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INVESTIGATIONS ON THE RECYCLING AND USE OF POLYETHYLENE TEREPHTHALATE - PET (PLASTIC BOTTLE) IN ASPHALT MIXTURE

BY

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Abstract. The article analyzes the issue of plastic waste, with a particular focus on PET (polyethylene terephthalate), both at the national and global levels, highlighting their environmental impact and the recycling strategies employed to reduce their negative effects. Recipients made of polyethylene terephthalate are among the most widely used plastic materials, especially in the beverage and food packaging industries, and their accumulation in the environment is a major concern due to their high resistance to decomposition. The use of plastic waste, particularly PET (polyethylene terephthalate) bottles, in asphalt mixtures is an innovative solution that is gaining increasing attention both nationally and internationally, in the context of reducing the amount of plastic that ends up in the environment and improving the performance of road infrastructure. PET is one of the most common types of plastic used in packaging, and recycling it presents a significant challenge. In this regard, integrating PET bottles into asphalt mixtures can contribute to reducing plastic waste and improving the durability of road infrastructure.

Keywords: pollution, plastic waste, recycling, roads, sustainable.

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1. Introduction

Plastic is a key material in the modern economy, with widespread uses in both industrial and consumer sectors. Its advantage lies in the fact that it is inexpensive, versatile, lightweight, and durable, making it suitable for use in packaging, agriculture, construction, the automotive sector, and electrical appliances (European Court of Auditors, 2020).

There are two categories of plastics: thermoplastics and thermosets. The first category is one that softens when exposed to heat (becoming plastic) and hardens again upon cooling. For the second category, once heated, they do not become plastic, so they cannot be reheated or reshaped and can degrade if exposed to excessive heating temperatures (The Trade Association for Plastic Manufacturers in Europe, 2017).

Table 1

Categories of plastics

Thermoplastics	**Thermosets**
1. Polypropylene (PP)	1. Polyurethane
2. Polyethylene or primary plastic (PE)	2. Phenol formaldehyde
2.1 LLDPE – LLDPE – Low-Density Linear Polyethylene	3. Epoxy resins
2.2 LDPE - Low-Density Polyethylene	4. Unsaturated polyester
2.3 HDPE - High-Density Polyethylene	5. Acrylic resins
3. PVC – Polyvinyl Chloride	6. Phenolic resins
4. PS - Polystyrene	7. Silicone
5. PET – Polyethylene Terephthalate	

General Characteristics of Plastic Materials:

- Low specific gravity, below 1.8 g/cm³, due to the fact that the main components (mainly H and C) have a low atomic mass.

- Good resistance to bending, stretching, and compression. Remarkable chemical stability against most aggressive environments.

- High coefficient of thermal expansion due to the Van der Waals bonds (weak bonds) between chains and their conformations.

- Flammability (in most cases) and low thermal stability because plastics are organic substances; for the same reason, they can be degraded by microorganisms (biodegradability).

- Adjustable porosity (closed or open pore structure).

- Simple processability (easy to shape and mold).

- Zero electrical conductivity and low thermal conductivity.

- Properties affected by radiation from the visible spectrum, ultraviolet light, and ionizing radiation, which can break the bonds between chains and/or between monomers, thus altering the original structure by reducing the polymerization degree.

- Aesthetic appearance (products can be mass-colored, translucent, or transparent).

- Low cost, etc.

When considering global plastic production, excluding polyethylene terephthalate (PET), polyethylene (PE), polyacrylic fibers, and recycled plastic materials, production increased from 335 million tons in 2016 to 367 million tons in 2020. In Europe, during the years 2016–2020, plastic production showed a downward trend, from 60 million tons in 2016 to 55 million tons in 2020 (The Trade Association for Plastic Manufacturers in Europe, 2021).

Furthermore, without a doubt, the process of manufacturing and using plastic materials results in waste that has a harmful effect on the surrounding environment, birds, wildlife, and, implicitly, humans.

For example, plastic materials have been found in the stomachs of marine birds (over 90%) and sea turtles (over 50%).

In Europe (EU member states), plastic production by category is divided as follows:

- 39.9% for plastic packaging.
- 19.8% for construction.
- 9.9% for the automotive industry.
- 6.2% for electrical and electronic equipment.
- 4.1% for household, recreational, and sports products.
- 3.4% for agriculture.
- 16.7% for other products (such as appliances, machinery, furniture, medical equipment, etc.) (European Parliament, 2021).

According to European legislation, Romania's commitment in 2020 was to achieve a 50% rate for the reuse and recycling of municipal waste, a target that was not met. As a result, the "infringement" procedure was applied until the target is reached.

Another pressing issue within the scope of plastic waste is pollution caused by PET (polyethylene terephthalate) bottles.

PET is the result of polymerizing ethylene glycol and terephthalic acid, spun into fibers for fabrics, permanently pressed, and molded by blowing into containers.

According to Greenpeace, half of the PET bottles sold are never recycled, and only about 7% of those collected are turned back into new bottles.

The recycling of PET bottles involves the following advantages:

- One ton of recycled PET equals 0.61 tons of crude oil.
- One ton of recycled PET saves 10.96 MWh of electricity (the average electricity consumption per capita is 10.3 MWh per year).

- Recycled plastic has a much lower manufacturing cost compared to pure raw material.
- 10 recycled PET bottles can be turned into one t-shirt.
- Recycled plastic has numerous uses in society.
- Plastic can be recycled up to five times without losing its properties.

A solution for utilizing recycled PET is its incorporation into road construction, specifically by using it in the composition of asphalt mixtures. This process would allow us to address two major issues: the plastic crisis and the infrastructure crisis.

2. Asphalt mixtures, additives and their role in asphalt mixtures

The production of asphalt mixtures has, over time, been the subject of research and studies that have led to the achievement of high performance, based on the introduction of materials beyond the conventional ones, with the aim of developing the properties of the mixtures. Moreover, as is well known, the world's oil reserves are decreasing, which makes it more difficult to obtain bitumen (Iliescu *et al.*, 2015).

According to AND 605, the bituminous binders used in the composition of asphalt mixtures in Romania are:

- Penetration grade bitumen: 35/50, 50/70, or 70/100.
- Polymer-modified bitumen: Class 3 (penetration 25/55), Class 4 (penetration 45/80), or Class 5 (penetration 40/100).

Another important aspect is that at the national level, there is currently only one refinery–the Vega Refinery in Ploiești–which supplies about 16% of the total required bitumen, which is insufficient for market demand. The remainder of the required bitumen is imported. The Romanian company produces both simple bitumen and polymer-modified bitumen.

In this context, we can also refer to the widely publicized term of sustainability, which, according to the Romanian Academy (2012), is defined as "the quality of an anthropogenic activity to be carried out without depleting available resources and without destroying the environment, thus not compromising the ability to meet the needs of future generations".

These factors all point to the need to find alternative solutions, one of which is the use of additives in the composition of bitumen, and implicitly in asphalt mixtures, to improve the physicomechanical characteristics of the asphalt, thus increasing its service life.

According to SR EN 13108-1, paragraph 3.1.12, the definition of an additive is: "A component material that can be added in small quantities to the asphalt mixture, such as mineral or organic fibers, polymers, to modify the mechanical characteristics, workability, or color of the asphalt mixture."

Given the challenges related to bitumen production and the environmental concerns surrounding fossil fuel depletion, incorporating additives in asphalt mixtures offers a promising alternative. These additives can enhance the performance, durability, and sustainability of asphalt, ensuring longer-lasting infrastructure while supporting resource conservation and environmental protection.

3. Use of waste in the composition of asphalt mixtures

Three of the most commonly used waste materials in the composition of asphalt mixtures are recycled rubber (RTR), recycled asphalt shingles (RAS), and recycled asphalt pavement (RAP).

Recycled rubber is typically mixed either with the binder or directly with the asphalt mixture to improve the asphalt's properties, making it more resistant to deformation and cracking. It was introduced in the 1960s in Arizona. In 2019, a survey conducted by asphalt producers showed that only 10 states still use recycled rubber in asphalt mixtures (Williams *et al*., 2019).

Recycled asphalt shingles (RAS) were first used in 1980 as a potential substitute for asphalt binder. Some states allowed the addition of recycled shingles at rates of 5%, 7%, or even 10% in new mixtures. Their use was significant between 2009 and 2012, with 1.863 million tons used, 1.964 million tons in 2014, and dropping to 0.921 million tons by 2019 (Williams *et al*., 2019).

Recycling of asphalt pavements obtained by milling existing road surfaces helps reduce the amount of bitumen and aggregates, making it a valuable material since the 1970s, even though in-situ recycling was invented in the 1940s (Epps *et al.*, 1980).

We refer to two types of recycling: cold recycling and hot recycling. For example, in the US, in 2019, the recycling rate was 21% (Williams *et al*., 2019).

As an alternative to the three solutions mentioned above, the use of recycled plastic waste in asphalt mixtures is currently an area of interest. It is important to understand that plastic recycling can be quite complicated due to the large variety of plastic types, each with different chemical compositions. For example, plastics have different melting points.

Generally, there are two methods for incorporating plastic materials into asphalt: the wet process and the dry process. In the wet process, recycled plastics are added to the asphalt binder as a polymer modifier or replacement. Recycled plastics with a low melting point, such as LLDPE, LDPE, and HDPE, are typically added in percentages ranging from 2% to 8%. In the dry process, recycled plastics are added directly into the mix as a substitute for aggregates, a modifier for the mix, a modifier for the binder, or any combination of these. The approach of replacing the aggregate is usually used with plastics that have a high melting point (above the typical asphalt production temperature), such as polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), and polycarbonate (PC) (Willis *et al*., 2020).

The impact of adding synthetic fibers to asphalt concrete on its mechanical properties, including rutting resistance, tensile strength, water stability, and cracking resistance, is then examined (Jia *et al.*, 2023).

In the United Kingdom, for example, the Scottish company MacRebur has developed three products made from 100% recycled plastic, known as MR6, MR8, and MR10. These products are predominantly used in the wet process as part of the asphalt mixture.

The idea came from the company's manager, Tobby McCartney, who, after visiting India, observed how locals would fill potholes by melting plastic and adding it to the holes.

The three products offered by MacRebur are polymer-like materials, with MR6 and MR8 being shredded plastic, and MR10 in the form of pellets/granules (White, 2019).

4. Use of PET (bottle) in asphalt mixture composition worldwide

Due to its high melting point (260°C), PET (Polyethylene Terephthalate) has been predominantly used in research studies as a replacement for aggregates or as a solution to reinforce the asphalt mixture.

In a study by Usman *et al*. (2016), experimental trials were conducted by adding recycled PET fibers in proportions of 0.30%, 0.50%, 0.70%, and 1% by the total weight of the asphalt mixture. The objective was to determine the effects of PET fibers and temperature on the asphalt mixture.

In the initial stage of the experiment, the PET containers were cut into paper-like sheets and then shredded using a paper shredder.

Three samples were made for each mixture type, and the test was performed using a Universal Testing Machine (IPC UTM-5P). The samples and testing equipment were kept in chambers at temperatures of 25°C (low temperature) and 40°C (high temperature) for 2 hours before testing.

After testing the samples, the following conclusions were made:

- PET fibers improved fatigue resistance and deformation resistance in the asphalt mixture.
- The optimal dosage of PET fibers was found to be 0.70% of the total weight of the mixture.
- The modulus of resistance of the asphalt decreased with increasing temperature.

This suggests that PET fibers can enhance the performance of asphalt mixtures, especially in terms of resistance to fatigue and deformation, with an optimal fiber dosage of 0.70%. However, the effect of temperature on the modulus of resistance indicates that the material may be sensitive to thermal changes, which is an important factor to consider in its use in various climates and road conditions.

A. Hassani *et al*. (2005) conducted a study investigating the use of PET (Polyethylene Terephthalate) as a substitute for aggregates in asphalt mixtures.

In their study, PET was added to asphalt in the form of granules with a diameter of 3 mm, at a percentage ranging from 20% to 60% of the aggregate volume. The diameter of the aggregates replaced was between 2.36mm and 4.75mm, and the replacement of aggregates with PET granules represented 5% to 15% by weight of the asphalt mixture.

The following parameters were evaluated:

- Marshall Stability
- Flow Index
- S/I Ratio (Stability/Flow ratio)
- Density

The study found that with an increase in the PET dosage, Marshall Stability decreased, and the Flow Index increased. All PET dosages, except for the 5% dosage by weight of the asphalt mixture, showed lower stability and S/I ratio values. This decrease in stability was attributed to the reduced friction between the PET granules. For the 5% PET dosage, the S/I ratio slightly increased, which was attributed to the lower density of the asphalt mixture due to the PET granules.

Environmental Benefits: The study concluded that by replacing 5% of the aggregate with PET granules, the construction of 1 km of road would result in the following environmental benefits:

-625 tons of natural resources would be saved.

-315 tons of recycled PET could be used, demonstrating significant environmental benefits through recycling.

This study highlights the potential for using recycled PET in asphalt mixtures, not only improving the sustainability of road construction by reducing the use of natural resources but also promoting the recycling of PET waste. However, careful consideration of dosage is necessary, as higher PET content can negatively impact the mixture's stability.

5. Conclusions

Increase in plastic consumption and its impact: global plastic production has significantly increased in recent decades, and its use across various industries, from packaging to construction and automotive sectors, makes it essential in the modern economy. However, this massive consumption creates a major environmental problem due to plastic waste, especially PET, which negatively impacts ecosystems and human health.

Reuse and recycling of plastic: despite the economic and technical advantages of plastic, only a small portion of plastic materials are effectively recycled. For example, about half of the PET bottles sold are never recycled, and only 7% of those collected are repurposed into new bottles. However, recycling

PET offers significant benefits, saving natural resources and reducing environmental impact.

Use of PET in road construction: incorporating recycled plastic, particularly PET, into asphalt mixtures represents an innovative solution to address both the plastic waste crisis and the infrastructure deficit. This can help reduce plastic waste and conserve natural resources, particularly aggregates and bitumen, by using PET as a substitute.

Environmental and economic benefits: the use of recycled PET in asphalt can significantly reduce the number of natural resources extracted (e.g., aggregates) while also cutting down the amount of PET waste that ends up in landfills. Studies show that replacing aggregates with PET can save tons of natural resources and reduce manufacturing costs, making road construction more sustainable.

Challenges in using PET in asphalt: although using PET in asphalt provides significant benefits, it is important to note that excessive PET content can reduce the stability and performance of the asphalt mixture. Therefore, the optimal dosage needs to be adjusted to ensure adequate performance while maximizing the ecological benefits.

Need for regulations and further research: given the significant environmental impact of plastic and the potential benefits of using recycled plastic materials in road infrastructure, it is essential to develop clear regulations and conduct further research to optimize this process and ensure its widespread application.

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STUDIU PRIVIND RECICLAREA ȘI UTILZAREA POLIETILENEI TEREFTALATE – PET (STICLE DIN PLASTIC) ÎN COMPOZIȚIA MIXTURII ASFALTICE

(Rezumat)

Articolul reliefează problema deșeurilor din plastic, cu un accent deosebit pe polietilena tereftalat - PET, atât la nivel național, cât și la nivel mondial, evidențiind impactul acestora asupra mediului și strategiile de reciclare utilizate pentru a reduce efectele lor negative. Recipientele din polietilenă tereftalat sunt printre cele mai utilizate materiale plastice, în special în industria ambalajelor pentru băuturi și alimente, iar acumularea lor în mediu reprezintă o preocupare majoră datorită rezistenței lor ridicate la descompunere. Utilizarea deșeurilor din plastic, în special a recipientelor din PET

(polietilenă tereftalat), în mixturile asfaltice este o soluție inovatoare care beneficiază de o atenție tot mai mare atât la nivel național, cât şi internațional, în contextul reducerii cantității de plastic care ajunge în mediu și al îmbunătățirii performanței infrastructurii rutiere. PET - ul este unul dintre cele mai comune tipuri de plastic utilizate în ambalaje, iar reciclarea acestuia reprezintă o provocare semnificativă. În acest sens, integrarea recipientelor din PET în mixturile asfaltice poate contribui la reducerea deșeurilor de plastic și la îmbunătățirea durabilității infrastructurii rutiere.