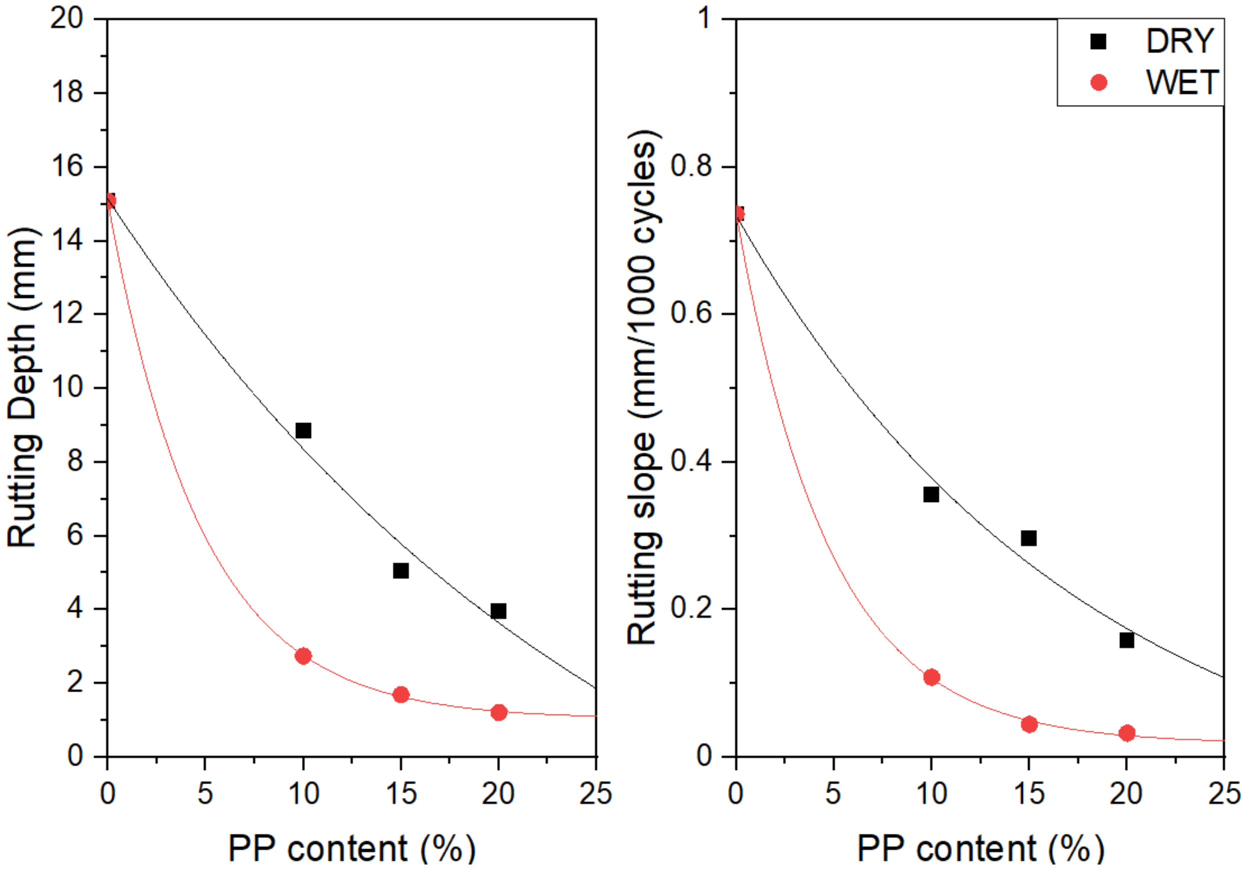

Fig. 6. Wheel Tracking Test Result on Different Mixing Method

The rutting depth and slope were both in exponential relationship with respect to PP content. The rutting depth represents the final rutting deformation after 10000 cycles of pavement which is a short-term deformation of the pavement while the rutting slope shows the long-term deformation ratio of the pavement under loading. It shows that both mixing method can enhance the rutting resistance of PMA but wet mixed PMA had nearly double improvement to the dry mixed PMA.

5. CONCLUSIONS

The polymer additive with either mixing methods were aimed to increase the service life on the road pavement in order to achieve the sustainability on transportation system to adopt the increasing traffic load in the coming future. From the overall result, it showed that adding PP can enhance the performance of PMA. In terms of PP, there is a better performance on fatigue and rutting behaviour compared to the pure asphalt. PP modified asphalt in dry mix method and wet mix method can cause different results on the pavement based on their different combining mechanism. A higher adhesive strength on the interface of aggregate and asphalt by adding PP is the fundamental mechanism of dry mixing method. PP with dry mixing is satisfied as predicted, which is acting a filler and interface adhesive additive between coarse aggregate and bitumen, so the fatigue life of dry mixed PMA should increase with slightly less tensile deformation. Inversely, PP with wet mixing method were treated as modifier to the bitumen to enhance the thermomechanical properties of the bitumen, but it leads a heterogeneous problem between some of the molecules. As a result, wet mixed PMA had a higher fatigue resistance and low tensile deformation. The actual reasons and working mechanisms on the improvement of performance between different mixing methods are mainly dependent on the microstructure development between PP, bitumen and aggregate. A higher adhesive strength on the interface of aggregate and asphalt by adding PP is the fundamental mechanism of dry mixing method, while strengthen the molecular bonding is the purpose of wet mixing method. Despite the conclusions can be drawn above, further studies are suggested below.

1) The research on the mechanical properties of PP modified asphalt is concentrated on the unaged bitumen and asphalt. When the bitumen and asphalt are placed on the normal environment, bitumen will cause an oxidation on the pavement and become more brittle. Therefore, there is an aging effect on bitumen and asphalt. For the aging bitumen, it will also affect the mechanical properties on asphalt. In the future research, the mechanical properties of aged PE and PP modified asphalt can be investigated.
2) To enhance the effectiveness of the sustainable construction material, the recyclability of PP modified asphalt is also valuable in the pavement studies. Since reclaimed asphalt pavement is commonly reused in the real construction, the feasibility of reclaimed PMA can also be investigated in the further research.
3) Investigating the mechanical properties of PP modified asphalt, the reason for improving the rutting resistance and fatigue resistance is evaluated in the discussion. To ensure the estimation, the microstructure of PP modified asphalt should be investigated in the future studies.
4) Apart from the rutting and fatigue cracking resistance, there are also some pavement performances such as moisture resistance and thermal cracking resistance which were important studies before the practical trail application. Those performances will cause the failure to occur on the pavement by weathering. As a result, further mechanical properties on weathering are required to be investigated.
5) For the gradation, there is only one type of gradation included in the experiment. The properties of asphalt with other gradations can be investigated in the future experiment to provide other usages of asphalt.

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