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The Fatigue Performance Of Asphalt Mixtures Incorporating Recycled Polyethylene Terephthalate

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أداء الانهيار لخليط الأسفلت المحتوي على البولي إيثيلين تيريفثالات المعاد تدويره

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Abstract:
A significant volume of waste plastic is generated by various industries, making plastic an integral component of everyday life. Polyethylene terephthalate (PET) is a prevalent type of plastic predominantly utilized in the beverage and food sectors. The global production of waste PET is substantial. Conversely, the presence of vehicles with heavier axle loads on roadways contributes to a reduction in the service life of asphalt pavements. Various forms of failure can manifest in asphalt concrete mixtures, including permanent deformation and fatigue failure. This research focuses on assessing the stiffness and fatigue performance of asphalt mixtures that incorporate crushed PET particles as an additive. The study employed different proportions of crushed PET, with a maximum particle size of 2.36 mm. Stiffness modulus tests and indirect tensile fatigue tests were performed on both the PET-modified and unmodified mixtures at optimal asphalt content levels. The findings indicated that the stiffness of the asphalt mixture improved with the addition of lower quantities of PET; however, an increase in PET content led to a decrease in stiffness. Furthermore, it was noted that the fatigue life of the mixtures containing waste PET was considerably extended compared to those without PET reinforcement.

Keywords: Asphalt mixture, Waste PET, Fatigue life.

الملخص
يتم توليد حجم كبير من النفايات البلاستيكية من قبل مختلف الصناعات، مما يجعل البلاستيك عنصراً أساسياً في الحياة اليومية. يُعد البولي إيثيلين تيريفثالات (PET) نوعاً شائعاً من البلاستيك يُستخدم بشكل أساسي في قطاعات المشروبات والأغذية. ويُعتبر الإنتاج العالمي من نفايات PET كبيراً للغاية. من ناحية أخرى، فإن وجود المركبات ذات الأحمال المحورية الثقيلة على الطرق يساهم في تقليل عمر الخدمة لرصف الأسفلت. ويمكن أن تظهر أشكال مختلفة من الفشل في خلائط الخرسانة الإسفلتية، بما في ذلك التشوه الدائم وفشل الإجهاد المتكرر. يركز هذا البحث على تقييم صلابة وأداء الإجهاد المتكرر لخلائط الأسفلت التي تحتوي على جزيئات PET المسحوقة كمادة مضافة. وقد استخدمت الدراسة نسباً مختلفة من PET المسحوق، مع حجم جسيمات أقصى يبلغ 2.36 ملم. وتم إجراء اختبارات معامل الصلابة واختبارات الإجهاد غير المباشر على كل من الخلائط المعدلة PET وغير المعدلة عند مستويات المحتوى الأمثل من الأسفلت. وأظهرت النتائج أن صلابة خلطة الأسفلت تحسنت مع إضافة كميات منخفضة من PET؛ ومع ذلك، أدى زيادة محتوى PET إلى انخفاض الصلابة. علاوة على ذلك، لوحظ أن عمر الإجهاد المتكرر للخلائط التي تحتوي على نفايات PET قد ازداد بشكل ملحوظ مقارنة بتلك التي لم يتم تدعيمها بالـ PET.

الكلمات المفتاحية: خليط الأسفلت، نفايات البولي إيثيلين تيريفثالات، عمر الإجهاد.

Introduction

Roads are vital infrastructure, acting as the lifeline of a nation's economy and society by facilitating the movement of people and goods. Their maintenance, care, and development are therefore high priorities because they improve road safety, boost economic growth, reduce poverty, and connect communities to vital services like education and healthcare. A well-maintained road network also increases land value, enhances supply chain reliability for businesses, and contributes to overall national development and improved living standards [1-7]. At the end of 2024, the total road network globally was estimated to be over 64.7 million kilometers in size [8].

In recent decades, plastics have been extensively utilized across various facets of daily life. The pervasive use of plastic materials has indeed led to significa6nt environmental challenges, primarily due to the generation of substantial quantities of plastic waste. The repurposing of waste plastics, particularly in construction applications such as road surfacing, has gained recognition as a viable method for enhancing materials through modification or reinforcement. Various types of recycled polymer materials are employed in asphalt pavement, including high-density polyethylene (HDPE), medium-density polyethylene (MDPE), low-density polyethylene (LDPE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), and acrylonitrile butadiene styrene (ABS). Among these, LDPE and HDPE are the most widely favored; however, PET and PVC are generally considered unsuitable for this application due to their higher melting points, which exceed the temperature required for mixing [9-12].

The longevity of asphalt pavement is a critical factor that must be taken into account in the design of road surfaces, particularly as the volume of vehicular traffic increases. Various strategies exist to address this challenge, with the incorporation of additives often emerging as the most effective solution for enhancing the durability of asphalt pavement. These additives can be classified into two primary categories: fibers and polymers. Both fibers and polymers are capable of absorbing the stresses that arise within asphalt mixtures. Additionally, they contribute to a three-dimensional network effect on the surfaces of aggregate particles, thereby reinforcing the bond between the aggregate and the asphalt binder [13-16].

The financial implications of utilizing additives represent another critical factor that warrants attention. The incorporation of additives in asphalt mixtures results in increased expenditures for governmental bodies [17]. Consequently, in numerous instances, the adoption of higher-cost additives may not be a viable option for road pavement projects due to the associated financial burdens. Therefore, additives derived from waste materials that are more economical are deemed more suitable [18,19].

In this study, waste PET is evaluated as both an additive and a reinforcement material. The stiffness and fatigue characteristics of the asphalt mixture were assessed and analyzed at varying percentages of PET content.

Material and methods

Materials Utilized For the fabrication of all samples, a uniform bitumen type was employed, specifically the 80/100 penetration grade bitumen. The samples were produced at the optimal bitumen content. Additionally, the gradation of the aggregate particles was selected in accordance with the Jabatan Kerja Raya (JKR) standards for stone mastic asphalt 14 (SMA 14) mixtures, as detailed in Table 1. The aggregates were sourced from the Kajang quarry located in Malaysia. The properties of both the bitumen and aggregates were thoroughly characterized and are presented in Table 2.

Recycled PET is derived from discarded plastic bottles. Crushed waste PET particles, measuring less than 2.36 mm, were incorporated into SMA mixtures at varying proportions (0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1%) as an additive.

Table 1: Used aggregate gradation

Sieve size (mm)	12.5	9.5	4.75	2.36	0.6	0.3
Used gradation (%)	100	77.5	31.5	20	14	13.5

Table 2: Used aggregate specification

Property Coarse aggregate	Value	Criteria
L.A. Abrasion (%)	19.45	ASTM C 131
Bulk Specific Gravity	2.60	ASTM C 127
Absorption (%)	0.72	ASTM C 127
Fine Aggregate		
Bulk Specific Gravity	2.63	ASTM C 128
Absorption (%)	0.4	ASTM C 128
Soundness loss (%)	4.1	ASTM C 88
Bitumen		
Penetration at 25 C (0.1mm)	87	ASTM D 5
Softening Point (C)	46	ASTM D 36
Viscosity at 135C (mpas)	325	ASTM D 4402
Viscosity at 170C (mpas)	62.5	ASTM D 4402
Specific Gravity	1.03	ASTM D 70

The stiffness modulus and indirect tensile fatigue tests were performed to assess the stiffness and fatigue properties of asphalt mixtures, following the guidelines set forth in AASHTO TP31 and EN 12697. These tests were executed at three distinct stress levels (250, 350, and 450 kPa) and at a temperature of 20˚C. The fatigue life of the asphalt mixtures was evaluated based on the number of cycles at which the sample either failed or the vertical deformation reached the maximum threshold of 9 mm.

Results and discussion

Figure 1 depicted the test results of the stiffness related to the plastic existing percentage in the mixture under various stress levels.

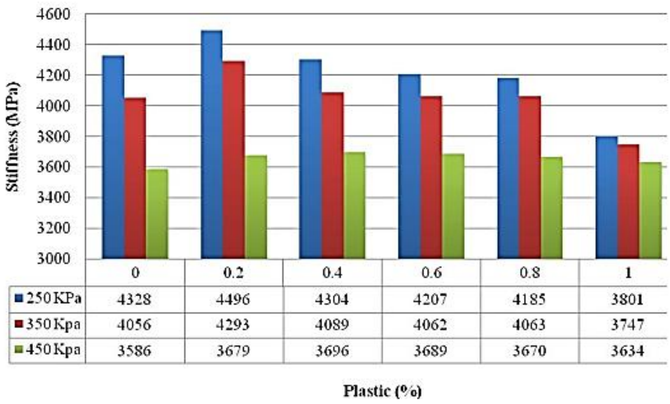
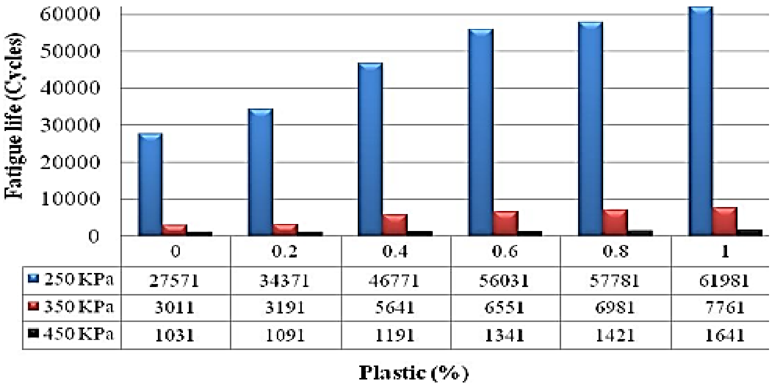


Figure 1: Stiffness vs. Plastic

As illustrated in Figure 1, mixtures containing plastic reinforcement exhibited increased stiffness with lower quantities of PET. Conversely, the incorporation of greater amounts of PET resulted in a reduction of stiffness in the mixtures. This phenomenon can be attributed to the elevated melting point of PET, which exceeds the temperature used during the fabrication of the mix. Consequently, PET particles do not undergo melting, remaining as solid particles within the mixture. This presence of solid particles contributes to a more flexible composite. Therefore, under the same stress conditions, the flexible mixture demonstrates a greater displacement relative to the non-reinforced mixture, leading to a decrease in stiffness.

While Figure 2 illustrated the test results of the fatigue life related to the plastic existing percentage in the mixture under various stress conditions.



Plastic (%)	0	0.2	0.4	0.6	0.8	1
250 KPa	27571	34371	46771	56031	57781	61981
350 KPa	3011	3191	5641	6551	6981	7761
450 KPa	1031	1091	1191	1341	1421	1641

Figure 2: Fatigue life vs. Plastic

The data presented in Figure 2 indicates a significant enhancement in the fatigue life of asphalt mixtures with the incorporation of PET particles. Specifically, mixtures containing 1% plastic exhibit the most substantial fatigue lives, exceeding double those of unreinforced mixtures at lower stress levels of 250 Kpa and 350 Kpa. Conversely, at all tested stress levels, the unreinforced mixtures demonstrate the least favorable performance. This improvement can be attributed to the increased flexibility of the mixture, as previously discussed. In essence, the addition of PET particles to SMA mixtures enhances their flexibility, thereby contributing to an increase in fatigue life.

Conclusion

The investigation focused on the stiffness and fatigue characteristics of SMA mixtures, both with and without the inclusion of plastic reinforcement. The findings are summarized as follows:

The stiffness of asphalt mixtures incorporating plastic reinforcement exhibits an initial increase with the addition of a small quantity of PET (0.2%). However, a significant decline in stiffness is observed when larger amounts of plastic are introduced. Furthermore, the fatigue life of asphalt mixtures containing PET reinforcement is notably extended compared to those without such reinforcement. These findings suggest an enhancement in the flexibility of the mixtures at equivalent stress levels. By enhancing flexibility, the onset and progression of fatigue within the asphalt mixtures may be delayed.

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