A FEASIBILITY STUDY OF USING ELECTRONIC WASTE AS BITUMEN MODIFIER FOR SUSTAINABLE ROAD CONSTRUCTION AND MAINTENANCE

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Abstract
The generation of electronic waste is increasing annually due to the demand for newer electronic products, creating an urgent need for effective management strategies. This research explored the reuse of electronic waste as a modifier for bitumen. Waste electronic circuit boards were crushed into powder, and plastics were sized to 10 mm. The powder partially replaced bitumen, while the plastics partially replaced coarse aggregates in a bituminous mix, with replacement percentages between 10% and 20%. Penetration, ductility, flash point, fire point and softening point test was conducted on the electronic waste modified bitumen while the Marshall stability, flow and Quotient test were performed on the electronic waste plastics modified bituminous mix both with pure and modified bitumen binder at varied quantities. The result showed that a 16% replacement of electronic waste powder significantly improved bitumen properties. For the plastics-modified bituminous mix, enhancements were noted with stability at 40.66 kN, flow at 4.12 mm, and quotient at 10.37 kN/mm, using 12% waste printed circuit board plastic. Additionally, the modified binder required only 4.5% bitumen, compared to 6% for the natural binder, making the modified mix more cost-effective and suitable for light and medium traffic road construction.

Keywords: *Bitumen, waste printed circuit board, modifier, road construction, electronic waste, marshall properties*

Introduction

Bituminous pavements are the most common type of pavemet used in Nigeria and around the world. One of the key materials in bituminous pavement is bitumen, a non-renewable resource primarily derived from the distillation of crude petroleum. In road construction, bitumen is mixed with aggregates to act as a binder, creating the asphalt mixture. The performance characteristics and overall durability of asphalt mixtures depend greatly on the quality of the bitumen binder. Failures in bituminous pavements are often directly linked to issues with the bitumen, which can result from thermal cracking at low temperatures or rutting at high temperatures that reduces the elasticity of the bitumen (Tahmoorian et al., 2020). Additionally, increased traffic volumes, loading, rainfall, and temperature fluctuations contribute to premature road failure and higher maintenance needs.

To address these challenges, modified bitumen has been developed to enhance the properties of conventional bitumen using various modifiers, which improves pavement performance (Meijer *et al.,* 2022). Waste materials are increasingly being used as constituents or substitutes in the production of modified bituminous binders. These waste materials are sourced from households, commercial entities, and industrial by-products. The rapid advancement of technology has led to a significant rise in electronic waste (e-waste) generation globally. E-waste is characterized by a high composition of plastics that are non-degradable and can lead to harmful reactions. The disposal of e-waste poses serious environmental challenges due to the presence of hazardous components. This study aims to tackle the issue of electronic waste by exploring the feasibility of using e-waste from the ICT industry as a modifier for bitumen in sustainable road construction and maintenance. Managing electronic waste through this strategic approach, can pave the way for its sustainable management.

Materials and Method

Materials

Bitumen

Bitumen penetration grade 60/70 was used for this study. The bitumen would be procured from KK Hassan Limited, Owo, Nigeria.

Aggregate

Coarse aggregates with the size of 10mm were used for this study. River sand was used as the fine aggregates. The fine sand was checked to be free of any deleterious materials. The filler material used was stone dust. All aggregates were procured from a quarry in the Ijare Town of Ondo State.

Electronic waste

Waste Printed Circuit Boards (PCBs) were the focus of this study. These wastes were collected from the scrap materials of various shops that specialize in repairing different ICT devices located at the FUTA South Gate area in Akure. This area has a large portion of its commercial space dedicated to the sale and repair of ICT devices. There was a backlog of ICT device parts stored in large quantities, awaiting disposal in landfills. The printed circuit boards were carefully selected from the discarded materials and processed for use in this study.

Sample Preparation

Printed circuit board waste was collected and sorted to remove harmful substances like lead and lithium. The waste was sun-dried for 5 to 7 days to eliminate moisture. It was then divided into two batches: one batch was crushed into powder, while the other was crushed to 10 mm, matching the aggregate size used in this study. The powdered ICT waste was sieved through a 600-micron sieve to ensure smoothness.

Two sets of bituminous mixes were prepared. The first set, or BM mixes, included bitumen with powdered ICT waste replacing 10%, 12%, 14%, 16%, 18%, and 20% of the bitumen by weight, resulting in seven mixes. The second set, or MS mixes, contained bitumen, aggregates, and crushed ICT waste, also replacing 10%, 12%, 14%, 16%, 18%, and 20% of the coarse aggregates by weight, totaling another seven mixes as shown in table 1. These percentage mixes were selected based on work done by Ramesh et al. (2020). In total, fourteen bituminous samples were prepared for testing to evaluate their performance as road construction materials.

Geotechnical Tests and Specifications

Penetration tests measured how deep a standard needle penetrated into BM bituminous mixes, following ASTM D5-97 specifications. Flash and fire point tests were conducted per ASTM D92-01. Ductility and softening point tests used methods from Needhidasan and Agarwal (2022).

For MS bitumen mixes, the Marshall test was performed according to ASTM 1559 guidelines, with specimens prepared as per ASTM D6927. The tests determined the Marshall stability value (kN), flow value, and unit weight. The maximum force from compression testing was recorded as the Marshall stability value, while the stiffness of the mixture was reported as the Marshall Quotient (MQ in kN/mm), indicating the pavement's resistance to permanent deformation.

Statistical Analysis

With the aid of Origin Pro statistical tool, analyses and evaluation were performed on the data obtained from the test conducted on the powdered electronic waste modified bitumen and the crushed electronic waste plastic modified bitumen mixes to ascertain its properties.

Results and Discussion

Bitumen Mechanical Performance Result

Penetration, ductility, softening point, flash point, fire point, specific gravity and viscosity test were conducted on natural bitumen and the bitumen modified with the waste printed circuit board powder. The results of the test conducted on the samples were as follows:

Table 1: Study Bituminous Mixture Mix

Name of Mixes	Bitumen (%)	E-waste Powder (%)	Name of Mixes	Bitumen (%)	E-crushed waste (%)	Coarse aggregate (%)	Fine aggregate with fillers (%
BM0	100	0	MS0	100	0	80	20
BM1	90	10	MS1	100	10	70	20
BM2	88	12	MS2	100	12	68	20
BM3	86	14	MS3	100	14	66	20
BM4	84	16	MS4	100	16	64	20
BM5	82	18	MS5	100	18	62	20
BM6	80	20	MS6	100	20	60	20

Penetration

Figure 1 illustrates the penetration of bitumen modified with varying percentages of waste printed circuit board (PCB) electronic waste. Higher penetration values indicate greater resistance and improved performance against vertical and sharp loads, leading to increased durability. The penetration increased with the addition of e-waste powder, continuing to rise until a 14% e-waste powder content was reached. Beyond this point, a decline in penetration was observed, with a peak value of 70 mm noted at the 14% e-waste powder addition.

A similar trend was reported by Ramesh et al. (2020), who also examined the treatment of bitumen using e-waste powder. However, in their study, the peak penetration occurred at 12% e-waste powder with a lower value of 64.3 mm. A closer examination revealed differences in the specific gravity and water adsorption properties of the e-waste plastics crushed into powder. The materials used in this study had a higher specific gravity and a lower adsorption rate compared to those used by Ramesh et al. (2020), specifically having values of 1.01 and 0.75, respectively. This discrepancy may significantly contribute to the higher penetration values observed in this study at increased e-waste content.

Additionally, the higher silica content, which is the oxide of silicon found in the printed circuit board waste, compared to the micro-chips used in Ramesh et al.'s study, could further explain the increased penetration values recorded here.

Ductility

The ductility of bituminous materials is quantified by the distance, in centimeters, that they elongate before breaking at a specified speed and temperature. Observations from Figure 2 indicate that as the e-waste content increases, the ductility of the bitumen decreases. This decline in ductility continues up to a 16% inclusion of printed circuit board e-waste powder. A slight uptick in ductility is noted at 18% e-waste content, followed by another decline; however, this final decrease does not reach the level observed at 16% e-waste content, resulting in the steepest decline recorded, with a ductility measurement of 66.7 cm compared to 75.2 cm for pure bitumen, representing an 11.3% decrease. This

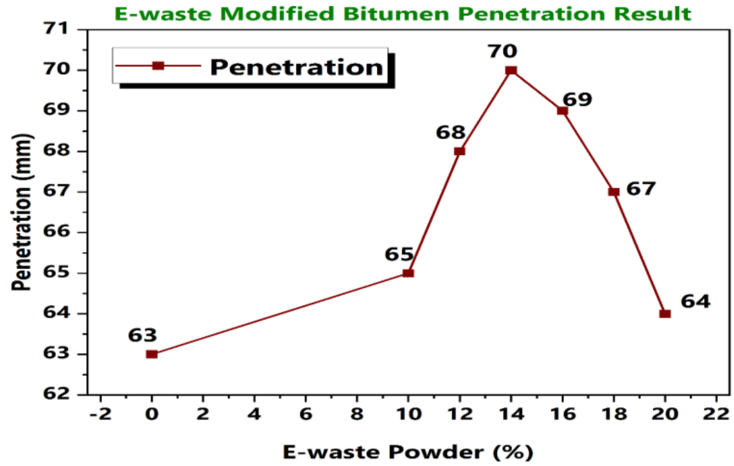

Figure 1: Powdered E-waste Modified Bitumen Penetration Properties

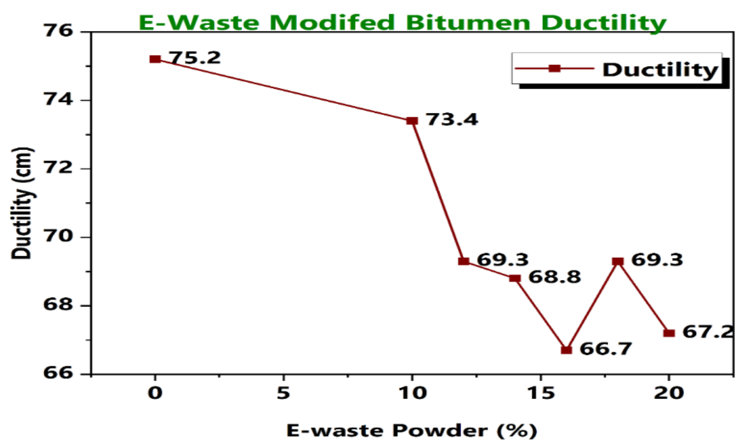

Figure 2: Powdered E-waste Modified Bitumen Ductility Properties

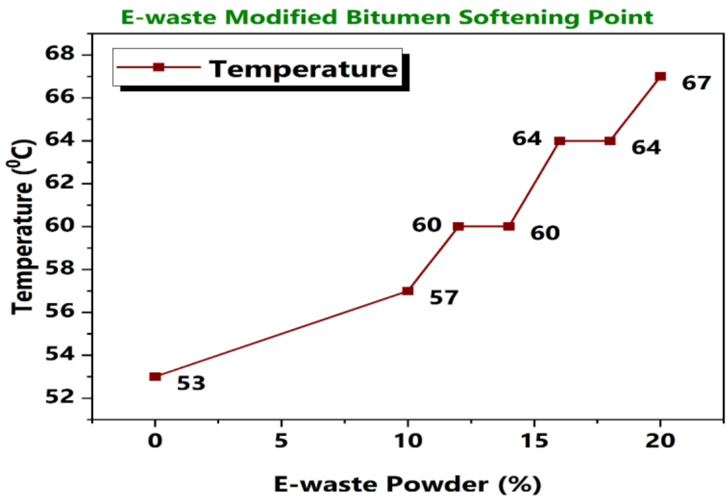

Figure 3: Powdered E-waste Modified Bitumen Softening Point Properties

reduction in ductility presents a challenge for bitumen modified with e-waste powder, as lower ductility increases the likelihood of cracking under repeated traffic loads due to heightened strain. Moreover, the presence of silicon from the e-waste seems to enhance the bitumen's resistance to stress, as indicated by the high penetration value, but simultaneously reduces its resistance to strain, as evidenced by the low ductility observed. In cold weather conditions, bitumen with lower ductility is often preferred, making it more suitable for colder climates rather than hotter ones. Consequently, e-waste modified bitumen is more advantageous for use in road construction in areas with light traffic. A similar trend was reported by Ramesh et al. (2020) in their study of bitumen treated with micro-chips e-waste powder, which showed a decrease of 6.69%. This reduction is notably less than the 11.3% decline observed with the printed circuit board e-waste powder, suggesting that the latter is more effective at longer strain rates.

Softening Point

The softening point of bitumen is the temperature at which the material reaches a specific degree of softening. A higher softening point ensures that the binder will not flow during use, as it is less susceptible to temperature changes; otherwise, it may lead to bleeding and the development of ruts. Bitumen with a higher softening point is preferred in warmer climates.

From Figure 3, it was observed that the softening point of the bitumen increases with the addition of e-waste content, with the highest strength achieved at 20% e-waste content. This resulted in a softening point temperature of 67°C, compared to 53°C for natural bitumen, representing an increase of 26.42%. This indicates that adding e-waste powder enhances the binder's ability to remain solid and firmly bound to aggregates for flexible pavement construction throughout its service life. Notably, the highest temperature recorded in Nigeria does not reach the peak softening point temperature when incorporating the e-waste powder. A similar trend was reported by Ramesh et al. (2020), where the treatment of bitumen with e-waste powder showed an increase in softening point. This increase was observed with microchip waste powder, similar to that of printed circuit board waste powder. However, the peak softening point occurred at 18% e-waste content with an increase rate of 4.44%, which is significantly lower than the increase observed with the printed circuit board e-waste powder used in this study.

Flash and Fire Point

The flash point and fire point properties of a binder are indirect indicators of its volatility, and they are assessed to determine the safe mixing and application temperature for a specific bitumen material. The flash point represents the maximum temperature to which a binder can be safely heated, while the fire point is the lowest temperature at which a binder ignites and burns for at least five seconds under defined testing conditions. Higher values for these two properties indicate that the binder is safer, more durable, and more flexible for use in road construction.

As shown in Figure 4, both the flash point and fire point of the bitumen increased with the addition of e-waste powder. The peak flash point was observed at 16% and 18% e-waste addition, reaching a temperature of 360°C. This represents an enhancement of 20% in applicability and durability compared to natural bitumen. Similarly, the fire point was improved with the incorporation of

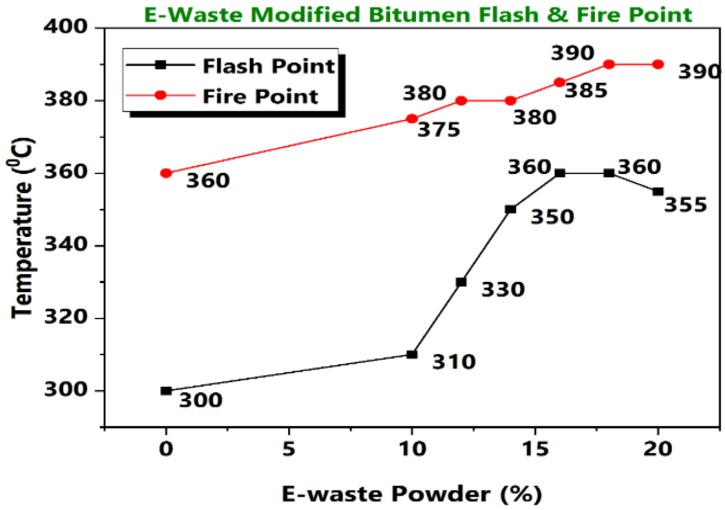

Figure 4: Powdered E-waste Modified Bitumen Flash and Fire Point Properties

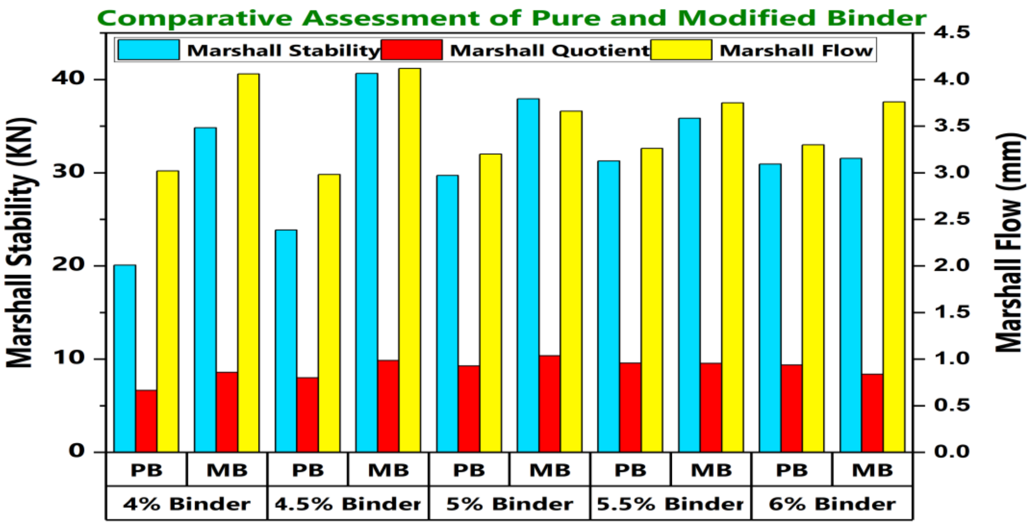

Figure 5: Comparative Assessment of the Performance of the Bitumen Binders

printed circuit board waste powder, with peaks at 18% and 20% e-waste powder content, both achieving a temperature of 390°C. This corresponds to an increase of 8.33% compared to the natural bitumen, which has a fire point of 360°C.

Comparative Assessment of the Bituminous Mix Performance with the Pure and Modified Bitumen

The Marshall stability tests were conducted on a mixture containing stone dust fillers, coarse aggregates, plastic e-waste, fine aggregates, and bitumen binder. The plastic e-waste was used to partially replace the coarse aggregate at varying percentages by weight, while the overall mix featured different binder contents. Both natural and modified bitumen binders were utilized, and their Marshall stability performance was analyzed.

Figure 5 illustrates the performance comparison between the optimal performing pure and modified bituminous mixes for each binder content in terms of Marshall stability, Marshall flow, and Marshall Quotient. The parameters for the modified bitumen showed higher values across all binder contents, with the most significant differences observed at 4%, 4.5%, and 5% binder content. The differences were less pronounced at 5.5% and 6% binder content. Notably, the highest difference occurred at 4.5% binder content, which demonstrated the best performance for the modified bitumen. At this content, the stability, flow, and quotient values were recorded at 40.66 kN, 4.12 mm, and 9.87 kN/mm, respectively, with 12% e-waste plastic aggregates, all conforming to the standards for road pavement construction.

Conversely, the lowest difference was found at the 6% binder content for the pure bitumen, representing the optimal Marshall stability, flow, and stiffness values of 31.55 kN, 3.76 mm, and 8.39 kN/mm, respectively, at 16% e-waste plastic replacement content. The results demonstrate the effectiveness of the e-waste modified bituminous mix, as it exhibited peak performance at lower binder requirements while incorporating larger percentages of waste materials in both powder and plastic forms as replacements for coarse aggregates. The inclusion of electronic waste not only reduces the amount of e-waste plastic needed to replace coarse aggregates but also enhances the bituminous properties beyond those achieved with natural bitumen binders. The optimal combination for sustainable road pavement construction is 84% bitumen, 16% printed circuit board waste powder, and 12% waste printed circuit board plastics by weight of the coarse aggregates.

Conclusions

The following conclusions were made from the study:

- Peak performance in six bitumen properties occurred at 14% e-waste powder (penetration), three times at 16% (flash point, specific gravity, viscosity), twice at 18% (flash and fire point), and twice at 20% (softening and fire point).
- The maximum Marshall stability for the bituminous mix with natural bitumen was 31.25 kN at a binder content of 5.5% and 16% waste printed circuit board (PCB) as coarse aggregate, an improvement of 38.58% over mixes without e-waste.
- The highest Marshall stability for the e-waste modified mix was 40.66 kN at a lower binder content of 4.5%, using 12% crushed e-waste plastics.

For optimal road pavement construction, it is recommended to use 84% bitumen, 16% printed circuit board waste powder, and 12% waste printed circuit board plastics by weight of the coarse aggregates.

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