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Plastic as the Fill-In Material for Pothole Repairing

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Abstract: Plastic is used all over the world because it is durable, lightweight, and affordable for a lot of product manufacturing. It becomes a major source of use in human daily life because most of the products are made of plastic. Therefore, this study is an initiative to use the plastic modified asphalt for road construction. Road distress like pothole may become worse if it is not repaired immediately. The objectives of this study are to study the strength of plastic modified asphalt for pothole repairing and to analyze the optimum plastic content (OPC) in the asphalt mixture. The study is focus on plastic waste materials that are often used in asphalt pavement. It is related with the performance of modified asphalt mix that use plastic waste as the additives in asphalt. The method used to conduct the study is systematic review. The relationship of plastic modified asphalt with the stability, tensile strength and resilient modulus were identified in the study. It has been proved that the plastic modified asphalt provides better stability, strength and resistance to the pavement. It is suggested to perform research of modified asphalt with various types of thermoplastic waste as it can be recycled and comes from variety of uses.

Keywords: Potholes, Plastic Modified Asphalt, Plastic Waste, Optimum Plastic Content

1. Introduction

Goods made of plastic are increasingly used in this globalization era to produce various products such as electrical appliances, kitchenware, product packaging and many other products. Plastic is used all over the world because it is durable, lightweight, and affordable for a lot of product manufacturing. It becomes a major source of use in human daily life because most of the products are made of plastic. Ease of manufacturing causes high demand of plastic due to the immense variety of properties that have been indicated by them. To improve the quality of life in modern living, the demand for plastics has been increasing. In Municipal Solid Waste (MSW), the rate of plastic waste is increasing because of the increment of population growth, development activities and lifestyle change [1]. Most common of plastic used for packaging purposes are Polyethylene Terephthalate (PETE) and High-Density Polyethylene (HDPE) [2].

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Globally, up until 2015, the plastic waste produced has been estimated as much as 6,300 metric tons (Mt) which are 78% is piled up in landfills or washed away into the sea 12% of the waste has been disposed of by combustion and the remaining has been recycled. Approximately by 2050, 12,000 Mt will be piled up in landfills or washed away into the sea if the production and waste management is consistent with the trend [3]. The sustainability objectives can be achieved through the possible use of plastic waste in the construction industry. Effective measure for plastic waste is by recycling, therefore the packaging industry has been widely explored many ways to recycle plastic waste, but it is less common in the construction industry [4].

Pavement failure may contribute to accidents and fatalities if the road users are not aware about the road condition. There are many types of pavement failure such as cracking, potholes, rutting, shoving and many other failures. Every type of pavement failure occurs from various factors and have many different methods to repair it according to the needs of the affected pavement. Surface defects and elevation-oriented defects are the classification for pavement failure. Surface-elevation defects such as bleeding, potholes and patching can be classified based on loss of road layer aggregates and area-depth. Surface area and elevation information is very important to determine the extent and severity for these types of pavement failure [5]. Involvement of government, civil society from the public and private sector is a collective responsibility that is needed for road safety. Annual loss of Gross Domestic Product (GDP) in the range of 2%-5% is because of poor road safety in societies and economies globally, coordinated approaches to road safety management only followed by a certain number of countries. However, the countries that are in needs of development are suffer the most [6].

The objective of the study is to identify the strength of modified asphalt by using plastic waste as additives for pothole repairing based on the previous study. The strength performance of plastic modified asphalt can be compared to the conventional asphalt. Other than that, the aim is to analyze the optimum plastic waste content in modified asphalt based on the previous study. The percentage of plastic content in asphalt mixture is varied according to the different types of research.

2. Literature Review

Humans' daily lives were altered dramatically over the last few decades. Around 8 percent of oil production in the world has been used to produce more than 260 million tons of plastic per year [7]. Plastic was a critical resource; hence, its uses are continuously growing in the manufacturing field. Plastics are growing day-to-day at unprecedented rates of people, fast economic growth, constantly urbanizing and transforming the lifestyle [8]. Plastic also known as polymer, it is created by multiple units and a molecular chain. Oxygen, hydrogen, carbon and/or silicone are the components to link the chain. Myriads of links are hooked or polymerized together to create the chain. Petroleum and other materials are heated and separated into smaller molecules, known as monomers, under controlled conditions to manufacture polymers. The monomers are the polymers' building blocks. Therefore, plastic resins with a different properties can be created with different mix of monomer [9].

The term plastic encompasses a vast variety of materials that can be extruded, cast, rotated or applied in the manufacture at any point [7]. Polymers have various properties according to its structure and composition. Ergo, polymers can be categorized into two major classifications which are thermoplastics and thermosets. Thermoplastics is a polymer in which the molecules are held by weak bonds, producing plastics which are softened when exposed to heat and return to its initial form in ambient temperature [9]. They can be formed and handled more easily at high temperatures, and during use, they are constrained to a moderate temperature [10].

2.1 Physical properties of polyethylene

Polyethylene is a material that has white waxy translucent color and it is also inflammable. The PE has a low rate of water resistance, but it has a higher rate in transmitting the organic vapor [11] Therefore, Table 1 shows the physical properties of a few types of PE which are Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE) and Ultra-High-Molecular-Weight Polyethylene (UHMWPE). With the increase of crystallinity, the transparency of PE decreases. The level of PE crystallization depends on the number of branches. Therefore, it will become complicated to crystallize because of more branches. The number of branches may influence the melting temperature of PE crystals that can be distributed 90 ℃ to 130 ℃ [11].

Table 1: Typical physical properties of HDPE, LDPE and UHMWPE [12]

Resin material	Coefficient of thermal expansion, 10 −5 in/ in/°C	Thermal conductivity 10 −4 cal-cm/ sec-cm 2°C	Water absorption 24 h, %	Flammability, * in/min	Specific gravity
LDPE	10 - 20	8	<0.01	Slow burning	0.910 – 0.925
HDPE	5 - 11	11 - 12	<0.01	Slow burning	0.941 – 0.965
UHMWPE	13 – 20	-	<0.01	Slow burning	0.94

2.2 Chemical properties of polyethylene

The chemical stability of PE is very good because it is tolerant with basic solution and acid, for example formic acid, hydrochloric acid, hydrofluoric acid, phosphoric acid, potassium hydroxide and sodium hydroxide at ambient temperature. Nonetheless, a great damaging effect can occur on PE are nitric acid and sulfuric acid. It is susceptible to degradation under the action of ultraviolet ray. Carbon on PE has an outstanding effect on the light defense. The unsaturated groups, broken chain and cross-linking will take place after irradiation [11].

2.3 Flexible pavement

Asphalt concrete pavement, also known as flexible pavement, is mixed, placed and compacted mixture of sand, aggregate, filler material and asphalt cement. The range of filler material can be from cellulose which is wood fibre, and quarry crushing dust. There are various additives to enable stronger cement coatings, more elastic forms, stiffer compounds and less temperature-sensitive mixes that can be used in asphalt concrete mixture [13]. Flexible pavements are created for the subgrade to bend and rebound. The deformation behaviour of flexible pavement is shown in Figure 1. The design principle consists of adding appropriate layers of base and intermediate pavement layers to monitor the strains of subgrade to ensure that there are no lasting deflections. Loading of an asphalt pavement allows the stiffest layers to be put on the surface and the weaker layers is successively lower to the subgrade [13].

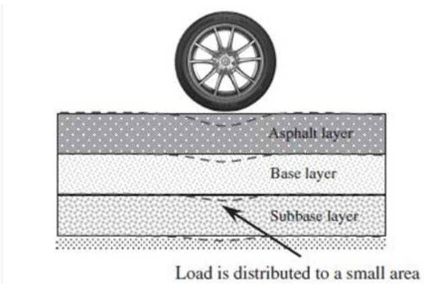

Figure 1: Deformation behavior of flexible pavement [14]

2.4 Hot mix asphalt (HMA)

Hot-mix asphalt provides a convenient and compact alternative that offers a more effective adhesion to the existing asphalt pavement. Full focus is required for the compaction mixing temperature with hot-box equipment need to be used to preserve the temperature of the mixture for repeated minor repairs [15]. The main layer for flexible pavement is hot mix asphalt (HMA) because it is subjected to traffic loads and environmental circumstances that demand great resistance, long lifespan, and good stability, to avoid structural deformities leading to functional and structural failure [16]. As widely recognized, HMA is a mix of aggregates (about 95%), which is coated by a petroleum derivative known as bitumen. In the previous decades, waste materials were utilized as an aggregate in order to conserve our environment and to maintain our natural resources and contribute to the sustainable development of construction and demolition waste (CDW) [17].

3. Methodology

Systematic reviews have stringent search strategy requirements and the selection of articles to be included in the review, it is successful in integrating what the studies collection shows in a particular issue and can provide proof of the findings that can inform policy and practice. Relevant literature is required when doing research activities and research discipline. When the author reads an article, despite the research topic, he describes the previous study and evaluates the field of research to justify the purpose of the study [18].

A thorough and systematic search is performed in both datasets using the boolean search approach and terms in the title, abstract, and keyword fields. Boolean operators AND, OR, and NOT employ integration or limitation phrases to discover optimal search criteria [19]. For the first phase of the article finding, the combination of the keywords with the boolean operator will be used: "bitumen AND plastic" or "pavement OR road" or "construction AND pavement" or “bitumen OR asphalt” or “asphalt AND polymer”.

In the first phase of the journal review process, a total of 60 articles were identified. It is highly recommended to collect as many related articles as possible rather than collecting only a few articles. This is because all of the collected articles need to be filtered out before proceeding to the next phase. If the articles collected are few, then the number of the articles will be less after filtering process. The findings were subsequently filtered according to the related topic which are environment engineering, highway engineering, infrastructure, road repairing and polymer.

The screening process was carried out as the first stage of this study was conducted. It was performed through observation when finding information based on the designated research area and result of the finding involve 60 journal that is related with the research area. By limiting the research area, it was contributing to 8 journals being withdrawn. Type of article has been filtered whether it is in form of conference, text and journal article. The year of released starting from 2007 to 2021 was used as the filter component and it led to withdrawn three articles from the designated research area. Total current remainder of the article in first stage are 49 articles.

Next, the second stage of this research is still filtering the remaining article by conducting review for the eligibility of the article. Evaluation has been done based on the titles and keywords of the publications. Related keyword should be included in the title to ensure that the article is relevant to be used. Through this stage, contribution of 6 article have been withdrawn and proceeded to the next stage with the remaining 41 articles.

The third stage is proceeded by assessing the eligibility of the article through reviewing the abstract and conclusion. By doing so, 8 articles have been withdrawn and remaining 33 articles were proceeding to the next stage. For the fourth stage, reading full text of the remaining articles is required in order to confirm that the article is appropriate to be used. The main objective and methodology applied in the article can be identified. This stage has withdrawn 16 articles and the remaining of 17 articles has been proceeded to the last stage for a final review to be used in the research.

4. Results and Discussion

4.1 Marshall stability

Based on the result of Marshall stability test in Figure 3 shows that 4% of plastic has the maximum stability of 184 kN and with the increase of plastics in the asphalt, the stability will decrease significantly. A huge gap is observed between the plastic modified asphalt and conventional asphalt with a different of more than 100% [20].

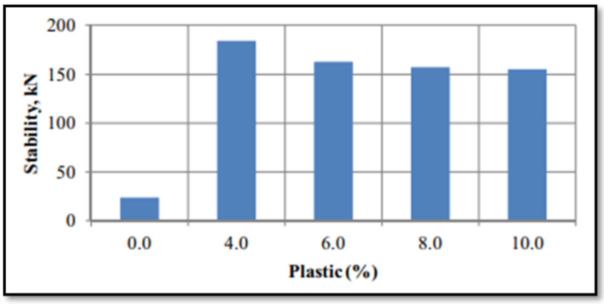

Figure 2: Different percentage of plastic to stability [20]

Table 2 and Table 3 below shows Marshall stability values at one day and 30 days for the PET and PE asphalt mixture respectively. For both plastic contents, the stability value increased at different percentages. With increasing PET content, the stability increased by 17.46 kN, 13.36 kN, 11.26 kN, and 10.06 kN at 5%, 10%, 15%, and 20% of replacement PET content in the asphalt, respectively. In addition, the stability values of asphalt mixtures based on PE were constantly improved after one-day testing from 18.24 kN, 23.87 kN, 26.59 kN, and 30.03 kN, respectively. The highest PET stability value was observed at 5%. The stability values obtained from the PE asphalt mix were higher than those produced by the asphalt PET-based mixture due to larger dispersal of PE gas pipes in polymer modified bitumen (PMB) which indicating greater stiffness and more stability [21].

Table 2: Stability of PET modified asphalt under different testing day [21]

Plastic type	Day(s)	Stability value (kN) of different polymer modified bitumen mixture				
		0% PET	5% PET	10% PET	15% PET	20% PET
PET	1	15.56	17.46	13.36	11.26	10.06
	30	29.21	35.18	21.15	17.12	12.09

Table 3: Stability of PE modified asphalt under different testing day [21]

Plastic type	Day(s)	Stability value (kN) of different polymer modified bitumen mixture				
		0% PE	5% PE	10% PE	15% PE	20% PE
PE	1	15.56	18.24	23.87	26.59	30.03
	30	29.21	25.30	38.17	41.04	43.91

4.2 Indirect tensile strength (ITS)

PET content from 2% to 10% by weight of bitumen was added to the mixture by using a dry process and have been tested with different temperature of 5°C and 20°C.The temperature has been showing to have a significant impact on the Indirect Tensile Strength (ITS) of samples as shown in Figure 4. The 2% of PET was added and it leads to augment the ITS at both test temperatures. Then, with the addition of PET content, ITS has steadily dropped. Bitumen develops on the PET particles surface with increasing PET percentage. The problem results in the thickness of the bitumen layer around the added particles decreased and reduced the aggregate-bitumen adhesion, and tensile strength of the modified mix also reduced [22].

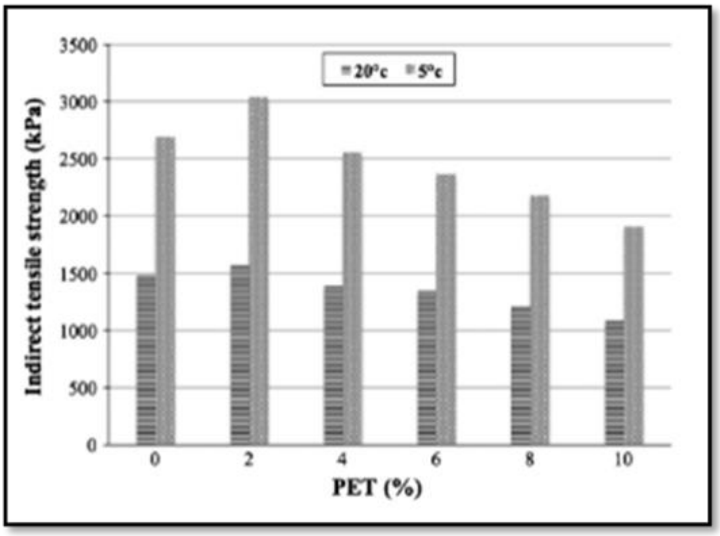

Figure 3: Indirect tensile strength at 5°C and 20°C [22]

Five different PET percentages which are 10%, 11%, 12%, 13%, 14, and 15% by asphalt binder weight were taken into account for the study. The study is based on the link between the indirect strength of tensile and waste PET content of different mixtures as shown in Figure 5. The value of indirect tensile strength reaches its optimum point with 12% of waste PET content. This is because of the high voids content that was achieved by the increment of PET percentage. 12% of waste PET content in asphalt mixture is the most suitable as its main objective is to strengthen the flexibility of the pavement and thus, the resistance to the cracking in the pavement can be improved [23].

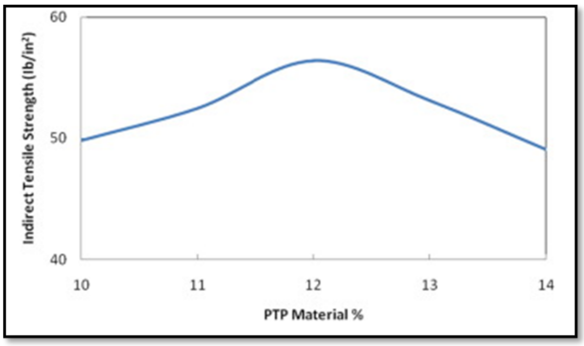

Figure 4: Relationship between the percentage of PET content and Indirect Tensile Strength [23]

4.3 Resilient modulus

The temperature of 25°C and 40°C, a similar trend is observed in Figure 6. With the increase of the plastics until it reaches the optimum plastic content (OPC), the resilient modulus also increases. Thus, with a further increase of plastic, the resilient module then decreases. The highest resilient modulus, which was near twice the conventional mix of asphalt was recorded at 3422MPa for 25°C and 464MPa for 40°C. The modified asphalt mixture with the highest resilient modulus containing 8% of plastic. Other than that, the lowest resilient modulus is 4% plastic, with 69% and 51% lower than the conventional asphalt mix at temperatures of 25°C and 40°C [20].

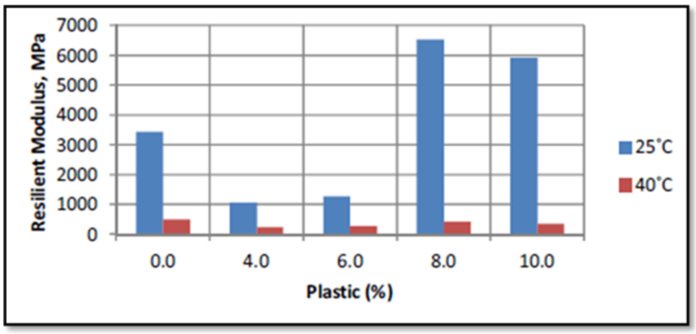

Figure 5: Effect of different percentage plastic to resilient modulus at 25˚C and 40˚C [20]

The resilient modulus was evaluated at 25°C by conducting dynamic indirect tensile testing as shown in Figure 7. The 48-hour and 96-hour aging period indicate a higher modulus value of PEMCMs and PPMCMs than the control mixture. The findings of the test indicate that M_r increases by 8.9% and 3.5%, and 13.3% and 7.5% respectively, at aging levels of 48-hour and 96-hour. The aging process has thereby increased PEMCM and PPMCM diametrical resilience module [24].

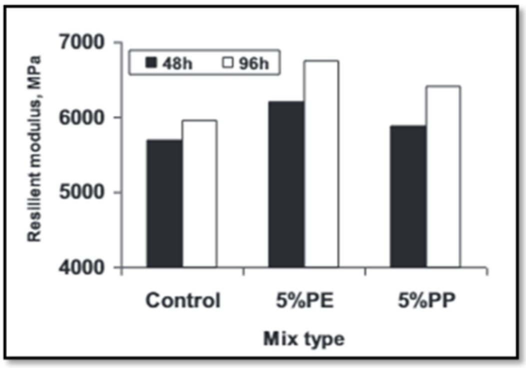

Figure 6: Effect of aging levels on dynamic (resilient) modulus [24]

4.4 Optimum plastic content (OPC)

Table 4 indicates that the addition of 4%, 5%, 6%, and 8% LDPE in the asphalt mixture fulfills the requirements for specifications, however, the addition of 10%, 15%, and 20% LDPE does not meet the requirement for specification arrangements. It is a must to limit the addition of LDPE content, as the addition of higher LDPE content does not fulfill the requirements. Based on the specification of the retained stability, addition 10%, 15%, and 20% of LDPE content exceed 90% of the specifications. From the Marshall test parameter, the inclusion of 6% LDPE indicates its optimum stability. In the wheel tracking machine (WTM) test, 6% LDPE was used to increase the dynamic stability value and decrease the deformation rate. The stability value increase to the contents of 8%, then declines with the addition of LDPE to the asphalt concrete-wearing coarse (AC-WC) asphalt mixture. With increasing LDPE content, the flow value declines, and the nature of a mixture becomes more rigid and enabling cracking more easily because of the brittleness [25].

Table 4: Marshall test result of LDPE modified asphalt by optimum asphalt content (OAC) [25]

Parameter	HDPE Content (%)								Spec.
	0	4	5	6	8	10	15	20	
Density (%)	2.28	2.28	2.27	2.27	2.27	2.27	2.27	2.27	-
Stability (kg/cm2)	1008	1354	1525	1586	1635	1577	1489	1477	Min. 900
Flow (mm)	3.03	3.30	3.27	3.17	3.10	2.93	2.83	2.77	2 -4
Marshall Quotient (kg/mm)	332	410	467	501	527	538	545	549	Min. 250
VMA (%)	15.03	15.07	15.11	15.13	15.23	15.26	15.27	15.36	Min. 15
VFB (%)	72.43	71.39	69.88	69.36	68.57	67.98	65.70	63.62	Min. 65
VIM (%)	4.16	4.31	4.55	4.64	4.79	4.89	5.24	5.59	3 - 5
Retained Stability (%)	90.57	92.13	93.02	93.55	90.52	86.63	84.32	82.24	Min. 90%
VIM PRD (%)	2.03	2.37	2.54	2.71	2.85	2.99	3.08	3.15	Min. 2

5. Conclusion

Most common plastic that is widely used in daily life has produced a lot of waste and the waste is very hard to decompose. Therefore, the research was performed as an initiative to recycle and reuse plastic waste in road construction. In the research, plastic modified asphalt contributed good Marshall stability with the optimum percentage of plastic in asphalt mixture. However, the addition of too much plastic in the asphalt mixture can result in deteriorating stability. Other than that, the tensile strength of plastic modified asphalt shows greater strength compared to the conventional asphalt. Plastic modified asphalt can improve the resistance of the moisture damage of the asphalt mixture. Lastly, the modified asphalt mixture has higher resilient modulus than the conventional asphalt. This means that the deformation of modified asphalt decreases, thus, it possessed higher stiffness. The usage of this recycled plastic waste in the pavement leads to a better and longer road life.

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