

# Literary Review of Incorporation of Plastic Waste in Pavement Layers

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**Abstract** This review article explores the utilization of plastic waste as an environmentally conscious alternative in road construction projects. It mentions several countries that have implemented plastic waste management mechanisms to incorporate them into pavement, thus promoting a circular economy. The aim of this review is to offer an up-to-date synthesis of the application of plastic waste in various pavement layers and the corresponding benefits. Research was compiled from several authors from different countries that applied plastic waste in subgrade, bitumen, asphalt and rigid pavement. These studies evaluated the behavior of standard and modified samples through different tests to determine how pavement properties are affected by the incorporation of polymer wastes. In addition, different types of plastics and their physical properties, such as melting point, which is important in determining the method of incorporating waste plastics into asphalt, are described. A table is included that provides information on the recycling of plastics, their acronyms, densities, biodegradability and applications in daily use, which facilitates the visual identification of the types of plastics. The plastics examined in this analysis include low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyethylene terephthalate (PETE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), and acrylonitrile butadiene styrene (ABS). The conclusions of this review are related to the application of the flooring. The conclusions of this review are related to the application of the pavement in different layers and how this can improve its properties depending on the layer where the polymer is

applied.

**Keywords** Plastic Waste, Roads, Pavement, Recycling, Mechanical Properties, Environment

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## 1. Introduction

The increase in waste is a major global challenge. Various countries around the world have put in place different waste management mechanisms with the aim of effectively addressing this problem [1]. Numerous researchers from various disciplines are constantly engaged in exploring different alternatives to efficiently reuse different forms of plastic. One such example is plastic roads, paved roads using plastic waste, which are now being widely used [2]. It is important to note that the incorporation of plastic waste into pavement can be applied in various layers and through different methods. Therefore, the objective of this research is to conduct a review of how plastic waste is applied in different ways to pavement such as in bitumen, asphalt, rigid pavement and subgrade. The potential utilization of plastic waste in road construction projects could lead to further benefits for the industry. Historically, waste plastics have been poorly considered as suitable materials for road construction due to the paucity of evidence supporting their compatibility and feasibility in this area [3]. However, the following review comprehensively compiled various articles incorporating plastics in road construction and their positive impact, both

in terms of improved mechanical properties and cost reduction. Consequently, it can be asserted that the use of plastic waste as an alternative to virgin polymers can be an exceptionally eco-friendly concept for the construction or rehabilitation of road pavements [3]. Furthermore, solid waste materials, such as plastics and pavers, are recognized to be versatile, cost-efficient, functional, visually appealing, and require minimal or no maintenance if properly manufactured and installed [1].

## 2. Materials and Methods

Table 1 is a summary of the research articles that have been compared in this review, and a comparison of the different applications of plastic to pavement has been made. These articles have been grouped according to the application to the different pavement layers, and it is worth mentioning that these researches have been carried out in different countries, which allows us to have a broader

vision of the subject from different contexts.

## 3. Types of Plastics and their Characteristics









Different types of plastics have varying physical properties, with one important characteristic being the melting point. The melting point helps determine the potential applications for plastic, such as whether it can be used in dry or wet conditions. One application that utilizes the melting point of plastic is its incorporation into asphalt binders for pavement. For this application, the plastic must be able to melt before being mixed into the asphalt. Table 2 provided outlines the melting point, properties, acronyms, and biodegradability of different types of plastics. Knowing the melting point and other characteristics allows for the appropriate selection and use of plastics in various applications, including pavement construction.

**Table 1.** Article Summary

Fountain	Country	Author	Plastic	Application layer
ScienceDirect	Ethiopia	Shelema Amena	General waste	Subgrade
ScienceDirect	Australia	Zhu, Saberian, Li, Masqsood, & Yang	PETE	Subgrade
ScienceDirect	Türkiye	Bozyigit, Bulbul, Alp, & Altun	PETE	Subgrade
ScienceDirect	Iran	Koohmishi & Palassi	PETE	Subgrade
ScienceDirect	Ghana	Kofi Tulashie S., Kofi Boadu, Kotoka, & Mensah	General waste	Rigid pavement
ScienceDirect	Pakistan	Ali, Ali Qureshi, & Kurda	PP	Rigid pavement
ScienceDirect	Portugal	Costa, Silva, Peralta, & Oliveira	HDPE and EVA	Bitumen
ScienceDirect	China	Xiong, Zhen, Wei, Jiangmiao, Yawei, Anand and Jing	PETE, TETA and EA	Bitumen
ScienceDirect	India	Biswas, Goel, & Potnis	General waste	Bitumen
ScienceDirect	Saudi Arabia	Muhammad, Muslich, Kaffayatullah, Mudassir, Madzlan, Salh.	PET	Bitumen
ScienceDirect	Iraq	Hadidy	PP	Asphalt
ScienceDirect	USA	Ghabchi, Dharmarathna, & Mihandoust	PETE	Asphalt
Sky	Costa Rica	Cruz Cajina, Camacho Garita, Baldi, & Aguiar Moya	PVC	Asphalt
ScienceDirect	China	Yao, Lan, Chen, & Jiang	PETE	Asphalt
ScienceDirect	Singapur	Gengren, Meibo, Sin Mei, Ghim Ping, Angraini & Sothinathan	LDPE, HDPE y PP	Asphalt

Source: own elaboration

**Table 2.** Properties of plastic waste that can be recycled according to [4], [5]

Type of plastics	Recycle symbol	Acronym	Main properties	Biodegradability
polyethylene terephthalate		PETE	- Thermoplastic - Semi-crystalline - Density: 1.15 +- 0.03 g/cm <sup>3</sup> - Tensile strength: 0.8 +- 0.14 N/mm <sup>2</sup> [5]. - Melting point: 250-255 °C [4].	Biodegradable
High density polyethylene		HDPE	- It is not transparent - Density: 0.940 to 0.965 g/cm <sup>3</sup> - Melting point: 131 °C - Flow rate: 6.12 g/10min [5]. - Melting point: 130-149 °C [4].	Not Biodegradable
Polyvinyl chloride		PVC	- Density: 0.77 to 0.88 g/cm <sup>3</sup> - Resistant to sunlight [5]. - Melting point: 100-260 °C [4].	Not biodegradable
Low density polyethylene		LDPE	- Density: <0.930 g/cm <sup>3</sup> - Softening point: 85 °C - Tensile strength: 8.96 Mpa [5]. - Melting point: 110-120 °C [4].	Biodegradable
Polypropylene		PP	- Density: 0.9 g/cm <sup>3</sup> - Flow index: 12 g/min [5]. - Melting point 160-165 °C [4].	Biodegradable
Polystyrene		PS	- Density: 1.1+-0.19 g/cm <sup>3</sup> - Tensile strength: 3 +- 1.13 N/mm [5]. - Melting point: 210-249 °C - Melting point: 210-249 °C [4].	Not Biodegradable
Acrylonitrile Butadiene Styrene		ABS	- Does not resist ultraviolet radiation - Glass transition temperature: 105 °C [5]. - Melting point: depends on the types of plastic [4].	Not biodegradable
Ethylene acetate		EVE	- Processing temperature: 65-80 °C - Melt flow rate: 2.5 g/10 min [5]. - Melting point: 75-102 °C [4].	Not Biodegradable
Polycarbonate		PC	- Water absorption: 0.15% - Compressive strength: 86.1Mpa - Tensile modulus: 2.37 Mpa - Tensile strength: 69 Mpa - Modulus of elasticity: 1960Mpa [5]. - Melting point: depends on the type of plastic [4].	Biodegradable
Polyurethane		PU	- Density: 1.12 g/cm <sup>3</sup> - Tensile strength: 45 N/mm <sup>2</sup> [5]. - Melting point: depends on the type of plastic [4].	Non-degradable

Source: own elaboration

## 4. Plastic Waste

The term "plastic waste" encompasses materials composed of diverse types of plastics that have been discarded or disposed of following their intended use. These plastic waste materials often have diverse chemical compositions and were originally intended for different commercial applications [6]. In addition, they can include a wide variety of objects, such as plastic bottles, food containers, bags, wrappings, toys, disposable utensils, pipes, and many other plastic products. Generally, polyethylene terephthalate (PETE), LDPE and HDPE wastes are available in larger quantities and are more suitable for reuse than the others, so they have relatively high recycling rates [6]. However, there are different plastics that prove to be a significant environmental problem due to their slow decomposition and low recycling rate. These wastes generate negative impacts on the

environment, such as the release of toxic chemicals as they decompose, soil and water contamination, and danger to animals that ingest or become entangled in them.

## 5. Types of Polymers and their Application

It is important to know the different plastics by their technical names; on the other hand, it is also essential to know how to identify them in our environment, in order to achieve efficient recycling, since not all of them are recycled in the same way, due to their different properties. Also, not all plastics are suitable for flooring applications and choosing the wrong plastic would be detrimental. The following table 3 compiles the types of plastics and their presentations in everyday life.

**Table 3.** Types of plastics and use according to [4], [7] and [5]

Type of plastics	Acronym	Application
Polyethylene Terephthalate	PETE	Bottles, butter containers, vegetable oil containers, and food containers [4]. Only use drink bottles, vegetable oil containers and salad dressing [5].
High-density Polyethylene	HDPE	Juice bottles, bleach bottles, shampoo bottles [4]. Engine oil and bottles Toys [5]. Shopping bags, Home furniture, Bottlecaps [7].
Polyvinyl Chloride	PVC	Pipes, Plumbing fixtures, blister packaging, cooking oil bottles, retaining rings [4]. Cable insulation profiles, Garden hoses, Window frames [5].
Low-density Polyethylene	LDPE	Sheets, collapsible bottles, shopping bags, durable sacks [4]. Shopping bags, cosmetic and detergent bottles, garbage bags and milk bags [5].
Polypropylene	PP	Straws, wrappers, syrup bottles, packing tapes [4]. Automotive parts [5]. Detergent wrappers, bottle caps and holders, food containers and steamers, icrowaveable food trays [7].
Polystyrene	PS	Disposable plates and cups, egg cartons, CD cases, Test tubes [5].
Acrylonitrile butadiene styrene	ABS	Computers, mobile phones, pipes, toys, Legos, Helmets [4].
Ethyl Vinyl Acetate	EVA	Home tools and Toys [5].
Polycarbonate	PC	CD y DVD [4].
Polyurethane	PU	Mattresses, medical devices, building thermal insulation [4].

Source: own elaboration

## 6. Methods of Incorporating Plastic into the Pavement

There are two types of incorporation of plastic into the pavement and they are the following:

### 6.1. Wet Method

This process consists of adding the plastic waste to the hot asphalt binder, mechanically mixing to obtain a uniform plastic mixture, and then mixing this modified mixture with the aggregates and possible additional filler materials to obtain the final mixture to be used in road construction or other similar applications [8]. Briefly, this method involves mixing the plastic material with bitumen between 140 and 180 °C before adding the mixture to the hot aggregates [9].

The incorporation of plastic through the wet method is depicted graphically. As shown, the polymer is mixed with the asphalt binder, and this modified asphalt is then mixed with the aggregates to produce a final mixture of asphalt modified with polymers (Figure 1).

### 6.2. Dry Method

In the dry method, recycled plastics are added directly to the mixture, serving as a replacement for aggregates or mix modifiers [4]. By incorporating these plastic waste materials alongside the aggregates, they fulfill a role as modifying or reinforcing agents within the composition of the mixture. The mixing temperature and duration are adjusted based on the specific characteristics of the plastic waste and the asphalt binder being used [8]. This technique

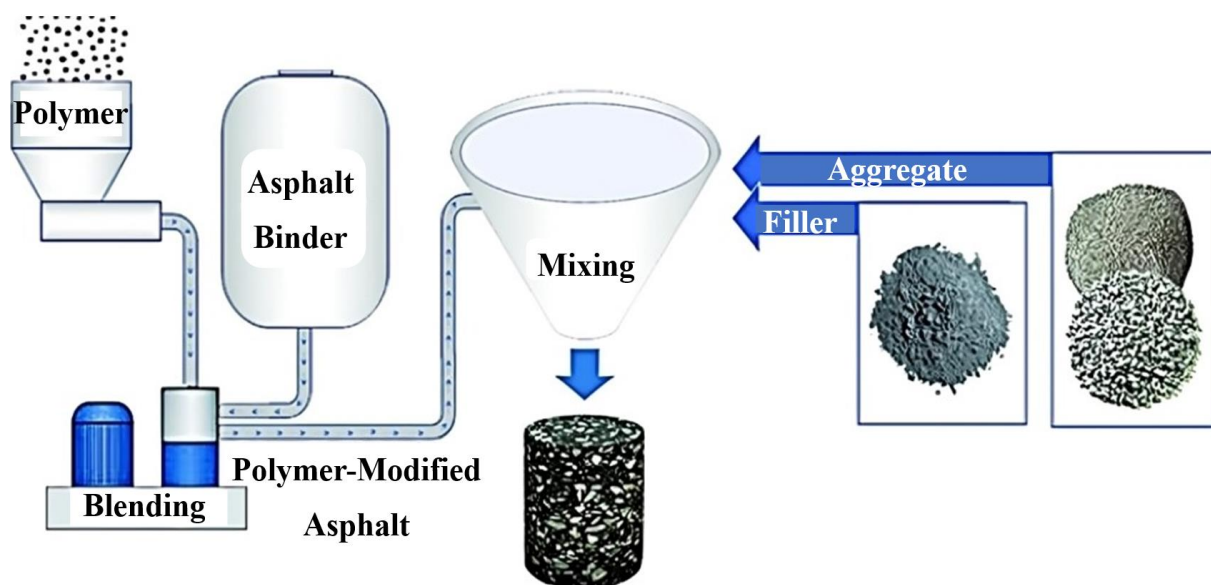
involves mixing plastic waste, which has a high melting point or is of an amorphous nature, with aggregates that have been heated to a temperature between 140 and 180 degrees Celsius. This is done prior to the addition of the bituminous binder [9].

One key advantage of this dry method approach is that it does not require any modifications to existing mixing plants. However, the successful performance of the resulting mixtures will depend on closely controlling the polymer addition process, as well as the duration of mixing and "digestion" before incorporating the bitumen binder [10].

Utilizing recycled plastics in road and asphalt pavement construction holds substantial promise for addressing plastic waste issues. Given the ubiquity of asphalt pavements globally, incorporating these recycled materials into their production could provide a meaningful avenue to repurpose plastic waste, rather than it ending up in landfills or the environment [11].

### 6.3. Influence of Melting Point to Determine the Incorporation Method

It is essential to understand and identify the interactions between plastics, bitumen and aggregates, as it has been observed that their compatibility differs depending on the incorporation method [10]. In the dry method approach of aggregate substitution, recycled plastics with high melting points, such as PET and PS, are commonly used. On the other hand, the "blend modifier" method, which employs a wet process, can accommodate a wider range of recycled plastics, including PE, PP, PET, and PS. The exception is PVC, which is avoided due to concerns about hazardous chloride emissions [11].



**Polymer-Modified Asphalt Mixture**

Figure 1. Polymer incorporation process by wet method [8]

## 7. Three Types of Sources of Plastic Waste

The concept of "direct transmission" denotes plastic waste that was analyzed immediately following its initial use. In contrast, "municipal waste collection" describes plastic waste that was gathered by local government sanitation services and then incorporated into the research. Lastly, the term "recycling facility" refers to plastic waste that had undergone various processing steps before being included in the studies.

Most of the plastic used in the studies came from direct transmission, suggesting that it was not subjected to any pretreatment. Conversely, when the plastic waste was sourced from a recycling facility, it was known to have undergone multiple processing steps before being incorporated into the research studies [12].

## 8. Polymer Applications to Pavement Components

### 8.1. Incorporation of Plastic Waste into Subgrade

The application of plastic waste to pavement subgrade is a practice that aims to take advantage of plastic waste and give it a beneficial use in road and pavement construction. This technique, known as plastic waste stabilization, involves mixing shredded plastic waste with materials used in the pavement subgrade, such as soil, sand, or aggregates [4].

There are different investigations in which plastic waste is applied to the pavement subgrade in order to improve road properties. Some results of projects where plastic was

applied in this way and the results obtained will be presented below.

An investigation that took place in Ethiopia carried out by Amena [13] incorporated rectangular plastic strips (5x8 mm, 8x15 mm, 15x25 mm) in percentages of 0.25%, 0.5%, 1%, 1.5% and 2% in the form of chips in the pavement subgrade layer, and it is worth mentioning that this investigation was carried out on expansive soils (soils that change their volume as a function of their temperature) [13]. Various tests were conducted, and the following results were obtained:

As the size and percentage of plastic waste additions increase, the free swelling values of the soil decrease, indicating a reduction in the swelling properties. This means that the potential swelling of expansive soils will decrease [13]. On the other hand, with respect to compressive strength, the application of 8x15 mm strips at percentages of (0.5%, 1% and 1.5%) increases the strength from 80kPa (untreated soil) to 192.8kPa (amended soil), indicating a considerable increase in strength [13]. Similarly, the CBR (California Bearing Ratio) value increases as the percentage of plastic waste addition increases, up to a point of 1.5% plastic content [13]. Additionally, the direct shear test showed that when plastic strips are placed vertically perpendicular to the failure plane, the specimen can resist a higher shear force [13].

In another investigation that took place in Australia, highlighted by Zhu, Saberian, Li, Masqsood, & Yang [14], researchers used waste from clean and dry PET bottles, which they cut into strips measuring 25 mm in length and 10 mm in width. These plastic strips were incorporated into the soil samples at percentages of 0.1%, 1.5%, and 2% [14]. (Figure 2) The dimensions of the plastic that were used for this research are shown.

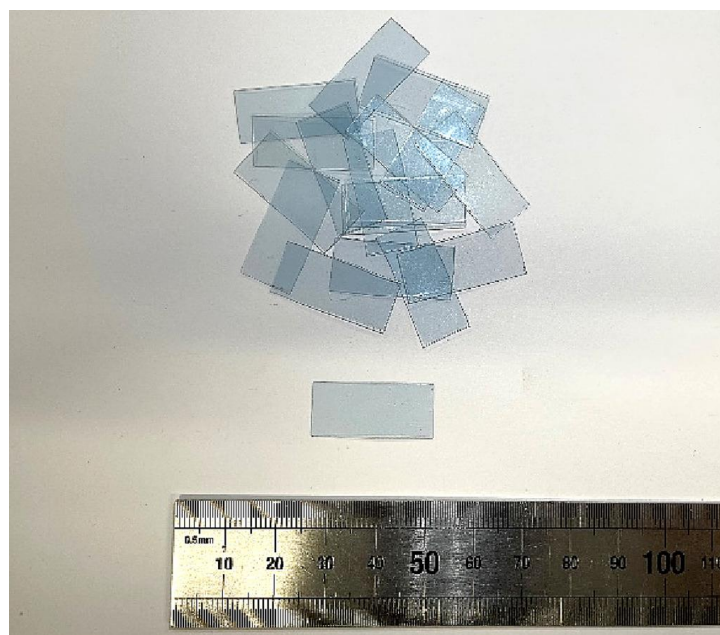


Figure 2. PET plastic strips [15]

After several tests, the following was determined; with respect to compressive strength, the inclusion of 1% PET strips increases this property, but if this percentage increases, the property decreases, since the PET strips are stacked together, minimizing compaction and expanding void spaces. In contrast to the unreinforced soil, which exhibited an increase in shear failure, the soil samples reinforced with 1% PET strips displayed a "bulging" failure mode. This suggests that the PET strips helped bind the soil particles together and distribute the applied stresses more evenly, resulting in a different failure mechanism compared to the unreinforced soil [14].

On the other hand, research conducted in Turkey by Bozyigit, Bulbul, Alp, & Altun [15] was responsible for investigating the potential use of polyethylene terephthalate (PET) bottle strips as a reinforcement material to improve the strength properties of cement-stabilized clay [15]. In this research, PET bottle scraps were used, which were cut into strings and random pieces with shredding scissors. The percentages of plastic that was applied are 0.5%, 1%, 1.5% and 2% [15]. (Figure 3) Next, it is observed how the procedure to randomly cut the plastic strips was performed. For this purpose, in image (a) the materials to be used are shown, in (b) it is observed how they placed the sharp object stuck to the table and then rotated the bottle to obtain the plastic strips, in (c) it is observed that these strips were cut transversely with scissors to obtain smaller pieces.

The findings indicated that the maximum dry unit weight of the soil-plastic mixture increased as the plastic bottle strip (PBS) content was raised to 1.5%. Beyond the 1.5% PBS content, the maximum dry unit weight started to decrease. This was attributed to the reduction in voids

within the fiber-cement-soil matrix. However, when the plastic fiber content exceeded 1.5%, the formation of lumps and air pockets was observed, depending on the structural arrangement of the fiber-cement-soil matrix [15]. The test results indicated that the optimal plastic content for cement-stabilized clay ranged from 1% to 1.5%. Another study conducted in Iran by Koohmishi and Palassi explored an alternative application. Koohmishi and Palassi evaluated the mechanical and physical characteristics of clay soil blended with PET particles obtained from discarded water bottles [16].

Different types of recycled PET were used for this investigation. The PET forms were long fibrous and round granular. The application percentages of the polymer are 0.5%, 1%, 1.5%, 1.5%, 2%, 3%, 5% and 10%, and these will be mixed with the clay soil [16] (Figure 4). The different forms of PET plastic used for this research are observed, and mainly recycled bottles were used, as shown in Figure 5.

In general terms, it is observed that the incorporation of PET reinforcement improves the resistance index to point loads in both unsterilized and lime-stabilized soils, provided that less than 2% is added. The incorporation of PET improves the flexibility of the material, allowing mixtures containing clayey soil and plastic admixtures to be more tolerant at lower stress levels. However, this improved flexibility can also aggravate induced stresses in the mix. In addition, stabilization with lime increases the stiffness of the mix [16].

Table 4 compares the results obtained from the application of plastic to the subgrade, the percentages of the different investigations and the properties that improved.

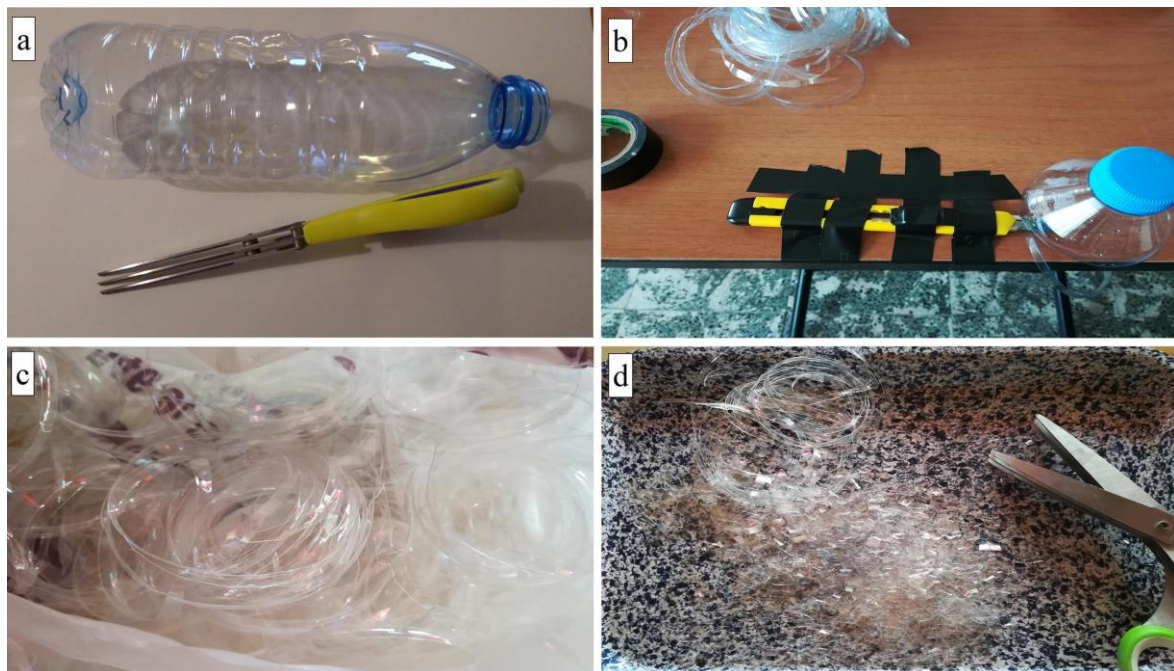


Figure 3. PET plastic cutting procedure [16]



Strips



Pellets

Figure 4. Types of PETE [16]



Figure 5. PET plastic shapes [16]

Table 4. Comparison of optimal percentages of polymers to the subgrade

Plastic	Dimension	Optimal percentage	Property
General waste	8mm x 15mm	0.5%, 1% and 1.5%	Compressive strength 192.8 kPa
			CBR increases [13].
PET	25mm x 10mm	1%	Compressive strength increases 1%
			Reduces shear failure [14].
PET	Random strips	1% and 1.5%	Maximum dry unit weight
			Improves compressive strength [15].
PET	long fibrous	<2%	Prop load resistance
			Improves flexibility [16].

Source: own elaboration

## 8.2. Incorporation of Plastic Waste into Rigid Pavement

In a study conducted in Ghana by Kofi Tulashie S., Kofi Boadu, Kotoka and Mensah [1], the conversion of plastic waste into pavement blocks was studied. The samples were crushed in the Beston plastic shredding machine in Zhengzhou (China) to a particle size of 3 mm. The plastic flakes were then combined with well sand or sea sand and processed in a batch extrusion machine. The batches were melted at 175 °C in a closed extrusion system until the flakes disappeared. The researchers carried out various tests, including Fourier Transform Infrared Spectroscopy, Scanning Electron Microscopy, Water Absorption analysis, as well as assessments of compressive strength, tensile strength, and penetration resistance. The findings from these evaluations showed:

- ✓ Compressive strength reached equilibrium at 80% plastic content.
- ✓ The tensile strengths of PPPB (Plastic-Portland Cement Bricks) and PSPB (Plastic-Sand-Portland Cement Bricks) were directly proportional to the percentage of plastic in the blocks.
- ✓ The maximum tensile strength of PPPB (8.2 N/mm<sup>2</sup>) was higher than that of PSPB (6.1 N/mm<sup>2</sup>).
- ✓ Similar to compressive strength, tensile strength remained relatively constant when the plastic content reached 90% [1].

In Pakistan, Ali, Ali Qureshi, & Kurda [17] sought to analyze the carbon footprint cost of smooth concrete pavement articulated with different fibers, in this case it will be mentioned how the incorporation of polypropylene fibers influenced. Portland cement type I was used as binder, the length of the polypropylene is 12 mm and its diameter is 30 µm [17]. Different tests were performed, which are as follows: Tensile strength, where it was determined that FCCs incorporating polypropylene fibers (PPF) show lower performance compared to the other fibers, but still show improvements of 9% and 18% with a fiber dosage of 0.5% and 1%, respectively. In terms of residual strength, PPF (polypropylene fibers) fibers can easily slip under very high tensile stresses, resulting in lower residual strength compared to high carbon steel fibers (HSF). Finally, in terms of economic and environmental impact, the FCC-0.5%PPF blend can produce cheaper pavements by 6% compared to conventional Portland cement (PC) pavement [17].

## 8.3. Incorporation of Plastic Waste into the Bitumen

In a study conducted in Portugal by Costa, Silva, Peralta and Oliveira [18], uncontaminated residual polymers, such as DHPE, EVA and virgin SBS, were used to modify a conventional bitumen with a penetration grade of 35/50 [18]. For this study, the SBS (Styrene-Butadiene-Styrene) and DHPE (Dehydrogenated Polyethylene) particles were

reduced to a powder form to improve their dispersion within the asphalt. In contrast, the EVA (Ethylene-Vinyl Acetate) plastic maintained its initial size [18].

The researchers manufactured several polymer-modified binders in order to assess their fundamental properties, including softening point temperature, penetration value, and resilience. The results showed that the virgin SBS (Styrene-Butadiene-Styrene)-modified binder exhibited the greatest increase in softening point temperature, approximately 58%. This was followed by the recycled EVA (Ethylene-Vinyl Acetate)-modified binder, with an increase of approximately 25%. The recycled HDPE (High-Density Polyethylene)-modified binder showed an increase of approximately 19%. Based on the results, the SBS-modified binder displayed the strongest resistance to rutting. However, all the polymer-modified binders had softening point temperatures above 60 °C [18].

The resilience test results indicated that the elastomer-modified binders, specifically the SBS (Styrene-Butadiene-Styrene) and EVA (Ethylene-Vinyl Acetate) modified binders, demonstrated superior performance in terms of fatigue cracking resistance and rutting resistance compared to the unmodified bitumen.

Viscosity is a crucial property for asphalt binders, as they need to exhibit a sufficiently low viscosity to effectively coat the aggregates during the mixing process and provide adequate workability during the compaction stage. The results of the study revealed that the binders modified with recycled HDPE (High density polyethylene) and EVA (Ethylene vinyl acetate) demonstrated a lower viscosity compared to the binder modified with virgin SBS (Styrene butadiene styrene). This lower viscosity is advantageous as it enhances the workability of the asphalt mixture [18].

In a separate study carried out in China, Xiong et al. [19] examined the recycling mechanisms of PET (Polyethylene terephthalate) derived additives, particularly triethylenetetramine (TETA) and ethanolamine (EA). The researchers investigated the performance of these PET-derived additives, specifically TETA and EA, in the modification of rubberized bitumen (bitumen modified with rubber). For this study, the PET waste was collected locally and cut into 10 mm pieces. The TETA and EA were supplied by Sigma-Aldrich Corporation and were used as chemicals to degrade the PET particles. The rubber was obtained from a local tire, and the bitumen used was of 60/70 penetration grade [19]. The researchers then performed FTIR spectroscopy, viscosity tests, dynamic shear rheology (DSR), and multiple stress creep recovery (MSCR) to assess the modifying effects of the PET-derived additives on the rubberized bitumen. The results from these analyses showed the following:

- ✓ The incorporation of small amounts (2%) of PET-derived additives did not significantly impact the workability of the rubberized bitumen.
- ✓ The inclusion of PET-TETA as an additive significantly improved the fatigue resistance of the rubberized bitumen mixture.

- ✓ The addition of the PET-derived additives allowed the rubberized bitumen to retain its original resistance to deformation at 64°C and under an increased strain level of 3.2 kPa [19].

Biswas, Goel, and Potnis [2] conducted a comparative study on the performance of conventional bituminous roads and plastic-modified bituminous roads in the city of Pune, India. This study was carried out in December 2016 and 2017, during which several roads in Pune were surfaced with bituminous mixes containing 8% plastic waste by weight of the mix [2]. To conduct this comparative study, the researchers first collected data from the study area in Pune. They then performed various field tests, including:

- ✓ Benkelman beam deflection test
- ✓ Field relief survey
- ✓ Roughness test using a bump integrator
- ✓ Benkelman resistance test

These field tests were carried out to assess and compare the performance of the conventional bituminous roads and the plastic-modified bituminous roads in Pune. The results from the field tests conducted by Biswas, Goel, and Potnis [2] showed that the use of plastic-modified bituminous roads can lead to substantial economic savings for local authorities in developing countries, such as India. The incorporation of plastic waste into the bituminous mix helped reduce the amount of costly bitumen required for the maintenance of urban roads, thereby making them more cost-effective. Furthermore, the efficient utilization of waste plastics in the preparation of modified bitumen increased the value of this material, transforming it from a waste product that pollutes urban areas into a desirable resource [2].

Hake, Damgir, & Awsarmal [20] focused on exploring ways to use plastic waste as a component to develop a more adaptable asphalt. In the conventional road construction process, bitumen is used as the material. In this case, bitumen can be mixed with recycled plastic scraps, creating a bitumen combination that can be used as an improved and more adaptable asphalt layer [20].

Different percentages of bitumen substitution for plastic were tested, including 5%, 7.5%, 10%, 12.5%, and 15%. The optimum content was found to be 10% plastic, with a bitumen content of 5.25%. Marshall tests and performance evaluations of the hot-mixed black asphalt were performed. The results showed that the overall cost of mixes containing plastic is reduced by 5.18% compared to traditional bitumen. This shows that it is effective and beneficial to incorporate plastic waste in the development of bituminous pavements [20]. Another study, carried out in Saudi Arabia, focused on developing an effective method for recycling PET (polyethylene terephthalate) waste into a usable form for semi-flexible pavement surfaces [21]. In this study, the researchers exposed PET waste in powder form to gamma rays as a means of processing it. They then conducted various tests on the resulting PET-based slurries, including:

- ✓ Compressive strength

- ✓ Flow behavior
- ✓ Shrinkage

The study evaluated the physical, mechanical and microstructural properties of the grouts, and developed artificial neural network (ANN) models to predict the flowability value and compressive strength of the grouts. The results of the study show that partial replacement of cement with plain PET or irradiated PET increased the flowability value of the cementitious slurries. However, the use of plain PET significantly reduced the compressive strength at all curing ages, with reductions of 53-78% at 1 day, 24-46% at 7 days and 23-36% at 28 days. In contrast, the use of irradiated PET was able to partially restore compressive strength, with recovery rates of 20-30% at 1 day, 17-24% at 7 days, and 7-12% at 28 days [21].

#### 8.4. Incorporation of Plastic Waste into the Asphalt

Likewise, in Iraq, Hadidy [22] mentioned a new approach to the application of recycled polymers, since his research seeks to determine the influence of aging of binders and asphalt mixtures modified with polypropylene. To prepare the mixture, Iraqi penetration asphalt (AC-50), crushed coarse aggregates and polypropylene modifier were used. The following results were obtained: For the Marshall test, the PPMCM mixtures subjected to aging periods of 48 hours and 96 hours show greater stability compared to the control mixtures and their stability increases by 68.2% and 81.6%. On the other hand, the ITS values of the control samples at 60 °C increased by 4.0 and 4.87 times for the aging levels of 48 hours and 96 hours, respectively. This indicates that the tensile strength of the samples aged at high temperatures is notably higher compared to the control samples. Furthermore, when examining the TSR results, it is observed that the aging levels increased by 2.61% and 4.5% at 48 hours and 96 hours, respectively. This suggests that aging improves the ability of PPMCMs to resist water damage, as the TSR value is directly related to the surface adhesion resistance [22].

Similar results are provided by the research carried out by [23], where he carried out an experimental study on using PET plastic waste with TiO<sub>2</sub> to build roads, since he mentions that when using plastic waste mixed with TiO<sub>2</sub> in the classified dense bitumen mixture (DBM), there is an increase in the resistance value, specifically in Marshall stability. The study found that the addition of TiO<sub>2</sub> (titanium dioxide) and PET (polyethylene terephthalate) to the mixture increased 35% of the maximum resistance.

Another study, carried out in the USA, explored the impact of incorporating varying percentages (0%, 5%, 10%, 15%, and 20%) of micronized PET (MPET) as a modifier in an asphalt binder. Researchers also evaluated the use of MPET-modified asphalt binder in mixtures to improve their cracking, resistance to rutting, and moisture induced damage. The researchers utilized a rotational viscometer to

measure the properties of the modified binders. They also conducted binder bond strength tests on both dry and moisture-conditioned samples [24]. The findings of the study showed that asphalt mixtures containing Granite 1 aggregate and PG 58-28 asphalt binder modified with MPET demonstrated improved resistance to moisture-induced damage compared to the same mixtures prepared with the unmodified binder. This suggests that the addition of MPET to the asphalt binder can improve the mixture's ability to withstand the negative effects of moisture exposure, thereby reducing the risk of premature deterioration of the pavement.

The study also found that MPET-modified PG 58-28 asphalt binder, when used in a mixture with Granite 2 aggregate, exhibited greater resistance to moisture-induced damage compared to the same binder grade without any modification. Furthermore, the results of the Semi-Circular Bend (SCB) tests showed that asphalt mixtures containing MPET-modified binder demonstrated improved resistance to cracking, in comparison to the mixtures prepared with the unmodified binder. This enhanced cracking resistance was more pronounced in the mixtures with MPET contents greater than 5% by weight of the asphalt binder (the 10%, 15%, and 20% MPET-modified binder mixtures) [24].

Cruz Cajina, Camacho Garita, Baldi, & Aguiar Moya [25] used blister-type waste material, with a density of 1.401 g/ml. This material was incorporated through the dry method into the asphalt. 91.12% of the particles used in the mixture had a size ranging between mesh No. 4 (4.75 mm) and mesh No. 16 (1.18 mm). This allowed for obtaining a uniform mixture with adequate workability (Figure 6). The plastic particles are small and of different shapes, unlike previous research, they do not follow a pattern or the same form, but they are adequately incorporated into the asphalt.

The modified sample presented greater resistance to fatigue, humidity and permanent deformation. Specifically, regarding fatigue, the modified mixture required more cycles to reach failure, and these cycles depend on the deformation state, the type of mixture and the interaction between these factors. In addition, the modified mixture presented greater sensitivity to changes in deformation.

Table 5 shows the results of the investigation and the variation of the properties of the modified sample and the control sample, this will allow us to better see how much the results vary.

According to the Hamburg Wheel test, the data indicate that the modified mixture shows greater initial stiffness for both controlled deformations. However, a greater loss of stiffness is also observed compared to the unmodified mixture. This means that the modified mixture requires a greater number of cycles to reach failure compared to the unmodified mixture. In other words, the modified mix is initially stiffer but degrades more quickly with time and use, meaning its useful life may be shorter compared to the

unmodified mix. Furthermore, a study carried out in Hong Kong by Yao, Lan, Chen, and Jiang [26] adopted a life cycle approach to quantitatively assess the economic and environmental performance of PET modified asphalt mixtures containing reclaimed asphalt pavement (RAP). To produce the PET-derived additive, the process began with the collection of used PET bottles from various locations, which were then transported to a recycling facility. At the recycling plant, the collected bottles underwent a cleaning process, followed by crushing into small flakes.

For the chemical recycling of PET plastic, an aminolysis process was applied. In this process, triethylenetetramine (TETA) was used as the amine reagent, with a ratio of TETA to PET flakes of 2:1. It was heated to a temperature of 140 °C, which was maintained for 2 hours.

The researchers conducted a thorough examination that included a life cycle assessment, a life cycle cost analysis, and a sensitivity analysis. The aim was to evaluate the economic and environmental performance of the asphalt mixture modified with PET and reclaimed asphalt pavement (RAP) in comparison to conventional modified asphalt. The findings of this study showed that substituting the conventional modified asphalt with the PET and RAP-modified asphalt formulation could lead to cost savings of up to 31.8% and a reduction in greenhouse gas emissions of up to 37.6%. Furthermore, the sensitivity analysis conducted as part of the study highlighted the importance of the long-term durability of alternative materials, such as the PET-modified asphalt, in order to maintain their economic and environmental advantages throughout the entire life cycle of the pavement. To address the identified impacts, the researchers proposed potential mitigation strategies. These included improving the long-term performance characteristics of the PET-modified asphalt and exploring the alternating use of innovative and conventional materials in pavement construction [26].

A study conducted in India by Hake, Damgir, and Awsarmal [20] aimed to reduce the bituminous content in pavement mixtures by replacing a portion of the bitumen with plastic waste. The researchers evaluated the properties of bituminous mixtures modified with different percentages of plastic, ranging from 5% to 15% in 2.5% increments. The researchers carried out a range of laboratory tests to assess the properties of the aggregates and the bituminous binder material. For the aggregates, the tests included water absorption, impact resistance, Los Angeles abrasion, and aggregate crushing. As for the bitumen, the tests comprised softening point, penetration, and ductility (Figure 7). The plastic was incorporated during the preparation of the asphalt, as illustrated in the image on the left. On the right side, the sample arrangements made in the Marshall test configuration can be observed.



Figure 6. Blister type waste material [25]

Table 5. Hamburg Wheel test result

Deformation	400 micro strains	
	Modified	Control
Mix		
Initial stiffness (MPa)	7296	6513
Failure cycle stiffness (MPa)	2955	3380
No. Cycles for failure	524077	190149

Source [25]



Figure 7. Mixing crushed plastic waste into aggregates and sample arrangement in Marshall test setup [20]

In this study, the use of PET bottle plastics in different proportions (5%, 7.5%, 10%, 12.5% and 15%) as substitutes for bitumen in the bituminous mixture was examined. A proportion of 10% plastics with a bitumen content of 5.25% resulted in better performance. The results of the Marshall and extreme performance tests of hot mix asphalt showed a cost reduction of 5.18% compared to the standard mix. This shows that the use of plastic waste is an efficient and economical option [20]. A study carried out in Singapore [27] sought to evaluate the sustainability of incorporating recycled plastic waste into

porous asphalt pavement through a wet process. The results showed that the mixture modified with plastic can improve the rolling and wear resistance of the pavement, but if a high amount is incorporated it can lower its abrasion resistance [27]. The study focused on incorporating three types of common plastic waste found in Singapore: LDPE, HDPE and PP. These were incorporated into a porous asphalt mixture through a wet process, in three percentages (5%, 10% and 15%) [27]. In the laboratory, LDPE sheets were cut into dimensions between 2 and 4 millimeters, while PP packaging waste was shredded into sizes between

0.5 and 4 millimeters. According to the conclusions of the research, a higher proportion of plastic waste generally had a more beneficial effect on the porous asphalt mixture. However, it was found that the optimal plastic content was below 10%, as exceeding this level resulted in lower resistance and a greater tendency towards disintegration and cracking [27].

The study found that among the plastic waste types tested, LDPE (low-density polyethylene) exhibited the best performance. This type of plastic had a positive impact on the porous asphalt mixture's resistance to rutting, tearing, and adhesive strength. Additionally, the effect of LDPE on abrasion and cracking resistance was relatively lower compared to the other plastic types. These findings highlight the potential of LDPE to be effectively incorporated into porous asphalt pavement applications [27].

## 9. Life Cycle of Pavements Modified with Plastic Waste

A research study conducted in the London Borough examined the comparative life cycle of traditional pavement and its sustainability alternative asphalt mixes developed and tested in the laboratories of the London South Bank University. Unlike traditional paving methods, these asphalt mixtures are produced at lower temperatures, classifying them as "warm mixes." To analyze the environmental impacts and sustainability of this alternative pavement approach, the researchers used SimaPro software to model the different asphalt mix formulations and characterize all the life cycle input and output flows associated with their production and use. This life cycle assessment approach allowed the researchers to comprehensively evaluate and compare the environmental performance of the traditional pavement systems versus the newly developed sustainable asphalt mix alternatives [28]. They applied the IMPACT World+ method during the life cycle impact assessment phase. Additionally, they conducted an uncertainty analysis using Monte Carlo simulation to validate the results of the life cycle assessment, strengthening the robustness and credibility of the study's findings. The results show reductions in the environmental impact of roads that incorporate recycled plastic and carbonated aggregates, compared to traditional pavements. Decreases of 40 to 60% were observed in Climate Change emissions, up to 30% in Marine Eutrophication and up to 20% in Freshwater Eutrophication. This suggests that this type of pavement can significantly reduce environmental loads [28].

## 10. Conclusions

This study compiles information from various investigations on the application of recycled polymers in

different pavement layers, with the aim of comparing results. Regarding the methods of incorporating plastic into the asphalt mix, the choice depends on the melting point of the plastics used. Commonly used approaches are:

Aggregate replacement method (dry process): Typically used with high melting point plastics such as PET and PS. It involves directly replacing a portion of the aggregates with crushed plastic waste.

Mixture modifier method (wet process): Applied to almost all types of recycled plastics except PVC. Plastic waste is mixed with the bituminous binder to create a modified asphalt mix.

Each method has its advantages and considerations, and the most suitable choice will depend on factors such as the type and properties of the plastic, the requirements of the asphalt mix, and processing capabilities. Regarding the incorporation of plastic into the subgrade, studies show benefits in the mechanical and physical properties of pavements, with the optimal range being 0.5% to 2% recycled plastic. Furthermore, the use of polymers as modifiers in asphalt mixtures, especially polypropylene and PET, has shown improvements in properties such as stability, tensile strength, water damage, fatigue and permanent deformation. Finally, the study highlights the significant environmental and economic benefits of asphalt modified with PET and RAP, in terms of cost savings and reduction of greenhouse gas emissions.

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## REFERENCES

- [1] Kofi Tulashie, S., Kofi Boadu, E., Kotoka, F., & Mensah, D., "Plastic wastes to pavement blocks: A significant alternative way to reducing plastic wastes generation and accumulation in Ghana", *Construction and Building Materials*, vol. 241, p. 118044, 2020. DOI: 10.1016/j.conbuildmat.2020.118044
- [2] Biswas, A., Goel, A., & Potnis, S., "Performance comparison of waste plastic modified versus conventional bituminous roads in Pune city: A case study" *Case Studies in Construction Materials*, vol. 13, p. e00411, 2020. DOI: 10.1016/j.cscm.2020.e00411
- [3] Abukhettala, M., & Fall, M., "Geotechnical characterization of plastic waste materials in pavement subgrade applications", *Transportation Geotechnics*, vol. 27, p. 100472, 2021. DOI: 10.1016/j.trgeo.2020.100472
- [4] Ma, Y., Zhou, H., Jiang, X., Polaczyk, P., Xiao, R., Zhang, M., & Huang, B., "The utilization of waste plastics in asphalt pavements: A review", *Cleaner Materials*, vol. 2, p. 100031, 2021. DOI: 10.1016/j.clema.2021.100031
- [5] Montalvo, L., & Wua, S., "Repurposing waste plastics into cleaner asphalt pavement materials: A critical literature review", *Journal of Cleaner Production*, vol. 280, Part 2, p. 124355, 2021. DOI: 10.1016/j.jclepro.2020.124355
- [6] You, L., Lingyun, Z., You, Z., Ge, D., Yang, X., Xu, F., Diab, A., "Review of recycling waste plastics in asphalt

- paving materials”, *Journal of Traffic and Transportation Engineering (English Edition)*, vol. 9, no. 5, pp. 742-764, 2022. DOI: 10.1016/j.jtte.2022.07.002
- [7] Abdy, C., Zhang, Y., Wang, J., Yang, Y., & Artamendi, I., “Pyrolysis of polyolefin plastic waste and potential applications in asphalt road construction: A technical review”, *Resources, Conservation and Recycling*, vol. 180, p. 106213, 2022. DOI: 10.1016/j.resconrec.2022.106213
- [8] Andrews, K., Dernayka, S., Amin Mir, M., & Ali Khasawneh, M., “Review of the utilization of plastic waste in asphalt pavements in hot climate conditions – KSA as a case study”, *Materials Today: Proceedings*, 2023. DOI: 10.1016/j.matpr.2023.05.463
- [9] Audy, R., Enfrin, M., Jia Boom, Y., & Giustozzi, F., “Selection of recycled waste plastic for incorporation in sustainable asphalt pavements: A novel multi-criteria screening tool based on 31 sources of plastic”, *Science of The Total Environment*, vol. 829, p. 154604, 2022. DOI: 10.1016/j.scitotenv.2022.154604
- [10] Quesada, M., Raposeiras, Klein, S., González, L., & Fresno, C., “Use of plastic scrap in asphalt mixtures added by dry method as a partial substitute for bitumen”, *Waste Management*, vol. 87, pp. 751-760, 2019. DOI: 10.1016/j.wasman.2019.03.018
- [11] Gengren H., Meibo H., Sin M., Ghim P., Anggraini Z., “Recycling of plastic waste in porous asphalt pavement: Engineering, environmental, and economic implications”, *Journal of Cleaner Production*, vol. 440, p. 140865, 2024. DOI: 10.1016/j.jclepro.2024.140865
- [12] Cordoso, J., Ferreira, A., Almeida, A., & Santos, J., “Incorporation of plastic waste into road pavements: A systematic literature review on the fatigue and rutting performances”, *Construction and Building Materials*, vol. 407, p. 133441, 2023. DOI: 10.1016/j.conbuildmat.2023.133441
- [13] Amena, S., “Utilizing solid plastic wastes in subgrade pavement layers to reduce plastic environmental pollution”, *Cleaner Engineering and Technology*, vol. 7, p. 100438, 2022. DOI: 10.1016/j.clet.2022.100438
- [14] Zhu, J., Saberian, M., Li, J., Masqsood, T., & Yang, W., “Performance of clay soil reinforced with PET plastic waste subjected to freeze-thaw cycles for pavement subgrade application”, *Cold Regions Science and Technology*, vol. 214, p. 103957, 2023. DOI: 10.1016/j.coldregions.2023.103957
- [15] Bozyigit, I., Bulbul, F., Alp, C., & Altun, S., “Effect of randomly distributed pet bottle strips on mechanical properties of cement stabilized kaolin clay”, *Engineering Science and Technology, an International Journal*, vol. 214, no. 5, pp. 1090-1101, 2021. DOI: 10.1016/j.jestch.2021.02.012
- [16] Koozmishi, M., & Palassi, M., “Mechanical Properties of Clayey Soil Reinforced with PET Considering the Influence of Lime-Stabilization”, *Transportation Geotechnics*, vol. 33, p. 100726, 2022. DOI: 10.1016/j.trgeo.2022.100726
- [17] Ali, B., Ali Qureshi, L., & Kurda, R., “Environmental and economic benefits of steel, glass, and polypropylene fiber reinforced cement composite application in jointed plain concrete pavement”, *Composites Communications*, vol. 22, p. 100437, 2020. DOI: 10.1016/j.coco.2020.100437
- [18] Costa, L., Silva, H., Peralta, J., & Oliveira, J., “Using waste polymers as a reliable alternative for asphalt binder modification – Performance and morphological assessment”, *Construction and Building Materials*, vol. 198, pp. 237-244, 2019. DOI: 10.1016/j.conbuildmat.2018.11.279
- [19] Xiong, X., Zhen, L., Wei, W., Jiangmiao, Y., Yawei, B., Anand, S., & Jing, H., “Sustainable Practice in Pavement Engineering through Value-Added Collective Recycling of Waste Plastic and Waste Tyre Rubber”, *Engineering*, vol. 7, no. 6, pp. 857-867, 2021. DOI: 10.1016/j.eng.2020.08.020
- [20] Hake, Damgir, & Awsarmal, “Utilization of Plastic waste in Bitumen Mixes for Flexible Pavement”, *Transportation Research Procedia*, vol. 48, pp. 3779-3785, 2020. DOI: 10.1016/j.trpro.2020.08.041
- [21] Muhammad I., Muslich H., Kaffayatullah K., Mudassir I., Madzlan B., Salah E., Jarom f K., Awais B., Waqas R. “Effective use of recycled waste PET in cementitious grouts for developing sustainable semi-flexible pavement surfacing using artificial neural network (ANN)”, *Journal of Cleaner Production*, vol. 340, p. 130840, 2022. DOI: 10.1016/j.jclepro.2022.130840
- [22] Hadidy, “Engineering behavior of aged polypropylene-modified asphalt pavements”, *Construction and Building Materials*, vol. 191, pp. 187-192, 2018. DOI: 10.1016/j.conbuildmat.2018.10.007
- [23] Shamim, S., & Vikram, A., “Experimental study on usage of (PET) waste plastic incorporating with (TiO<sub>2</sub>) titanium dioxide for the construction of plastic roads”, *Materials Today: Proceedings*, 2023. DOI: 10.1016/j.matpr.2023.01.320
- [24] Ghabchi, R., Prashan Dharmarathna, C., & Mihandoust, M., “Feasibility of using micronized recycled Polyethylene Terephthalate (PET) as an asphalt binder additive: A laboratory study”, *Construction and Building Materials*, vol. 292, p. 123377, 2021. DOI: 10.1016/j.conbuildmat.2021.123377
- [25] Cruz Cajina, Camacho Garita, Baldi, & Aguiar Moya., “Performance evaluation of modified asphalt mix with blister PVC waste”, *Infrastructure Vial*, vol. 23, no. 42, pp. 13-22, 2021. DOI: 10.15517/iv.v23i42.44688
- [26] Yao, L., Lan, J., Chen, R., & Jiang, J., “Environmental and economic assessment of collective recycling waste plastic and reclaimed asphalt pavement into pavement construction: A case study in Hong Kong”, *Journal of Cleaner Production*, vol. 336, p. 130405, 2022. DOI: 10.1016/j.jclepro.2022.130405
- [27] Ziari, H., Nasiri, E., Amini, A., & Ferdosian, O., “The effect of EAF dust and waste PVC on moisture sensitivity, rutting resistance, and fatigue performance of asphalt binders and mixtures”, *Construction and Building Materials*, vol. 203, pp. 188-200, 2019. DOI: 10.1016/j.conbuildmat.2019.01.101
- [28] Russo, F., Veropalumbo, R., & Oretto, C., “Investigating the environmental and mechanical properties of sustainable asphalt mastic solutions for road flexible pavements”, *Transportation Research Procedia*, vol. 69, 2023. DOI: 10.1016/j.trpro.2023.02.166