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## THE IMPROVEMENT OF HOT MIX ASPHALT USING WASTE PLASTIC

### ABSTRACT

Plastic waste is a significant environmental and ecological problem that requires urgent action. Indeed, plastic waste pollutes our oceans, rivers, and lakes, harming aquatic life and marine ecosystems. Plastic debris also poses a threat to terrestrial wildlife, as animals can mistake plastic for food or become entangled in it, leading to injury or death. In addition, plastic production requires fossil fuels, leading to greenhouse gas emissions contributing to climate change. That is why recycling plastic waste is an important step towards reducing the environmental impact of plastic and creating a more sustainable future. The present work is part of this approach, and it aims to investigate the effects of the size of the plastic fibers and their percentages on the performances of Hot Mix Asphalt (HMA) in road pavement. Marshall Tests were carried out on the reference asphalt (without adding plastic) and the asphalt containing plastic waste in order to highlight the effect of these additives on the mechanical performance of asphalt mixtures. It has been found that the addition of PET plastic waste considerably improves the mechanical properties of the HMA. The findings revealed that additives composed of plastic fibres of size ranging between 0.125 and 1.25 mm give the best results in terms of Marshall's Stability and Flow, by acting as reinforcement to the bitumen-aggregate mixtures. Furthermore, the optimum plastic content was found to be about 3.75% by weight of bitumen. It can be noted that the proposed solution fits very well with sustainable development.

**Keywords:** hot mix asphalt, plastic waste, Marshall Test, performance, sustainable development

## 2. INTRODUCTION

Waste materials, particularly plastic waste, are finding their way into the world's oceans and waterways. This pollution can harm marine life, as animals may ingest plastic or become entangled in it. Additionally, plastic waste can take hundreds of years to break down, meaning it accumulates in the environment over time. Many waste materials, such as metals and plastics, are derived from finite resources. As we continue to produce and discard these materials at a rapid pace, we risk depleting these resources and exacerbating environmental problems. Waste materials can have a significant impact on the environment, and it is important to properly manage and dispose of them to minimize their environmental impact. According to a report by the World Economic Forum, the world produces approximately 300 million tons of plastic waste every year; it actually represents 12% of global waste. Two strategies can be employed to address the issue of waste plastic. One approach is to reduce the use of single-use plastics, such as plastic bags, straws, and water bottles, by using alternatives like reusable bags, metal straws, and refillable water bottles. Another strategy is to recycle plastic products, which involves breaking down the plastic into new materials that can be used to make new products. The most promising way to recycle plastic waste would be to use mechanical recycling to make new products. Another promising way to recycle these materials is to use chemical recycling, which involves breaking down the materials into their component molecules and then using those molecules to make new materials [1]. On the other hand, the weight of vehicles, especially heavy vehicles such as trucks and vans, can cause damage to road pavement over time. This damage, known as pavement distress, can include cracks, potholes, and rutting. There are two approaches for preventing the deterioration of pavements. The first one is increasing pavement thickness, and the second one is improving the properties of materials used for the construction of roadways [2]. Constructing a high-thickness pavement can significantly increase construction costs, which can be a major obstacle for many infrastructure projects. However, using additives can be a cost-effective solution to improve the performance and durability of pavement without significantly increasing construction costs [3]. There are two ways to use additives in asphalt mixtures: either by the wet process, in which the additives are added to the asphalt or modified asphalt before it is mixed with the aggregate particles, or by the dry process, which involves adding the additives to the aggregate particles before they are mixed with the asphalt. In the first process, the additives are blended with the asphalt using specialized equipment to ensure a uniform mixture. However, in the dry process, the additives are directly added to the aggregate in the form of small pellets or fibres using a spreader or other similar device [4], [5]. Polymer modification of asphalt binders involves adding certain types of polymers to the asphalt binder, which can improve its performance in several ways. These polymers can increase the binder's elasticity and flexibility, making it more resistant to cracking and deformation under heavy traffic loads [6], [7]. They can also improve the binder's durability and resistance to ageing and weathering [8], leading to longer pavement lifetimes. In recent years, there has been increasing interest in using plastic waste as a modifier for asphalt binders, and several research works have been carried out to investigate this approach using a wet process. The research works of Naskar et al. [9] showed that adding plastic waste films (2mm X 2mm) to bitumen can improve its thermal stability, particularly when using them at 5 % weight of bitumen. The results of the study of Köfteci et al. [10] showed that adding PVC waste to bitumen can improve its rheological and mechanical properties at high temperatures. Khan et al. [4] studied the use of LDPE (Low-density polyethylene), HDPE (High-density

polyethylene) and Crumb Rubber (CR) as modifiers for asphalt binders. The findings showed that these additives lead to significant improvements in the rheological properties of the modified binder. Arabani and Pedram [11] investigated the rutting and fatigue in glassphalt by adding waste plastic bottles to the binder. They found that studied behaviours were improved by adding waste plastic. Tran et al. [12] studied the effect of using recycled polyethylene to improve bitumen, and they concluded that the additives could create a new Asphalt concrete with better quality. Nevertheless, the dry process for asphalt paving may not have received as much attention as the wet process. It is an area of ongoing research and development, and it is becoming increasingly important in certain regions and applications. A few research studies have investigated the use of various additives and binders in dry-process asphalt mixtures, aiming to improve their performance and reduce their environmental impact. Moghaddam et al. [14] studied the use of plastic bottles in road pavement as a sustainable alternative to traditional asphalt mixes. This involves shredding plastic bottles into small pieces and incorporating them into the asphalt mix, which can improve the mix's properties and reduce the amount of plastic waste that ends up in landfills or the environment. The waste plastic particles used are smaller than 2.36 mm and are added to the asphalt mixtures in percentages ranging from 0.2% to 1% by weight of aggregate materials. Research has shown that the addition of plastic bottles can improve the mechanical properties of asphalt mixes, such as their stability and flow values. This can result in a longer-lasting and more durable road surface, reducing the need for frequent repairs and maintenance. However, the size of plastic fibers can influence how they interact with the asphalt mixture. It is important to notice that the dry process is still little studied despite its simplicity, possibly because researchers are focused on the modification of bitumen. The present work is aimed to study both the size effect and the percentages of PET (polyethylene terephthalate) plastic fibers on the mechanical performances of asphalt mixes using the Dry process.

### 3. MATERIALS AND METHODS

#### 3.1. MATERIALS

Three types of materials were used in this study, namely Untreated Crushed Gravel (UCG), bitumen and recycled Polyethylene terephthalate (PET).

##### 3.1.1. Untreated Crushed Gravel (UCG)

The Untreated Crushed Gravel (UCG) is provided by GTF Company located in Tiaret Department (Algeria). The UCG is a calcareous aggregate whose main characteristics are summarized in Table 1. In Figure 1, we present the particle size distribution curve of the UCG, which indicates that the curve is inserted in the reference granular zone and overlaps the max curve at its upper part. The coefficient of uniformity (Cu) indicates that the material is of spread grain size, while the curvature coefficient (Cc) denotes a poorly graded material.

Table 1. Main characteristics of Crushed Gravel (0/20mm)

Sieve at 80μ (%)	Dmax (mm)	VB <sup>a</sup>	SE <sup>b</sup> at 10% of fines	LA <sup>c</sup> (%)	MD <sup>d</sup> (%)	CaCO <sub>3</sub> (%)	Gs (t/m <sup>3</sup> )	Cu	Cc
8	20	0.68	71	18	20	90	2.81	18.9	3,5

<sup>a</sup>Methylene blue value; <sup>b</sup>Sand Equivalent Test ;<sup>c</sup>Los Angeles abrasion value; <sup>d</sup>Micro Deval Test

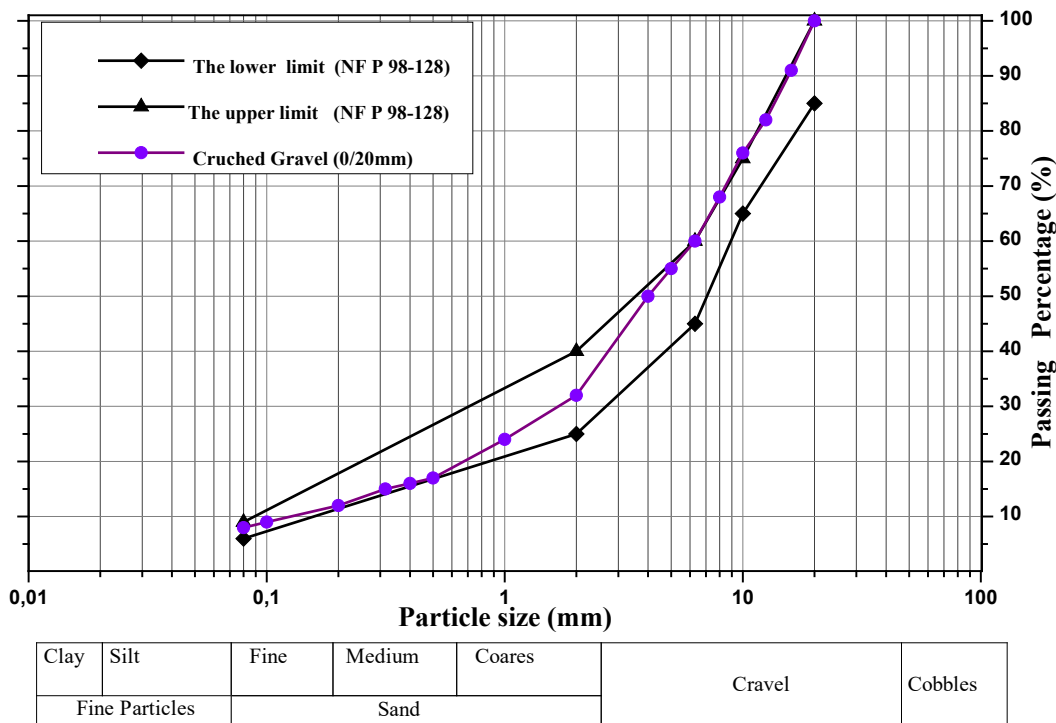


Figure 1. Particle size distribution curve of crushed gravel

### 3.1.2. Bitumen (40/50)

The bitumen 40/50 penetration grade was obtained from GBS company, which specializes in hydrocarbon materials and is located in the Tiaret Department (Algeria). The main characteristics of the binder are summarized in Table 2.

Table 2. Physical properties of bitumen

Specific Gravity	Penetration (25°C, 0.1 mm)	Softening point (°C)	Flash point (°C)	Ductility (mm)
1.02	42	54	240	>60 mm

### 3.1.3. Waste plastic PET

The waste PET bottle (Figure 2) used in this study was provided by SARL DJAIB, specializing in waste recycling, located in Tiaret Department (Algeria). It is important to note that smaller fibres can be dispersed more uniformly throughout the mixture. It is for this reason that small plastic fibres < 1.25 mm were chosen. The waste plastic fibres are separated by size into five classes using the sieving method: (0.125/0.200 mm – 0.200/0.315 mm – 0.315/0.630 mm – 0.630/1.25 mm – 0.125/1.25 mm).



Figure 2. PET Waste Fibers used in the study

## 3.2. METHODS

In order to highlight the benefit of adding plastic waste to the mechanical characteristics of hot mix asphalt (HMA), the Marshall test was adopted, which is a common method used to evaluate the mechanical properties of asphalt mixtures, including its stability, flow, and deformation, in accordance with the European Standard EN 12697-34 [14].

The additive is dispersed at mixing time by varying both the size of the plastic waste and its proportion (2.5%, 3.75%, 5%) by the weight of bitumen in order to determine the optimum content and class of polymer, which contributes to a better improvement of the mechanical characteristics of asphalt mixes. Initially, the aggregates are dried in an oven at a temperature of 105°C and then preheated between 135°C and 160°C. At the same time, the bitumen is heated to a specific temperature (160 °C±5 °C) and then mixed together using a

mechanical mixer, while adding the dispersion of plastic particles until a uniform mixture is achieved. The mixture is placed into a Marshall mold and then compacted with a Marshall Compaction hammer to achieve a specified density. After demolding, sample dimensions are taken: Determine the height and diameter of the compacted specimen to calculate its physical characteristics. Finally, the compacted specimens are tested for stability, flow, and deformation by subjecting them to a vertical load applied by a Marshall testing machine until failure occurs. The maximum load and deformation at failure are recorded. The optimum bitumen content was determined by preparing a series of specimens with varying bitumen contents from 5.69 to 6.55 per cent by the weight of the total mixture. The specimens are compacted and tested for stability and flow, and the results are plotted on a graph known as the stability and flow curve. The optimum bitumen content was about 5.69%, corresponding to the Marshall Stability value of 10.15 kN and a flow of about 34.6/10 mm.

#### 4. RESULTS AND DISCUSSION

The results of Marshall Tests carried out on the mixtures without PET (reference mixture) and with PET fibres, at a percentage of 2.5% by the weight of bitumen, are presented in Figure 3. As shown in Figure 3a, all the mixtures containing the plastic fibres gave much higher stability compared to the reference mixture (10.15 kN). It can also be noticed that by increasing the size of plastic fibres, the stability also increases. It should be pointed out, in particular, that the mixture containing all the plastic fibres (0.125/1.25 mm) gave the highest stability, i.e. 11.15 kN. It can also be observed that the mixtures containing the intermediate classes of PET fibres have approximately the same values of Marshall Stability. Regarding the Marshall Flow (Figure 3b), it can be noted that for all the mixtures, the flow values are lower than 40/10 mm (the maximum threshold defined by the standard Marshall Test). Furthermore, the mixtures containing PET fibres give better Flow values, particularly the small PET fibres (0.125/0.2 mm and 0.2/0.315 mm).

In the Marshall method, the void percentage is used to determine the degree of asphalt mixture compaction. For the same binder content and the same proportion of the PET waste, the various mixtures have shown different values of Void percentage (Figure 4.), but all of the results are within an acceptable range. However, the compaction energy may differ from one mixture to another to have a more compact material.

It is important to evaluate the water resistance of different asphalt mixtures to test the asphalt to withstand the most adverse conditions. Figure 5 shows the results of the water resistance tests for the different mixtures. The water resistance represents the Marshall Stability ratio for specimens kept in water and those in the open air. According to the asphalt mix standards, this ratio must be greater than 0.70. As can be seen in Figure 5, all mixtures exhibited an acceptable water resistance (> 0.70), and those containing PET exhibited better values (> 0.90), which shows the benefit of adding PET fibres to Hot Mix Asphalt.

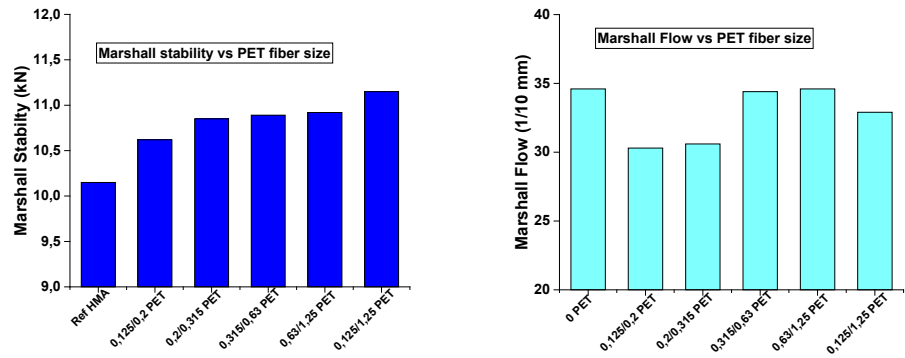


Figure 3. Marshall Results Vs. PET fibre size: (a) Marshall Stability; (b) Marshall Flow

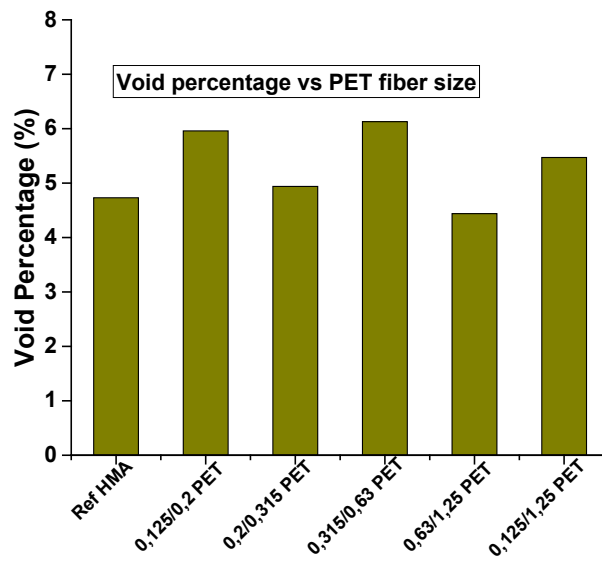


Figure 4. Void percentage Vs. PET fibre size



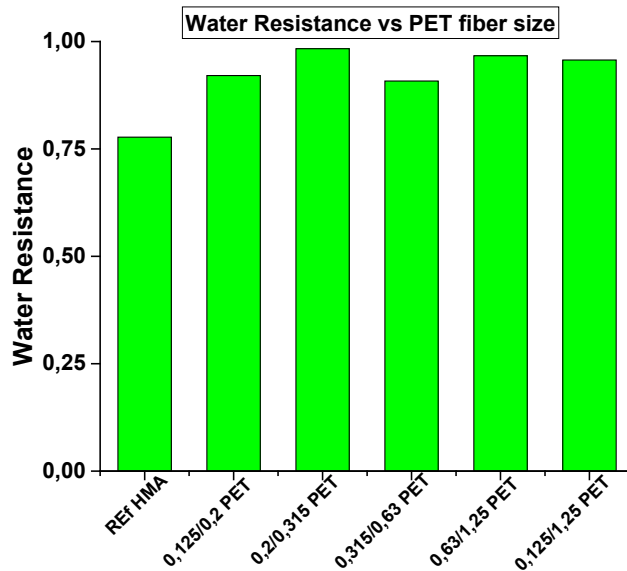


Figure 5. Water Resistance Vs. PET fibre size

Regarding the influence of the dosage of plastic fibres on Marshall Stability and Marshall Flow, it can be observed in Figure 6 that the PET dosage acts in the same way for all classes of plastic fibres. Indeed, the optimum PET content is found to be about 3.75% for all PET fibre sizes. It can be noticed, particularly, that the class of 0.63/1.25 mm of PET gives the best Marshall Stability at the optimum dosage. Concerning the Marshall Flow (Figure 7), it can be observed that the flow values are lower than 40/10 mm for all the mixtures. It should be pointed out that the optimum dosage of PET obtained for Marshall Stability does not give the best values of Marshall Flow. However, the optimum dosage gives very acceptable flow values for PET particles greater than 0.315 mm in size.

By adding the PET fibres, we can expect they will give an additional plasticity that can generate low stability. Still, on the contrary, they have considerably improved the asphalt, reaching a Marshall stability of about 12.5 kN. This is due to the fact that the plastic fibres do not melt at the preparation temperature of the asphalt, which is around 160°C. By exceeding the glass transition temperature estimated at 70°C, the polymer chains are able to move more freely, and the material becomes more flexible and deformable. Indeed, the glass transition temperature of a plastic is the temperature at which the plastic material transitions from a hard and brittle state to a soft and rubbery state. Thus, the plastic fibres acquire new mechanical properties that result in a solidification of the material with a high deformation capacity (flexibility). The plastic fibres act as reinforcement to the bitumen-aggregate mixtures. However, using the plastic fibre at its optimum percentage is better for reaching the best asphalt performance.

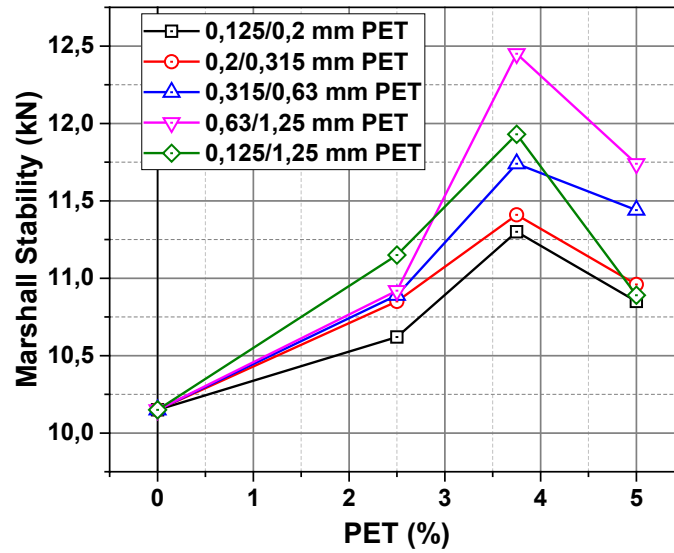


Figure 6. Influence of PET content on the Marshall Stability of HMA

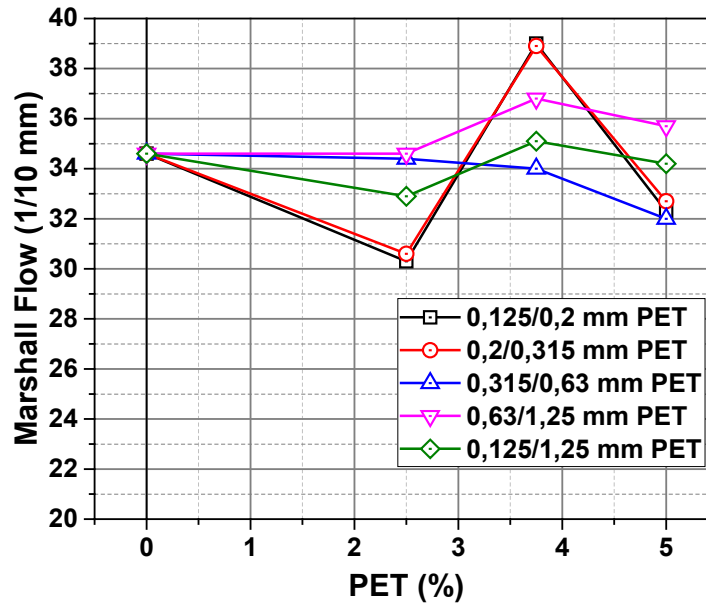


Figure 7. Influence of PET content on the Marshall Flow of HMA

Regarding the size of plastic fibres, it has been found that additives composed of plastic fibers between 0.125 and 1.25 mm in size give the best results in terms of Marshall Stability and Marshall Flow. This is due to the fact that when they are mixed with asphalt mixtures,

they act as reinforcement in which the different fibre sizes are present and contribute in an effective way to improve the performance of HMA.

In order to make a comparison between the PET waste used and industrial additives, such as PR-Plast, SBS and ZQ1, we present in Figure 8 the Marshall Stability and Marshall Flow for the various additives by fixing the dosage at 3.75%. It can be noted that the different additives give Marshall Stability values greater than that obtained for the reference mixture (without additive). The maximum Marshall stability is obtained for the SBS additive, 14 kPa. Nevertheless, PET waste gives a value superior to those of other additives (PR-Plast and ZQ1), which shows the benefit of adding plastic fibres to HMA in terms of mechanical performance and ecological and environmental issues. For the Marshall Flow, Figure 8b shows that the mixture in which SBS is used gives the most effective result. The class of PET (0.630/1.25 mm) gives an average result and remains below the threshold set by the standard Marshall Test.

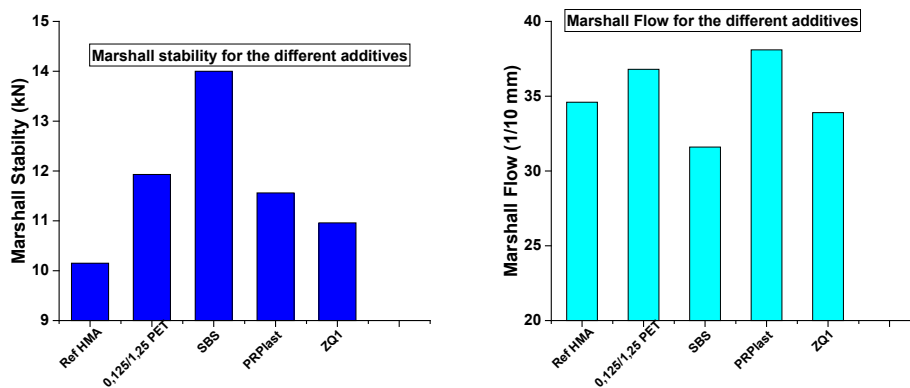


Figure 8. Marshall Results for different additives : (a) Marshall Stability; (b) Marshall Flow

## 5. CONCLUSION

The paper aimed to study the influence of adding PET waste on the performance of Hot Mix Asphalt used in road pavement, with the goal of enhancing its mechanical properties. Five classes per size of PET waste ranging between 0.125 mm and 1.25 mm were investigated. The Marshall method was applied in order to highlight the mechanical advantages of PET additives. Based on the outcomes and the analyses of the result, the following conclusions can be drawn:

- The size of the plastic fibres and their percentages are two key factors that can influence the effectiveness of the improvement of Hot Mix asphalt.
- The mixtures containing the plastic fibres gave much higher stability compared to the reference mixture (without plastic).
- The Marshall stability increases by increasing the size of plastic fibres up to the maximum size, which is, in our case, 1.25 mm.
- Adding 3.75% of PET fibres to the Hot Mix Asphalt enhances Mechanical performance in terms of Marshall's Stability and Flow, particularly with large PET fibres.

- The HMA, containing PET fibres, has better water resistance compared to the reference material, indicating that adding waste plastic improves the long-term performance and durability of the asphalt mixtures.
- Smaller fibres can be dispersed more uniformly throughout the mixture, leading to more uniform reinforcement of the asphalt. However, larger fibres may provide more structural support.
- The Dry process represents an easy way to improve the mechanical properties of HMA by just adding PET waste fibres when preparing the asphalt mixtures.

Finally, we can consider that the present results contribute to reducing plastic waste, preserving natural resources and improving the performance of Hot Mix Asphalt.

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## ПОБОЉШАЊЕ АСФАЛТНЕ МЈЕШАВИНЕ ПО ВРУЋЕМ ПОСТУПКУ КОРИШТЕЊЕМ ПЛАСТИЧНОГ ОТПАДА

**Сажетак:** Пластични отпад је значајан еколошки проблем који захтијева хитно дјеловање. Пластични отпад загађује наше океане, ријеке и језера, штети воденом животу и морским екосистемима. Пластични остаци такође представљају пријетњу копненим дивљим животињама, јер животиње могу замијенити пластику за храну или се заплести у њу, што може довести до повреда или смрти. Поред тога, производња пластике захтијева кориштење фосилних горива, што доводи до емисије гасова стаклене баште доприносећи климатским промјенама. Зато је рециклажа пластичног отпада важан корак ка смањењу утицаја пластике на животну средину и стварању одрживије будућности. Овај рад је дио овог приступа и има за циљ да истражи утицај величине пластичних влакана и њиховог процента на перформансе асфалтних мјешавина по врућем поступку (НМА) у коловозним конструкцијама. Маршалови тестови су спроведени на референтном асфалу (без додавања пластике) и асфалу који садржи пластични отпад како би се истакнуо утицај ових адитива на механичке карактеристике асфалтних мјешавина. Утврђено је да додавање ПЕТ пластичног отпада значајно побољшава механичка својства асфалтне мјешавине по врућем поступку. Резултати су показали да адитиви састављени од пластичних влакана величине између 0,125 и 1,25 мм дају најбоље резултате у погледу Маршаловог теста стабилности и течења, ојачавајући мјешавине битумена и агрегата. Даље, утврђено је да је оптимални садржај пластике око 3,75% масе битумена. Може се примијетити да се предложено рјешење веома добро уклапа у одрживи развој.

**Кључне ријечи:** асфалтна мјешавина по врућем поступку, пластични отпад, Маршалов тест, перформансе, одрживи развој.