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by A. Arwin Amiruddin Teknik Sipil Unhas

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The sustainable performance challenge of asphalt mixture using polypropylene due to environmental weather

Sukrislistarto¹, M I Ramli¹, M Pasra¹ and A A Amiruddin¹

¹Department of Civil Engineering, Faculty of Engineering, Universitas Hasanuddin, Makassar, Indonesia

E-mail: sukrislistartopal2018@gmail.com

Abstract. Virgin Polypropylene (PP) has been widely used as polymer additive to modify asphalt concrete mixtures. An attempt to reduce plastic waste including waste PP is to use it to modify concrete asphalt mixtures. In an effort to develop the use of PP waste, this study designed a concrete asphalt mixture using petroleum bitumen as the main binding material and modified it with PP waste to produce concrete asphalt that has good resistance to environmental weather impact. Indirect Tensile Stiffness Modulus (ITSM) value is one of the main characteristics of the asphalt mixture design which represents the characteristics of the stiffness of the asphalt concrete mixture in elastic conditions when it receives a load that produces tensile stress on the asphalt concrete layer. The relationship between temperature and ITSM value of concrete asphalt used to determine the effect of environmental weather on the stiffness properties of the asphalt concrete mixture made with petroleum bitumen and waste PP. ITSM values obtained from the test results show that modification by using waste PP in concrete asphalt mixes using petroleum bitumen as the main binder produced a slightly stiffer mixture without negative effect on mixture.

1. Introduction

One of the main causes of early damage to asphalt concrete layers is the effect of temperature or extreme weather. Temperature is one of the important parameters in asphalt concrete planning where high temperature will cause initial damage to the asphalt concrete layer. Temperature or weather greatly influences the viscosity of elastic asphalt material. Therefore, it is very important to know the effect of temperature on the modulus of rigidity and the influence of road environment temperature. Considering the importance of the road sector as the main aspect of the urban landscape and observing the use of materials. A number of failures identified on several roads, which require precise measurements to avoid these failures, including the correct level of mixing control of asphalt concrete in the standard and the proper use of bitumen of the intended coating of coarse aggregate particles and the successful use of material based laboratory tests to ensure proper implementation. Cracking and rutting fatigue are the main distress that degraded the condition of the sufficient road system, making it risky and dangerous for road users and affecting the country's economy. What is important in this scenario to decrease the early damage of asphalt concrete is that making asphalt mixtures with modified characteristics using additives such as polymers is the main resolution for building durable asphalt. Polymers are able to improve the properties of concrete asphalt mixture because it gives the



possibility to produce a mixture that can resist cracking and rutting [1]. Using polymers depends on several factors such as cost, construction capability, availability, and expected performance. The use of virgin PP as additive will increase the cost of asphalt concrete mixture so that this research attempts to use waste PP derived from disposable waste glass as polymer additive.

Indirect Tensile Stiffness Modulus (ITSM) value is one of the prominent characteristics of asphalt mixture design. ITSM value is a stiffness property or elasticity of asphalt mixture measured by using tensile strength testing [2, 3]. The present paper deliberated the useful application of waste PP as a modifier in a concrete asphalt mixture made with petroleum bitumen as the main bituminous binder. The principal goal of this paper is to study the effect of waste PP addition in conjunction with temperature on the stiffness of concrete asphalt mixture. The study outcomes expected to be important bases for improving asphalt concrete mixture properties.

2. Materials and methods

2.1. Outline of continuous studies to utilize plastics in concrete asphalt production

At the fundamental level, the continuous research is needed on the development of asphalt mixture containing waste plastics such as waste PP and petroleum bitumen. Figure 1 shows the outline of continuous studies to utilize plastics including waste PP in asphalt concrete.



Figure 1. The outline of continuous studies to utilize plastics including waste PP and petroleum bitumen in concrete asphalt production.

2.2. Mixture proportions

All aggregates were collected from Jeneberang river located in the Southeast Sulawesi Province of Indonesia. Crushed stone obtained from the local crushed stone plant. Table 1 shows physical properties of coarse aggregates. River sand was used as fine aggregate. Table 2 shows properties of fine aggregate. Table 3 shows the recommended gradation limits by the road specification of the Directorate highway Indonesia, for AC-BC mixtures and the selected gradation in this investigation was in the middle of the limits. Table 4 shows properties of petroleum bitumen. Waste PP was collected from one of the plastic waste treatment plants. The waste plastic used has been cut into small pieces, in dry and clean conditions.

Table 1. Physical properties of coarse aggregates.

| Property | Test value |
|--|------------|
| Bulk specific gravity (kg/m ³) | 2698 |
| S. S. D. specific gravity (kg/m ³) | 2703 |
| Apparent specific gravity (kg/m ³) | 2712 |
| Water absorption (%) | 2.08 |
| Water absorption of filler (%) | 2.28 |

Table 2. Physical properties of fine aggregates.

| Property | Test value |
|--|------------|
| Bulk specific gravity (kg/m ³) | 2684 |
| S. S. D. specific gravity (kg/m ³) | 2710 |
| Apparent specific gravity (kg/m ³) | 2756 |
| Water absorption (%) | 0.962 |

Table 3. Type 2 binder course gradation.

| Sieve size (mm) | Gradation limits (%) | Passing (%) | Retained (%) |
|-----------------|----------------------|-------------|--------------|
| 19 | 90 - 100 | 100 | 0 |
| 12.5 | 75 - 90 | 95.00 | 5.00 |
| 9.5 | 66 - 82 | 81.00 | 14.00 |
| 4.75 | 46 - 64 | 53.00 | 28.00 |
| 2.36 | 30 - 49 | 33.55 | 19.45 |
| 1.18 | 18 - 38 | 22.30 | 11.25 |
| 0.6 | 12 - 28 | 16.05 | 6.25 |
| 0.3 | 7 - 20 | 12.25 | 3.80 |
| 0.15 | 5 - 13 | 9.50 | 2.75 |
| 0.075 | 4 - 8 | 7.00 | 2.50 |
| Pan | - | 0 | 7 |

The prescribed requirements of specification for concrete asphalt mixtures were taken in account to obtain the optimum binder content. The field compaction mechanisms can be resembled in the laboratory simulation by applied Marshall compaction practices. Laboratory cylindrical specimens with diameter of 100 mm and height of about 65 mm were compacted using seventy five blows of the Marshall hammer per side. Based on the Marshall design procedure, the optimum bitumen content established was 4.5%. Triplicate specimens were fabricated for ITSM test. Mixture without waste PP and the others with waste PP in concentrations of 0.5% and 1.0 % were prepared.

Table 4. Properties of petroleum bitumen.

| Properties | Value | Unit |
|-----------------------------------|--------|--------|
| Penetration at 25°C | 69,07 | 0.1 mm |
| Softening Point | 55,42 | °C |
| Ductility | 112 | cm |
| Flash Point | 322,67 | °C |
| Density | 1,15 | |
| Loss on Heating TFOT | 0,030 | % wt |
| Penetration after loss on heating | 78,00 | 0.1 mm |

As mentioned previously, the binder content corresponding to 4% air voids was chosen as OBC. The following steps were performed for the formulation of compacted specimens:

- The mixture of aggregate and filler was heated to 160°C .
- The binder was heated up to 150°C.
- The wasted PP was heated up to 150°C.
- The combination of aggregate, filler, waste PP and binder was mixed at a temperature of 150°C
- The specimens formulated were then compacted at 135°C using Marshall apparatus.

2.3. Resilient modulus (Indirect Tensile Stiffness Modulus (ITSM) Test)

Figure 2 shows ITSM test equipment. Resilient modulus presumes that the asphalt concrete mixture is recoverable under repeated loading in the elastic range. The indirect tensile stiffness modulus (ITSM) test was applied to obtain the stiffness moduli or resilient moduli of the asphalt mixture specimens. The load pulses are applied to the vertical diameter of a cylindrical specimen. A peak transient horizontal deformation of 0.005% of the specimen diameter is attained by controlled the peak load value. The indirect tensile stiffness modulus (ITSM) test is a non-destructive test and has been identified as a potential means of measuring stiffness property [4, 5,6].

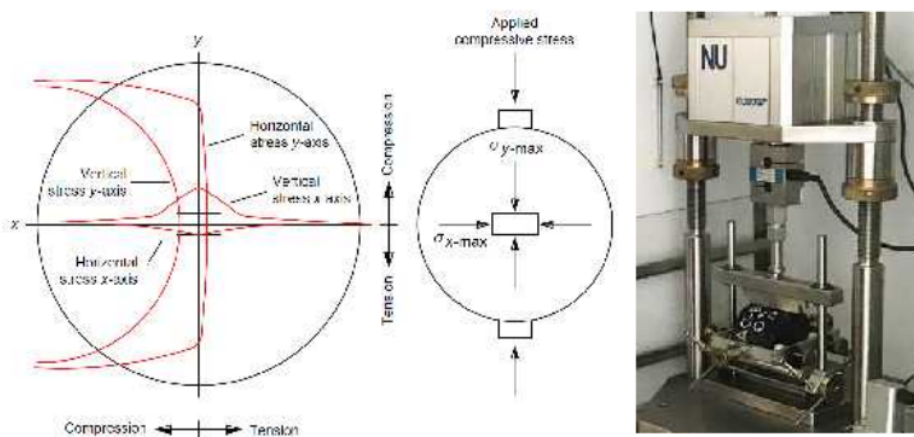


Figure 2. Typical ITSM test equipment.

3. Results and discussion

Table 5 shows relationship between temperature, waste PP content and ITSM value. At a temperature of 25°C, the mixture without waste PP and the use of waste PP of 0.5 and 1.0% resulted in ITSM values of 1844.264, 1838.026 and 1838.026 MPa, respectively. At a temperature of 30°C, a mixture without waste PP and the use of waste PP of 0.5 and 1.0% produced ITSM value of 1930.332, 1858.222 and 1679.457 MPa, respectively. At a temperature of 35°C, a mixture without PP waste and the use of waste PP of 0.5 and 1.0% produced ITSM value of 1977.669, 1918.809 and 1712.963 MPa, respectively. At the same temperature, the ITSM value was of the mixture without waste PP was slightly lower than mixture containing 0.5% and 1.0% showed that waste PP was able to blend with petroleum bitumen and have a positive effect on stiffness of asphalt concrete mixtures. ITSM values obtained from the test results show that modification by using PP waste in concrete asphalt mixes using petroleum bitumen as the main binder produced a slightly stiffer mixture.

Table 5. Relationship between temperature, waste PP content and ITSM value.

| Temperature | Waste PP (%) | ITSM (MPa) |
|-------------|--------------|------------|
| 25 | 0 | 1844.264 |
| | 0,5 | 1838.026 |
| | 1,0 | 1668.287 |
| 30 | 0 | 1930.332 |
| | 0,5 | 1858.222 |
| | 1,0 | 1679.457 |
| 35 | 0 | 1977.669 |
| | 0,5 | 1918.809 |
| | 1,0 | 1712.963 |

4. Concluding remarks

The relationship between temperature of 25, 30 and 35°C and ITSM value used to determine the effect of environmental weather on the stiffness properties of the asphalt concrete mixture without PP and containing 0.5 and 1% waste PP. ITSM values obtained from the test results show that modification by using waste PP in concrete asphalt mixes using petroleum bitumen as the main binder produced a slightly stiffer mixture without negative effect on mixture.

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