Waste Plastic as Additive in Asphalt Pavement Reinforcement: A review

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ABSTRACT

This review paper focuses on certain essential factors of bituminous mixtures as well as polymer modified asphalt mixture and of waste materials. The application of polymer to asphalt mixture has been promoted as a means to improve the performance of asphalt mixtures. Adding polymer usually contributes to an increase in the stiffness of the bituminous mixture and improvement of its susceptibility to temperature variations and fluctuations. This, in turn, improves the resistance of the mixture to rutting. However, these days, asphalt mixtures modified by polymer are more expensive for road pavement purposes. Using waste polymers, as modifiers is one of the several ways to cut the expenses and reduce the overall cost of road pavement projects. Recycling and reusing plastic waste can significantly contribute to saving the environment from further pollution and the economy from extra expenses. It is also helpful in controlling discarded waste such as plastic beverage container to the other materials, which adds to the importance of the problem with their long-term negative effects on the ecosystem and environmental balance. In particular, analysis and discussion on using waste plastic in asphalt pavement will also attempt to clarify some of the terms and notions related to the discussions to give the readers the needed background to be able to actively join the experiments and discussions along with the researcher.

Keywords: plastic waste, polymer modified asphalt, environmental impact, engineering properties

1. INTRODUCTION

With increasing world population, the amount of waste production will increase substantially. This amount of waste causes a huge rise in the cost of waste disposal and also is filling the future sites for land fields. To solve the problem, considerable effort is being put into recycling waste and producing re-useable items [1]. Reusing is a kind of recycling which can reduce the amount of waste, reduce the cost for transport and production energy, lessen the demands for new resources and contribute to solve the disposal of waste problem [2].

Under the Environmental Public Health Act (EPHA), “waste” is defined as any substance or particle which is required to be disposed of as being broken, worn out, contaminated or otherwise spoiled, and for the purpose of this Act anything which is discarded or otherwise dealt with as if it were waste shall be presumed to be waste unless the country is proved [3]. Recently, environmental issues have become more and more important in our society. Social life scientists, politicians and economists are becoming more and more concerned about the environment. In most developed countries, lifestyle changes have contributed to grater national waste production. This change has called for concern over conservation of resources and a need for recycling and reusing to reduce waste production. Many studies are going on to research about advantages of reusing waste material in an economically and environmentally sustainable way [4]. Many investigations on the effect of reusing hazardous material on the construction material properties and its environmental impacts have been done [5]. Due to the lack of raw material and natural resources, using waste solid material in civil engineering projects especially roads construction has become a considerable issue [4,5,6]. Recycling of waste materials can include some solid and non-decomposable materials such as plastic bottles, plastic bags, containers, or covers, which, due to their longer biodegradation period, cause serious harm to the environment disturbing the balance of the ecosystem. Therefore, to minimise the negative effects of such materials on the environment, it is totally reasonable and logical to recycle such materials through civil construction and industrial production [7,8].

2. WASTE MATERIALS AND THE ENVIRONMENT

The construction of hundreds of kilometres of roads around the world every years results in the consumption of tonnes of raw materials and the impoverishment of natural resources in different parts of the globe. In addition, as an outcome of a consuming society, developed countries are currently facing a major problem from the huge waste materials produced daily by their residents. The disposal of these waste materials has turned into one of the critical issues of municipalities in modern cities. However, disposed waste material is not only limited to civil life, as they also come from some other source such as commercial, industrial, and the like. The worst part of the problem is that the major portion of the produced waste materials remain intact in nature for a long time or is expected to decompose at some time in the distant future. This consequently results in long-term environmental contamination obliging the authorities to find solutions, most of which are temporary, such as dumping the waste in landfills around large cities [9].

However, the currently available middens are running out of their capacity. In addition, the establishment of new sites for this purpose have encountered regulation stalemate, which restrict the conventional way of waste disposal through its burial around the living areas. This further complicates the issue of waste disposal and calls for a new method of waste disposal. Furthermore, assigning of new middens will add to the disposal costs that are imposed on the municipal authorities, and, ultimately, the taxpayers [10]. Solid and synthetic waste material consume natural resources for their production, as well as cause serious environmental pollution of the water, land, and air. It is noteworthy to mention that pollution, in any form, is a kind of waste itself. Therefore, waste middens and landfill can contribute to serious environmental problems both in the long-term and short-term.

3. RECYCLE OF WASTE PLASTIC IN PAVEMENT

Finding reasonable and cost-effective solutions for waste material disposal, such as recycling waste plastic, is one of the important responsibilities of scientist, engineers, researchers, and governments. These solutions should not only consider the environmental advantages but also reuse the solid waste materials in projects, such as road construction [5]. Therefore, effective recycling of waste plastic is one of the solutions sought by many researchers. Well managed reuse of waste has several advantages as shown in Figure1. There are different types of waste plastic which is employed as an additive in asphalt pavement like polyethylene terephthalate (PET), Low-density polyethylene (LDPE), High -density polyethylene (HDPE), and polyethylene (PE) [5-10]. 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. 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. Plastic is useful in packaging and other industrial, medical, food services and appliances, artificial implants, land/soil conservation, water desalination, flood prevention, housing, communication, and security applications, and so on. 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 [11].

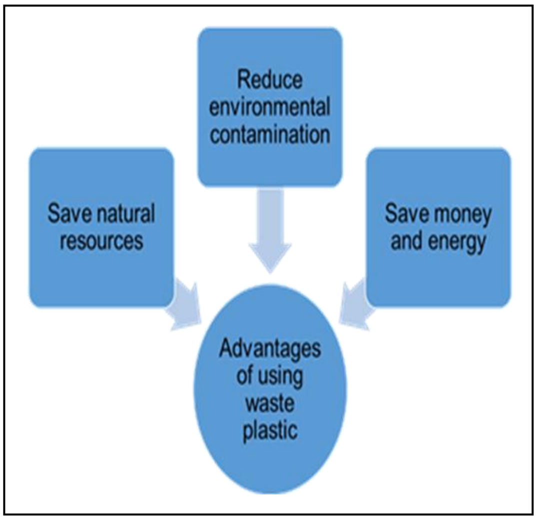

FIGURE 1 Advantages of using waste plastic

3.1 Modification and Reinforcement of Asphalt Pavement

Road pavements start experiencing functional deterioration once they are faced with heavy traffic, or freezing of groundwater during the cold season. Deterioration can include fatigue or alligator cracks, edge cracking, grade depressions, slippage and block cracking, potholing, ravelling, shoving, 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 [5-8]. One way to increase the service life of road surfaces is using certain additives such as polymers or fibers to modify and improve the properties of the mix. Modification of the bituminous mixture using polymers or fibers appear to have the greatest potential for successful application in the design of flexible pavements to increase the service life of the pavement or to reduce the pavement layer or its base thickness [12-14].

Polymers or fiber modified asphalt mixture is a mixture with a wide variety of different uses in civil engineering and construction projects [15]. The addition of polymers to mixtures increases the stiffness of the bitumen and significantly improves 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 allow the use of softer base bitumen, which can provide superior low temperature performance. The addition of polymers to binders results in a significant increase of 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 produces as superior asphalt mixtures [16]. Studies that have been conducted to classify bitumen modifiers according to their composition, categorised into several main groups, such as polymers (elastomeric and plastomeric), fillers, fibers, hydrocarbons, anti-stripping agents, and crumb rubber. These additives vary significantly in their physical and chemical properties, which have a wide variety of effects on asphalt concrete pavement performance, accordingly. Asphalt additives render the mixture stiffer, especially, in hot conditions and less stiff at colder temperatures. They control the elasticity of the mixture in normal temperature conditions [17].

3.1.1 Fiber in asphalt reinforcement

Fiber modified asphalt mixture is a mixture with a wide variety of different uses in civil engineering and construction projects. During a shared study, Wu et al.[18] conducted an investigation concerning the impact of polyester fibers on fatigue and the rheological properties of bitumen and bituminous mixtures. Their studies reveal that the binder viscosity increases with the addition of more polyester fiber contents into the mixture, particularly, at lower temperatures. The results of their research confirm the possibility of an improvement in the mixture, in term of fatigue property through adding fiber, specifically, where the stress level is low.

Huang [19] also carried out a research on asphalt overlays modified with polypropylene fiber. The modified and normal asphalt mixture samples of cores were transferred to the laboratory to be investigated and analysed under controlled conditions. It was revealed that the modified asphalt mixtures were stiffer and displayed improvements in durability and fatigue resistance. However, the main problem with polypropylene fiber was that due to its low melting point, the fiber was inherently incompatible with hot bitumen. According to Huang and White, further studies were required to rightly perceive the visco-elastic properties of the fiber-modified bituminous mixtures.

Another research was conducted [21] in which they analysed the possibility of applying waste carpet and tyre fibers in the SMA mixture. The added fibers play the role of a stabiliser in the SMA to prevent drain down, which is a result of high asphalt binder contents. In this study, the researchers compared the performance of SMA mixtures modified by tyre fibers and carpet with mixtures made with normally used cellulose fiber and other polyester fibers produced specifically for use in HMA. Concerning the permanent deformation and susceptibility to moisture, there was no significant difference between the two fibers in their results. However, carpet and tyre fibers significantly contributed to an improvement of the mixture toughness in contrast to the cellulose ones [21].

3.2 General studies of Using plastic as additive in Pavement construction

Normal bituminous mixtures conventionally used in pavement construction are susceptible to extreme temperature variations and climatic conditions, which usually lead to problems, such as cracking that may end up in fractures. Moreover, at higher temperatures during the hot seasons in tropical and hot regions bitumen mixture suffers from creep or flow. A stable pavement surface should not creep or flow under heavy traffic loadings. With this in mind, many researchers are involved in studies investigating the way they can modify bituminous mixtures by adding various additives to enhance its performance against the aforementioned problems. Table 1 shows different type of plastic has been used as additive in pavement construction. Casey et al., (2008) [15] also studied the potential of recycled polymer to modify binder. Basic tests were prepared and conducted on bitumen to evaluate the impact of the recycled polymer on the properties of the bitumen. The results of the experiments showed that 4 % of recycled HDPE in a pen grade binder can result in the most promising outcome and improve the properties of the binder.

A joint research by [16], 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 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

VTM and voids of the mineral aggregate (VMA) in it, as well as the reduction of the asphalt mixture density [16].

In this regard, A.I. Al-Hadidy and Yi-qiu Tan [20] employed LDPE plastic polymer to SMA mixes. Then physiochemical tests were carried out on modified and unmodified bitumen mixtures including performance tests such as Marshall stability, tensile strength, tensile strength ratio and resilient modulus. The tests results reveal that damage caused by moisture and susceptibility of the mixture against temperature fluctuations and variations can be reduced through the addition of ST and SBS into the bituminous mix. According to the same results, ST can also play the role of an anti-stripping agent in the mixture, reduce the plant emissions, save energy by about 30%, and increase its resistance to chemicals and solvents. As per the multi-layer elastic analysis results, pavement mixtures modified by ST and SBS consume less construction materials for the pavement.

TABLE 1 Data from previous research on using Plastic as Additive in Pavement

Authors	Type of plastic	Shape/size	Specifications
Ahmadinia et al, [12]	Waste PET	Chips/ shredded 1.18mm	Specific gravity: 1.3 g/cm3
Al-Hadidy & Yi-qui [13]	PP	Powder	Density: 0.82 g/cm3
Casy et al., [15]	Waste PP Waste HDPE Waste LDPE	Mulch PP Powder HDPE &LDPE	Melting point HDPE: 131˚C LDPE: 110 ˚C
Awwad & Shbeeb [16]	Waste HDPE & LDPE	Grinded and not grinded/ 2-3mm	Melting point HDPE: 125 ˚C LDPE: 110˚C Specific gravity (g/cm3) HDPE: 0.035 LDPE: 0.033
Al-Hadidy & Yi-qui [20]	LDPE	Gridded to powder	Melting point: 113.2˚C Specific gravity: 0.9205g/cm3 Tensile strength: 10MN/m2
Zoorbo & Suparma [22]	Waste LDPE	Pellet/ 5.00-2.36mm	Melting point= 140˚C Specific gravity= 0.92 g/cm3 Softening point= 120C
Kamada & Yamada [23]	Waste PP & PET	Pellet	Specific gravity PP: 0.921g/cm3 PET: 0.900 g/cm3
Hinislioglu & Agar [24]	Waste HDPE	Powder/ 2mm	Specific gravity= 0.935 g/cm3
Ho et al., [25]	Waste PE & LDPE	PE : wax LDPE: pellet and shredded	Not given
Attaelmana et al. [26]	HDPE	Pellet	Melting point: 149˚C Density : 0.9430g/cm3 Tensile strength: 3MPa
Vansudevan et al., [27]	Waste PE,PP & PS	Foam/powder	Softening point 120- 210˚C
Modarres et al, [28]	Waste PET	Chips/ crushed then sieved ; 0.425- 1.18mm	Not given
Khan et al., [29]	Waste LDPE & HDPE	Powder 0.15-0.75 mm	Density LDPE: 922kg/m3 HDPE: 961 kg/m3 Softening point LDPE: 95˚C HDPE: 127˚C

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 [13]. 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.

Another study concentrating on the prospective potential of LDPE was jointly done by Al-Hadidy and Tan Yi-qiu [20] 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 is comparatively higher, while its ductility values were fixed at the minimum specifications range (100+ cm), which, in turn, resulted in a reduction in the percentage loss of weight 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 [20].

A study by Zoorob and Suparma [22] revealed that using recycled waste plastic materials mainly composed of LDPE in bituminous mixtures resulted in a significant enhancement of its stability, i.e., approximately 2.5 times greater than the stability of the control mixtures, and durability, while decreasing 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.

Another relevant research by Osamu. [23] Investigated the possibilities of the application of disposed waste plastic, i.e., polypropylene and polyethylene, as part of the aggregate in the asphalt mixture. In their research, they found that the application of polyethylene or polypropylene contributes to a considerable improvement in the resistance to fluidity of dense-graded asphalt mixes. Moreover, it was also revealed that the addition of polyethylene would also contribute to significant enhancement in the bending fatigue destruction-resistance and anti-stripping properties of the dense-grade asphalt mixtures. Furthermore, the adding of polyethylene into the porous asphalt mixture can also result in significant improvements in its oil-resistance properties.

Hinishoglu and Agar [24] used other kinds of waste plastic materials with HDPE to modify binders with various blending temperatures, times lengths, and HDPE percentage. For this experiment, they used Marshall Stability, Marshall Quotient (Marshall Stability to flow ratio), and Marshall Flow. They concluded that 4 % of HDPE at 165ºC mixing temperature blended continuously for 30 minutes is the best condition for Marshall Stability, Marshall flow, and Marshall quotient (MQ). As a result, a new condition was 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 [24] it also suggested that using such waste possibly may lead to reduction of Carbon-dioxide (CO_2), Sulphur-dioxide (SO_2), Nitrogen-oxide (NO) emissions [20-24]. There have also been other studies on the topic among which was tried in his research to investigate the effects waste plastic materials with HDPE and LDPE on bituminous mixtures. During this experiments, he noticed that adding the polymer significantly enhanced the rutting-resistance of the modified mixture [25,26, 29]. Table 2 shows data of selected content of different types of waste plastic as asphalt modifier. Other studies [12, 27, 28,30] applied waste PET obtained from plastic bottle as a polymer to bituminous mixture. The results of previous experiments confirmed that by addition of the polymer the Marshall stability of the mixture was significantly improved. Using waste PET up to 10% display significant impact on increasing fatigue life of asphalt mixture [28].

TABLE 2 Data from previous research of selected content and type of waste plastic as bitumen modifier

Authors	Type of plastic	% of Plastic used	ideal % of plastic
Ahmadinia et al, [12]	Waste PET	2%,4%,6%,8% and 10%	6% by weight of bitumen Improving Marshall stability and resistance to permanent deformation up to 20%.
Al-Hadidy & Yi-qui [13]	Commercial LDPE	2%,4%,6% and 8%	6% LDPE Improving the softening point by 26%
Casy et al., 2008 [15]	Waste PP Waste HDPE Waste LDPE	2%,3%,4% and 5%	4% HDPE improve binder rheological properties
Awwad & Shbeeb [16]	Commercial HDPE & LDPE	6%,8%,10%,12%,14%, 16% and 18%	12% HDPE Increasing Marshall stability
Hinislioglu & Agar [24]	Waste HDPE	4%,6% and 8%	4% HDPE Improving Marshall stability Increase MQ by 50%
Ho et al., [25]	Waste PE & LDPE	2-4%	4% LDPE with lower molecular weigh
Attaelmana et al. [26]	Waste HDPE	1%,3%,5% and 7%	5% HDPE Tensile strength ratios greater by 85%. Increase resilient modulus by 59%.
Vansudevan et al., [27]	Waste PE,PP & PS	5%,10%,15% and 20%	10% PP, PE Showing higher Marshall stability by 58-60%
Modarres et al, [28]	Waste PET	2%,4%,6%,8% and 10%	8% Increase fatigue life by 20%
Khan et al., [29]	Waste LDPE & HDPE	2%,4%,8% and 10%	4% HDPE & 10% LDPE Better rutting resistance.

4. CONCLUSIONS

Asphalt pavement materials are increasingly subjected to heavy loads, heavy traffic, frequent stresses and various climactic and environmental conditions. When the produced asphalt mixture does not meet the climate, traffic and pavement structure requirements, to qualify as an optimal mixture, this kind of asphalt mixture needs to be modified by an additive to gain the required properties to be able to overcome the stresses and distresses that the pavement undergoes resulting from bitumen deficiencies in the mixture. Modification and reinforcement of asphalt offers one answer to overcome this problem and thereby improve the overall performance, engineering properties and durability of the pavement. According to the previous studies reported in this paper, an asphalt modifier can be added to the binder or the mixture to improve its properties. The choice of the modifier for a specific project depends on various factors, such as construction ability, cost and expected performance. There are several key factors affect the performance of the modified binder or mixture including asphalt properties and additive properties. Using waste plastic as additive in asphalt reinforcement has shown significant improvement on its engineering properties, which enhances the modified asphalt resistance to rutting, fatigue, deformation and moisture stability. Based on data of previous studies, 4% of waste HDPE is recommended as best content to achieve better asphalt performance properties in term of stiffness and rutting resistance, however; other had recommended waste PET up to 6-8% as an ideal modifier that increase fatigue life and, as such improve the long term performance and durability of the asphalt mixture.

From environmental point of view, previous studies suggested that recycling the disposable plastic items, or those that need to be discarded after a lifetime, can yield several advantages as follows:

i. Preservation of limited fossil resources such as oil of which at least 8% is consumed for the production of plastic items in the world, 4 % for petrochemical feedstock and 4 % during manufacture, respectively,
ii. Reduction of energy consumption
iii. Reduction of disposed and discarded solid materials
iv. Reduction of Carbon-dioxide (CO_2), Sulphur-dioxide (SO_2), Nitrogen-oxide (NO) emissions .

Considering the points discussed above, re-use of plastic waste 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.

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