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# EFFECTS OF PLASTIC WASTE ADDITION TO NEAT BITUMEN IN ASPHALT CONCRETE PRODUCTION

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**Abstract:** Currently, huge amount of waste materials are being generating from different industries on the world. Among these plastic waste bottle is the most dangerous materials to the environment which needs solution. Ethiopia is on the verge of quick industrial development in different areas, along with high population growth. This development is an evident increase in the consumption of plastic bottle water. A disposal of huge consumed plastic bottles cause an environmental hazard and are considered non-biodegradable materials. The solution to this problem is reprocessing these non-biodegradable materials to save natural resources and minimizing environmental effects. This paper assessed the technique on how plastic waste materials can be reused in road construction. In this study, the plastic waste was used as an additive in the mix with 2%, 4%, 6%, 8% and 10% by weight of optimum bitumen content. The addition of plastic waste improved the workability of bitumen by reducing the ductility and improving the penetration and softening point. Also, the addition of plastic content (pc) to the mix improved the Marshall Stability, stripping resistance and rutting resistance. Conversely, plastic waste has an impact on the fatigue resistance of the mixture if it is added excessively. Finally, the addition of plastic waste could be applicable in stripping resistance if it is added up to 5% to the neat bitumen.

**Keywords:** Marshal Stability; plastic content; ductility; penetration; softening point; fatigue resistance; stripping resistance



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## INTRODUCTION

Asphalt pavement materials costs are escalating immensely, which paved the way of searching alternative low cost and sustainable materials. In addition, more concerns are directed for saving natural resources and minimizing environmental effects, thus more considerations are focused on the use of reprocessed materials in the asphalt pavement industry (Abdo, 2016). Moreover, it can be argued that carbon footprint on road construction could be minimized by using salvaged materials. The application of salvaged waste materials as modifier additives in hot mix asphalt (HMA) could have numerous economic and environmental advantages (Essawy *et al.*, 2013; Modarres and Hamedi, 2014; Chakraborty and Mehta, 2017).

The plastic waste and its disposal is an environmental hazard which results contamination and comprehensive warming. The use of plastic waste in bituminous mixes enhances its properties as well as its strength. Also, it will also be a solution to plastic disposal and different distresses in pavement viz., pot holes, corrugation, ruts, and others. The plastic waste used is poly-ethylene, poly-styrene, and polypropylene. The waste plastic is shredded, coated over aggregate, mixed with hot bitumen, and resulting mix is used for roadway construction. These will increase both pavement's strength and durability. The titanium-dioxide is used as a smoke absorbent material, which will absorb the smoke from the vehicles. This innovative technology will be boon for Indian hot-humid climate. It's economical and eco-friendly (Dhundalwar *et al.*, 2017).

The use of plastic waste as bitumen binder modifier with 4, 6 and 8% by weight of bitumen binder content is investigated in previous study. It is highly resistant to rutting and give maximum Marshall stabilities and the minimum flows at 4% plastic content (Hinislioglu and Agar, 2004; Abdullah *et al.*, 2017). Marshall Stability and indirect tensile strength for the outputs from dry process in comparison with wet process was improved. This indicates higher resistance to withstand at higher loads and to resist deformation (Zulkati *et al.*, 2012). The application of plastic waste is to improve the engineering properties of asphalt mixes. The outcomes revealed that plastic waste improved asphalt mix resulted in higher Marshall Stability, retained stability, and indirect tensile strength than the conventional mix with 10%, 7%, and 9% respectively (Al-Humeidawi, 2017).

The pulverized plastic waste is mixed with asphalt before adding to the aggregates. It is confirmed that there is a uniform mix of plastic and asphalt at the temperature variation of 155ºC to 165ºC and proposed a 6% - 8% of plastic waste pulverize within the asphalt mix (Asare, Kuranchie and Ofosu, 2019)(Sahu and Singh, 2016). The realization of improving bitumen binder by the addition of different percentages of plastic waste is proved experimentally. It indicated that as penetration values and temperature susceptibility decreased, the softening point is increased with increasing the amount of plastic waste content in the mix. Also, the improved asphalt mixes revealed higher results of stability, tensile strength ratios, and resilient modulus with lower strain results at high temperatures (Attaelmanan, Feng and Ai, 2011).

The performance of hot mix asphalt could be improved by the addition of 0.2% and 0.5% plastic waste to the mixes. Thus, the application of 0.5% plastic waste by weight of aggregates in the mix makes flexible pavement design become eco-friendly and more sustainable as a huge quantity of plastic waste could be used without affecting the performance of the mix (Abdo, 2017). Viscoelastic behavior and rheological properties can be enhanced by adding thermoplastic modifiers to conventional bitumen. The plastic waste improved asphalt conveys great promise as a choice reprocessing method of plastic waste management for road construction (Appiah, Berko-Boateng and Tagbor, 2017).

The interest of sustainable pavement technologies with recycled plastic waste extension and improvement of bitumen binder for asphalt production is an encouraging aspect in road construction. The improvement and extension of the asphalt binder with low melt-temperature plastic is being definitely different from the extension of the aggregate in the bitumen mixture with higher melt-temperature plastics such as plastic bottles and plastic bags. The reprocessed plastic waste improves the deformation and fracture resistance, had mixed and less impact on the stripping resistance and improved the structural role of the bitumen to the pavement. The impact of plastic waste was not detected in terms of toxic emission generation or hazardous leachate. It has been suggested that reused low melt-temperature plastic could be considered as choice to conventional polymers for asphalt binder extension and improvement, specifically in high stress areas, where resistance to deformation is needed to long-term surface performance (White, 2019).

The addition of plastic waste to the hot mix asphalt has an advantage in improving the pavement quality. The occurrence of plastic waste in hot mix asphalt increases the Marshall stability and the resilient modulus of the mix, improves stripping resistance, moisture sensitivity and also the rutting resistance. The addition of plastic waste improves the fatigue life and the raveling resistance of the mix up to a certain level. On the contrary, undue addition of the plastic waste reduces the fatigue life and raveling resistance as compared to the traditional mix (Suaryana, Nirwan and Ronny, 2018).

Asphalt pavements are deteriorating rapidly and the pavements life is becoming shorter than what asphalt pavements were designed for. This is because a permanent deformation (rutting) is happening when asphalt pavement is subjected to hot temperature and heavy traffic loads simultaneously. Adding plastic waste to asphalt binder increases viscosity and G*/sin δ values. When waste plastic is added to bitumen binder, it meets Super pave Asphalt Binder Specifications for higher binder grades. Thus, the addition of plastic waste to asphalt binder could be considered as a cheaper and environmental friendly solution, when compared to the use of higher binder grades to reduce rutting in asphalt pavements (Abu Abdo and Khater, 2018).

## MATERIALS AND METHODS

Bitumen and plastic waste bottles were used as a binding material in the production of asphalt concrete. Bitumen having penetration grade of 80/100 was used as a control binding material. It was taken from Jimma district ERA batching plant found at Deneba, Jimma, Ethiopia. Various tests were conducted in the laboratory to examine the physical properties of bitumen. The physical properties of bitumen are presented in **Table 1**. A waste plastic bottle was collected from Jimma City. Plastic waste bottles were shredded, grinded, and added to neat bitumen with 2%, 4%, 6%, 8% and 10% by weight in the preparation of specimens. A number of laboratory tests were conducted to examine the performance of asphalt mixtures due to plastic waste bottle addition. The changes of mixture properties were also observed.

### Marshall Test

Marshall Stability test was carried out to determine the optimum bitumen content and optimum plastic content. Test specimens are prepared by varying percentages of bitumen from 4% to 7% by dry weight of aggregates. The plastic content was replaced the bitumen from 2% to 10% by the weight of optimum bitumen content. Sample preparation, compaction, and testing were conducted following ASTM D1559. The mixture prepared from neat bitumen was named as control specimen. Marshall Stability and flow tests were carried out. The cylindrical sample specimens were put in water at 60℃ for a period of half-hour and compressed on the tangential surface at a constant rate of two-inch/min until the maximum loads were reached. The governed resistance load and flow value were recorded. The bulk specific gravity and density, theoretical maximum specific gravity and percent air voids were determined from each specimen.

### Stripping Resistance

The striping resistance of the mixture was assessed by decrease in the loss of the indirect tensile strength (ITS) after immersion in water for 24hrs at a temperature of 60℃ (Moghadas Nejad *et al.*, 2012). In this research study, the moisture vulnerability of asphalt concrete was examined by performing an indirect tensile strength ratio (ITSR) test of mixtures. The indirect tensile strength ratio was determined using **Eq. (1)** for six mixtures from the addition of plastic waste.

$$\mathrm{ITSR} = 100\left(\frac{S_{\mathrm{cond}}}{S_{\mathrm{uncond}}}\right), \quad (1)$$

where $S_{cond}$ is the average indirect tensile strength of the wet specimens and $S_{uncond}$ is the average indirect tensile strength of the dry specimens

### Fatigue Resistance

Previous study was carried out on the influence of plastic waste addition to asphalt mixture performance on the fatigue criteria as the other main mechanism of pavement failure. In general, fatigue cracking is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The applied tensile stress is always less than the tensile stress required to fracture the material after only one loading, that is, the material's tensile strength (Nikolaides, 2015). The fatigue test in this research is by using the strain control. Comparing with the stress control, the failure stage in the strain control is a lot more difficult to be identified because the strain level is constantly maintained while the stress level is gradually decreased as the stiffness of the asphalt mixture is decreased. The fatigue test will stop immediately after reaching 50% of the initial stiffness which represents the specimen failure.

The correlation between tensile strain and the cycles to failure for each material was developed. A linear correlation was verified when the strain was plotted against the cycles to failure, and the fatigue life prediction equations were developed (Arabani and Azarhoosh, 2012). The fatigue equations were developed using regression analysis, which was in the form of Wohler's fatigue prediction model of **Eq. (2)** as shown below.

$$N_f = K_1(\varepsilon_t)^{K_2}, \quad (2)$$

where $N_f$ is the number of cycles to failure of the specimen; $\varepsilon_t$ is the applied strain; $k_1$ and $k_2$ are the coefficients related to mixture properties.

### Rutting Resistance

The investigation which was carried out to evaluate the resistance of mixture to permanent deformation are the Marshall test, and the wheel-tracking test (Arabani, Moghadas Nejad and Azarhoosh, 2013). For this research, the resistance to rutting was investigated using wheel-tracking test. As a polymer, plastic is able to increase the stiffness of asphalt mixture. Rutting of road pavement due to traffic loading and high temperature is one of the major issues of flexible pavement performance. The model of the rutting resistance was

**Table 1**. Physical Properties of Bitumen

| Property | Test Method | Test Result | Standard Values |
|---|---|---|---|
| Penetration, 100gm,5sec at 25 °C | ASTM D-5 | 83 | <80 |
| Ductility, 5cm/min at 25 °C | ASTM D-113 | 92 | >75 |
| Specific gravity at 25 °C | AASTO T-228 | 1.02 | 1.01-1.03 |
| Softening point, °C | ASTM D-36 | 46.5 | >42 |
| Flashpoint, °C | AASTO T-48 | 280 | ≥232 |
| Solubility ,% | AASTO T-44 | 99.34 | ≥99 |
| Loss on heating | AASTO T-47 | 0.04 | ≤100 |

**Table 2**. Effect of plastic waste on bitumen consistency

| Amount of PET added to bitumen, % | Property test | | |
|---|---|---|---|
| | Penetration, 1/10mm | Ductility, cm | Softening point,℃ |
| 0 | 83 | 92 | 46.5 |
| 2 | 78.76 | 75.72 | 47.96 |
| 4 | 74.52 | 59.44 | 49.42 |
| 6 | 68.01 | 49.46 | 53.57 |
| 8 | 59.4 | 44.42 | 60.38 |
| 10 | 50.6 | 35.3 | 67.1 |
| Standard value | <80 | >75 | >42 |
| Test method | ASTM D-5 | ASTM D-113 | ASTM D-36 |

developed by adding plastic waste using the wheel tracking test. The dynamic stability (DS) of the mixture, which means the number of pass to develop 1mm depth of rutting, was estimated with this model.

### Resilient Modulus of Binders

The Resilient Modulus ($M_R$) of binder was determined using the Dynamic Shear Rheometer as per AASHTO T315-12. Asphalt binder contains different plastic waste percentages were tested at 20°C, 25°C, 30°C, 35°C, 40°C, 45°C and 50°C.

## RESULTS AND DISCUSSION

As indicated in (**Table 2)**, ductility was abruptly decreased as plastic waste content increased in the combination of binder. The ductility of neat bitumen was 92 cm. The value of ductility was decreased to 35.5cm at 10% addition of plastic waste which results loss in ductility by more than 61.63% as compared to that of neat bitumen. This implies that using plastic waste as a modifier in HMA has significant effect on the ductility of neat bitumen. Also, the addition of 10% plastic content to bitumen improves the penetration and softening point of the neat bitumen by 39.04% and 44.30% respectively. This indicates that plastic waste increases the workability of the neat bitumen.

### Marshall Characteristics

The effects of plastic waste addition on Marshall properties of the traditional and improved bitumen concrete mixture comprising the average value of stability, flow, density, air voids (AV) in the entire mix, voids filled with bitumen (VFB) and voids in mineral aggregates (VMA) were gained and depicted at different bitumen content and plastic content.

### Specific gravity

Irrespective of the plastic waste content, the specific gravity of the plastic waste mixture was lower than that of the neat bitumen. As illustrated in (**Fig. 1)** for each of the bitumen contents, increasing the addition of plastic content in the binder reduces the specific gravity of the mix. The cause of decline in the specific gravity result in case of plastic waste addition into mixtures is due to the lower specific gravity of the plastic waste in comparison with the mineral aggregates.

### Marshall Flow

As shown in **(Fig. 2)** an increase in plastic waste content results in increasing the flow value of the mixtures than that of neat bitumen. As elaborated in the last section, this result can contribute to the formation of a softer mixture. However, adding the amount of plastic content beyond 4% causes the flow value to increase while the stability decreases.

### Voids with aggregate and bitumen

To have the required durability of the mixture, minimum VMA requirements are recommended. Voids in mineral aggregate (VMA) provide space for binder films on the aggregate particles .The durability of the mix increases with the film thickness on the aggregate particles. The relationship between bitumen contents and VMA value for a percentage range of plastic content is shown in (**Figs 3 and 4)**.

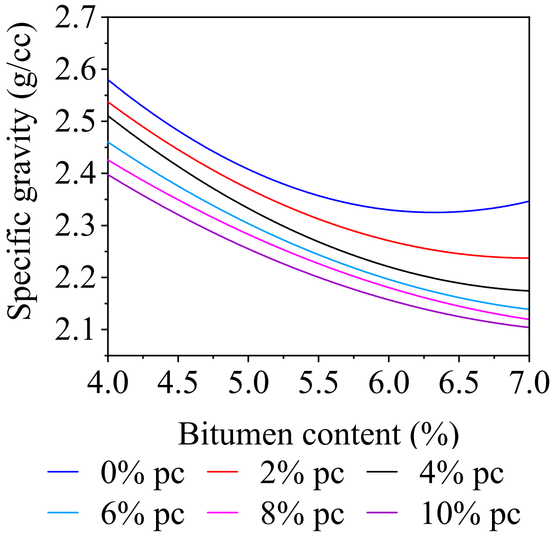


**Fig 1.** Effect of plastic waste on specific gravity.

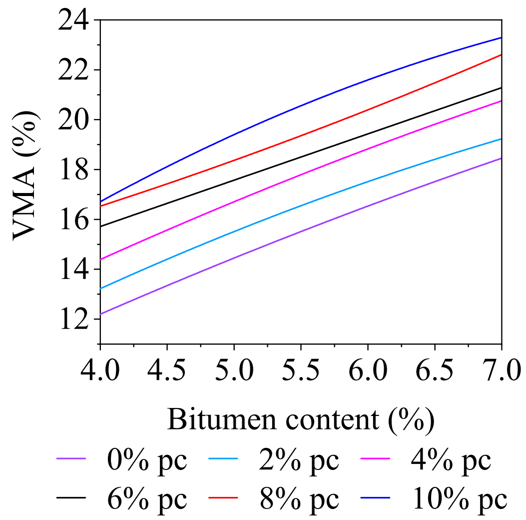


**Fig 3.** Effects of plastic content on VMA.

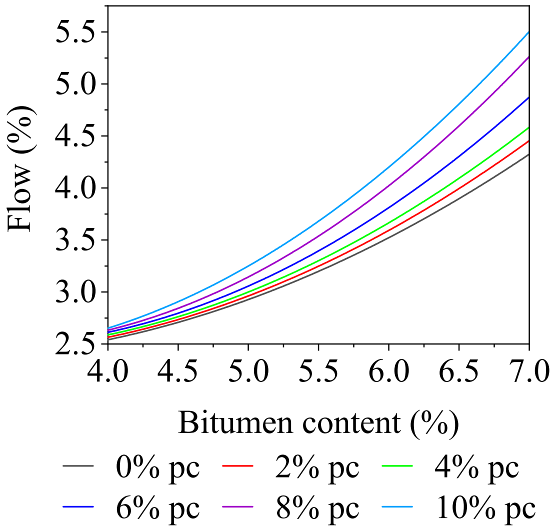


**Fig. 2** Effect of plastic waste on flow.

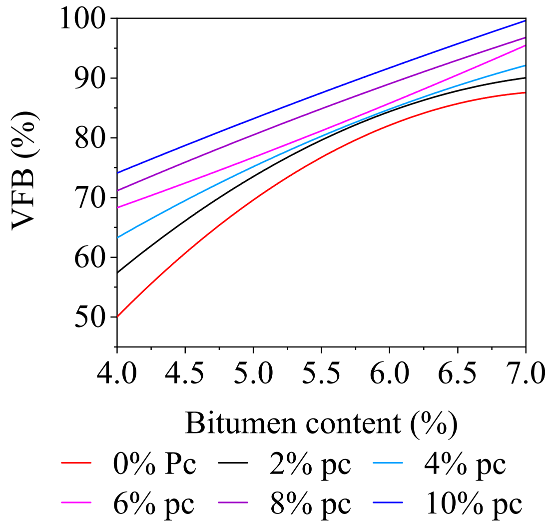


**Fig. 4** Effects of plastic content on VFB.

The graph indicates that the value of VMA in relative to the bitumen content, utilizing the same plastic content, is increased by increasing the plastic content in the combination. The values of VMA were also higher than those of the neat bitumen mix. The modified bitumen mixes are higher than the traditional mix. It can be seen that the VMA and VFB of the modified bitumen mix increases as the plastic content increases.

## Marshall Stability

The increase in stability by adding polymers to the hot mix asphalt is attributed to better adhesion developed between the materials in the mix (Awwad and Shbeeb, 2007; Chen *et al.*, 2009; Sabina *et al.*, 2009). The correlation between bitumen content and Marshall Stability of mixtures at different percentage of plastic content is shown in **Fig. 5**. The graph revealed that the stability outcome at varied bitumen content depend on their relationship with the plastic content, which follow the same trend. After adding plastic waste, the stability value is increased until it reached the maximum level, which was approximately 4% of plastic content at 4.75% bitumen content, after which it started to decrease. The mixture values of Marshall Stability were generally lower in comparison to the neat bitumen. The only mixture that gave a lower stability value was the mixture with greater than 6% plastic content.

## Air void

The air void is one of the vital bituminous mixture parameters used for pavement design and the achievement of optimum asphalt content (Ahmedzade and Yilmaz, 2008)(NAPA, 2002)(Sengoz and Topal, 2007). Excessive air voids results cracking due to the inadequate asphalt binder coating the aggregate, while low air voids may induce more plastic flow (rutting) and asphalt bleeding (Chen *et al.*, 2009). As shown in **(Fig 6)** increasing the plastic content in the mixture results

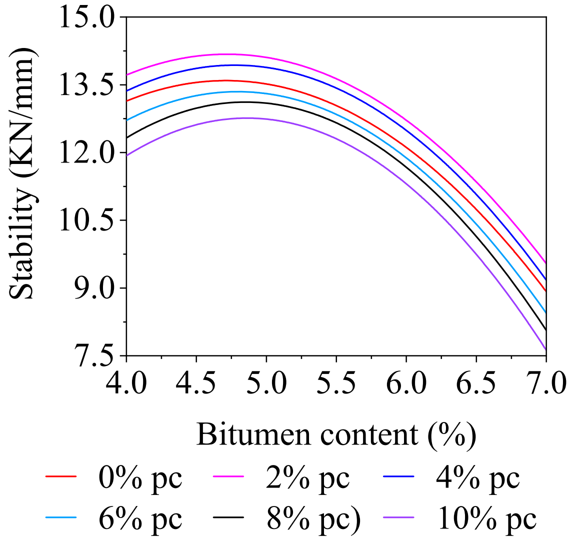


**Fig 5.** Effect of plastic content on stability.

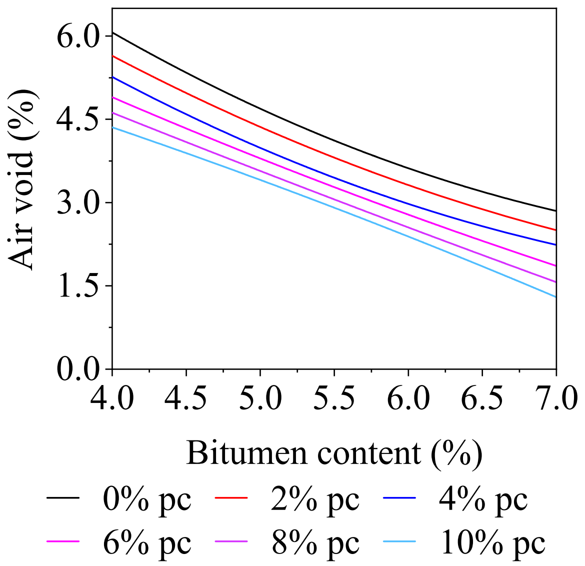


**Fig. 6** Effect of plastic content on Air void.

reduces the air voids in the mixture as a result of the chopped plastic waste used in the mixture, which remained in the form of crystal, thereby increasing the surface area. The increased surface area, however, needs to be wetted with binder, which would finally lead to an increase in voids in the mixture. Furthermore, when PET was used in the mixture, it seemed to reduce its compatibility, therefore, a higher air void value might be obtained (Chen *et al.*, 2009; Mahrez and Karim, 2010).

## Stripping Resistance

The indirect tensile strength ratio for specimens prepared with different plastic contents is shown **(Fig 7)**. The data also show that the indirect tensile strength ratio is significantly improved with the addition of plastic waste, which led to better resistance against moisture damage. All of the indirect tensile strength ratio values of the plastic waste treated mixtures were relatively above 80%. The addition of 2%, 4%, 6%, 8% and 10% plastic waste increases the tensile strength ratio by 3.22%, 6.43%, 5.60%, 0.72% and -4.17%, respectively, compared to that of mixtures prepared with neat bitumen. The specimen with 5% plastic waste had the highest TSR value, showing that plastic waste could improve the stripping resistance if it is added up to 5% to the neat bitumen.

## Rutting Resistance

According to the wheel tracking test result shown in **(Fig 8)** the addition of plastic waste to the asphalt mixture has a significant value in increasing the dynamic stability of the asphalt mixture. The more plastic waste added to the asphalt mixture, the higher the dynamic stability of the mixture. The increase of dynamic stability occurs due to the improvement of adhesion between aggregate and asphalt during bitumen-plastic mixing process in high temperature. The contact between asphalt and plastic in this condition is potentially changing the viscosity of the asphalt afterwards, so the resistance to deformation of the asphalt mixture is increased.

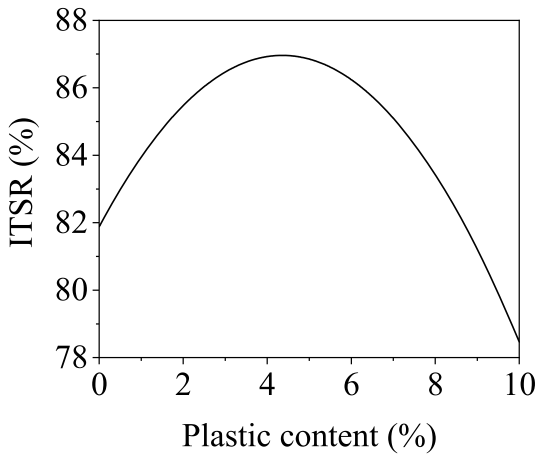


**Fig 7.** Stripping Resistance of mixtures.

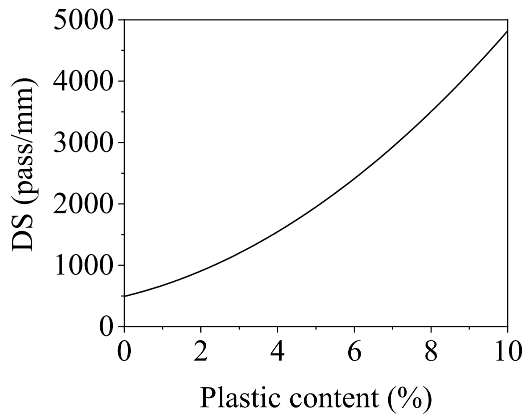


**Fig. 8** Dynamic Stability of mixtures

**Fatigue Resistance**

Based on **(Fig 9)** it shows that the strain value is inversely proportional to fatigue life, where the higher the strain applied, the lower the number of loading cycles will become. To see the resistance to the fatigue cracking of the asphalt mixture using plastic waste, the extended trend line of fatigue life is being developed to the condition of 150μs as the limiting point. The strain value is decreased as the percentage of plastic waste increased in the mix. This indicates that excessive plastic addition has a bad effect to the fatigue resistance of the mixture. If the stiffness modulus of asphalt mixture is too high, it will prone to early fatigue cracking.

**Resilient Modulus**

The Resilient Modulus ($M_R$) is the elastic modulus based on the recoverable strain under repeated load (Yang H.Huang, 2005). It is used because the bitumen mixtures are not completely elastic material; these materials involve nearly permanent deformation after individual pressure application. In addition to stress and strain effect, the temperature and time of loading effects also give a major impact to the resilient modulus results of the asphalt mixture. Higher temperature will reduce the resilient modulus value whereas higher frequency will increase the resilient modulus value, and vice versa. The resilient modulus test result at temperature of 45°C has a lower value compared to the test at temperature of 20 °C and 50 °C as shown in **(Fig 10)**. It can be seen that the addition of plastic waste to the asphalt mixture would change the resilient modulus value of the asphalt mixture. At all temperature test of 20 °C, 25 °C, 30, 35, 40, 45 and 50 ° C, the resilient modulus value would be higher along with the more plastic waste to be added in the asphalt mixture.

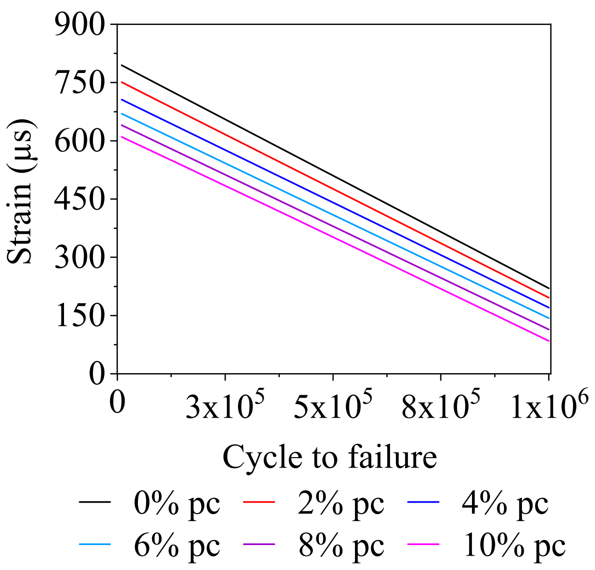


**Fig 9.** Resistance to fatigue.

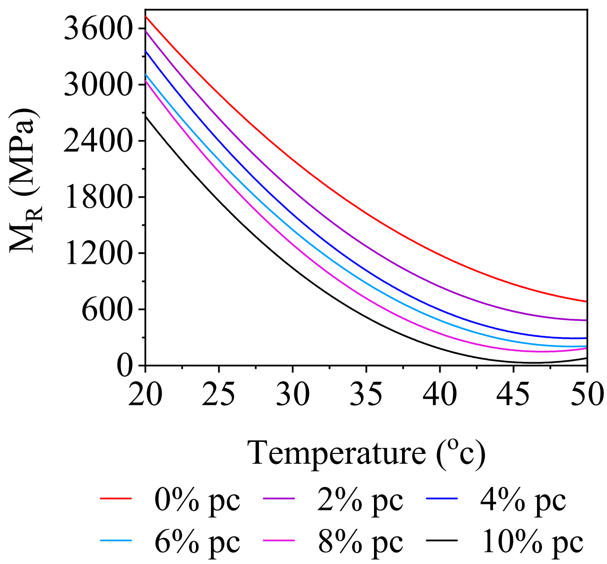


**Fig 10.** Effect of plastic on resilient modulus.

The resilient modulus value shows that the plastic waste will influence the stiffness of the asphalt mixture. Other than that, the reduction of the resilient modulus value due to the increasing temperature of asphalt mixture using plastic waste is lower than the conventional asphalt mixture.

## CONCLUSIONS

The addition of plastic content to Hot Mix Asphalt will increase the Marshall stability and the resilient modulus, improves stripping resistance, moisture sensitivity and also the rutting resistance. The addition of plastic waste to bitumen decreases the penetration values; conversely it increases the softening point of bitumen which will improve the workability of bitumen. However, the plastic waste addition will reduces the ductility of the bitumen. The addition of plastic waste could be good in stripping resistance when it is added up to 5% to the neat bitumen. The strain value is decreased as the percentage of plastic waste increased in the mix. Excessive addition of plastic has a bad effect to the fatigue resistance of the mixture. If the stiffness modulus of asphalt mixture is too high, it will prone to early fatigue cracking. The resilient modulus value shows that the plastic waste will influence the stiffness of the asphalt mixture. On the other hand, the reduction of the resilient modulus value due to the increasing temperature of asphalt mixture using plastic waste is lower than the conventional asphalt mixture.

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