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The Utilization of E-Waste in Asphalt Pavement: A Review

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Abstract: E-waste generation has increased due to the rapid rate of modernization and technology development. The total amount of E-waste is estimated to be 65.3 million metric tonnes by 2025 globally. This rapid growth is making E-waste management a global issue. Electronic waste includes electronic devices, which reached their end-of-life such as computers, screens, televisions, smartphones, tablets, radios, air conditioners and refrigerators. The disposal of electronic waste is difficult because of highly toxic and non-degradable plastic contents and metals such as lead, lithium, copper and chromium, which can result in adverse effects on the environment. To deal with this issue, several studies have confirmed that electronic waste can be used in experimental works related to asphalt pavements, bitumen and bituminous mixes can be modified in order to improve the performance of bituminous concrete mixtures. According to the obtained results from previous and ongoing research efforts, the use of E-waste plastics in asphalt pavement materials have enhanced the asphalt pavement properties such as resistance to permanent deformation, high-temperature properties and asphalt stability. This paper affords an overview of the studies that have been conducted using E-waste in flexible pavement. This review transacts through the applications of electronic-waste plastics within the asphalt modification in an environmentally friendly manner. Furthermore, the impact of E-waste on the durability, stability, viscosity, penetration, softening point and low and high-temperature performance are discussed.

Keywords: E-Waste, asphalt pavement, asphalt modification, asphalt performance, friendly environment

1. Introduction

E-waste generation has increased due to the rapid rate of modernization and technology development. The electronics and electrical industries have witnessed a marked increase with the rise in urbanization [1]. This rapid growth is making E-waste management a world issue. Electronic waste includes discarded computers, mobile phones, televisions, tablets radios, printers, air conditioners and refrigerators. In short, the electronic devices that have reached their end-of-life. According to the Global E-Waste Monitor 2020, the world generated a record of 53.6 million tonnes (Mt) of E-waste in 2019. Out of this, only 17.4% of E-waste was officially documented as formally collected and recycled, which means that 44 million tonnes of E-waste were placed in the landfill, burned or illegally sold and handled in an ineffective way. The total amount of E-waste is expected to increase to 65.3 million metric tonnes by 2025 globally (Fig. 1) [2], with a yearly generation rate of 3 to 5% [3].

Most of the electronic waste materials are repairable and recyclable but due to the higher cost of processing worthless pieces, such electronic waste is discarded usually. Untreated E-waste is disposed of in landfills, which poses a concern due to heavy metal leaching into groundwater and incineration, which releases toxic materials into the air. Thus, a well-designed, controlled E-waste recovery and reuse system is required. Therefore, the thrust area of today's research is to find an eco-friendly way to dispose of e-waste materials.

The utilizing of E-waste materials as an alternative to conventional material for road construction, will not only help in reducing the production cost of asphalt but also reduce the harmful effects and pollution in the environment, reduce landfill cost and leads to substantial savings in our natural resources. Several studies have shown that E-waste

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can be used in bitumen and bituminous mixtures for flexible pavements. Consequently, the researchers observed the improvement of the performance characteristics of E-waste bituminous mixtures. Focusing on the plastic part of E-waste, the re-use of E-plastics as recycled aggregates (Recycled Plastic Aggregates—RPAs) in the construction industry is considered by many researchers as one of the main recycling routes for E-plastics in developing countries [4]. This paper affords an overview of the studies that have been conducted on the feasibility of using E-waste plastics in cleaner and eco-friendly asphalt pavement materials. This review transacts through the value of using e-waste in the bituminous materials and the impact of E-waste at the flexibility, durability, stability, viscosity, penetration, softening point and low and high-temperature performance.

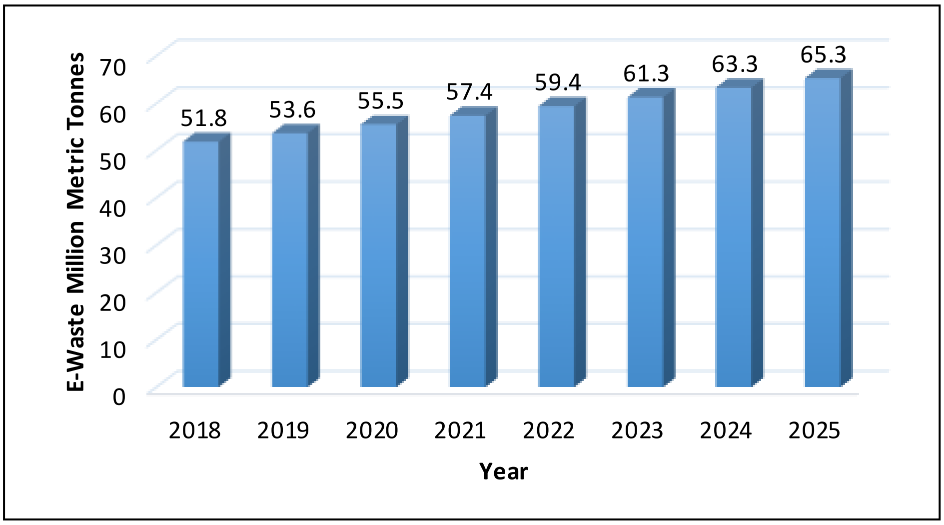

Fig. 1 - Total E-waste generated and expected [2]

2. Composition of E-Waste

Waste electrical and electronic equipment (WEEE) is a complex stream because electrical and electronic equipment (EEE) includes a wide range of items, from mechanical devices such as hair dryers to fully integrated systems such as mobile phones and computers [5]. Therefore, the composition of E-waste depends strongly on factors such as the type of electronic device, the model, manufacturer, date of manufacture, and the age of the scrap [6]. Ferrous is the most common element about 50% in Waste electrical and electronic equipment (WEEE), followed by plastics (with or without Brominated Flame Retardants (BFRs) contained in them) that account for about 20%, while glass, copper and aluminum are found in respective individual percentages of less than 10%. Fig. 2 illustrates the material fractions in electronic waste [7] [8].

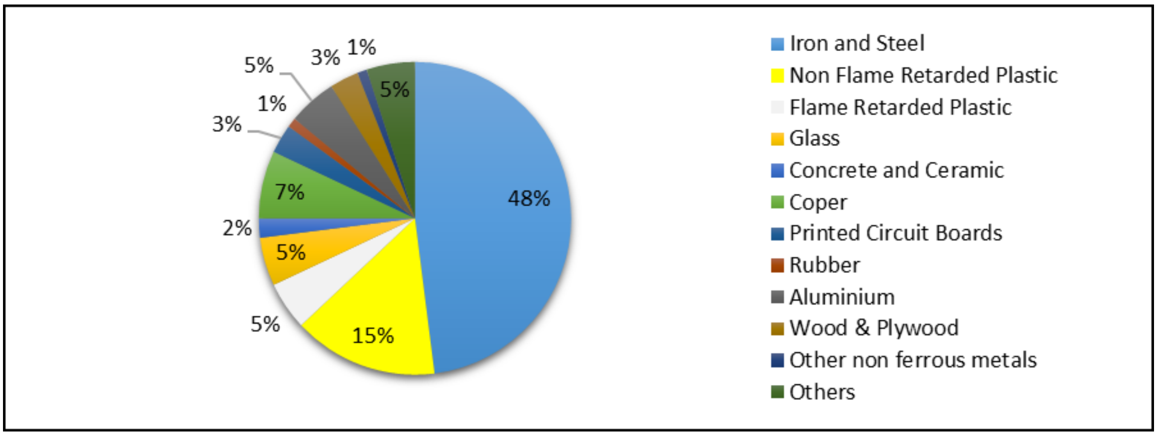

Fig. 2 - The composition of WEEE [8]

3. Asphalt Modification

The asphalt pavement industry is based on mixing conventional mineral aggregates, mineral fillers and asphalt binder binding to form an asphalt mixture with different aggregates and gradation for specific conditions [9]. The aggregate serves as the pavement's structural skeleton, while the asphalt cement serves as the glue of the mixture [10]. However, mixtures are susceptible to various primary structural, and functional distress, namely: fatigue cracking, permanent deformation or rutting, and moisture damage [11]. The unsatisfactory asphalt mixture performance is due to the rapid increase of traffic load, axle weight and weather conditions [12]. The modifications of asphalt mixture are made commonly by blending asphalt with synthetic products namely polymers or through the integration of mineral fillers to improve technical characteristics [13]. Polymer modification, however, is expensive due to the cost of the raw polymer [14], skilled persons and specific equipment application which lead to asphalt mix modification through mineral fillers to achieve favourably balanced cost and performance. The utilization percentage of mineral filler is a delicate formulation. A stiff dry asphalt binder is obtained when there is insufficient asphalt to fill mixture voids, whereas overfilling with asphalt imparts a viscous character to the mixtures [15]. Apart from the dosage, selection of fillers in terms of physical and chemical properties, shape and texture, size and gradation are vital for the optimal performance of asphalt mixture [16][17].

In recent times, the diminishing availability of natural resources along with the need to recycle the growing mass of waste materials has pushed the asphalt industry to find novel ways to use recycled materials in paving. The usage of solid waste material in pavement construction could substantially reduce waste production and reduce the possibility of those waste materials ending up in landfills [18]. Among those waste materials, but still little studied [19], waste of electrical and electronic equipment, or WEEE (Fig. 3) [20]. The modification of asphalt with waste additives would allow additive materials to be provided at very low costs [21]. The use of E-waste to modify asphalt not only relieves pressure on landfills by offering a viable use for electronic waste plastics but also results in significant infrastructural resource savings.

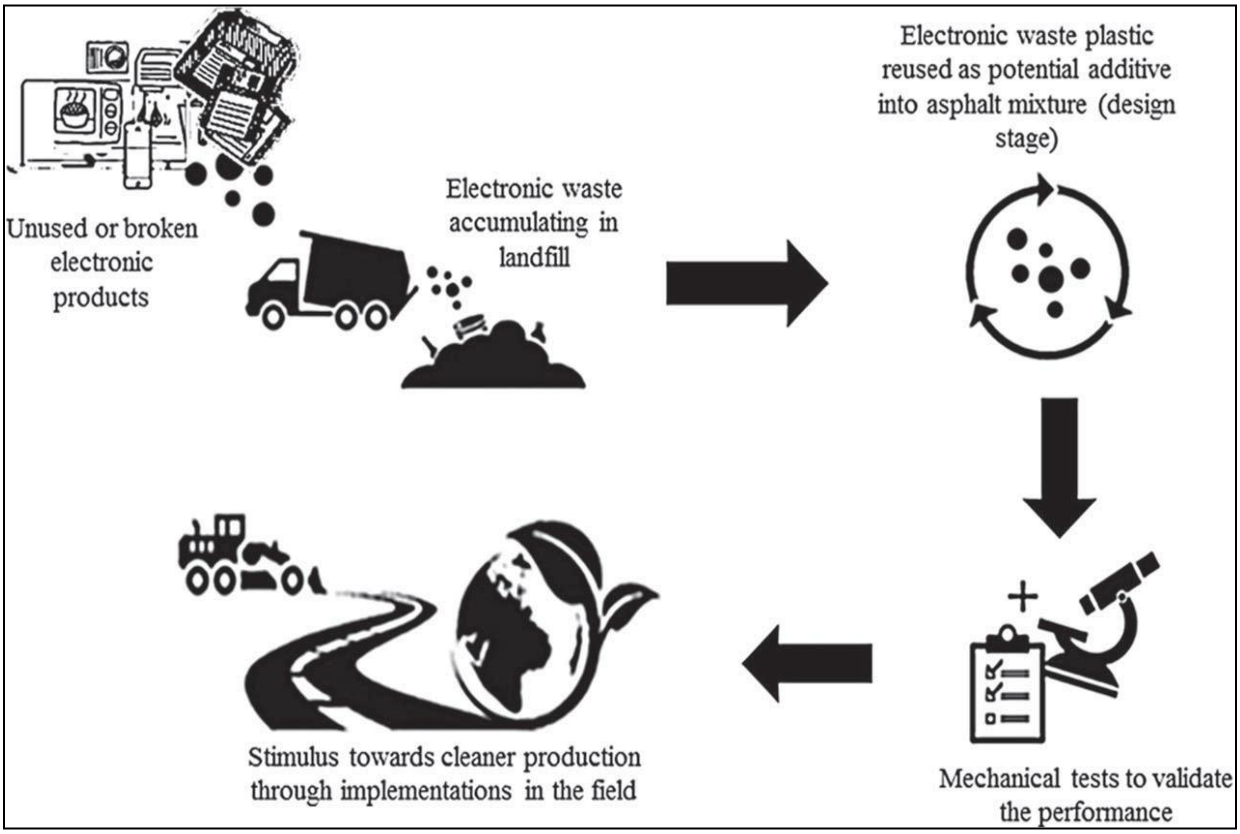

Fig. 3 - Applications of E-waste as novel additive in asphalt pavement [20]

4. Approaches to Incorporate E-Waste into Asphalt Pavement

E-waste can be incorporated in two principal ways either by infusing into just the asphalt binder or by blending with asphalt mixture. Utilization of E-waste in asphalt mixture can be further implemented by the dry mixing process where E-waste is blended with heated aggregates before pouring of asphalt binder, or the wet mixing process where solid waste is introduced as asphalt binder modifier [22].

4.1 Incorporation of E-Waste as Aggregates

M.S.Ranadive et al., [23] investigated the effect of replacing filler in asphalt concrete by E-waste and fly ash on the strength parameters of asphalt pavement. This study was to solve the problem caused by E-waste in our environment by releasing toxic gas and other harmful materials etc. also, to reduce the cost of the asphalt construction. The e-waste is used with percentages of 5%, 10% and 15% on the filler mass and the used binder of penetration grade

60/70. The results obtained show higher values of Marshall Stability and Marshall flow with an increase in the using percentage of E-waste up to 10% and 5.5% binder content. Using E-waste as filler replacement improved the Stability with an 11 % achieved increase in strength. It was found that using fly ash, as filler helps to obtain strength nearly equal to the control mix without any enhancement. In related research, Darshit et al., [24] studied the use of electronic waste and fly-ash as an alternative to conventional material in the asphalt concrete layer of flexible pavement. In their study, different percentages of aggregate were volumetrically replaced by the different percentages of electronic waste and fine aggregate with fly-ash in the asphalt layer. According to the authors, Marshall Stability is an important test for flexible pavement in terms of bituminous mix efficiency since it is used to define the mix design's strength. Thus, the method followed in this study was only the Marshall Stability test and analyzing the flow value for the bitumen. They have concluded that 7.5 % of aggregate was volumetrically replaced by electronic waste and exhibited maximum strength. While stability decreased when the E-waste percentage increased above 7.5 %. Authors also found that the Marshall Stability value increased by about 25% by the addition of 4% fly-ash material with the replacement of aggregate and shows the maximum stability.

Ramesh Kumar et al., [25] studied the use of E-waste as an aggregate replacement in a Dense Bituminous Macadam (DBM) layer of flexible pavement along with a partial replacement of asphalt binder with plastic using a wet mix process. The results of the laboratory investigation showed not only an increase in strength but also a considerable decrease in cost. The laboratories properties of the DBM designed bituminous mix was superior to those of the control mixes and can be effectively used in practical applications. It was concluded that a bitumen content of 5.5% with 7.5% of bitumen substituted by waste plastic and 7.5% aggregate replaced by E-waste showed an increase in stability while all the other parameters remain within limits. In other related study, Dombe et al., [26] made a laboratory investigation on studying the effect of using E-waste and E-waste plastic as a partial replacement of filler and bitumen in the asphalt mixes of the top layer in flexible pavement. According to the authors, electric and electronic waste (E-waste) is the fastest-growing waste source. Therefore, the use of E-waste materials for the construction sector may not only help to reduce costs but also will help to protect the environment from harmful effects and emissions. The used percentages of E-waste were varied from 7.5% to 15% with an increment of 2.5%. The percentage of plastic was 4.5% to 6% with an increment of 0.5%. Plastic waste with a size of 2-4.75 mm sieve was mixed with the binder by the wet-mix process. The results obtained were interpreted in terms of density, air voids, stability and flow. It was found that partial replacement of neat materials with waste plastic and E-waste is possible and there is an increase in strength with a cost-effective approach towards E-waste disposal. The results showed a potential use of E-waste as an aggregate replacement with a varying percentage of 7.5% to 15% with 5% e-waste plastic as bitumen modifier. In another related research, A. Deshmukh [27] carried out an experimental work by replacing E-waste with coarse aggregate and plastic waste with bitumen by the wet-mix process. E-waste was varied at 5%, 10%, 15% and 20% of the total coarse aggregates. The authors found that the modified bituminous mix was superior to that of the conventional bituminous mix in terms of strength and stability. They observed that as the E-waste increases, stability and flow values increases. However, after the addition of 20% E-waste, the stability decreases. However, the density of the modified bituminous mixes showed a significant decrease with the addition of E-waste. This is because the density of E-waste is less than that parameter of coarse aggregate.

S. Muthukumar et al., [28] investigated the use of E-waste as a partial replacement of coarse aggregate and implemented recycled High Impact Polystyrene (HIPS) in the molten state as a partial replacement of the binder. The study's main aim was to find out how to use these hazardous waste products efficiently in asphalt applications. The E-waste used to replace coarse aggregate was from computer boards, which were crushed to a nominal size of 20 mm. All the samples with various percentages of substitutions of E-waste were tested using the Marshall Stability test. The obtained results indicated an improvement in stability values due to the adhesiveness of the HIPS that has been added to the mixtures. The stability values increased when replacing bitumen with HIPS and there was an increase in the stability values with an increase in the percentage of replacement. The authors concluded the study by recommending the use of 20% of E-waste and 15% of HIPS in asphalt mixtures, which they considered to be the most strength and cost-effective.

Murugan, L. [29] studied the managing of E-waste plastic which increasing rapidly in India by utilizing the E-waste plastic granules as coarse aggregate in asphalt mixes. Various percentages of E-waste plastic of 4% to 16% with an increment of 4% and a size of 6.7mm were designed to determine the best performance of asphalt contained waste plastic. Bitumen of penetration grade 60/70 was used with a dosage of 4.5% to 6%. Marshall Stability test was carried out to analyse the performance of the modified mixes following the standard of ASTMD 1559. It was found that stability values vary for different binder contents by the weight of aggregates. Asphalt mixes with 5.5% binder content exhibited the maximum stability value for both control and modified plastic mixes, which meet MORTH specifications. The bitumen mix of 12 % plastic results in maximum Marshall Stability, which is approximately three times higher than the control mix. It was also observed that the replacement of aggregate by plastic particles produced higher MQ values when compared to the conventional mix. This will result in increased asphalt pavement resistance against pothole failure, shear failure and permanent warping failure.

Table 1 illustrates the characteristics of E-waste aggregates, while Table 2 summarized the results of the modified E-waste asphalt mixtures.

Table 1 - Characteristics of E-waste aggregates [25] [28][29]

Characteristic type	A range of value obtained
Specific Gravity	1.01 - 2.43
Size (mm)	6.7 - 20
Water Absorption (%)	0.04 - 0.2
Crushing Value (%)	2 - 2.35
Impact Value (%)	< 2
Abrasion Resistance (%)	3.57
Fineness Modulus (%)	7.69

Table 2 - Summary of the modified E-waste asphalt mixtures

Ref.	Test	O.A.C %	E-Waste Content %	Specifications	Flow	Stability	Density	Stiffness/ Marshall Quotient	Cost concern
[23]	Marshall	5.5	5,10,15	MORTH	increased	increased	decreased	-	√
[25]	Marshall	5.0	5,10,15	MORTH	-	increased	-	-	-
[27]	Marshall	5.0	5,10,15,20	MORTH	increased	increased	decreased	-	-
[28]	Marshall	5.0	10,20,30	MORTH	-	increased	-	-	√
[29]	Marshall	5.5	4,8,12,16	MORTH	increased	increased	-	√	-

Note: (√) included in literature; (-) is not in literature.

4.2 Incorporation of E- Waste as Binder Modifier

Ramesh Kumar et al., [25] investigated the reuse of Electronic printed circuit boards (E-PCB) as a partial substitute of bitumen with a certain percentage in the form of fine powder and nonmetallic chips. This study investigates the binder properties in terms of ductility, penetration value, softening point, viscosity and flash & fire point. The bitumen used in the study was of a penetration grade 60/70. E-PCB was collected, the metallic components were separated, and the non-metallic board was used. The modified bitumen was produced by replacing bitumen with a particular percentage of E-waste powder i.e., 6%, 12%, and 18%. They have concluded that 12% was the optimum ratio of E-waste powder and a 10% addition of non-metallic chips showed better stability and binder capability compared to other results.

S. Muthukumar et al., [28] investigated the use of E-waste as a partial replacement of coarse aggregate and implemented recycled High Impact Polystyrene (HIPS) in the molten state as a partial replacement of the binder. HIPS material has good resistance to heat and its ability to take loads. Hence, HIPS were applied to the binder in a molten state to get a good strength value with an inclination to tolerate high temperatures. The obtained results indicated an improvement in stability values due to the adhesiveness of the HIPS that has been added to the mixtures. The stability values increased when replacing Bitumen with HIPS and there was an increase in the stability values with an increase in the percentage of replacement. The authors concluded the study by recommending the use of 20% of E-waste and 15% of HIPS in asphalt mixtures, which they considered to be the most strength and cost-effective.

Mani, S.S. et al., [30] conducted an experimental study to develop a modified bitumen from E-waste and fly ash as mineral filler in road concrete. This study was to find an innovative technology with its effective use of producing asphalt mix for flexible pavement and to reduce the hazards of waste materials in the environment. The binder was partially replaced by E-waste with different percentages of 5% to 20% with an increment of 5% and fly ash used as mineral filler in an eco-friendly manner. Several tests were carried such as the binder content test, softening point test, Marshall Stability test. The results indicated a suitable use of 10% to 15% of E-waste in asphalt mixes. The Marshall Stability test value was 8.5 KN and the softening point mixed design value 4.80, which is higher than the standard value 4.69.

Santhanam, N.et al., [31] have studied the addition of partially E-waste plastic powder as a replacement to the neat binder in the asphalt layer of flexible pavement to find the strength in the asphalt binder with viscosity grade (VG30), in different percentages of 5% to 20% with an increment of 5% in 100 g of bituminous. The source of the E-waste in this experimental work was originated as waste from computer boards, phones and other electronic devices. E-waste was collected and segregated the one, which did not contain materials such as copper, lead, lithium and aluminum. This investigation was to study the binder behavior using basic tests as per Indian standards including the Ductility test, Penetration test, Viscosity test, Softening point and Marshall Stability test. The ductility value was found to be gradually decreased when the percentage of E-waste increased. The penetration and viscosity values increased with the increasing addition of E-waste powder. The softening point result showed an increase in the temperature with an increase in E-waste percentages. The authors have concluded that the bituminous contains E-waste plastic powder have shown a better strength and can be used in asphalt pavement with a 10% replacement of E-waste powder which showed the best strength value. In related research, Needhidasan et al., [32] have reviewed the recent trends of the possibility of using E-waste plastics powder as an alternative to the conventional materials used in flexible pavement structures such as aggregate and bitumen. The E-waste used in this experimental investigation is waste from computer boards, phones and other electronic devices. E-waste powder mixed with bitumen of penetration grade 80/100 at 160℃. They found from the study that the E-waste bituminous has a large amount of strength when compared to the neat binder. The authors concluded by recommending the utilizing of E-waste in the form of bituminous asphalt, which results in reducing the cost and protecting the environment and human health.

Colbert, Baron W., conducted research on the usage of electronic waste as an asphalt binder modifier [33] along with the impact of using electronic waste on the minimum design thickness of the asphalt pavement [34]. This study also included a limited emissions-performance estimation using SimaPro and MEPDG software to compare the E-waste asphalt mixture emissions and performance [35]. The authors investigated two approaches to utilizing electronic waste plastics into asphalt pavement materials. The first approach was to blend electronic waste powders directly into asphalt mixtures and binders, and the second approach was to chemically treat electronic waste powders with hydro-peroxide before blending into the asphalt mixtures and binders. The purpose of the chemical treatment was to increase the molecular bonding between the E-waste powders and the asphalt binders to improve the low and high-temperature performance. In the study, they used the common E-waste powders, which were acrylonitrile butadiene styrene (ABS) and High Impact Polystyrene (HIPS) to modify Hot Mix Asphalt (HMA) mixtures. The E-waste powder was blended into the asphalt binders with percentages of 2.5, 5, and 15%, respectively. This study was conducted using Superpave-testing procedures to evaluate the rheological and mechanical properties of the asphalt modified binders and mixtures. The tests were conducted using rotational viscosity, Dynamic Shear Rheometer (DSR), and Bending Beam Rheometer (BBR). The outcomes of the study showed an increase in the binder viscosity, blending, and mixing temperatures with the addition of e-waste powders and the results fulfilled the Superpave specification. The authors also found that E-waste modified asphalt binders met the virgin binder high-temperature performance criteria. Meanwhile, the E-waste modified asphalt binders were found to be stiffer at low temperatures compared to virgin asphalt binders and tended to meet the low-temperature performance specifications at the minimum amount of E-waste plastic. They also observed that treating electronic waste plastics delayed the onset of tertiary flow in electronic waste mixtures, the electronic waste mixtures showed some improvement in dynamic modulus results at low temperatures versus the conventional mixture and the tensile strength ratio values for the chemically treated E-waste asphalt mixtures were improved compared to the conventional mixture. In addition, the design thickness of chemically treated Acrylonitrile Butadiene Styrene (T-ABS) with a percentage of 2.5 by weight of asphalt binder exhibited the smallest pavement thickness among all the studied mixes. The authors concluded that using E-waste materials as bitumen modifiers would improve the binder properties and asphalt performance and reduce the design thickness of asphalt pavements.

In recent research, Mohd Hasan et al., [19] evaluated the performance of asphalt binders modified by three E-waste plastic powders, Acrylonitrile Butadiene Styrene (ABS), Acrylonitrile Butadiene Styrene-Polycarbonate (ABS-PC) and High Impact Polystyrene (HIPS). The modifiers were used after 100% of the material passed through a #50 (300 lm) sieve. A neat binder PG-58-28 was used as a control binder. The E-waste powders were mixed with the control binder under two different conditions, which were untreated and chemically treated. The chemically-treated modifiers were processed with cumene hydroperoxide before mixing with the neat binder. Using this free radical initiator to improve the performance of E-waste modified binders. Also, introduced this radical was expected to enhance covalent bonding between the additive and the bitumen to promote interfacial adhesion and between different parts of the asphalt itself to enhance branching. This molecular bonding was to improve the low and high-temperature performance of the modified binder. The proposed bonding scenarios was to show the ability of radical to improve the performance of E-waste modified asphalt binder in terms of tensile strength, molecular weight and intermolecular interaction. The Dynamic Shear Rheometer (DSR) was used to evaluate the rheological properties of the modified binders through a Peltier system. The Bending Beam Rheometer (BBR) was used to evaluate the low-temperature performance of the modified asphalt binders. The analysis of activation energy was used to evaluate the effect of E-waste materials on the intermolecular forces. Based on the results obtained, using e-waste as an asphalt modifier increased the stiffness and the elastic behavior of the asphalt binders with more resistance to rutting compared to the conventional binder. The chemically-treated E-waste plastic modified asphalt significantly outperformed the untreated binder. The chemical E-waste treatment enhanced the resistance to rutting behavior by an average of 30 times higher than that of the unmodified bitumen. The integrity between these materials improved the resistance of the asphalt binder to rutting. The asphalt viscosity increased with increasing the percentages of E-waste modifiers. They have concluded that using 5% of Acrylonitrile Butadiene Styrene (ABS-T) and Acrylonitrile Butadiene Styrene-Polycarbonate (ABS-PC-T) E-waste significantly improved the elastic and viscous modulus of the bitumen binder. However, the addition of High Impact Polystyrene (HIPS) was found to be ineffective. Authors have recommended avoiding using untreated E-waste powder as this will result in unstable molecular bonding between the E-waste particles and the asphalt binder. Therefore, it would not improve the high-temperature performance of the asphalt binder. Also, the presence of treated E-waste particles in the asphalt binder allows the matrix to reduce the rate of change in stiffness at lower temperatures. The treatment process of E-waste plastics is as shown in Fig. 4.

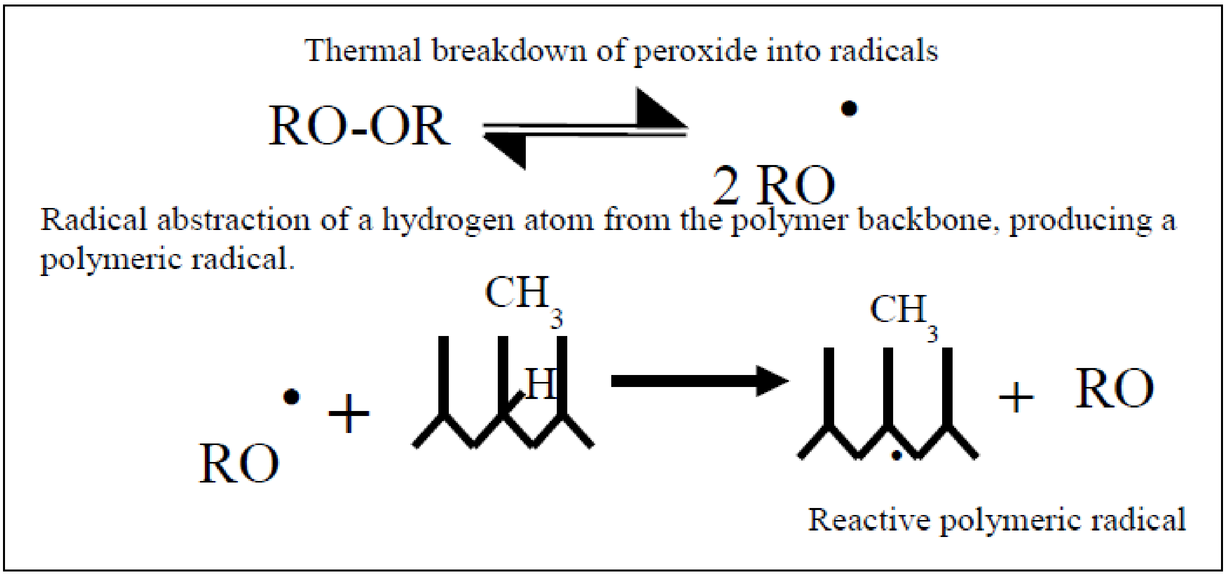

Fig. 3 - Treatment process of E-waste plastics [36]

Piyush Kumar Singh et al., [37] conducted a laboratory study of asphalt binder modified with recycled Acrylonitrile Butadiene Styrene (ABS) polymer. ABS is a thermoplastic polymer that can be obtained from recycled E-waste plastics that have been recycled. This study was to investigate the effect of the addition of ABS polymer on the physical, rheological and mechanical properties of the bitumen binder. The properties were investigated using a viscosity test, penetration test, softening point and Dynamic Shear Rheometer (DSR). ABS in powdered form has been blended with viscosity grade (VG 30) bitumen in a variety of percentages ranging from 1% to 5% with a 1% increment. ABS powder was mixed and stirred mechanically for 30 minutes in a shear mixer at a temperature of 165 °C and a speed of 2000 rpm. It was found that a maximum improvement was for 4% ABS content. The result showed a reduction in penetration and an increase in softening point, dynamic viscosity up to 4% modifier content, followed by a reversal of the trend. The increase in viscosity will cause an increase in adhesion between aggregate and binder, which will enhance the asphalt performance. The blending of bitumen with ABS also increased the rutting resistance parameter ($G^*/\sin\delta$) indicating an improvement in the high-temperature performance of the asphalt binder. The phase angle decreased for ABS modified bitumen samples, which will improve the low-temperature performance of the pavement due to an increase in the elastic properties of the binder. The stripping properties of the modified binder also are improved thus the modified mix is less susceptible to moisture damage. They concluded that recycled ABS material can be used as a bitumen modifier with a content of 4% by weight of bitumen and recommended the use of a modified binder in warm climates.

Shahane et al., [38] have studied bitumen as a viscoelastic material, which sometimes needs modification for its strength under adverse environmental conditions. The bitumen of viscosity grade (VG 30) was modified using E-waste plastic powder and termed E-waste plastic powder modified bitumen (EPPMB). The properties of the modified and neat binder were tested using a Dynamic Shear Rheometer (DSR) and conventional tests. The results exhibited an improvement in the rheological properties of EPPMB. Cyclic triaxial tests were conducted to examine the complex modulus parameters at 10, 25 and 40°C for the frequency of 0.1–10 Hz. It was found that the binder modified with 5% E-waste plastic powder by the weight of bitumen met the Indian specification. The strength of the modified binder was found to be improved. The dynamic modulus value was improved up to 10% at 40°C with a reduction in the phase angle (δ) value at 40°C, which may be attributed to the higher elasticity of EPPMBC. The results showed that the rutting resistance was improved by 28% at 40°C along with an enhancement in fatigue resistance by 19% at 10°C.

Table 3 illustrated the Physical properties and mixing characteristics of bitumen and E-waste, while Table 4 summarized the results of the E-Waste modified binder.

Table 3 - The Physical properties and mixing characteristics of bitumen and E-waste

Ref.	E-waste Type	Binder	E-waste Content %	Size	E-waste Specific gravity	Melting Temp. (°C)	Mixing Time (mins)	Mixing Speed (rpm)	Mixing Temperature (°C)
[25]	E-PCB	60/70	-	Powder	1.06	-	-	-	-
[28]	HIPS	80/100	5,10,15	0 - 2.36	1.04	120-130	-	-	-
[30]	E-waste	40/50	5,10,15,20	Powder	-	-	-		-
[31]	E-waste	VG 30	5,10,15,20	Powder	1.3	-	-	-	160
[32]	E-waste	80/100	-	Powder	1.01	-	-	-	160
[33]	ABS HIPS	PG58-28	2.5,5,15	75-600 µm	-	-	15-45	3000 - 5000	-
[19]	ABS ABS-PC HIPS	PG58-28	5,15	300 µm	-	105 125 180-260	15-45	3000 - 5000	
[37]	ABS	VG 30	1,2,3,4,5	<375µm	1.07	-	30	2000	165
[38]	E-waste	VG 30	2, 2.5, 4, 5, 6	300 µm	-	-	40	150	175-180

Table 4 - Summary of E-Waste modified binder

Ref.	Strength	Softening Point	Viscosity	Penetration	Rutting Resistance	Stiffness	Low-temperature cracking resistance	Phase separation	Aging
[25]	↑	↑	↑	↑	-	-	-	-	-
[28]	↑	-	-	-	-	-	-	-	-
[30]	-	↑	-	↓	-	-	-	-	-
[31]	↑	↑	↑	↓	-	-	-	-	-
[32]	↑	-	-	-	-	-	-	-	-
[33]	↑	-	↑	-	↑	↑	√	√	√
[19]	-	-	↑	-	↑	↑	√	√	-
[37]	↑	↑	↑	↓	↑	-	√	√	-
[38]	↑	↑	↑	↓	↑	↑	√	√	√

Note: (↑) (↓) (√) are increase, decrease and improve in properties of asphalt binder respectively; (-) is not in literature.

5. Conclusion

The current state of using E-waste in the asphalt pavement was discussed within this paper. The paper reviewed the performance characteristics results from using e-waste as a binder modifier and for aggregate replacement. After reading all the reviewed papers, research indicates that the use of E-waste improved the strength of the bituminous comparing to the normal bitumen. Each review has different values but all approve of the suitability of using electronic waste in asphalt mixtures. The addition of E-waste improved the asphalt binders and mixtures properties. The use of E-waste in road construction will serve to reduce the cost of construction, reduce the sustainable use of asphalt binder and aggregates and will contribute towards efficient waste management of this hazardous material.

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