Wearing Course Materials Modified with Waste Plastic

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Roads and bridges are one of the most crucial components of infrastructure engineering and they play a vital role in lifetimes. Bituminous mixture is a composite material made up of other distinct materials, employed in a range of civil engineering tasks, such as the construction of roads. It consists of mineral aggregate, bitumen, and air voids, which are the main components of bituminous mixture, blended and then laid and compacted to form the surface of roads. Asphalt pavement or flexible pavement is widely employed throughout the globe. Asphalt pavement has good riding quality, and it is much cheaper to construct, in comparison to concrete or rigid pavements. HMA mixtures for asphalt pavement are divided into three main categories: dense-graded mixture, open-graded mixture, and gap-graded mixture.

Keywords: bitumen ; waste plastic ; SMA ; asphalt mixtures

1. Introduction

The structural stability of the road is usually supplied by the pavement consisting of crushed and carefully selected stone and rock of suitable sizes, which is finally compacted by applying a limited amount of binder. It is known that the standard layers from top to bottom within a pavement are road surface (wearing course), base course (crushed gravel and stone), sub-base course (selected granular material), and sub-grad (natural soil layer). It is noteworthy that it is possible to further strengthen the used granular material with lime, bitumen, or cement. In heavily loaded roads, in the structure of pavements, concrete or asphalt usually substitute the granular material, especially in the base and sub-base layers [1][2].

Frequently, Portland cement concrete or bitumen base surface are used to form the road surfacing. There are several reasons that necessitate surfacing, some of which are to provide a suitable and safe surface for vehicles to turn on easily, to protect the structure and sub-grade of the pavement from the environmental effects, such as moisture, and to reduce the stress imposed on the pavement to protect it against any possible deformation or destruction [3].

2. Stone Mastic Asphalt

According to the case studies on using SMA in pavement construction, the application of SMA in road surfacing shows a significant role in enhancing the mixture's durability, improving rutting resistance and fatigue life. The rutting resistance of SMA is more than that of dense-graded mixtures because of "skeleton coarse aggregate"—this feature offers the contact of stone to stone between the coarse aggregate particles [4]. The major reason for utilising fully crushed aggregate gap gradation (100%) is the enhancement of the degree of pavement stableness through the interlocking resulting stone-to-stone contact [5]. This interlock provides the mix with a stronger stone-on-stone skeleton, which is stuck more stably simultaneously as a result of a strong composition of bitumen binder, filler, and other additives in the mixture to enhance its stability [4].

SMA is characterised by a mixture of gap-graded aggregate, which minimises the fine and medium-sized aggregate, resulting in a stable and structurally tough mixture. The strength and stability of the SMA is because of the stone portion of the coarse aggregate skeleton, which consequently increases internal friction rate and the resistance of the mixture to shear, thereby enabling it to resist rutting and wearing out caused by repetitive studded tyre contact. However, some weakness is distinguishable in the SMA structure, such as drain down, which ensues from the absence of mid-sized aggregate in the gap-graded mixture, which has a high asphalt binder content instead. Since the SMA is assembled in the silos and then transported by trucks to the construction site, after it is placed, the asphalt binder tends to drain down, which is called mixture drain down. Mix drain down is usually avoided by adding cellulose fibres, mineral fibres, or other modifiers to hold the binder in place, thereby providing the mix with durability [1][6].

SMA was developed and used in Germany in the mid-1960s to surface pavements to enhance their resistance against rutting, as well as enhance the durability (Ibrahim et al., 2006 [5]). It was then introduced to the rest of Europe because of its better resistance to damage from studded tyres than other types of HMA [7]. The abbreviation of SMA is obtained from the German term for slip stone mastic asphalt [8].

2.1. Advantages and Disadvantages of SMA

In addition, there are several benefits and advantages of application of SMA, mainly including SMA provides a pavement with a durable, textured, and rut-resistant surface; similarly, SMA surface texture features are closer to those of OGA, which reduces the noise to a minimum, even down to a level lower than DGA but slightly higher than or equal to OGA. It is possible to produce, compact, and process SMA using the same equipment and plant used to produce normal HMA (DGA); SMA is especially applicable to intersections and other parts where traffic stress is high and OGA is not suitable; due to the flexible mastic used in SMA, it can reduce reflective cracking brought by underlying cracked pavements; and the SMA durability should be greater than or at least equal to the durability of DGA, but it needs to be significantly greater than that of OGA [3][9].

Moreover, SMA can also increase skid resistance because of the considerable percentage of fractured aggregates used in it, especially in wet environments. Even though SMA does not let water drain through it, the texture of its surface is like that of open-graded aggregate that absorbs the noise produced by the contact of the tyre with the asphalt surface. Surfaces with coarser texture can absorb not only tyre noise, but also glare and water spray on the pavement. SMA was initially used in asphalt mixes to enhance their level of resistance against studded tyre wear. Another advantage of SMA is that it can increase the resistance of the mixture against plastic deformation, which is one of the common problems that result from heavy traffic loading, which exerts severe stress on the pavement. Moreover, its rough surface provides adequate friction, especially when the asphalt loses its surfacing cement film, which wears out through heavy and frequent vehicle traffic. However, other advantages of SMA make it the most preferred mixture for pavement construction projects around the globe in comparison with other conventional HMA types. Some of these properties are showing improved durability, high resistance to reflective cracking, and improvement against aging [5][10].

However, some drawbacks and disadvantages that may be relevant to the application of SMA can be summarised as follows: more expensive material due to application of higher filler content and binder; and longer time needed for mixing to inject the extra filler, which may result in lower productivity level. Thus, more time is needed to cool the spread SMA on the roads down to 40 degrees C, which may result in completing road construction or repair to prevent flushing problems. Until removal of the thick binder film off the pavement surface due to traffic, the initial skid resistance is expected to be lower than satisfying level. In urgent cases, tiny grit is needed to be splashed over the surface before launching the road [3][11].

SMA surfacing generally requires more care and attention; the initial SMA resistance against skid may be low. This is another disadvantage of SMA, which also needs further care during mixing, producing, transporting, and placement on the road. Nevertheless, after achievement of the required capabilities and expertise, SMA is not harder than other mixtures used for pavement surfacing. When polymers are employed, in hot areas or seasons, the distance of the material transportation may be limited [10][12].

In summary, as the literature reveals, there are many fundamental advantages, such as high durability, improved resistance against fatigue and reflective cracking, and excessive rut resistance, less noise pollution of traffic, and high skid resistance [6][11]. SMA mixtures also suffer from some disadvantages, including delays in opening (the roads) to traffic, drainage of the binder, and higher initial costs [1]. Due to the gap-graded structure of SMA mixtures and the high amount of bitumen binder, stabilisation is required to control bitumen drain down [6][9]. In order to achieve this feature, polymer modifiers or fibres should be added to the SMA mixtures to make the desired modification, reinforcement, and stabilisation in the mixture.

2.2. Characteristics of Materials Used in SMA Mixtures

The characteristics of aggregate, bitumen, filler, and additive in SMA mixtures will be researched. The quality of aggregates employed in SMA needs to be high with a highly rough texture and cubic shape to be able to resist any displacement or rutting. The hardness of the aggregate content helps the pavement to resist breaking under heavy loadings of frequent tyre traffic. The aggregate should also have high resistance to polishing and abrasion [3].

The grade of bitumen content employed in SMA usually equals the same grade or slightly stiffer grade than that used in dense-grade mixtures. When bitumen is stiffer, it minimises any potential drain down and helps to reduce rutting, which is usually expected in higher temperatures. Nevertheless, stiffer bitumen might result in thermal cracking. Using high optimum bitumen content and increased film thickness in the SMA, minimises the possibility of thermal cracking, especially in comparison with dense-graded mixture [13]. The utilisation of binders modified by polymer(s) along with fibre would enhance the resistance of the pavement against problems, such as rutting or fatigue cracking. The modified bitumen can be achieved through incorporating a quantity of stabilising (such as polymers) to conventional bitumen.

The function of filler in the SMA is essentially to stiffen the bitumen-rich SMA. The application of higher amounts of too fine a filler can lead to excessive stiffness of the mixture, rendering it difficult to work, which might result in the mixture being susceptible to cracking. A mineral filler is usually added into the mixture as part of the gradation of the aggregate. The content of the filler (passing the 75 um sieve) in the SMA mixture can range from 8 to 10% of the total amount of aggregate. This high content of mineral filler in the mixture plays a significant role in the properties of SMA, especially relating to the air voids (VIM), optimum bitumen content (OBC), and mineral aggregate voids (VMA). Due to the relatively large amount of the filler, the performance of SMA becomes very different from the other types of HMAs [5].

During the last decade, a range of additives have been introduced and developed to help improve the physical properties of the bituminous mixtures. Some additives, e.g., rubbers, fibres, artificial silica, polymers, carbon black, or a combination thereof, have been utilised in the mixtures. The role of these materials is to increase the stiffness and durability of the mastic during production and placement in hot conditions, especially in hot or tropical climates [1].

When polymer is used, it is normally mixed with bitumen before being delivered to the plant; however, in some cases, it has been added at the plant. Adding polymer can further stiffen the bitumen and enhance its resistance to drain down. Furthermore, polymer can enhance the adhesion property of the bitumen to the aggregate, especially in wet conditions. The polymers are added to the mixture usually in the range of 3.0–8.0% by weight of the bitumen [5].

2.3. SMA Mixtures Design Methods

The methods used for SMA designing, production, and placement are comparable to those applied to the design and production of dense-graded mixtures, normally carried out by Superpave or Marshall procedures. SMA primarily uses gap-graded aggregate, while the standard mixture utilises an aggregate gradation that is smoother and evenly distributed throughout the gradation, resulting in the production of a denser mixture [9].

The design of an SMA plays a key role in the provision of an aggregate grading that will accept a high amount of bitumen, which provides a durable mixture, without binder drainage. However, an unsuitable or incorrect SMA design can develop drainage in the truck bodies and fatted areas of the surfacing, particularly in thick surfacing areas. Conversely, the design of an aggregate that requires a low binder content in order to prevent binder drainage may result in a mixture with weak and short durability and having a reduced life.

Unlike an open-graded asphalt mixture, most of the voids among coarse aggregates within an SMA are usually filled with binder and mineral filler. Normally, 3–5% air void content is provided in the designed SMA. Excessive bitumen will push the coarse aggregate particles apart with a sudden reduction in the resistance of the pavement against shear deformation. The application of too little matrix may, however, lead to higher air voids in the mixture, resulting in a reduction in the durability of the pavement, its fast aging, and susceptibility to damage caused by moisture [1].

2.4. Marshall Method

The Marshall method is the most conventional and common method employed for making and evaluating trial mixtures in obtaining the optimum bitumen content. This method was initially introduced by a civil engineer collaborating with the Mississippi State Highway Department; his name was Bruce Marshall [9]. However, the initial features of this method have been improved through time by the American army corps of engineers, and standardised and elaborated in ASTM D1559. Usually, the Marshall method is used in the design of SMA to provide verification of the acceptable number of voids in SMA mixes. Specimens were prepared in the lab using 50 or 75 blows per side produced by a Marshall hammer. It is easier to achieve the compaction of the SMA on the road and the desired density level in comparison to that required by conventional HMA [5]. The procedures for heating, mixing, and compacting the mixture of aggregates and bitumen are specified by the Marshall method, which is then subjected to a test of stability–flow test and an analysis of density–voids.

A bitumen specification based on climate and traffic loadings, a volumetric mixture design and analysis system, mixture analysis tests, as well as a system of performance prediction including specific software, climatic database, and models of the environment and performance are the three main elements used in the Superpave. Nevertheless, the most important component of Marshall may be its new bitumen grading system, which is designed to link with pavement performance [14]. Therefore, Marshall can be considered as a system based on performance. It is a system of specifications applicable to asphalt pavement design that is strong enough to successfully tolerate traffic loadings and climactic stresses.

The volumetric properties include the percentage of air voids (VIM), voids in the mineral aggregate (VNA), and voids filled with bitumen (VFB). These properties enable highway engineers to fine-tune the asphalt mixtures to various climates and traffic loads. Therefore, pavements produced this way have proven to be of higher durability and less likely to rut in hot weather or to crack in cold weather.

3. Road Pavement and Modification

Road pavements start experiencing functional deterioration once they are open to heavy traffic or freezing of groundwater during the cold season. Deterioration can include fatigue stripping and rutting. In cold regions, groundwater freezing beneath the surface layer can result in serious cracks in the asphalt mixture even during a single cool season [15]. One way to increase the service life of road surfaces is using certain additives, such as polymers, to modify and improve the properties of the asphalt mixtures.

As mentioned before in the previous sections, several types of additives have been introduced and developed to help improve the physical properties of the bituminous mixtures. Some additives, e.g., rubbers, fibres, artificial silica, polymers, carbon black, or a combination thereof, have been utilised in the mixtures. The role of these materials is to increase the stiffness and durability of the mastic during production and placement in hot conditions, especially in hot or tropical climates [3].

Polymer-modified asphalt mixture is a combination with a wide variety of different uses in civil engineering and construction projects [16]. Adding polymers to the mixtures expands the bitumen's stiffness and significantly enhances its susceptibility against temperature fluctuations. This, in turn, enhances the mixture resistance to rutting, which is one of the commonest problems dealt with in pavement project agents and engineers in hot or tropical regions. In these cases, adding polymers to the mixture allows for the application of softer bitumen, which would offer outstanding low temperature performance. The accumulation of polymers to binders results in a significant increase in its cohesiveness and adhesiveness to effectively and strongly bind the mixture of components together. However, polymer plays another important role in the generation of an aggregate coating substance to improve the roughness of the aggregate surfaces and creates an improved asphalt mixture [10].

4. Polymer-Modified Asphalt

Different types of modifiers have been used in asphalt modification. These include polymers, which can be categorised as elastomeric and plastomeric, fibres, hydrocarbons, antistripping agents, and waste tyre rubber. Asphalt additives contribute to improvement in stiffness and elasticity [3]. Modified bituminous mixtures have higher stiffness and resistance against permanent and serious deformations and fatigue cracking [3][17]. The modifier type and polymer content have the main role of improving the asphalt rheology and, thus, in turn, improve the elastic recovery and reduce the rutting deformation [17][18][19]. A research study [20] indicated better binder–aggregate adhesion in asphalt modified mixtures, thus increasing its toughness level. Moreover, addition of polymer significantly improves the fatigue resistance and recovery properties [21][22][23][24]. This will result in better resistance to permeant deformation and increase the service life of road pavement [23]. One of the main advantages of applying polymer technology to bituminous mixtures is to improve the adhesion between the aggregates and binders. A study conducted by Khattak and Baladi [24] on the influence of polymer as a modifier revealed that the modification can increase the resistance of bitumen to loading, while making it less susceptible to temperature fluctuations.

Furthermore, some polymers increase the bitumen adhesion to the stones and its resistance to cracking. An ideal binder needs to have optimal cohesion and adhesion properties. The engineering properties of polymer-modified asphalt can be determined by the type of the applied modifier with respect to its content and depend on the type of bitumen employed. However, the main advantage of elastomers, such as styrene butadiene rubber (SBR) and styrene butadiene styrene (SBS), is their capability to increase the strength of the modified bitumen mixtures [25]. Numerous studies confirm that the application of crumb-rubber-modified binders to pavement mixtures can improve its resistance against fatigue cracking. According to Bahia and Davies [26], the impact of crumb rubber on engineering properties of bituminous mixtures is significant in a way that rubberised mixtures display higher resistance to rutting in comparison to the unmodified bituminous mixtures. Two kinds of blending process for bituminous mixtures are the wet and dry processes. In the wet process, the modifier is mixed with the bitumen prior to adding the aggregate, while, in the dry process, the modifier is first added to the aggregate and before the addition of the bitumen [3][17][21].

According to Brule [27], normal bitumen may not display tremendous engineering properties under "heavy loads and high or low temperature conditions". It becomes softer in high temperature and more brittle in cold regions. In order to solve this problem, polymer is usually added to bitumen to improve its engineering effect on the pavement performance, which enhances its resistance against fatigue cracking, permanent deformation, and moisture susceptibility. The stiffer the bituminous mixture, the more resistant it is to permanent deformation. Studies mentioned that polymer added to the mixture increases its elasticity and stiffness in hot climate temperatures [3][28].

Polymer can be described as a synthetic or natural compound of normally high molecular strength made up of repeated, linked molecules [29]. The polymers employed for modification purposes in bituminous mixtures are divided into three main categories: plastomers, thermoplastic elastomers, and reactive polymers. The addition of thermoplastic elastomers into binders gives them higher elasticity. However, the application of plastomers and reactive polymers make the binder stronger and more rigid against heavy traffic loadings that usually bring about serious deformation in the surfacing of the pavement [21]. Furthermore, plastomers increase the stiffness and viscosity of the bitumen in moderate temperatures. Nevertheless, the achieved performance through these modifiers concerning the enhancement of bitumen elasticity in sudden and frequent temperature fluctuations is not considered as satisfactory as expected [10]. However, some plastomeric polymers commonly employed for modification purposes are ethylene-butyl acrylate (EBA) and polyethylene (PE) [21].

Today, asphalt modified by polymer is quite costly in road pavements [13][30]. Therefore, it is important to analyse cost-effective methods to make the construction projects more economical and feasible before discussing its commercial use. For instance, block styrene-butadiene elastomer—also known as block SBS/SB rubber—is commonly employed by many countries to modify the engineering properties of the asphalt mixture. Nevertheless, even though it has excellent properties, the polymer-modified mixture has one main disadvantage, that is, the high price of the block styrene-butadiene elastomer, which restricts its wide application to most construction and pavement projects, especially in developing countries. One solution for this problem is the application of cheap polymers obtained from waste and disposed materials [30].

The first patent for bitumen modification processes with synthetic or natural polymers dates back to 1843, while the initial test projects in this field were launched in Europe as early as the 1930s and employment of neoprene latex was first enacted in North America in the 1950s [12]. However, 20 years later (1970s), Europe had already overtaken the US in the application of polymer-modified bituminous mixture for road pavement, since, in Europe, the warranties provided by contractors encouraged unprecedented interest in the reduced costs of the life cycle despite the higher costs in the initial phases of the projects. These initial costs restricted the use of polymer-modified bitumen in the United States. However, the mid-1980s witnessed the introduction and use of new types of polymers in Europe and then the US, where a poor economic outlook increasingly prevailed throughout the whole country. The Australian National Asphalt Specification has provided specifications and guides for polymer-modified binders [12].

An approach to life cycle cost analysis has been developed by the US Federal Highway Administration (FHWA) to assess and measure the life cycle costs applicable to pavement construction that use asphalt-modified binders and other additive treatments. The results of relevant studies reveal the cost-effective feature of asphalt rubber. A survey by the US States Department of Transportation carried out in 1997 discovered that 47 of the 50 states in the country were interested in the application of modified binders in their future projects, while 35 of the respondents said that they would employ the binders even in greater amounts in future construction projects [12]. Many studies have been conducted on the evaluation of the performance of polymer-modified pavement mixtures around the world. Furthermore, experiments on binders have been undertaken in various labs in different regions, the results of which are steadily being revealed. Based on a study known as Nevada, in 2003, the viscosity of binders modified by polymer at 60 °C is usually greater in comparison to the viscosity of unmodified binders despite the slight modifications of the penetration rate at all temperatures.

5. Waste Plastic

The growing quantity of plastic products, such as containers and bottles, consumed yearly all over the globe from the most developed to the least developed countries has turned the disposal of this material into a serious problem, especially in developing and developed societies. Plastic containers enjoy certain features that make them attractive and the preferred products of consumers. Plastic offers a strong material with low density that is ergonomic, durable, light, and cheap, which is usable in packaging and other industrial, medical, food services, and appliances, artificial implants, land/soil conservation, water desalination, flood prevention, housing, communication, and security applications. The annual consumption of plastic has globally jumped from about 5 million to 100 million tons within the second half of the last century. Hence, plastic has become one of the most important solid waste materials in recent decades [31].

However, some plastic items that are used to preserve food are disposable, which have to be discarded after one-time use and only a short time after purchase. Reusable plastic items are preferred since they can help save the resources and money of the consumers [32][33]. Therefore, multi-trip plastic containers have gained more appeal among manufacturers and consumers. This, in turn, contributes to a reduction in plastic waste materials in the environment.

Along with these solutions, recycling the disposable plastic items, or those that need to be discarded after a lifetime, can yield several advantages [31] as follows:

a. Preservation of limited fossil resources, such as oil, of which at least 8% is consumed to produce plastic items in the world, 4% for petrochemical feedstock, and 4% during manufacture, respectively;

b. Reduction in energy consumption;

c. Reduction in disposed and discarded solid materials;

d. Reduction in carbon dioxide (CO2), sulphur dioxide (SO2), and nitrogen oxide (NO) emissions.

Considering the points discussed above, recycling plastic waste materials contributes to a significant reduction in disposed plastic materials in the environment, as well as helping to preserve the natural fossil resources that form the main source of plastic production and manufacturing around the world. Plastic waste is increasing, and the investigation shows lack of the potential of secondary pollution. Thus, future research should be conducted to investigate this topic.

Application of Polyethylene Plastic in Asphalt

The modification of bituminous mixes with waste plastics seems to have great potential for use in flexible pavements to enhance their active service life or minimise the layer thickness of their wearing course or base layer. The application of waste plastic in asphalt modification increases the stability and service life of the pavement, in addition to improving its ability to tolerate high traffic loads, reducing its susceptibility to deformation, and imparting better aging resistance. In addition, waste plastic asphalt can meet the requirement for design, coating, and construction, and seems to be a substantial, practical, and economical alternative to other commercial polymers [14][33][34][35][36][37][38][39].

In this study, a kind of polyethylene was used as an additive in SMA. The studies specifically concentrating on the modification of asphalt mixtures through the application of polyethylene are inadequate [40]. The studies covering polyethylene-reinforced asphalt mixture and binders form only a small portion of the current publications and there is still a necessity for further studies focusing specifically on this topic.

Joint research by Awwad and Shbeeb investigated the results of the employment of polyethylene polymers to improve the engineering properties of asphalt mixtures. Their study was conducted to determine the best and the most proper polyethylene type and proportion to be used in the asphalt mixture to obtain the optimal result. Hence, they applied two types of polyethylene to the aggregate coating, namely, low-density polyethylene (LDPE) and high-density polyethylene (HDPE), respectively. The addition of the polymers to the mixture was carried out in two forms, ground and unground. The produced mixture samples displayed that the ground HDPE imparts better engineering properties to the resulting mixture. The most appropriate percentage of the modifier suggested by researchers to be added to the mixture is 12% by the bitumen weight. The results of this experiment further confirm that the introduced HDPE can contribute to the enhancement of mixture stability, slight increase of air voids (VIM), and voids of the mineral aggregate (VMA) in it, as well as the reduction of the asphalt mixture density [10].

Another study concentrating on the potential of LDPE prospects was jointly conducted by Al-Hadidy and Tan Yi-qiu to study the engineering properties of this polymer as a modifier that can be applied to asphalt mix modifications and improvements. The obtained outcomes confirm that the softening point of the binders modified by LDPE are comparatively higher, while its ductility values were fixed at the minimum specifications range (100+ cm), which, in turn, resulted in a decrease in loss weight percentage due to heat and air, which means a significant improvement in the overall durability of the original SMA. Furthermore, the results reveal that LDPE-modified SMA mixture can provide the optimal mixture for pavement construction and coating in regions with extreme temperature fluctuations and excessive moisture [41].

Sinan Hinishoglu and Emine Agar used other kinds of waste plastic materials with HDPE to modify binders with various blending temperatures, time lengths, and HDPE percentage. For this experiment, they used Marshall stability, Marshall quotient, and Marshall flow. They concluded that 4% of HDPE at 165 °C mixing temperature blended continuously for 30 min is the best condition for Marshall stability, Marshall flow, and Marshall quotient (MQ). As a result, a new condition applied to this experiment, the percentage of the Marshall quotient, was raised by 50% in comparison to the control mixture. Furthermore, the researchers noted that resistance of the HDPE-modified bituminous mix against serious deteriorations and deformation was significantly increased [42].

A study by Zoorob and Suparma revealed that using LDPE waste plastic in bituminous mixtures could result in a significant enhancement of its stability, i.e., approximately 2.5 times greater than the stability of the control mixtures, and durability, while decreasingly its density. In addition, the outcomes of the study showed that the plastiphalt fatigue life of the modified mixtures was longer than the control ones [43]. Furthermore, the adding of polyethylene into the porous asphalt mixture can also result in significant improvements in its oil-resistance properties.

There have also been other studies on the topic, among which some tried to investigate the effects of polyethylene on engineering and rheological properties of bituminous mixtures [44][45][46][47]. Based on the results of these experiments, adding the polymer significantly increased the rutting resistance of the asphalt-modified mixture. Moreover, using polyethylene as a polymer to asphalt mixture, the results confirmed that addition of the polymer results in improving the fatigue resistance, workability, and efficiency of the modified mixture [30][48].

According to investigation reports [49][50][51][52], using waste plastic in asphalt modification would essentially help reduce environment contamination and balance the economic system by sparing additional cost. Therefore, using waste plastic in asphalt enhances the temperature susceptibility and stiffness. Thus, waste-plastic-modified bitumen results in an enhancement in rutting and fatigue resistance [53][54][55]. Modifying and advancing the properties of bitumen and asphalt mix by using certain additives, such as plastic polymers, is one way of boosting the service life of road surfaces.

A study by Mashaan et al. [36] has investigated the impact of waste PET plastic on the engineering and performance properties of 14 mm dense-graded asphalt, which is widely used in course surfacing in Western Australia. The study emphasises that the 6% and 8% waste PET are the idealistic contents projected to modify and improve the strength, stiffness, durability, elasticity properties, and rutting resistance of asphalt mixtures. In addition, the rutting and fatigue properties of SMA mixture using waste high-density polyethylene (HDPE) have been enhanced as reported [56]. The study outcome shows that SMA mixtures modified with 4% HDPE have the best fatigue resistance at a fatigue life of 157,090 cycles; however, the 8% HDPE has the better rutting resistance at a rut depth of 1.05 mm.

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