

THE EVALUATION OF MOISTURE SENSITIVITY OF ETHYLENE-VINYL ACETATE (EVA) MODIFIED HOT AND WARM MIX ASPHALT MASTIC

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ABSTRACT

This study aims to evaluate the effect of applying ethylene-vinyl acetate (EVA) using the dry mixing method on the mechanical properties of the HMA and WMA mixtures on the mastic scale against moisture damage given various polymer contents; 2%, 5%, 6%, and 8% of bitumen weight. The tensile strength of dry hot and warm polymer-modified bituminous mastic was improved by 40% and 100% relative to the control mix, respectively, from the dosage of 0.6% EVA. Moreover, the fracture energy depicted a similar trend, with the gaps becoming 34% and 136%. Both parameters have shown increasing increment up to the dosage of 6%, beyond which the values declined. In contrast, the tensile strength ratio (TSR) and fracture energy ratio of the hot mastic mix was higher than the warm mix, while the increment of the ratio to control mix was less than that of the dry specimens. This indicates an insignificant influence of polymer on the adhesion bonding in the mastic upon being subjected to the moisture effect, especially in the warm mix. However, its impact on hot asphalt mastic specimens was still acceptable. The dosage of 6% can be depicted to give the best outcome in this study.

Keywords: Moisture Sensitivity, Ethylene-Vinyl Acetate, Hot Mix, Warm Mix, Asphalt Mastic

1. INTRODUCTION

An ever-increasing demand for high-quality pavement structures has introduced several discoveries, one of which was the application of polymer to modify and improve the properties of the asphaltic mixture. Polymers can be added to an asphalt concrete (AC) mixture using two methods, namely the wet and dry mixing methods. The scheme of both approaches is shown in **Figure 1**.

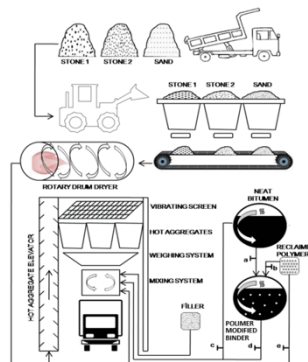


Figure 1. Scheme of dry and wet mixing method [1]

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Firstly, a polymer can be mixed with heated, liquid bitumen to form a polymer-modified bitumen (PMB). This method is called the wet mixing method. From **Figure 1**, making an AC mix with PMB requires a dedicated chamber to blend the virgin binder and the polymer (points a and b) first before being delivered to the mixing room (point d) with aggregates and filler. On the other hand, the polymer can be directly poured into the mixing chamber and blended with the heated bitumen and hot aggregates from the bin; this is called the dry mixing method. In contrast to the wet method, the initial stage of the dry method is described in **Figure 1** from (c), where neat bitumen is directly transferred to the mixing chamber with filler and the aggregate. At the same time, the polymer is sent simultaneously (e) to the mixing process with other components.

In general, polymeric products can be divided into three categories: elastomeric, thermoplastic and thermoset. Elastomeric is a long-chain, rubber-like polymer with a high degree of flexibility and excellent elastic recovery properties, meaning that it can be easily deformed under external load and recover rapidly without any residual stress [2]. This is similar to the behaviour of thermoplastic polymers since they could also be processed repeatedly by melting them. However, repetitive processes could deteriorate the material quality and shape with irrecoverable strain or residual stress [3]. Nowadays, there have been several attempts to combine the strength and stiffness of thermoplastic with the In general, polymeric products can be divided into three categories: elastomeric, thermoplastic and thermoset. Elastomeric is a long-chain, rubber-like polymer with a high degree of flexibility and excellent elastic recovery properties, meaning that it can be easily deformed under external load and recover rapidly without any residual stress [2]. This is similar to the behaviour of thermoplastic polymers since they could also be processed repeatedly by melting them. However, repetitive processes could deteriorate the material quality and shape with irrecoverable strain or residual stress [3]. Nowadays, there have been several attempts to combine the strength and stiffness of thermoplastic with the flexibility of the elastomeric product by the cross-linking process to form thermoplastic elastomeric (TPE). This results in a hybrid material whose behaviour is reaching a thermoplastic state below its glass transition temperature, making it stiff enough to become brittle while becoming more elastic above its melting temperature [4]. Ethylene-vinyl acetate (EVA) is an example of a TPE, where its tendency towards thermoplastic or elastomeric behaviour is predominantly determined by the vinyl acetate (VA) content, with the latter state could be governed by increasing the VA fraction [5]. Finally, thermoset generally has higher strength and stiffness than thermoplastic due to its robust covalent bond. However, its deformation when subjected to loading or heat is completely irreversible [6].

Many polymers have been employed throughout the decades to produce a PMB product. For example, rubber has been used to enhance fatigue life and dynamic stiffness at various temperatures, resulting in improved resistance to rutting and cracking caused by temperature and the ageing effect. Its close peer, the crumb rubber, has shared the same popularity and impact. Reports described that such influence came from the cross-linking polymer network inside the bitumen, which accounts for the enhanced stiffness [7][8]. Finally, the molecular weight of the bitumen is also added by the presence of the crumb rubber [9][10][11].

Another example is polyethylene (PE). The application of PE was linked to an improved rutting characteristic due to its improved stiffness and less phase angle of the modified bitumen [12][13]. However, molecular weights and chain structure differences could cause phase separation in the modified bitumen. Consequently, a cross-linking reaction



must be performed using catalysts such as polyphosphoric acid, sulphur, Trans-polyoctenamer, nano-silicate, and maleic anhydride, while the PE content was limited to 5% of bitumen weight [14][15][16][17][18][19][20].

Meanwhile, ethylene-vinyl acetate (EVA) is another alternative to produce a polymer-modified bitumen (PMB) product. This polymer's impact on the modified binder's properties was discovered to depend on the amount of VA fraction uniquely. Several studies indicated the shift from thermoplastic to elastic behaviour owing to the increase of VA content enhanced binder softening point and elongation capacity [21][22][23]. Nonetheless, the same problem as in the PE-modified binder also occurred in this application, notably when the dosage of EVA exceeded 5%, as the polymeric phase would swell by absorbing the maltene fraction and separated from the asphaltene-rich stage. Hence, constant stirring and the mixing temperature became critical [24][25]. Several cross-linking agents have also been employed to improve the compatibility, such as maleic anhydride, thermoplastic vulcanizates, and polyoctenamer; all of which have reported various extent of enhanced elastic properties, storage stability, resistance to permanent deformation and low-temperature cracking, thermal stability, and lower viscosity [26][27][28].

On the other hand, the polymer that is commonly used in the dry mix method to produce the polymer-modified asphalt (PMA) mix typically comes in a fibrous shape. Several factors that generally need to be considered when using fibre in an AC mix are strength, stiffness, density, and the network matrix formed in the body of a specimen through its length/diameter ratio [29]. A wide range of polymer types has been employed through the years, such as polyethylene, polypropylene, polyethylene terephthalate (PET), aramid, and a combination of those. Aramid is well-known for its high stiffness and strength/density ratio, as well as thermal and chemical stability [30][31], and it generally works by forming a highly durable fibre network inside of the AC mix, leading to improved fatigue life and rutting resistance [32][33][34]. The combination of aramid and PE has been established to improve strength, fatigue life, resistance to permanent deformation, and thermal cracking resistance of both dense and Stone Mastic (SMA) AC mixtures under various loading and temperature modes, where the bonding mechanism between the fibre and asphaltic matrix can vary depending on the loading modes and speeds [35][36][37][38][39][40].

This research attempted to employ the granulated-shaped EVA by Iterchemica under the brand name Superplast through the dry method. The use of this polymer has been firstly found to improve the dynamic modulus of AC mix specimen, indicating the enhancement regarding mixture stiffness and resistance to permanent deformation [41]. The product is shown in **Figure 2**, coming in a granulated shape.



Figure 2. Superplast EVA polymer



Specifically, the effect of this modification on the moisture sensitivity of the mastic part of the bituminous mixture was investigated in this study. Moisture-induced damage has been known to be major distress in an asphaltic blend, with stripping being the phenomenon highly linked to it as the main result. Since the adhesion between both acidic-binder and aggregate can be classified as a weak bonding, the interaction with water would easily break the bond [42]–[45]. The failure mechanism due to moisture could be divided into several categories, namely through the de-bonding that occurred without breaking the mastic, the displacement and breaking of the mastic phase, moisture diffusion, and spontaneous bitumen emulsification [46]. Therefore, the reinforcing effect brought by the polymer to the bituminous mixture against the moisture damage became vital to be examined.

2. SPECIMEN PREPARATIONS

The first phase of this research investigated the physical and volumetric properties of aggregate, bitumen, and additives. Two parameters, namely density and absorption of the aggregate, were inspected while several tests, such as penetration, density, flash point, and softening point, were conducted on the bitumen. All test results must comply with the boundary values taken from the national code called Bina Marga 2018, shown in Table 1.

Table 1. Bina Marga 2018 standards for the asphaltic mixture components [47]

Materials	Properties	Unit	Limit values
Bitumen	Penetration	PEN	60 - 70
	Density	kg/m ³	> 1000
	Softening Point	°C	> 48
	Flash Point	°C	-
Fine Aggregate	Density	kg/m ³	> 2500
	Absorption	%	< 3.0
Cement Filler	Density	kg/m ³	-

The mix design of the asphalt concrete (AC) specimens was developed following the national norm for a dense asphaltic mixture. The bitumen content of 5.5% w/t was selected for this research based on equation (1) [48].

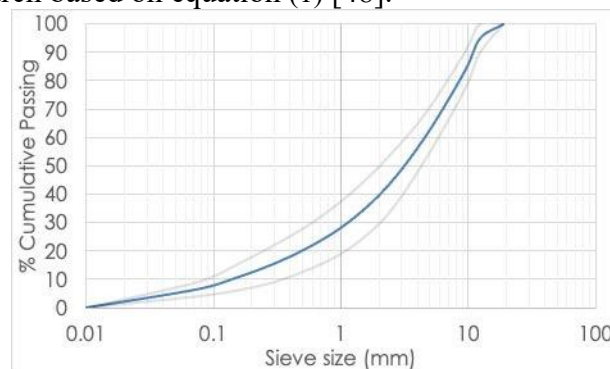


Figure 3. Mix design of Asphalt Concrete (AC) mix based on Bina Marga 2018 specification



$$\text{Bitumen content (\%)} = 0.035(\text{Coarse agg. content \%}) + 0.045(\text{Fine agg. content \%}) + 0.18(\text{Filler content \%}) + 1 \quad (1)$$

Finally, the Direct Tension Tests (DTT) were performed at room temperature with the adjusted loading speed of 0.1 mm/s. For this purpose, dog-bone-shaped specimens were prepared with the largest diameter at the edges of the sample of 18mm and the smallest one at the centre part by 16.4mm, and the specimen height was 34mm. This geometry was developed from the previous take, whose cylinder shape encountered severe issues that required adjustments [49]. This shape and geometry were first proposed by Erkens [50], and its application has been spread from examining the induction healing capacity of mastic samples [51] to observing the effect of fibre on mastic scale [52]. The load was subjected to a specimen until reaching its breaking point, with the crack expected to propagate from the centre part, in which the stress intensity became the largest (Figure 4).



Figure 4. Setup of Direct tension test

The examinations were carried out by the Universal Testing Machine (UTM) connected to a PC, from which the data can be acquired for further analysis. The outcome is displayed as a series of force-displacement data, which can be converted to a stress-strain curve. The first one is tensile strength, defined by Equation (2). The cross-section area denoted in this equation is located in the centre part of the specimen, where the diameter was the smallest and thus, became the critical location of failure. Furthermore, fracture energy is defined as the sum of the area under the stress-strain curve and is described in Equation (3).

$$\sigma_{max} = \frac{P_{max}}{\text{Cross - section Area}} = \frac{P_{max}}{0.25\pi d^2} \text{ N/mm}^2 \quad (2)$$

$$G_f = \int_0^\epsilon \sigma \, d\epsilon \text{ J/m}^2 \quad (3)$$

3. RESULTS AND DISCUSSIONS

3.1 Examination of Asphalt Mastic Components

The physical properties of each mastic component were carried out before the production of the mastic specimen for the DTT test. The results are shown in Table 2.

Table 2. Preliminary test (physical properties) result

Materials	Properties	Unit	Value	Boundaries (Bina Marga 2018)
Bitumen	Penetration	PEN	62.417	60 - 70



	Density	kg/m ³	1058	> 1000
	Softening Point	°C	53	> 48
	Flash Point	°C	270	-
Fine Aggregate	Density	kg/m ³	2215	> 2500
	Absorption	%	2.404	< 3.0
Cement Filler	Density	kg/m ³	2900	-
Superplast Polymer [53][54]	Softening Point	°C	150	
	Fusion point	°C	160	

All the materials used in this project were found to lie within the boundaries set in Bina Marga 2018, and thus, became eligible to use in further stages.

3.2 Examination of Asphalt Mastic Components

The composition for the mastic specimens was based on the mix design of the mixture scale in **Figure 3**. The calculation was then performed by taking into account only the fine aggregate (smaller than #8), shown in **Figure 5**. Meanwhile, the bitumen content for the mastic sample was converted to 21%, based on the weight ratio with the full mixture scale.

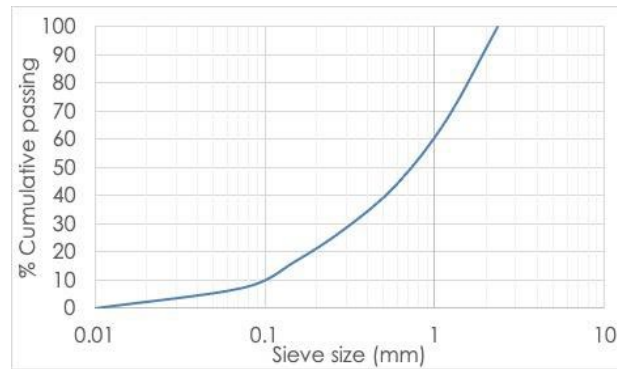


Figure 5. Mix design of mastic test specimens

3.3 Direct tension test (DTT) result

The outcomes of this research were tensile strength and fracture energy, all of which are presented in **Figure 6** and **Figure 7**.

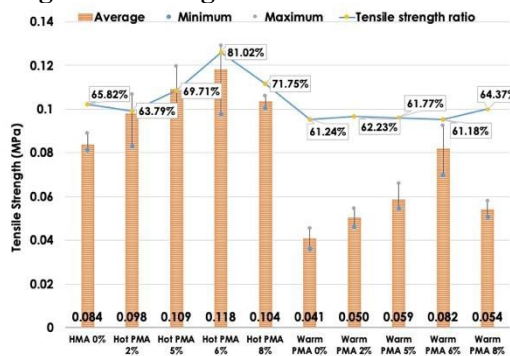


Figure 6. Tensile strength of Polymer-Modified AC mix (HMA and WMA)

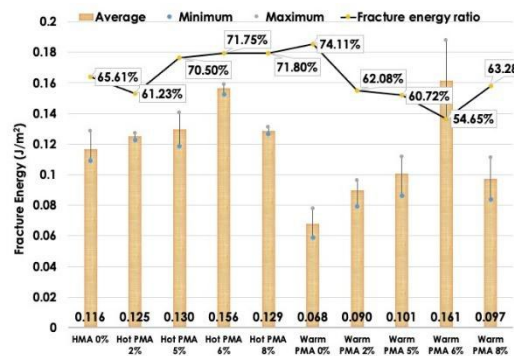


Figure 7. Fracture energy of Polymer-Modified AC mix (HMA and WMA)

As depicted in **Figure 6** and **Figure 7**, adding polymer to the hot and warm PMA mastic specimens has increased their tensile strength by up to 40% and 100%, corresponding to the polymer dosage of 6%, respectively. Similarly to the strength, fracture energy of the hot and warm



PMA mastic specimens also increased by 34% and 136%, respectively, corresponding to the dosage of 6% EVA. In addition, both parameters of the warm PMA of 6% EVA were comparable to the control HMA mastic samples. In general, the increment of fracture energy in WMA mastic is higher than that of the strength, which also indicates the role of a slightly increased deformation capacity. However, the same phenomenon did not occur in the HMA specimens. While this could mean that there was an influence of the polymer on the stiffness of the mastic, it could also have been caused by the various air void level in the specimens, especially in the WMA specimens, whose deviation seemed to be larger than the HMA mastic.

On the other hand, it is apparent that both the TSR and fracture energy ratio of the hot mastic mixture specimens were considerably higher than the warm mixture, particularly the former parameter. This is aligned with other studies that put the WMA mixture more susceptible to moisture than its counterpart. Moreover, the TSR values generally followed the equivalent trend as the strength, with the maximum percentage obtained from the mastic specimens added with 6% EVA. In the hot mastic mixture, the increase in the ratio could reach up to 15%. However, the fluctuation in polymer dosage did not significantly influence the ratio of the values, which once again indicated that the polymer did not contribute significantly to improving the strength of this type of specimen.

Furthermore, the typical values of fracture energy ratio of the modified specimens did not describe any illustrious improvement. This could be interpreted as the polymer did not exert any significant reinforcing effect against the moisture treatment. Even worse, the ratio in the warm PMA mastic declined in direct proportion to the increase in polymer dosage. Since the adhesion bonding in a warm mix asphalt is already a significant concern due to being lower than the hot bituminous mix, it could be concluded that while the polymer could increase the mechanical properties of both hot and warm bituminous mastic, it did not necessarily bring an improvement in the adhesion capacity of the warm mixture in particular. This can be attributed to the properties of the polymer itself, which did not exactly melt to perfectly bond with the mastic at the mixing and heating temperature of the warm mastic. However, the effect in the moisture sensitivity of the hot bituminous mastic was still acceptable, with the increased strength and fracture energy, as well as the strength and fracture energy ratio. Naturally, the polymer dosage of 6% gave the best outcomes in both the hot and warm mastic mixtures, albeit the effects were more apparent in the hot PMA mastic.

4. CONCLUSION

This study aims to evaluate the effect of applying thermoplastic ethylene-vinyl acetate (EVA) using the direct dry mixing method, known as the polymer modified asphalt (PMA) method, on the mechanical properties of the HMA and WMA mixtures on the mastic scale against moisture damage. The properties of the mastic specimens were examined employing the direct tension test (DTT) using two groups of samples: one group was subjected to a 24-hour curing regime, whereas another group was left in a storage box prior to the examination. The polymer dosages of 2%, 5%, 6%, and 8% of bitumen weight have been evaluated in this research. The DTT test was conducted at room temperature with a loading speed of 0.1 mm/s. It is found that the inclusion of polymer increased the tensile strength of the dry hot and warm bituminous mastic by 40% and 100% relative to the control mix, respectively; all of which were from the mastic sample added with 0.6% EVA. Moreover, the fracture energy depicted a similar trend, with the gaps becoming 34% and 136%. Both parameters have shown increasing increment up to the dosage of 6%, beyond which the values would decline. In contrast, both the tensile strength ratio (TSR) and fracture energy ratio of the hot mastic mix was higher than the warm mix, indicating the warm mixture was more prone to moisture-induced damage than its counterpart. While the TSR of the modified mix could increase by 15% compared to the control one, the extent of improvement was not as great as the increase in the dry specimens. Combining with the similar effect occurring in terms of the fracture energy ratio, a conclusion can be drawn that the presence of polymer in the mastic did not contribute significantly to its moisture sensitivity. This effect was worse in the warm mastic mix, where the improvement in TSR was almost irrelevant to the polymer dosage, and the fracture energy ratio of the modified specimens was lower than the control mix. This could



indicate that the polymer did not influence the adhesion bonding in the mastic, especially the warm mixture, upon being subjected to the moisture effect. However, in summary, the use of polymer to enhance the adhesive bonding in the asphalt mastic specimen was still acceptable, particularly in the case of the hot bituminous mix. Evidently, the dosage of 6% can be depicted to give the best outcome in this study.

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