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Reuse of waste plastic as an additive in asphalt concrete: An overview

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Abstract

This review is centered on the use of waste plastics as an additive for road construction. This review discusses extensively the state-of-the-art methods that can be employed in achieving a waste plastic bituminous mixture. These approaches may help by contributing to the reduction of plastic wastes which constitute nuisance to the environment. Plastics are currently at the top of the international waste management agenda - a global problem, but with regional variations. Several studies have shown that plastic can stay on earth for thousands of years without deterioration and poses a great threat to the atmosphere and humanity when disposed improperly. Hence, there is the need to find a solution to such menace. The utilization of waste plastic to enhance service properties in road paving applications was considered a long time ago. Nowadays, it has become a real alternative and several literature reviews in many countries have confirmed the significance and beneficial effects of utilization of waste plastic in a bituminous pavement construction. The utilization of waste plastic for road construction can also contribute in minimizing the disposal problem and environmental hazard caused by non-biodegradable waste plastic.

Keywords: Waste plastics; Bituminous mixtures; Road construction; Environmental impact; Asphalt

1. Introduction

The use of plastic in Nigeria has evolved to a catastrophic and uncontrollable extent due to everyday human and economic activities. The inadequate handling of solid waste typically presents a global threat. In recent times, the human population, standard of living, modernization, technological advancement and rapid urbanization have significantly increased, thereby contributing to the production of solid waste through industrial and domestic activities. The improper waste disposal technique, dumping of solid wastes in an unauthorized place has now become a normality in the country [1]. In today's lifestyle, the availability of disposable plastic is infinite, as in general, plastic material has become part of our daily life. Plastics generally are versatile materials. Most plastic materials are non-biodegradable (i.e. they cannot be broken down by natural organisms) material. Several research papers have affirmed that plastic can stay on the earth for thousands of years without degrading [2]. In addition, when such plastics are disposed of improperly, they constitute a nuisance to the environment and humanity. Hence, there is the need to find a solution to such menace.

Therefore, concerted efforts are globally being made to reuse these plastic wastes through various recycling techniques. Due to the rapid increase in population, industrialization, and urbanization, the yearly waste generation is predicted to increase by 70% from the year 2016 to 3.40 billion tonnes in the year 2050. Almost every sector globally, starting from Building and construction, agricultural packaging, textiles, industrial and machinery, transportation, electrical and electronics, has been revolutionized by the utilization of plastics. Nigeria is about 206 million in population, and its population is estimate ted to double by 2050, which means more solid waste will be generated. Nigeria produces an estimated value of about 32 million tonnes of solid waste annually. Plastic constitutes 2.5 million tonnes, one of the

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enormous contributors to solid waste in Africa. Additionally, it was reported that the average waste generation rate in Abuja is 0.55–0.58 kg per person per day [3].

The construction sector is one area where plastic wastes can be used as substitute/replacement material, especially in road construction. Tyagi and Argawal [4]opined that, in road construction, bitumen plays a vital role in binding the aggregates together, which helps in improving the strength of roads. However, its water resistance is poor. The utilization of waste plastic to enhance service properties in road paving applications was considered a long time ago, and nowadays, it has become a real alternative. Several literature reviews in many countries have confirmed the significance and beneficial effects of waste plastic in bituminous pavement construction [5], [6][7]–[10].The utilization of waste plastic for road construction can also contribute to minimizing the disposal problem and environmental hazard caused by non-biodegradable waste plastic.

Aim, Objectives and Motivation

The aim of this work is to undertake a review focused on the utilization of waste plastics as an improver/addictive for road construction.

This review presents a wide-ranging discussion of the state-of-the-art approaches that can be utilized in achieving a waste plastic bituminous mixture, which has comparative performance as conventional bituminous mixture. Whilst also providing some improvement to the properties of the bituminous mixture. Numerous studies have indicated that plastic can remain without deterioration or decomposition on earth for centuries and poses a great threat to the atmosphere and humanity when inappropriately dumped. Therefore, it is pertinent to explore for solution to such menace. The methods and approaches presented in this review can be beneficial by contributing to existing body of knowledge in the reduction of plastic wastes which create nuisance to the environment. Moreover, the application of waste plastic for road construction can also aid in lessening the dumping challenges and ecological hazard precipitated by non-biodegradable waste plastic

2. Asphalt Pavement

Pavements generally are broadly classified into Flexible (asphalt) and rigid (concrete) pavement. Flexible pavement comprises of mixtures of bituminous material, aggregates and sometimes additives while rigid pavement consists of Portland cement concrete slab [2]. Flexible pavements are made up of different layers with different materials consisting of aggregates, binder (bitumen), air voids and any other additive. Asphalt pavement materials are extremely subjected to frequent stresses, heavy loads, heavy traffic, and various climatic and environmental constraints such as temperature [11]. The load bearing behavior and subsequent failure of such material depends on several mechanisms which are directly connected to the transfer of local load between aggregate particles [12]. The most basic purpose of having a good mix and structural design is for the pavement is to withstand traffic loads without deforming or degrading to the point that it is unusable during the design era [2]. To mitigate this cycle, various ways may be effective, such as improving roadway design, securing maintenance funds, improving material quality control, and using more efficient construction methods. Consistent research is required to create better materials, processes and designs to make pavement safer, longer-lasting and more cost-effective[13].

The performance of flexible pavement is influenced by many factors, such as the component properties (binder, aggregate, and additive) and the components proportion in the mix. Through the use of different types of additives, the efficiency of asphalt mixtures can be improved, including: polymers, latex, fibers and several chemical additives [12]. It has been proven that adding some polymer additive to asphalt mix will enhance asphalt pavements performance. Usually, the application of polymers exhibits improved resilience, greater resistance to permanent deformation in the form of rutting and thermal crack. It also increases stability, and decreases damage to fatigue [12]. Various types of polymers have been identified to be effective polymer additives that would improve asphalt pavements life and also address many environmental problems [14]. Flexible pavements are constructed structures consisting of a group of layers of different materials placed on an existing (Subgrade) surface. Figure 2.1 demonstrates cross-section of a flexible pavement structure[15][16].

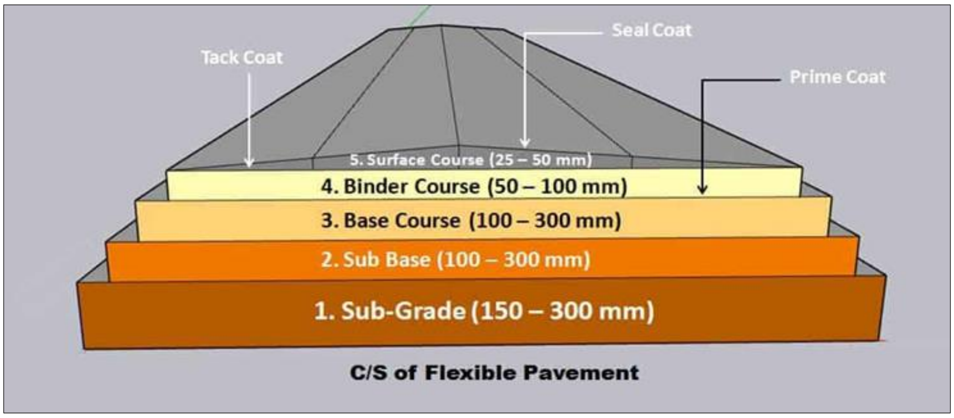

Figure 1 Cross-section of a flexible pavement

2.1. Asphalt Mix Design

The core objective of mix design is to identify and incorporate the various components in such a way as it would result in a mix and have the most optimal levels of all the relevant properties in order to produce good possible mix, within the limits of the available materials and the funds available for the mix. The ultimate goal in hot-mix asphalt design is to achieve an economical blend of aggregate and binder. The resulting combination will include [2].

- Sufficient binder of the appropriate form and adequate aggregate grading to ensure a strong layer.
- Sufficient resilience to plastic deformation and cracking to hold the anticipated traffic without serious distortion or cracking.
- Sufficient air voids in a compact mix to allow additional compaction without flushing, bleeding or loss of plastic deformation resistance under traffics.

2.1.1. Asphalt Mixing Plant

Asphalt plant is often referred as asphalt drum mix plant, hot mix plant etc. Asphalt plant operates at some temperatures on the principle of combining aggregate with bitumen / asphalt to provide a suitable mix for paving. Asphalt plant is an assembly of mechanical and electronic equipment where aggregates and minerals are mixed, dried, heated, and mixed with asphalt to produce hot mixed asphalt (HMA) to meet specific road building requirements. Asphalt plants are facilities built and constructed to produce asphalt and asphalt concrete, which are primarily used as the starting raw material for road layout and construction. For the asphalt to be formed, carefully measured quantities of the raw material are heated to a standard temperature and then removed from the plant.

Only with the production of the right quantity of aggregate, sand and stone dust in the plant at the optimum temperature is guaranteed the right quality of asphalt, which is absolutely necessary for laying quality roads. The Asphalt Plant is made of high-quality steel & reliable design to deliver long-term high performance without compromising the quality of the high-fuel efficiency product / mix, enhancing customer profit. The asphalt plant consists mainly of cold aggregate supply system, drum dryer, coal burner, coal feeder, dust collector, hot aggregate elevator, vibrating screen. All of these components have properties that have an impact not only on the asphalt overall quality but also the effect on the environment.

2.1.2. Hot Mix Asphalt

Standard type of asphalt is the Hot Mix Asphalt (HMA). The binding material and aggregate materials are heated to a temperature of between 275- and 300-degrees Fahrenheit and laid out while still intensely hot. Hot-mix asphalt (HMA) is mostly laid in a warm period, because cold temperatures will cause the base to cool quickly. For asphalt pavements, the asphalt binder is combined with aggregates to create hot mix asphalt (HMA). The Hot-Mix Asphalt (HMA) is the most commonly used paving substance worldwide. Many common names like: Hot-Mix Asphalt (HMA), plant mix, asphaltic concrete, bituminous mixture, bituminous concrete etc. The aggregates used in the mixture comprise coarse and fine materials, usually a blend of rock and sand of varying thickness [2].

Asphalt pavement primarily consists of aggregate binders and asphalt binder. Usually, the aggregate accounts for about 95% of the HMA mixture by weight, while the asphalt binder accounts for the remaining 5%. By volume a typical HMA mix is around 85% composite, 10% asphalt binder, and 5% air voids. Hot-mix asphalt (HMA) is manufactured at temperatures between 140 ° C and 160 ° C, and some mixtures, including asphalt rubber and polymer-modified asphalt (PMA) mixtures can require even higher mixing temperatures. Such temperatures ensure that the aggregate is dry, that the asphalt coats the aggregate, and that the mixture has the appropriate workability.

2.1.3. Polymer Modified Asphalt Mix

Many polymeric substances have been introduced into the asphalt mix as an additive in different forms to enhance the efficiency of asphalt pavements. The alteration of bitumen and asphalt mix in polymer has many benefits. These benefits include; improved thermal cracking resistances, enhanced fatigue resistance, improve rutting resistance, and decrease in temperature susceptibility [2]. Polymers are mainly incorporated as a binding agent (bitumen) modifier in an asphalt mix. Polymers can be added to form an aggregates coating material. In addition, in an asphalt mix, Polymers may be used as a partial replacement for certain amount of aggregates.

The qualities of a modified asphalt mix vary depending on several factors such as: polymer characteristics, mixing conditions, and polymer compatibility with content of asphalt mix. Polymers are of many types and classifications. Plastics are one the most widely used polymers nowadays. Extensive research has also been conducted to assess the suitability of plastic waste to be used in asphalt mix. Additives, which are used to modify or improve the quality of virgin materials is simply called the modifier of it. Modifiers are blended directly with the binder or added to the asphalt concrete mix during production to enhance the properties, and the performance of the pavement. It should be mentioned here that a huge quantity of bituminous binder is required every year for pavement construction.

2.2. Polymers structure and classification

Polymer is a derivative term meaning 'various pieces' Polymer generally refers to very large molecules which are produced by chemical reaction of many small molecules (monomers) in order to produce long chains. Chemical structure, molecular weight, and monomer sequence of particular polymer determines its physical properties [2]. In many ways, plastics can be classified but most popularly because of their physical properties. Plastics can also be classified according to their chemical origins. The twenty or more basic forms that are known fall into the four general groups: plastics of cellulose, synthetic resin plastics, and plastics of proteins, natural resins, elastomers and fibers. Nevertheless, depending on their physical properties, thermoplastic and thermosetting materials can be graded as. Thermoplastic materials can be molded under heat and pressure into desired shapes and become solids when refrigerated. If they undergo the same heat and pressure conditions, they can be remolded, while, thermosetting materials which cannot be remolded or softened once shaped by heat application. The examples of certain typical thermoplastics and thermosetting materials are given in Table 1 below.

Table 1 Typical Thermoplastic and Thermosetting Resins (Source: Central Pollution Control Board, 2016)

S/N	Thermoplastic	Thermosetting
1	Polyethylene Teryphthalate (PET)	Bakelite
2	Polypropylene (PP)	Epoxy
3	Polyvinyl Acetate (PVA)	Melamine
4	Polyvinyl Chloride (PVC)	Polyester
5	Polystyrene (PS)	Polyurethane
6	Low Density Polyethylene (LDPE)	Urea – Formaldehyde
7	High Density Polyethylene (HDPE)	Alkyd

2.2.1. Plastic Polymers

Plastic are natural or synthetic resins, or compounds that can be molded, extended, cast or used as films or coatings, which composed of carbon, oxygen, hydrogen and nitrogen. Plastics are mainly synthetic high molecular weight polymers. Natural products such as cellulose, coal, natural gas, salt and crude oil are the raw materials for producing plastics. Plastic materials have different structures in the polymer chain which determine many of their physical characteristics. Plastic is an important element of several items, such as water bottles, combs and containers for drinks. Understanding the difference, and the SPI codes, will help you make more educated recycling decisions. In 1988, the Society of the Plastics Industry (SPI) launched a special numbered coding system to enable consumers and recyclers to properly identify the type of resin used in producing a product. Manufacturers adopt a coding system and place an SPI code, or number, on each plastic product that is typically molded to the bottom.

2.2.2. Polymer-Modified Bitumen

Bitumen serves the function of binding the aggregate together when constructing flexible pavements by coating over the aggregate. It also helps to enhance road strength. But its water resistance is low and anti-stripping agents are being used. Modifying the rheological properties of bitumen by mixing with organic synthetic polymers such as rubber and plastics is a popular method for improving bitumen quality. At the national and international level, studies on this subject are ongoing. The type of bitumen formed by the modification of strength and the rheological properties of bitumen graded penetration is polymer modified bitumen. For this, 2 to 8 percent polymer is used here. Either rubber or plastic can be the polymer used. These polymers change the strength and viscoelastic properties of the bitumen. This is done by: Increase in elastic response, Providing ductility, Cohesive property enhancement and Enhancement of strength of fracture

Styrene block copolymers, synthetic rubbers, and natural and recycled rubbers are some of the examples of rubber polymers used. It also uses thermoplastic polymers.

2.3. Benefit of Polymer Modified Bitumen

The aim of bitumen polymer modification is to establish a long-lasting pavement with greater rigidity and stability in order to minimize the cost of maintenance. The use of polymer can increase construction costs some time. In this case the benefit is assessed through improving the quality of the pavement. The use of RPE (recycled polyethylene) and CR (crumb rubber) provides advantages in improving consistency and cost efficiency, as well as environmental hazards. The results are measured in three ways;

2.3.1. Quality improvement of binder

Bitumen polymers enhance the strength of bitumen as follows:

- Polymer Increases the viscosity of the binders which allows greater film thickness in paving mixes without excessive drain or bleeding
- It improves the consistency of the binder to better cope with the cracking and dynamic deformation of internal layers of the pavement.
- It improves the binder's fatigue behavior by increasing its mechanical resistance especially to tractive force.
- It elevates the binder softening point which helps to reduce bleeding.
- It increases resilience and elasticity at high temperatures;
- It improves binder cohesiveness.

2.3.2. A significant improvement in pavement is possible via

- Reduction in pavement deformations.
- Improved aging and oxidation resistance due to higher binding content, thicker binder films and tire rubber anti-oxidants.
- This offers greater resistance to fatigue.
- This provides greater stripping resistance.
- It has enhanced properties for self-healing.
- Gives more durability.

2.3.3. Improving the environment

The use of waste plastic in road construction will contribute to major regular consumption of waste plastic that would be helpful in keeping the environment clean and safe, reducing drain clogging that causes various hazards, including health hazards, reducing the disposal of waste plastic materials into land filling, etc.

2.4. Waste Plastic Utilization in an Asphalt Mixture

Different types of plastic become waste after use and require huge quantities of land for storage, which is also inconvenient for recycling[17]. Hazardous plastic struggles to fill land due to its poor biodegradability and is not a dominant disposal technique. Because of the stronger binding properties of plastics in their molten state, innovative waste disposal methods are investigated by using them in the construction of flexible paving. As a consequence, waste plastic was one of the plastomer polymers that can be used by three different processes in asphalt concrete mixing: dry process, wet process, and the third process requires the use of waste plastic as a partial replacement for some aggregate sizes.

The primary mixture of shredded plastic polymer waste over hot aggregates is involved in the dry process to create an aggregate coating layer usually by melting plastic over a hot aggregate surface. In addition to cement filler and crush sand, coated aggregates after coating are added to hot bitumen to obtain a homogeneous bituminous mix for versatile pavement course wearing. Depending on plastic properties and mixing conditions, this coating layer will enhance aggregate bonding and engineering properties, contributing to improved durability of asphalt mixtures. Dry process only applies to plastics polymers [18].

The wet process requires the simultaneous combining of bitumen and plastic waste. This method starts with the initial mixing of shredded plastic polymer waste into hot bitumen with continuous stirring. At around the same time, hot aggregates are inserted into modified bitumen along with crushed sand and cement filler to obtain a homogeneous bituminous mix for wearing flexible pavement [18][19].

The modification of bitumen by adding polymer offers many improvements to asphalt mixtures that may include improvements in thermal cracking, resistance to rutting and stripping, and sensitivity to fatigue damage and temperature. In many paving and maintenance applications, improving asphalt mixtures has resulted in polymer modified bitumen becoming a substitute for ordinary bitumen. The consistency of the modified bitumen depends on various factors, such as the properties of the polymer-bitumen, the mixing conditions and the compatibility of the plastic polymer with the bitumen. To blend plastic polymers into bitumen, two methods are used the first method is to apply latex polymer to bitumen, which allows reasonably fast dispersal of polymer. The second solution is to apply solid polymers to the bitumen, which typically requires a high shear mixer to achieve an evenly distributed mixture[20].Another way to incorporate plastics into the asphalt mixture is to substitute a portion of plastic polymer mineral aggregates of the same size that is mainly used to blend waste plastic and absorbs a greater proportion of plastic in the asphalt mix [18].

2.5. Laboratory Studies Related of Plastics Utilization in Asphalt Mixes

Several studies have been performed on the use of polymers to increase asphalt mixture quality. As one type of polymers, recycled plastics can replace a portion of aggregates or serve as a modifier of binding agents (binder modifier) and can also be used for aggregates as a coating material.

2.5.1. Utilizing plastics for binder modification

Justo and Veeraragavan [21] investigated on “Asphalt concrete mixes” in Bangalore University. Plastic bags were used as additive in the mixes. Laboratory tests were conducted on sample containing plastic bags and samples without plastic bags. It was claimed that with the increase in the proportion of the plastic additive added, the penetration value and the ductility values of the sample containing plastic bags reduce. [22] also identified the road construction carried out in Ghana using thermoplastic material (i.e. High-Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET)). Laboratory tests were conducted on the materials needed for pavement construction. The research concluded that bitumen containing waste plastic is a technique for recycling plastic waste in Ghana.

2.5.2. Utilizing plastics as an aggregate coat

[23] reported that the coating of waste plastics with aggregate and bitumen reduces the moisture absorption, porosity and enhances the soundness and the plastic coated with aggregate and bitumen mix forms suitable materials for road construction as the mix demonstrated a higher Marshall Stability value and an acceptable Marshall coefficient. As such, waste plastic recycling is one of the methods for disposing of plastic waste and avoiding contamination from the environment. [18] also established a method for using waste plastic for road construction. Bitumen is used as a binding agent and its properties can be improved with shredded waste plastic. The research proved that the use of plastic waste better the density, stability, binding property and its resistance towards water is good. [24] further researched on the use of bituminous mix of plastic waste. The aggregates and bitumen were subjected to different tests. The review also claimed that the use of plastic waste would not only strengthen road construction, but will also increase the life span of the road and lead to environmental improvement[25]. The use of plastic waste would help to reduce bitumen requirements by about 10 percent. Furthermore, [26] also investigated the reuse of aggregate-coated waste plastics and the composite bitumen mix for road application followed by a green method. Diverse wastes are measured by products and their characteristics have been identified. The waste plastics were heated and coated to aggregates and then tested.

The results concluded that plastic road performance is very good for heavy traffic due to it being better binding with increased strength and improved surface quality over a prolonged period of exposure to weather changes[27].

2.5.3. Utilizing plastics to replace aggregates

[28] investigated the use of recycled plastics consisting mainly of low-density polyethylene LDPE in the form of pellets to substitute (by volume) a fraction of equivalent size mineral aggregates (2.36-5.0 mm) forming a new mix called 'Plastiphalt.' The result concluded that 30 percent of recycled plastic pellet aggregate volume replacements reduce bulk density by 16 percent per recycled plastic pellet. The observed flow values were also higher, suggesting that both stronger and more elastic are Plastiphalt blends. In addition, the ITS value was found to be higher in the Plastiphalt blend. Finally, the mechanical properties are superior to those of mineral aggregates consisting of control mixes for aged recycled plastic mixes.

3. Previous research papers that employed the use of plastics in road construction

A firm pavement surface is often characterized by high resistance under heavy traffic loadings [29]. Consequently, many researchers have participated in studies that investigated how the use of additives in bituminous mixtures can help enhance the performance of the pavements. Table 2 illustrates the varieties of plastics that have been employed in the construction of pavements.

Table 2 Previous research with plastics as additives for pavement construction [5]

Authors	Plastic used	Shape	Properties
[30]	Discarded PET	Chips 0.118cm	Density =1.3 g/cm^3
[31]	PP	Powdery	Density: 0.82 g/cm^3
[32]	Waste PP Waste HDPE Waste LDPE	Mulch PP Powder HDPE &LDPE	Melting point HDPE: 131˚C LDPE: 110 ˚C
[33]	Waste HDPE & LDPE	Grinded not grinded/ 0.2-0.30cm	Melting point HDPE: 125 ˚C LDPE: 110˚C Specific gravity (g/cm^3) HDPE: 0.035 LDPE: 0.033
[34]	Waste LDPE	Pellet 5.00-2.36mm	Melting point= 140˚C Specific gravity= 0.92 g/cm^3 Softening point= 120C
[35]	Waste PP & PET	Pellet	Specific gravity PP: 0.921g/cm^3 PET: 0.900 g/cm^3
[36]	Waste HDPE	Powder/ 2mm	Specific gravity= 0.935 g/cm^3
[37]	Waste PE & LDPE	PE : wax LDPE: pellet and shredded	Not given
[34]	HDPE	Pellet	Melting point: 149˚C Density : 0.9430g/cm^3 Tensile strength: 3MPa
[23]	Waste PE, PP & PS	Foam/powder	Softening point 120- 210˚C

[38]	Waste PET	Chips/ crushed then sieved ; 0.425-1.18mm	Not given
[39]	Waste LDPE & HDPE	Powder 0.15-0.75 mm	Density LDPE: 922kg/m^3 HDPE: 961 kg/m^3 Softening point LDPE: 95˚C HDPE: 127˚C
[29]	PET PLASTIC	Different sizes were employed	Densities between 2.67g/cm^3 and 2.97g/cm^3

4. Conclusion

Research papers from previous studies presented in this review have shown that, waste plastic can be utilized as a modifier in asphalt mix for road construction. It is of no doubt that waste plastics are elements of environmental pollution which ought to be eradicated or recycled to ensure a pollution free environment. Statistics have also shown that the amount of waste plastic generated will continue to increase with rising world population – as most consumables are branded in plastics. Thus, adopting methods that would recycle waste plastic for the betterment of mankind has proved to be a valuable alternative over the past few years. Utilizing waste plastic as an additive in road construction pavement have been regarded as a valuable strategy for recycling waste plastics.

Nevertheless, this paper has identified numerous ways of adding plastic waste to an asphalt mix with the view to enhancing the properties of the asphalt mix. More so, it has been established that the quality of the asphalt mix is dependent on the type and quantity of plastic employed. Basically, there are four types of waste plastic that can be used as an additive in asphalt pavement – they include Polyethylene Terephthalate (PET), Low-density Polyethylene (LDPE), High -density polyethylene (HDPE), and Polyethylene (PE).

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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