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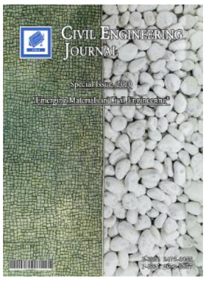

Review Article

A Review of the Utilisation of Recycled Waste Material as an Alternative Modifier in Asphalt Mixtures

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Abstract

The possibility of using waste materials in road construction is of great interest as their utilisation may contribute to reducing the problems of hazard and pollution and conserve natural resources. Thus, there is an urgent need to find a sustainable method for using waste materials as a substitute in the standard asphalt binders. There are several concerns about the physical and chemical properties and mechanical performance of asphalt pavements incorporated with waste material in the effort to reduce permanent deformation of the road surface. This review article presents a brief discussion of the asphalt mixtures modified with waste material, and the recycled materials used as a modifier in the asphalt mixture. The present paper summarises the use of crumb rubber, crushed concrete, steel slag, glass fibre and plastic waste in asphalt mixtures. The use of waste materials as a modifier in asphalt mixture resulted in improved asphalt pavement performance. Results advocate that rubberised asphalt mixture with desired properties can be designed as an additive with a friendly environmental approach in construction materials. The researches that adopted the influence of usage, recycle waste material to improve the performance of the asphalt of the road are still limited compared to other construction fields.

Keywords: Waste Materials; Properties; Asphalt Modifier; Asphalt Pavement; Recycling.

1. Introduction

In developed countries, the waste materials generated by the industries pose a serious environmental problem by manufacturers or individuals that lack any residual value is termed as waste [1, 2]. The feasibility engorging waste material used in the highways construction industry is playing a leading role worldwide as a green investment movement [3, 4]. In recent years researchers have been carried out to explore the possibility of using alternative waste material such as steel slag, plastic and scrap tires to construct Hot-Mix Asphalt (HMA) pavements to minimise the deterioration of road pavements [3]. In 2018, the total amount of waste generated, including those generated by households and economic activities in 28 European Union countries, exceed 2.5 billion tons. A total of 285 million tons of scrap tires are discarded in the USA yearly, as an example, as well as used in Portugal, China, Canada, and South Africa [5, 6]. Recycled scrap tires can be used as raw materials in the form or crumb rubber and powder rubber [7]. Research has shown that waste material such as rubber tires is suitable for incorporation in asphalt mixture since rubber tire can improve the performance of asphalt pavement and reduce the need to use new raw materials for the construction of road pavements [8-10]. Furthermore, the crushed concrete in several types of research confirmed that the recycled concrete aggregates (RCA) are applicable for reuse on the roads, concrete pavement when it is replaced

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with a proper percentage of new aggregate [11-14]. The use of recycled materials as an eco-friendly substitute has performance, economic and environmental benefits [15, 16]. Figure 1 shows the waste hierarchy applied to pavement materials. The most preferred choice is reducing the production of waste materials, whereas landfilling is the least preferable choice [15].

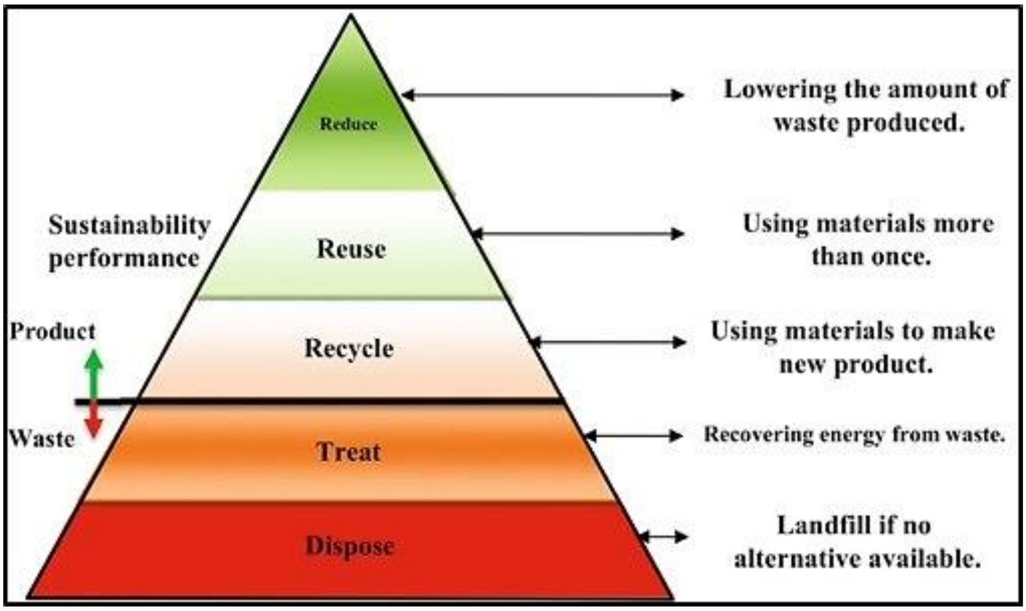

Figure 1. The waste hierarchy for pavement materials [15]

Recent studies have proven the economic advantage of adding tires to asphalt binders since recycled tires markedly reduce the need for using new materials [16]. The use of waste materials for asphalt stabilisation is regarded as a smart strategy for sustainable development. Many researchers have explored the methods for improving the use of waste materials such as crumb rubber, crushed concrete, steel slag, glass fibre and plastic waste in bitumen modifier for hot asphalt mixture properties and performance of factors affecting pavement damage. Table 1 summaries some of the previous research which used industrial wastes material in modified bitumen. The present study explores the possibility of using waste material to reduce/prevent permanent deformation of road surface and enhance the durability and strength of the road pavements. Section 2 describes the method used for sources of kinds of literature and strategies. Section 3 describes the primary property requirements for waste materials. Section 4 describes waste materials as modifiers for each type. Section 5 describes the challenges in incorporating waste materials in asphalt pavements, and Section 6 discusses the environmental and economic aspects. Finally, Section 7 presents the conclusions and final remarks.

Table 1. Summary review on the wastes materials used to modifiers in asphalt mixture

Author & Year	Additives by Percentage	Material Used	Test	Findings and Summary
Mashaan et al. 2013[17]	6, 12, 16, and 20%	Crumb rubber	1.Marshall test 2- Wheel tracking 3- Indirect tensile	1- Better stability 2- Better adhesion 3- The best enhancement was 12% in the wet process.
Arabani et al., 2018 [18]	1, 3 and 5%	Crumb rubber	1-Marshal tests	1-Improved stability. 2- Ideal percentage is 1%.
Pasandín et al., 2017 [19]	0, 35 and 42%	Crushed concrete & Waste tire rubber	1-Indirect tensile fatigue test (ITFT)	1-Improvement in fatigue performance 2-HMA containing RCA are suitable for medium and light traffic because of its low resistance to the fragmentation of RCA.
Ahmadinia et al., 2012 [20]	0, 2, 4, 6, 8 and 10%	Waste plastic bottles	1-Resilient modulus test 2- Drain down test 3- Wheel tracking test 4-Tensile strength test	1-Optimum PET is 4 and 6% by weight of optimum bitumen content 2- PET has better rutting resistance than the ordinary mixture.
Ziari et al., 2016 [21]	0, 0.25, 0.5, 0.75 and 1%	Waste plastic bottle (PET)	1- Dynamic creep test 2- Wheel tracking test	1-Reduced deformation on rutting.

Author & Year	Additives by Percentage	Material Used	Test	Findings and Summary
White 2019 [22]	6%	1- Plastic bags 2-Waste plastic bottle	1- Indirect tensile fatigue test (ITFT) 2- Wheel tracking test	1- Enhanced deformation resistance
Fu et al., 2017 [23]	0 to 0.8%	Glass fibre	1-Viscosity test 2- Direct tensile test	1- Improved crack resistance. 2-Improvement effects positively permeability. 3- High cost compare to the use of virgin asphalt.
Celauro & Pratico 2018 [24]	0 and 0.3%	Basalt fibre	2-Marshall test	1- Better rutting resistance. 2- Environmentally-friendly. 3-Cost effective
Wu. et al., 2014 [25]	0.3% and 0.4%	Lignin fibre Carbon fibre	1-Penetration test 2- Viscosity test 3- Cone penetration test 4-Rheological measurement	1-Significant improvement in mortar's softening point, penetration, viscosity, and cone penetration. 2-Optimal lignin fibre content of 0.3% and optimal carbon fibre content of 0.40%.
Maharaj et al., 2017 [26]	0 to 20%	Steel slag	1- Marshall stability test	1-The Marshall specification for the design of HMA is 15% of steel slag aggregate addition has similar features as the 0% formulation.
Gowtham et al., 2018 [27]	0 to 10%	Steel slag	1-Marshall test	1- Optimum stone substitution of 10% in the mixtures. 2- Increasing in the percentage of air voids and decrease in voids filled with bitumen because of the porous nature of the steel slag.
Li, et al., 2018 [28]	5%	Powder steel slag	1- Extended bending beam Rheometer test 2-Double-edge notched tension test	1- The addition of particles that are 5% larger can diminish the severity of reversible aging. 2- In regions with cold climate, steel slag has a better low-temperature performance than conventional limestone powder system.

2. Sources of Literatures and Strategies

This review focuses on the performance of five types of waste materials. All waste materials are readily available in their respective study areas as defined by the researchers. Highlighting is given to identifying effects on constrictions and environmental performance of asphalt mixtures after the incorporation of waste materials. This study also deliberates the effect of physical, chemical and mechanical modification of several materials and how these modifications affect the performance of the waste materials in the binder and mixes. Finally, the present study identifies the large gaps in the current literature and recommends future research. An organised literature review was carried out to meet the research objectives stated in the previous section. Pertinent works of literature are identified using keyword-based searches in various electronic databases and library services. Figure 2 shows the sources of literature that display two primarily explored the most famous indexed databases: The web of Science database and the Google Scholar database.

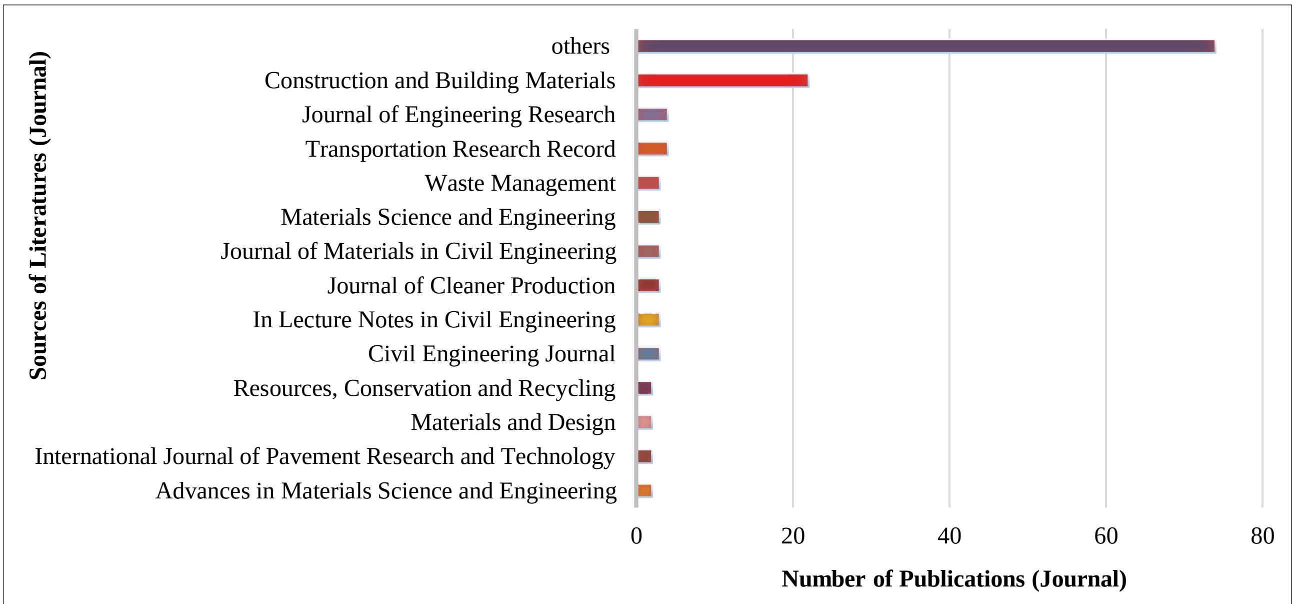

Figure 2. Sources of Literature

3. Property Requirements for Waste Materials

The feasibility use of waste materials comes with a list of reasonable engineering concerns such as the impact on production, strength and durability and future recyclability; environmental issues for instance processing and handling methods, leaching, emissions, fumes and economic issues for instance salvage value, life cycle costs and lack of funding [29-32]. Enhanced asphalt properties will improve the asphalt's resistance to many pavement problems. Various types of waste material are produced daily, and the volume of wastes generated continues to increase annually as consumption increases. The best method to deal with these wastes is by recycling and reusing them as modifiers or raw materials [33]. The recycled materials used in asphalt mixtures have to meet the same prerequisites as property classification. Figure 3 presents the requirements for incorporating waste materials in pavements. Lewandowski has researched and summarised the primary reasons for modifying bituminous materials with different types of additive [34]:

- To obtain softer blends at low service temperatures and reduce cracking.
- To improve the fatigue resistance of the blends.
- To increase the stability and strength of the mixtures.
- To obtain stiffer blends at high temperatures and reduce rutting.
- To reduce the structural thickness of pavements.

Finally, the modifier used in a specific project is influenced by various factors, such as construction ability, availability, cost, and expected performance. Several studies have shown that the technical reasons for incorporating modifiers in bituminous mixtures are to obtain stiffer mixtures at high service temperatures, prevent rutting, obtain softer mixtures at low service temperatures to minimise thermal cracking, and improve the fatigue resistance of asphalt pavement.

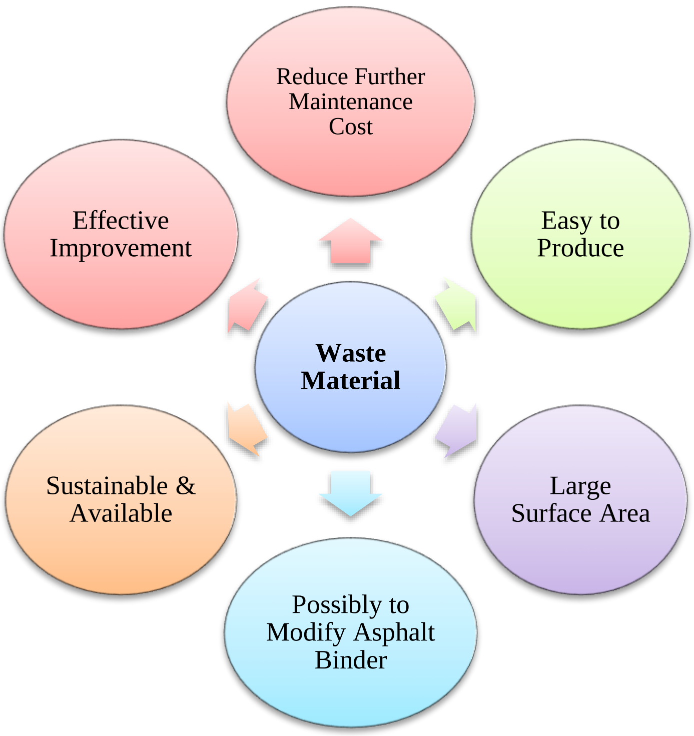

Figure 3. Requirements for incorporating Waste Materials in Pavement

4. Waste Materials as Modifier

4.1. Crumb Rubber

Disposal of used tires is a global problem as more than 50% of the tires are discarded without any treatment. About five billion more are expected to be discarded regularly by the year 2030 [35]. The use of crumb rubber as a modifier to enhance asphalt mixture is one way for ensuring sustainable development. Crumb rubber modifier (CRM) can be a substitute polymer material for enhancing the performance of HMA [5, 36]. CRM is a waste scrap tires disposed of in trash dumps, and each year about 1.5 billion tires are manufactured globally [37]. The use of crumb rubber in the design of asphalt pavements has reduced the amount of waste in the United States, where about 10% of the asphalt pavements contain 3% scrap tire [38]. Figure 4 shows the crumb rubber waste material before and after recycling. Two methods can be used to incorporate crumb rubber into asphalt mixtures, namely wet process and dry process. Scrap tire serves as a cement modifier in asphalt while another is used as a fine aggregate [39].

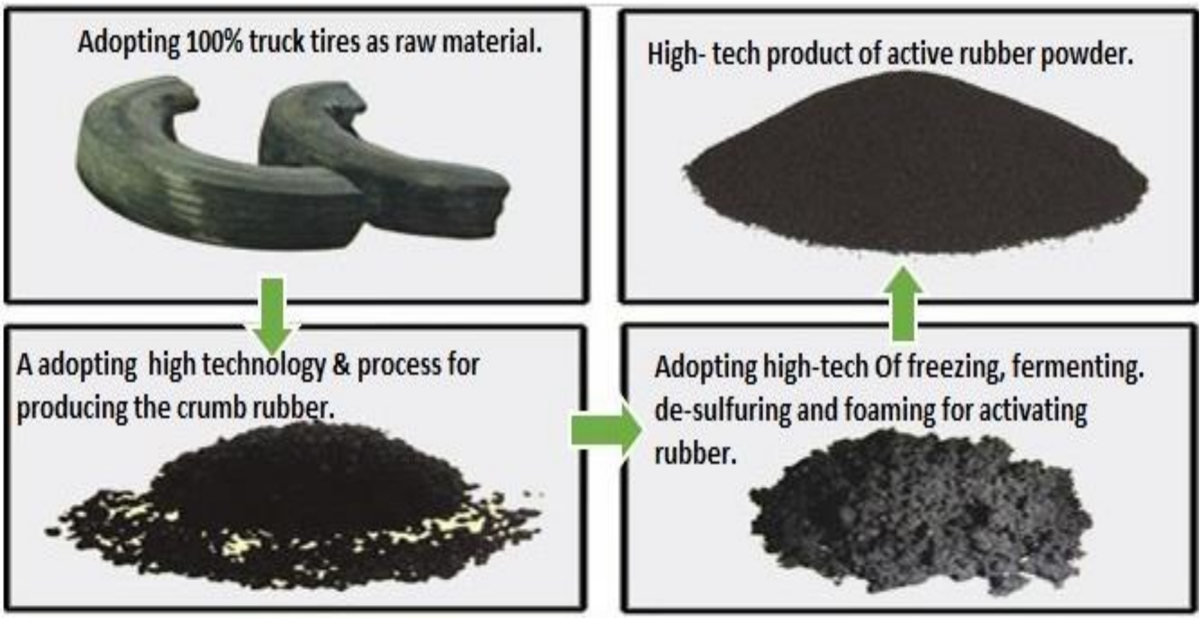

Figure 4. Crumb rubber waste material before and after recycling [40]

4.1.1. Physical Properties

The physical properties of modified bitumen are investigated to identify the improvement in the viscosity and softening point of bituminous binder. However, in order to attain a balanced and superior CRM low and high-temperature features, there are many factors, for example, temperature, time of mixing, source and characteristics of the bitumen and crumb rubber which need to be taken into account as these are the factors that govern the resulting performance of asphaltic mixes 80-100 penetration grade as displayed in Table 2 below.

Table 2. The physical properties of crumb rubber modified asphalt [41]

Binder property	Percentage of rubber (by weight of binder)						
	0%	6%	9%	12%	15%	18%	21%
Viscosity at 176°C (cP) (ASTM D2669)	60	550	800	900	1500	2500	6000
Cone penetration in 0.1 mm, 150 g, 5 seconds at 25°C (ASTM D5329)	48	40	43	44	40	30	27
Resilience (%) at 25°C (ASTM D5329)	-1	-1	12	19	23	40	47
Softening point, °C (ASTM D36)	50	52	58	60	61	63	72

The average loose density of tire shreds varies between 390 kg/m^3 to 535 kg/m^3 depending on the size of the shreds, while the compacted density range between 650 kg/m^3 to 840 kg/m^3 [42]. The stability, density, flow, air voids, and stiffness of HMA are markedly enhanced with the incorporation of up to 18% CR material by weight of optimum content significantly improved [43, 44]. Several researchers suggested the improvement of high-temperature long term storage stability without phase separation [45]. The incorporation of crumb rubber into asphalt mixture resulted in enhanced rutting and fatigue resistance, where the optimal percentage is 12% crumb rubber by weight of bitumen [17]. The incorporation of cryogenic rubber into asphalt mixtures can improve stability and reduce flow, improving fatigue resistance, rutting resistance, and low-temperature cracking.

4.1.2. Chemical Properties

The chemical properties of CR have a noticeable significant effect on asphalt, and each displays the nature of crude oil utilised to formulate it [46]. Asphalt consists of small amounts of various metals and hydrocarbons. Under normal atmospheric conditions, oxygen affects the weak bonding of the asphalt molecules and transform into water and carbon dioxide due to complete oxidation process [47]. However, the main chemical component of CRM is a blend of synthetic and natural rubber with various other components, including black carbon, polymers, sulphur, paraffin, oil, fabrics, pigments and bead or belt materials [48]. Chemical modification of CRMB changes the typical chemical bonding between the rubber particles and bitumen [51, 52]. The FTIR measurements from a previous study showed that the addition of CR modifiers into control asphalt binder could delay and weaken the aging and oxidation effects. CRMB also improved the binder's permanent deformation and thermal cracking resistance [51].

4.1.3. Mechanical Properties

The mechanical properties are based on the tensile strength ratio (TSR) and indirect tensile strength (ITS). The variation in shred size causes difficulty finding a considerable enough apparatus to carry out a significant shear test. A cohesion value of between 4.3 kPa to 11.5 kPa indicates that the tire chips have a permeability coefficient of between 1.5 to 15 ern/sec [52]. Tire chips have high insulating properties. The use of tire chips as fill material in subgrade applications results in a reduced depth of frost penetration relative to granular soil [32, 53, 54]. The dry process makes use of rubber as an aggregate. Typically, 2% to 3% rubber is prepended with the aggregates before charging the mixture with a pure asphalt binder [38]. However, the impact is mainly binder based, rubber content increases; the ITS value decreases.

4.2. Crushed Concrete

Recycled crushed concrete is a suitable material for incorporation into HMA used to construct flexible road pavements. The use of recycled crushed concrete requires removing, breaking and crushing the concrete into a material with specific quality and size. Hence, there is a new generation of planting concrete (PC) made from recycled aggregates of demolished concrete to improve the fertiliser retention features and enable cost reduction. There are many benefits of using crushed concrete, and one of them is enhanced performance of pavement construction. The process of producing new road materials by crushing old roads and using the materials as the base layer for the new asphalt pavement is known as rubblisation [55-58].

4.2.1. Physical Properties

Research have shown that the incorporation of crushed brick and crushed concrete has a small to minimal effect on the physical and mechanical properties of the original material [8, 56, 59]. Up to 15% of crushed brick can be safely added to enhance the physical properties and improve pavement performance. RCA is characterised by low gravity and high-water absorption compared to natural aggregates [60], and this has the effect of enhancing the physical properties of the mixture. Based on the result of penetration index and from another side, it has reduced using the natural aggregate in the asphalt mixtures.

Table 3. The Physical Properties of Crushed Concrete modifier asphalt [56]

Test Item	Test Result	Technical Requirement
Penetration (25°C, 100g, 5s)	53	40-60
Penetration index (PI)	0.06	≥ 0
Softening Point (°C)	87.0	≥ 75
Ductility at 5 °C (cm)	33.1	≥ 25
Dynamic viscosity at 135 °C (Pas)	2.99	≤ 3
Flashpoint (°C)	246	≥ 230

4.2.2. Mechanical Properties

The mechanical properties of the asphalt mix affected with a recycled concrete additive for the low-volume road classify them according to their applications in different pavement layers for different traffic volume roads. It is recommended that a certain percentage of RC additive in HMA be used for low-volume roads and useful for creating low-volume methods, as explained by the statistical model [61, 62]. The use of recycled concrete from damaged concrete can enhance the efficiency of asphalt mixtures, reduce the initial cost of production, and the volume of recyclable materials in the environment [64, 65]. In summary, compared to asphalt mixtures containing only natural aggregates, the mixtures containing recycled concrete RC additive have superior deformation strength, IDT strength, TSR, and rut depth properties. Also affected when the recycled concrete additive is added, which has enhanced the optimal bitumen content of the asphalt mixtures. Although the elastic modulus of the asphalt mixes was reduced, furthermore, the asphalt mixture modified with recycled concrete RC additive achieved lower stripping resistance than RC-free mixes [65].

4.3. Plastic Waste

Waste polyethene terephthalate (PET) makes up about 60% of the plastic waste and is the primary component of plastic waste. The addition of PET as a modifier in asphalt binder and asphaltic mixtures besides treating aggregates against moisture and can increase the mixture's strength [66-69]. Thus, incorporation of plastic wastes into asphalt mixtures perform a dual function of enhancing the flexibility of pavement performance and reducing environmental pollution [70].

Many types of plastic recycling are derivatives from PET of plastic waste rich in polyethene, polyvinyl chloride, polystyrene, and polypropylene-like bottles, cups, and bags are used as additives in asphaltic mixtures. The recycled plastic does not release any toxic gas during the softening process [71].

Adjusted binder demonstrated the tremendous improvement in rheological characteristics to further binder materials, known as shredded plastic and high-density polyethene HDPE. The addition helps to solidify the mix.

4.3.1. Chemical Properties

The chemical properties of asphalt modified binders were investigated using Fourier transform infrared spectroscopy (FTIR) and differential scanning calorimetry (DSC). These two methods complement each other [72]. Some mathematical equations showed significant correlations between the FTIR parameters and XRD parameters with PET parameters. Higher PET content increases aromaticity while reducing the oxygen-containing groups and aliphatic. Highly substituted aromatic rings are the primary aromatic features in low-rank bituminous PET, while condensed aromatic nuclei exist in the high-rank of bituminous PET and anthracite [59].

However, based on surface energy test to study the surface tension of the asphalt modifier, the functions of high-density polyethene (HDPE) and low-density polyethene (LDPE) will impact the composite surface. Hence, the contact angle was measured to prove the surface energy and changes in the composites. The dispersive contributions and polar of the surface energies were calculated for the PET component created upon the initial contact angle values [73].

4.3.2. Physical Properties

The physical properties of plastic waste as Polypropylene (PP) Plastic was used as a modifier for enhancement asphalt pavement durability. The result was very environmentally friendly [74], and the use of this material produced superior asphalt pavement relative to cement concrete pavement [75]. The incorporation of higher amounts of this plastic waste increased the softening point, penetration grade, and viscosity of the asphalt, and thus enhanced asphalt performance and reduced the effect of rutting [76, 77]. The mechanical performance of asphalt mixtures properties of PET is affected by crystallisation. Crystallinity is obtained by heating above the glass transition temperature; the chains become more flexible and can unfold under stress [78].

The rigidity of the binder increased as high as 4-6% of PET content due to the high compatibility between particles [79]. Two parameters that show the hardness, resistance to binder deformation under load, and fermentation or elasticity of asphalt, which are the complex shear and phase angle of the virgin binder, were drawn at different rates of LDPE, HDPE, against the temperature to deliver concurrent plots. The rutting border perimeter is plotted against temperature to obtain a master curve for the binders for investigation and analysis, as shown in Table 4 in some parts PP considered as the optimum in physical properties among LDPE and HDPE for the reason of PP chemical chain [80].

Table 4. The Physical properties for LDPE, HDPE and PP [79]

Physical property	Base bitumen	LDPE	HDPE	pp
Specific Gravity	1.019	Density=922 kg/m^3	Density=961 kg/m^3	910
Penetration @ 25 °C, 0.1mm	59.1	95	127	89
Softening point (°C)	49.45	57	54	53
Flashpoint (°C)	310			322
Ductility (mm)	126.5	134	130	111
Viscosity @ 135 °C (cP)	460.35	530	570	580
Super-Pave performance Grade PG	64-10	64-10	64-10	64-10

4.3.3. Mechanical Properties

The addition of plastic bottles to the asphalt mixture increases the performance of the asphalt mixture and promotes their reuse [81], and a comparison was made between the original asphalt mixture and polymer-modified mix. Varying percentages of waste PET was added for improving the fatigue and stiffness properties of asphalt mixtures at optimum asphalt contents at three levels of stress (450, 350, 250 kPa), at 20°C. Results showed that the temperature of plastic asphalt is higher than the unmodified asphalt, which increases the characteristics of the road mix [82].

However, stability improved and water damage resistance increased when plastic material in strip shape less thickness and that to increase the surface area for reinforcement asphaltic mixture with the amount of 7% by weight of total [83]. The properties of high-performance asphalt mixtures can be improved through the addition of various combination of plastic wastes, namely, Polypropylene (PP) plastic and polyethylene (low-density and high density) [84]. HDPE is superior than LDPE and less expensive [85], and is preferred over LDPE to improve the mechanical properties of asphalt mixtures. Modified bituminous mixtures contain packaging material that has properties like to retain stability, Marshall Stability, and ITS better than unmodified bituminous mixes [86]. Waste plastic, which was used as a stabilising additive in asphalt mixture, was subjected to performance tests, and results showed that the addition of 10% shredded plastic produced a durable pavement [87]. According to summary reports (Mashaan et al. (2019a) and Mashaan et al. (2019b)), the use of waste plastic as a modifier in asphalt mixtures is an economical and effective method for preserving the environment from being further polluted. The use of plastic waste also has the benefits of improving bitumen’s temperature susceptibility and stiffness, enhancing the rutting and fatigue cracking resistance of asphalt pavement [88, 89].

4.4. Glass Fibre

That fibre can oppose the additional snugness in asphalt because of an expanded heap of development, consequently enhancing weariness life by expanding split opposition and constant twisting, particularly at high-weight level [90].

The conceivable focal points of utilising filaments to fortify black-top clearing blends incorporate decreased weariness, warm and intelligent splitting, expanded administration life and financial advantages [91]. The types of fibres strengthening, to a great extent, limit the forming of longitudinal incisions. Figure 5 shows the glass fibre waste material before and after recycling. Glass fibres can be classified into three categories:

i. Natural fibres (banana fibre, cellulose, coconçut, jute, lignine, sisal).

ii. Synthetic fibres (aramid fibres polyester, polypropylene, etc.).

iii. Mineral fibres (carbon, asbestos, basalt, glass, steel fibres etc.).

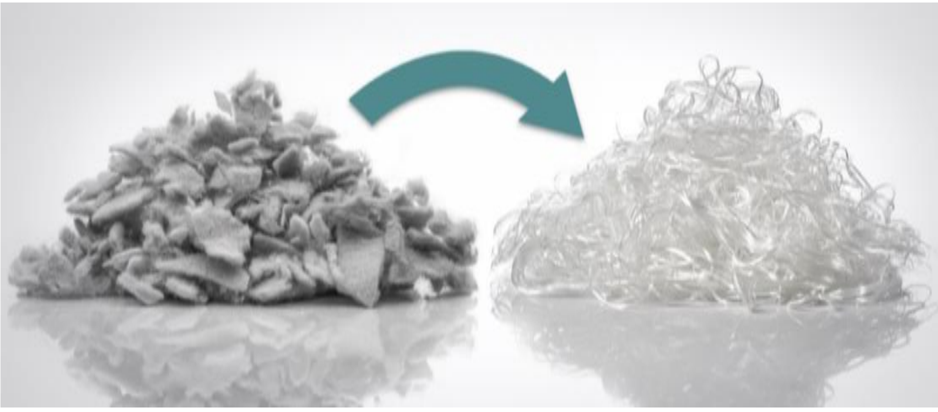

Figure 5. Glass fibre waste material before and after recycling [92]

4.4.1. Physical Properties

The expansion of fibre-glass influenced the properties of bituminous blends by an increment in the stream esteem and diminishing its dependability and, additionally, the spaces in the blend [90]. The filaments can confer physical changes to bituminous blends, for example, support and toughening [93]. Isolated filaments give a high surface territory for every unit weight and act much like filler materials, which mass the bitumen wiping out total keep running off amid development [94]. Investigation of physical properties suggest that different sizes of fibre-glass tend to reduce penetration while increasing hardness and softening point [95]. These fibre sizes are within the recommended fibre dimensions used in previous studies (Table 5).

Table 5. The recommended dosage and dimensions for mineral fibres used as reinforcement of asphalt mixture

Author	Fibre	Length (mm)	% Used
Park et al., 2015 [96]	Polyvinyl alcohol	13	0.5-1.5
Otuoze et al., 2015 [97]	Waste HDPP		0.5
Vadoo et al., 2015	Polypropylene & Polyester	10 – 20	
Woo et al., 2015 [98]	Carbon, Mineral & Cellulose	0.5 – 6	1 – 2
Xiong et al., 2015 [99]	Polyester	6	
Xue et al., 2016 [100]	Mineral fibre	2 – 8	3 – 9
Anurag et al.,2009 [101]	Waste Polyester	13	0.5
Chen et al., 2009 [102]	Polyacrylonitrile	5	0.3
Tapkin, 2008 [103]	Propylene	10	1

Given that each modifier has its advantage, the use of a combination of asphalt modifications could produce a competent asphalt binder. The length of fibre glass utilised significantly affects the versatile figure execution asphalt binder and its physical properties [7, 104, 105] It is accepted to transport physical changes to the bituminous blends by fortification and stress [93]. For activity, blends with filaments demonstrated a slight increment in the ideal cover content of the control blend [106].

The degree of sand dispersion in a blend determines the quality of the resulting mixture [107]. Adding fibre is valuable since it will help create an increasingly adaptable blend and in this way be progressively impervious to breaking [108, 107].

The results of conventional test of the physical properties showed that the addition of glass fibre enhanced the hardness of the modified asphalt binder. In general, an investigation on the conventional properties noted that adding glass fibre had a significant influence on asphalt binder rather than the unmodified [110].

Penetration value indicates the stiffness of an asphalt binder and softening point when the asphalt binder begins to become fluid. Table 6 shows the physical properties of modified glass fibre [111, 112].

Equally important, an illustration of the table noted that the optimum viscosity domain for asphalt binder was not too high for compaction asphalt mixture because the viscosity values reduce gradually with an increase in the temperatures [111-113].

Table 6. The physical properties of glass fibre-modified asphalt [111]

Bitumen	Penetration at 25 °C (0.1-mm)	Softening point (°C)	Viscosity at 135°C (Pa.s)
Fibre-glass modified binder	54	59	0.60
Rubber-modified binder with fibre glass	59	55	0.56
Polymer-modified binder with fibre glass	48	59	0.62

4.4.2. Chemical Properties

The chemical composition of a raw material determines which chemical propertied of asphalt is affected [114, 115]. Therefore, the interfering phenomena of the chains in the spectra are common in complex materials. The peaks in spectra present the infrared absorbance in the materials, and it also reflects the extent of bonds in the materials. Hence, if the quantity of bonds in the asphalt binder is too small, it means that the difficulty of revelation is growing. According to the surface composition, it is rich in rubber as confirmed by S from vulcanising and by Ca and Si utilised as oxides in fillers and HDPE. These aggregates are responsible for the crystalline part of the composite because of the HDPE content. Mechanical interfaces that were highlighted involved rubbers (with traces of Si, Zn, S) and HDPE. This finding has been proven by FTIR, which showed a null or slight presence of glass fibre, as this zone has deficient oxygen. The same result indicates the PET scrap, as recording a high percentage of oxygen and the amount of Na (sample 2a-CS) following glass fibre functionalization with SDS. Elemental analysis showed that the glass fibre functionalised composite involves large voids, particularly more abundant for the Type P composite. Hence, this ascertains that SDS promotes a better attraction among glass fibre and the hydrocarbon components, thus denser composites [73]. The addition of this modifier into a modified asphalt binder as a compatible modifier tends to disperse the asphalt matrix and create a homogeneous mixture that is susceptible to temperature with high-temperature storage stability [116].

4.4.3. Mechanical Properties

The performance testing of asphalt mixes is conducted to evaluate the glass fibre and enhance the performance of pavements [111]. The modification of asphalt mixtures with glass fibre can improve the mechanical properties of asphalt mixtures, including the flow value, stability, and voids. Several studies have shown that modification of asphalt with 1.25 mass of low density of glass fibre resulted in enhanced fatigue rutting and rheological properties of the mixture [117, 118]. A study with different factors to evaluate the performance of fibres in asphalt mixture and their findings revealed that 4 - 6% of this material could be added to the asphalt mixture for enhancement of resistance to permanent deformation, increase the stiffness (Marshall Stability), and control flow of the mixture. Results also provide lower binder drain down and save the environment by reducing waste plastic environmental pollution [81].

4.5. Steel Slag

Steel slags are the by-product from steel manufacturing [119]. There are two kinds of steel slag, namely basic oxygen furnace (BOF) and electric arc furnace (EAF) [120]. The type of steel slag is determined by the cooling down process and chemical composition of the slag [74, 121, 122]. In 2006, an estimated 114-280 million tons steel slag was produced globally [123]. In 2013, 37% of the steel slag was used in road pavement, and 97% of the steel slag produced in Germany is used as aggregates in the in the base, sub-base and surface layer of road pavements [124]. In Malaysia, steel slag is utilised as aggregate replacement for sustainable construction of highways. Steel slag aggregate benefits the environment and reduces the amount of granite used in the construction of highways [125]. It can be used to stabilise HMA. Pavement containing steel slag mixed with asphalt is better than ordinary asphalt pavement and hence utilised in road pavement, for example, construction of expressway [121, 126].

4.5.1. Physical Properties

The features of steel slag, for example, substantial ratio, excellent abrasion resistance, rough surface and firm combination with asphalt can be utilised widely in road engineering. In the same view, the aggregates of steel slag are flat shaped and too angular, with cells which are not well connected that it gives a firm surface area rather than the natural aggregates, and this steel slag aggregate provides a great bond with the bitumen [100, 127]. Table 7 shows the physical properties of steel slag.

Table 7. The physical properties of steel slag [128]

Property	Value
Los Angeles abrasion (ASTM C131), %	20-25
Sodium sulphate soundness loss ASTM C88), %	< 12
Angle of internal friction	40-50
Hardness (measured by Moh’s scale of mineral hardness)1	6-7
California bearing ratio (CBR), % top size 19mm (3/4 inch)2	Up to 300

4.5.2. Chemical Properties

The chemical evolution of slag needs further concoction arrangement of steel slag, an unpredictable lattice structure comprising mostly of straightforward oxides decided from an essential examination of x-beam fluorescence. Minor components incorporate sulphur, press, manganese, soluble bases and a few others. Table 8 presents the rundown of different scopes of mixes contained in steel slag as revealed by Yildirim and Prezzi (2011) [129].

Table 8. The chemical composition of steel slag [129]

Constituent	Open hearth steel slag	Basic oxygen
Calcium oxide (CaO)	258.8	41.3
Silicon dioxide (SiO_2)	16.4	15.6
Iron (FeO or Fe_2O_3)	26.0	20.0
Magnesium oxide (MgO)	10.0	6.9
Manganese oxide (MnO)	11.2	8.9
Aluminium oxide (Al_2O_3)	2.4	2.2
Titanium dioxide (TiO_2)	0.8	0.5
Free lime (free CaO)	2.1	3.3

Liu et al. (2019) evaluated the chemical composition of the steel slag using X-ray fluorescence spectrometer (XRF), and the mineral composition was examined and analysed using X-ray diffractometer (XRD). The asphalt was analysed by Fourier Transform Infrared Spectroscopy (FTIR). The primary minerals present in steel slag are Ferro ferric-oxide Fe_2O_3, i.e., dicalcium silicate, tricalcium silicate and triton tetroxide, which chemically react with asphalt to create new substances [130].

4.5.3. Mechanical Properties

According to The Federal Highway Administration (FHWA), steel slag has useful mechanical properties that can markedly improve the performance of asphalt pavement [131]. Economists recommend adding SSA to the asphalt mixture for road constructions to reduce the cost of extracting and processing natural aggregates as well as the cost of transporting and treating steel waste at vast number of stockpiles [28, 132]. The use of natural aggregates in the asphalt layers of road pavement is not cost-effective when steel slag is readily available. The use of waste materials is very beneficial for the environment, economy, and society [133, 134].

5. Challenges in Incorporating Waste Materials in Asphalt Pavements

The use of waste materials in road and pavement construction and throughout the globe has many advantages; among the benefits are the low initial cost to develop infrastructure and that requires advanced technology to prepare and process to be implementable to meet the requirements of pavement materials [5]. Besides, existences waste materials affecting the high costs of pavement construction. However, decrease the cost of pavement construction in the long-term. The potential difficulties and barriers in using waste materials in the pavement sector are related to the recycling process. Some sensors detect and sort waste based on chemical composition, the durability of the resulting asphalt and concrete mix can also be affected [41]. The private sector could adopt a possible solution way to such a logistical case. The recycling of infrastructure development based on the public-private partnership sector. Governments can offer incentives in the form of tax exemption might to encourage pavement technologists and contractors to use waste materials. This policy of sustainable production has been successfully implemented in China [53].

Moreover, training and facilitating paving crews and material technologists to use a different type of waste materials pavement construction and practice codes should be provided. Currently, there is no standardised practice code using waste glass, plastic, or steel slag. The appropriate number of uses depends on the type of waste material. It is impossible to define an answer that encompasses every composition. Furthermore, various waste materials must be ranked based on their potential for recyclability.

6. Considerations of Environmental and Economic Aspect

The use of recycled waste materials in asphalt mixture and asphalt binder is a method for managing waste material sustainably and to produce a superior binder for constructing asphalt mixture [135, 136]. Waste materials have promising potential in terms of economic and environmental benefits. Both developing and developed countries demolish buildings on a daily basis [2]. Countries that are densely populated and have scarce liveable land areas have to minimise landfill areas. The use of demolition waste in an asphaltic mixture can reduce the need for landfilling. On the other hand, tire rubber can be used in asphaltic mixture and asphalt binder [79]. This waste provides a low-cost solution both as an additive and binder modifier.

Different types of plastic waste, glass fibre and steel sludge can be recycled in the asphaltic mixture and contribute to sustainable practice and becomes an industry practice for constructing stone mastic asphalt and can be effectively used as a filler in asphalt mixtures [15]. The decision to use industrial waste materials in concrete pavements reflects environmental pollution, maintenance liability, technological risk, resources provided and cost of production. There are still a few problems faced by many researchers about leaching. For instance, the crumb rubber modified asphalt contains heavy metals such as polycyclic aromatic hydrocarbons (PAHs) and zinc (Zn) due to the high concentration of toxic chemicals that can affect our health and the environment [5]. The result of heavy metal analysis showed that heavy metals in steel slag do not pose any environmental risks or leaching problems when used as aggregates in road applications [137]. Besides, the environmental impact of waste materials has raised concerns about the possible environmental harm caused by the improper handling of recycled materials, as well as concerns about leaks, spills, dumps, or other forms of hazardous substances released into the environment.

7. Conclusions

This study has conducted a feasibility test on the alternative materials used in asphalt mixture and transportation infrastructure. These alternative materials, for instance, plastic waste, crumb rubber, glass fibre, steel slag and crushed concrete, showed promising results as they could be used as an alternative aggregates substance that could be used in the asphalt mixture design. These alternatives not necessarily be an aggregate replacement alternative but could be an additional substance to the aggregate to increase particular physical and chemical attributes from the asphalt mix design. Although there is research on the potential use of waste material in road pavements, there are knowledge gaps and concerns that need concentrated study and assessment in the interest of building better paving and preserving natural resources. There are many advantages in using waste material in asphalt mixtures as it is useful for environmental issues. The following conclusions are drawn and should be taken into consideration by future studies.

- Waste material can be utilised as a choice aggregate in asphalt mixtures. Nevertheless, the primary chemical properties and impurities must be taken into consideration.
- Waste materials are given a new chapter of life as a low-cost novel additive to asphalt mixture. Waste materials can give superior performance to asphalt binders and promote cleaner and sustainable production.
- The use of waste plastic as a recycled polymer to modify asphalt could produce the same result as commercially manufactured polymers by increasing rutting resistance, fatigue life, and reducing cost. The reuse of plastic waste can contribute considerably to protecting the environment from future pollution.
- All the studies on waste material revealed almost different possible ratios from others. Hence, the development of fixed replacement ratio is required. The reason was that the features of the waste materials depend on various factors, for example, quality, source of extraction, handling, variation in the composition of minerals etc.
- The problem of quality control: Wastes have a good potential for use as a replacement for conventional material in flexible pavement, but it is not feasible to use waste materials as they are made up of several undesirable mixtures of materials.

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9. Conflicts of Interest

The authors declare no conflict of interest.

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