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USE OF PET FIBERS – POLYETHYLENE TEREPHTALATE (PLASTIC BOTTLES) IN THE COMPOSITION OF ASPHALT MIXTURE TYPE BADPC 22.4

BY

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Abstract. The use of plastic waste in construction represents an innovative solution for reducing the environmental impact of these materials. One of the most commonly recycled plastic types in construction is polyethylene terephthalate (PET), due to its durability, lightweight nature, and availability. In the construction industry, plastic waste and PET are incorporated either into cement concrete or asphalt mixtures, contributing to improved mechanical performance and the sustainability of these materials.

In cement concrete, the addition of PET fibers can enhance crack resistance, durability, and flexibility while also reducing the need for conventional materials. In the case of asphalt mixtures, PET is used in the form of fibers or recycled aggregates, playing a role in enhancing road performance and extending their service life.

In this study, experiments were conducted on the BADPC 22.4 asphalt mixture. In the first stage, the optimal bitumen content was determined, and for this content, the asphalt mixture was reinforced with PET fibers in proportions of 2%, 4%, 6%, 8%, and 10% to analyze their influence on the material's physical and mechanical properties.

Keywords: laboratory studies, binder, roads, PET.

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1. Introduction

Plastic is a revolutionary material, often referred to as "a material with a thousand uses" (Nayanathara Thathsarani Pilapitiya and Ratnayake, 2024). Plastics have become a crucial global commodity due to their exceptional texture, durability, light weight, affordability, and excellent physical and chemical properties (Kapoor and Rafatullah 2025). On the other hand, plastic is commonly viewed as a hazardous, toxic material, with concerns often raised about its negative impact on wildlife, especially sea turtles (Nuno *et al.*, 2025). Worldwide, 40% of plastic waste went to landfills, 25% was burned, 16% was recycled, and the leftover 19% entered the ecosystem. Investing in circular technologies like feedstock recycling and enhancing infrastructure and environmental conditions is anticipated to make it possible to manage plastic waste flows during this crisis. Investing in valorisation approaches that transform plastic waste into value-added goods, such as fuels and construction materials, conveys a significant macroeconomic message as both plastic waste and the need for plastic are rising. A strong circular economy can be realized by finalizing the lifecycle of plastic waste (Ganguly and Chakraborty, 2024). Several researchers have recently explored the use of plastic waste in building materials, particularly as a substitute for cement in concrete, through conventional experimental testing. Additionally, MEP provides a straightforward mathematical formula that can be used as a design tool to estimate the Compressive Strength (CS) and Tensile Strength (TS) of plastic concrete. In sensitivity analysis, age showed the highest sensitivity (24.8% and 31%), indicating its significant effect on the model's outputs. Cement (17.63% and 17.3%) and plastic (17.4% and 15.3%) have similar contributions to both the CS (compressive strength) and TS (tensile strength) (Asif *et al.*, 2024). The widespread outbreak of diseases like COVID-19 has led to a significant increase in the use and disposal of Personal Protective Equipment (PPE). Plastic-based PPE wastes, such as masks, gloves, and gowns, have contributed to severe environmental pollution. Recycling PPE waste in asphalt pavement construction presents a promising solution to support sustainable development strategies. (Zhu *et al.*, 2024) For example, the plastics sector, accounting for a significant portion of global emissions, presents a challenge and an opportunity in achieving carbon neutrality. Despite Japan's commendable polyethylene terephthalate (PET) bottle recycling rates, most plastics are thermally recycled, creating environmental issues (Chapman *et al.*, 2024). Similar to previous experiments, this study involved the preparation of specimens from asphalt mixtures modified with fibers obtained from polyethylene terephthalate (PET) bottles.

2. Materials and methods

This chapter presents the laboratory results, with an emphasis on the physical and mechanical properties of asphalt mixtures containing PET. Polyethylene terephthalate (bottle) fibers are incorporated into the asphalt mixtures for reinforcement, with the percentage determined based on the optimal binder dosage. The fiber content is set at 2%, 4%, 6%, 8%, and 10% of the optimal binder amount. The volumetric and mechanical properties of asphalt mixes containing different percentages of PET (0%, 2%, 4%, 6%, 8%, and 10%) were calculated and evaluated through laboratory tests. It was determined that the optimal PET content is 6% by weight of the bitumen (Ahmadinia *et al.*, 2011).

2.1. Preparatory Operations

2.1.1. Bringing the materials needed for the preparation of asphalt mixtures:

– Filler – Hoghiz, Brașov County, Bitumen – Almatar, Buzău County, Natural Sand – Tupilați, Neamț County, Crushing gravel – Citadin, Iași.

2.1.2. Drying the aggregates

In order to determine the physico - mechanical characteristics of the asphalt mixtures, two asphalt recipes were prepared, namely BADPC 22.4 – control specimens and BADPC 22.4 – specimens made with PET fibers. A similar approach was applied to the asphalt mixture with PET of the AB 22.4 type (Chicus *et al.*, 2024; Chicus and Gugiman 2024a, 2024b) In order to create these asphalt mixture recipes, the following aggregate grades were required: crushing gravel 16 - 22.4 mm, crushing gravel 8 - 16 mm, crushing gravel 4 - 8 mm, crushing sand 0 - 4 mm, natural sand 0-4 mm and filler.

In accordance with the AND 605/2016 standard, Table 1 and 2 specify the limits for the percentages of aggregate and filler relative to the total amount of aggregates, as well as the gradation range of the aggregate mix for each type of asphalt mixture.

Table 1
The limits of the ratios of fillers and natural aggregates

Natural aggregates – fractions from the total mixture	Wear layer			Bonding layer	Base layer	
	BA 8 BAPC 8	BA 11.2 BAPC 11.2	BA 16 BAPC 16	BAD 22.4 BADPC 22.4 BADPS 22.4	AB 22.4 ABPC 22.4	AB 31.5 ABPC 31.5 ABPS 31.5

Filler and sand fractions < 0.125 mm, %	9.0…18.0	8.0…16.0	8.0…15.0	5.0…10.0	3.0…8.0	3.0…12.0
Filler and fraction (0.125-4 mm), %	The difference until 100					
Natural aggregates > 4 mm, %	22.0…44.0	34.0…48.0	36.0…61.0	55.0…72.0	57.0…73.0	40.0…63.0

Table 2
The granulometric area of bituminous concretes and bituminous coating

The mesh size of the sieve conforming to SR EN 933-2, [mm]	BA 8 BAPC 16	BA 11.2 BAPC 11.2	BA 16 BAPC 16	BAD 22.4 BAPC 22.4 BAPS 22.4	AB 22.4 ABPC 22.4	AB 31.5 ABPC 31.5 ABPS 31.5
45	-	-	-			100
31.5	-	-	-	100	100	90....100
22.4	-	-	100	90....100	90....100	82.....94
16	-	100	90....100	73......90	70.....86	72.....88
11.2	100	90.....100	-	-	-	-
8	90....100	75.....85	61....82	42...61	38.....58	54....74
4	56......78	52.....66	39.....84	28....45	27....43	37.....60
2	38......55	35....50	27.....48	20....35	19....34	22.....47
0.125	9.....18	8....16	8.....15	5....10	3....8	3.....12
0.063	7.....11	5....10	7.....11	3.....7	2....5	2.....7

Based on the granularity of each aggregate obtained through laboratory sieving, the following aggregate percentages were determined for the preparation of asphalt recipes, as shown in Table 3 and Fig. 1:

Table 3
Aggregate dosages for asphalt mixture - BADPC 22.4

Aggregates	%	0.063	0.125	2	4	8	11.2	16	22.4
Filler	5	3.83	4.41	5.00	5.00	5.00	5.00	5.00	5.00
Natural sand 0-4 mm	15	0.31	1.26	13.83	14.91	15.00	15.00	15.00	15.00
Crushing sand 0-4 mm	15	0.87	2.27	11.70	14.71	15.00	15.00	15.00	15.00
Crushing gravel 4-8 mm	14	-	-	1.24	4.16	13.43	14.00	14.00	14.00
Crushing gravel 8-16 mm	18	-	-	-	0.14	2.31	9.45	17.72	18.00
Crushing gravel 16-22.4 mm	33	-	-	-	-	-	0.56	14.62	32.92

Average curve BADPC22.4 AND 605-2016	100	3...7	5...10	20...35	28...45	42...61	....	73...90	90...100
Average curve laboratory	100	5.01	7.93	31.77	38.92	50.73	59.01	81.34	99.92

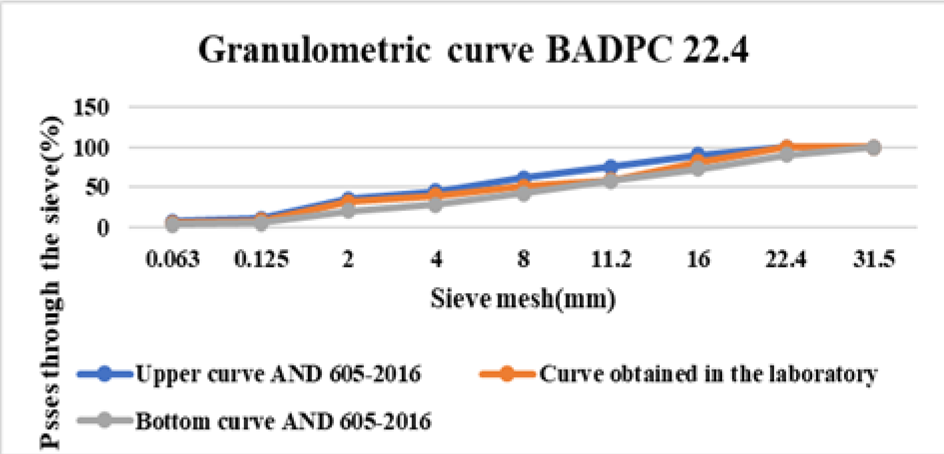

Fig. 1 – Granulometric curve BADPC 22.4.

Table 4 presents the dosage of the asphalt mixture recipe, prepared in the Roads Laboratory of the Faculty of Civil Engineering and Installations in Iași.

Table 4
Percentage values for preparing asphalt mixture recipes

Aggregate / Recipe	BADPC 22.4
Filler (%)	5.00
Natural Sand 0-4 mm (%)	15.00
Crushing sand 0 - 4 mm (%)	15.00
Crushing gravel 4 - 8 mm (%)	14.00
Crushing gravel 8 - 16 mm (%)	18.00
Crushing gravel 16 - 22.4 mm (%)	33.00

2.2. Determination of bitumen characteristics

The following displays the laboratory results for bitumen, including penetration at 25°C, softening point, and penetration index, as shown in Table 5.

Table 5
Bitumen characteristics

Characteristics of D50/70 Bitumen	Values obtained in the laboratory:	SR EN 12591-2009 (STAS 754-99)
Penetration at +25ºC, 1/10 mm	61	50…70
Softening point (I.B.), oC	49	46…54
Penetration Index I.P.	-0.995	-1.5…+0.7

2.3. Determination of bitumen dosages and preparation of Marshall specimens

The optimal bitumen dosage for the asphalt mixture recipe was determined through laboratory tests, taking into account the recommendations of AND 605-2016, as presented in the Table 6.

Table 6
Minimum binder content

Layer type	Asphalt mixture (type)	Binder content in the mixture (minimum) %
Binder	BAD 22.4 BADPC 22.4 BADPS 22.4	4.20

To establish the ideal binder amount, Marshall specimens were created, which included control specimens and those containing PET fibers, with varying bitumen dosages. The plastics from PET jugs to be utilized in blends for examine work. The measurements of plastic of 5%, 7.5%, 10%, 12.5% and 15% utilized as substitution of bitumen. The advance plastics content is 10% with 5.25% of bitumen content. In this paper concentrated on Marshall Test and extreme execution of hot blend black-top. In this examination work it is explored that the general cost of plastic blends bitumen spared 5.18% cost as contrast with customary bitumen (Hake *et al.*, 2020).

The following characteristics were determined:

- Determination of the asphalt mixture density;
- Determination of water absorption;
- Determination of Marshall stability

2.3.1. Determination of the asphalt mixture density

The density of the asphalt mixture was determined according to SR EN 12697-8:2019 (Figs. 2-7). The determination process involved the following steps:

a) Maintaining the samples in a water bath at a temperature of 20°C for one hour. Afterward, they are removed and wiped with a damp cloth to eliminate any surface water.

b) Measuring the mass of the specimen in its dry state by weighing it in air (m_1), followed by submerging the specimen in water to determine its mass (m_2).

c) The apparent dry bulk density of the specimen (ρ_{dry}) is calculated, rounded to the nearest 1 kg/m³, using the following formula:

$$\rho_{bdry} = \frac{m_1}{m_1 - m_2} x \rho_w \quad (1)$$

2.3.2. Water Absorption Determination

The water absorption test was performed following the AND 605-2016 standard (Figs. 3-8). Water absorption denotes the volume of water that enters the available pores on the external surface of an asphalt mixture sample when immersed in water under vacuum conditions. It is stated as a percentage of the original mass or volume of the specimen.

a. The specimens are placed in the vacuum chamber, which is maintained at a temperature of 20 ± 1°C. The chamber is then sealed and operated for three hours, reaching a pressure of 15–20 mm Hg after approximately 30 minutes.

b. After three hours, the vacuum chamber is turned off, and the specimens are kept in water for an additional two hours at atmospheric pressure.

c. After the 2 hours, the specimens are removed from the water and wiped with a damp cloth. They are then weighed in air (m_3) and in water (m_4).

d. The initial volume (V) and final volume (V_1) of the specimen are calculated using the following formulas:

$$V = (m_1 - m_2)\frac{1}{\rho_w}[cm^3] \quad (2)$$

$$V_1 = (m_3 - m_4)\frac{1}{\rho_w}[cm^3] \quad (3)$$

e. Water absorption is calculated as follows

Water absorption can be reported either to the volume of the specimen (A_v) or to its mass (A_m). The formulas differ depending on whether $V>V_1$ or $V<V_1$. The formulas are as follows:

e.1 When $V>V_1$

$$A_m = \frac{m_3 - m_u}{m_u}100 \quad (4)$$

$$A_v = \frac{(m_3 - m_u) - \rho_w}{(m_1 - m_2) - \rho_w} 100 \quad (5)$$

e.$_2$ When V<V$_1$

$$A_m = \frac{(m_2 - m_u) - [(m_2 - m_4) - (m_1 - m_2)]}{m_u} 100 \quad (6)$$

$$A_v = \frac{(m_2 - m_u) - [(m_2 - m_4) - (m_1 - m_2)]}{(m_1 - m_2) - \rho_w} 100 \quad (7)$$

2.3.3. Determination Marshall stability

This test measures the resistance of the asphalt specimen to plastic deformation when subjected to a load, providing an indication of the durability and stability of the mixture under traffic conditions, according to SR EN 12697-34:2020 (Figs. 4-6, 9-11). The results from these tests allow us to determine the optimal binder content, and subsequently, PET fibers will be added as a percentage of the bitumen dosage.

The goal of the test is to assess the breaking strength of a cylindrical sample, with the force exerted on a generator.

Working steps:

a. The unused specimens for the absorption test are placed in water at a temperature of 60°C and maintained for 30 minutes.

b. After 30 minutes, the specimen is removed from the water bath and placed in the Marshall test apparatus.

c. The test is started – the specimen is loaded at a rate of 50 mm/min. When it is observed that the test does not continue to increase, but instead starts to decrease, the test is stopped.

d. The Marshall stability represents the load, expressed in kN, that was reached when the specimen broke. The Marshall flow (creep) is the distortion attained by the specimen's vertical diameter at the point of failure and is measured in mm.

3. Results:

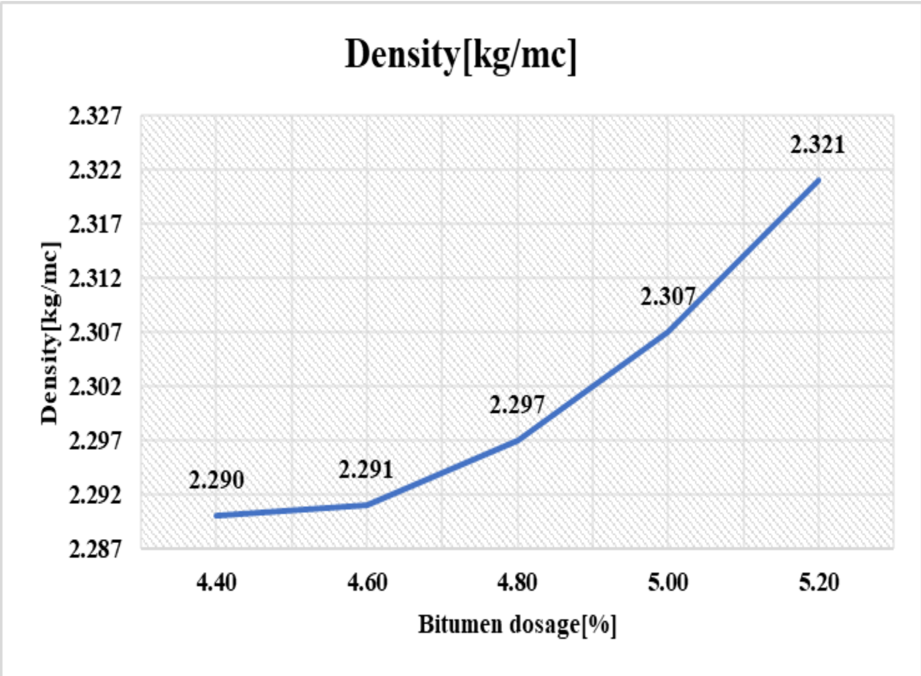

Fig. 2 – Density values for BADPC 22.4 - control specimen.

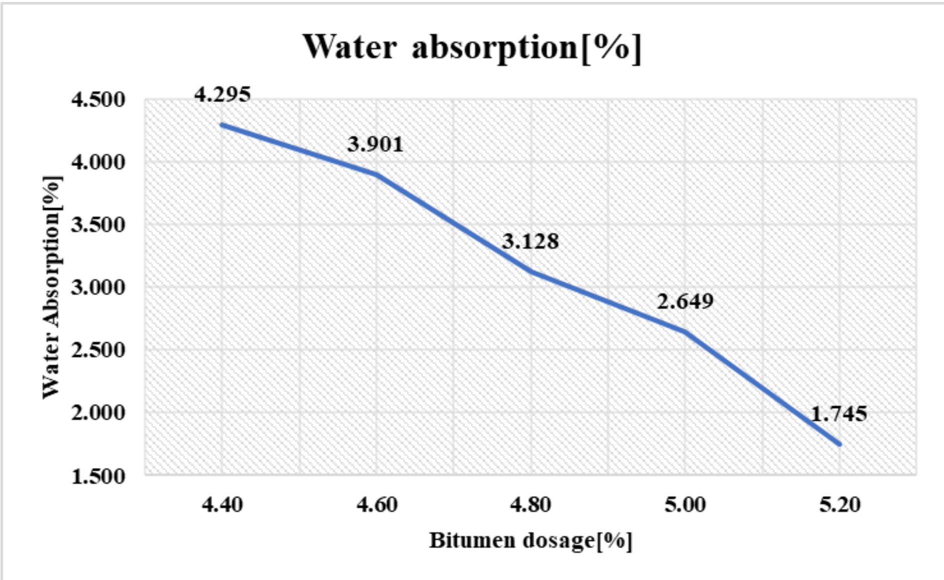

Fig. 3 – Water absorption values for BADPC 22.4 - control specimen.

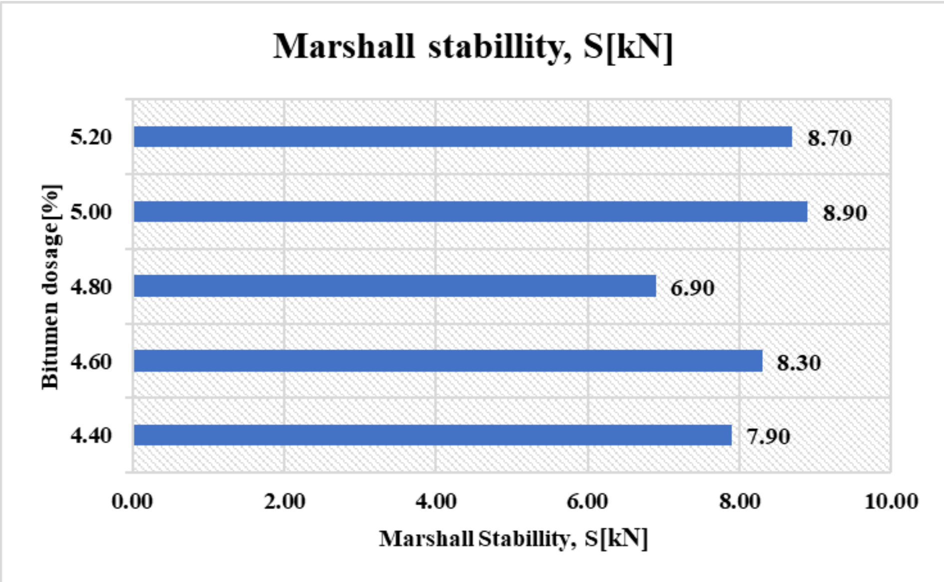

Fig. 4 – Marshall stability values for BADPC 22.4 - control specimen.

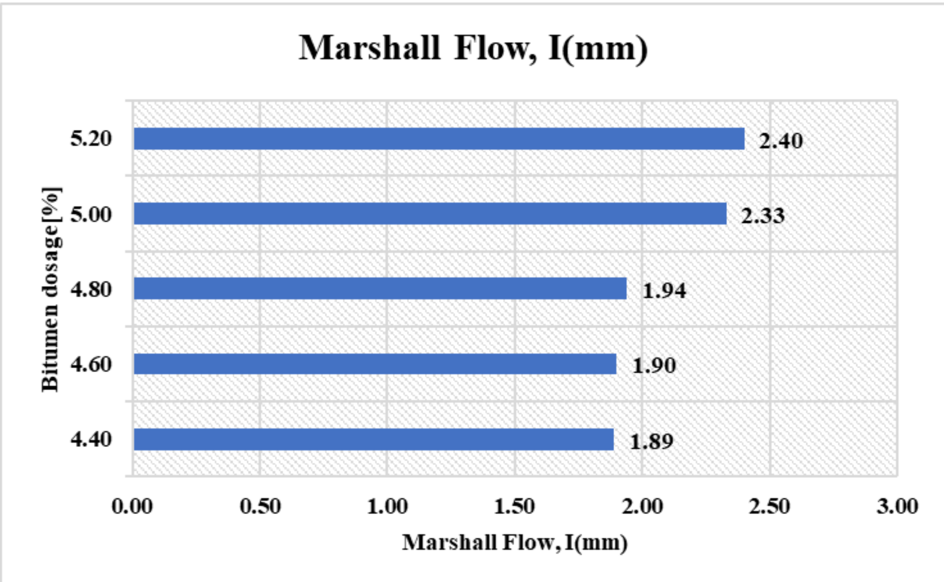

Fig. 5 – Marshall Flow values for BADPC 22.4 - control specimen.

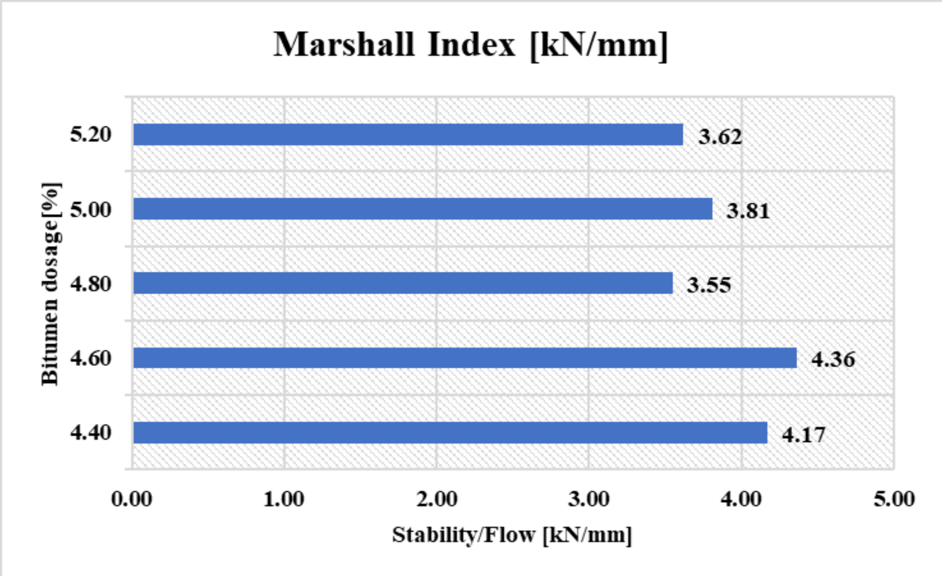

Fig. 6 – Marshall Index values for BADPC 22.4 - control specimen.

Table 7
Bitumen - optimum dosage

Mixture	Optimum dosage of bitumen, %	Minimum bitumen content in the mix, % AND 605-2016
BADPC 22.4	4.60	4.20

The optimum bitumen content is 4.60% as shown in Fig. 6 and Table 7.

For this optimal bitumen content, PET fibers were added in percentages ranging from 2% to 10%. Mashaan *et al.*, 2021 investigate the impact of using local waste Polyethylene Terephthalate (PET) plastic in binder class C320, which is a common bitumen type used for local road surfacing in Australia. The results showed that the ideal content of waste plastic is 6–8% to improve the rutting and aging resistances. Moreover, 8% PET improves the fatigue cracking resistance as it shows a low fatigue factor (G* sin δ). Haigh, 2024 focuses on the mechanical behaviour of concrete using waste plastic milk bottle fibres to replace 10% of the cement requirement. Both raw milk bottle fibres and surface modified fibres using silica fume (SF) were mechanically analysed for their compressive, flexural, and tensile strength. Non-modified fibres resulted in a lower mechanical strength however, SF modified fibres increased the compressive, tensile, and flexural strength by 16%, 16.6%, and 11%, respectively.

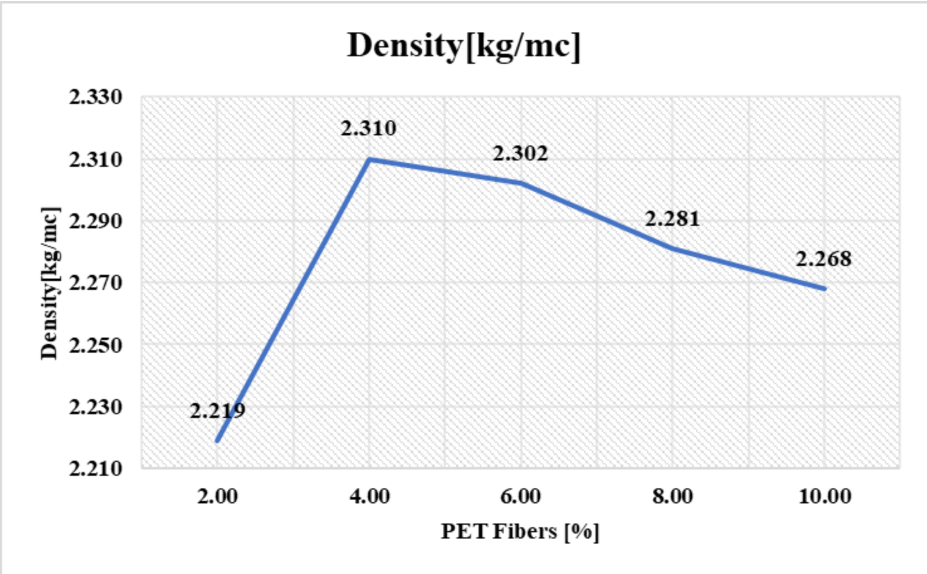

Fig. 7 – Density values for BADPC 22.4 – specimen with PET fibres.

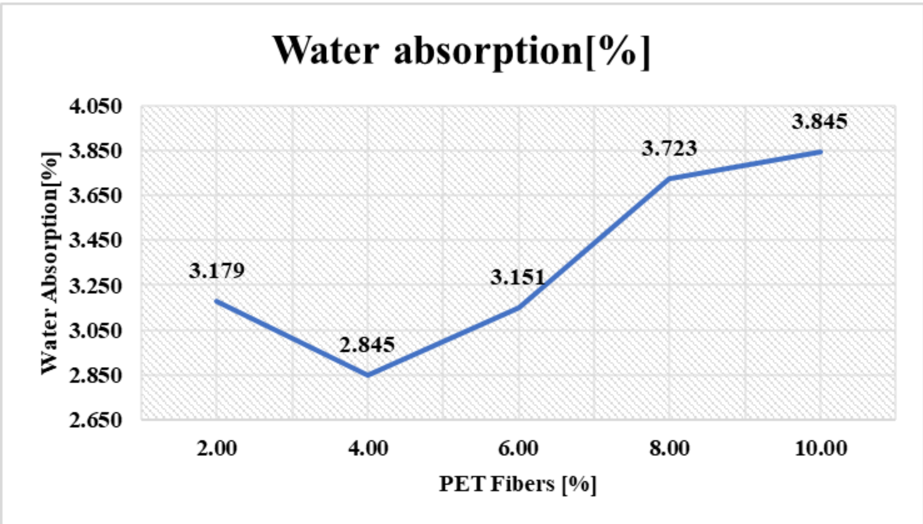

Fig. 8 – Water absorption values for BADPC 22.4 – specimen with PET fibres.

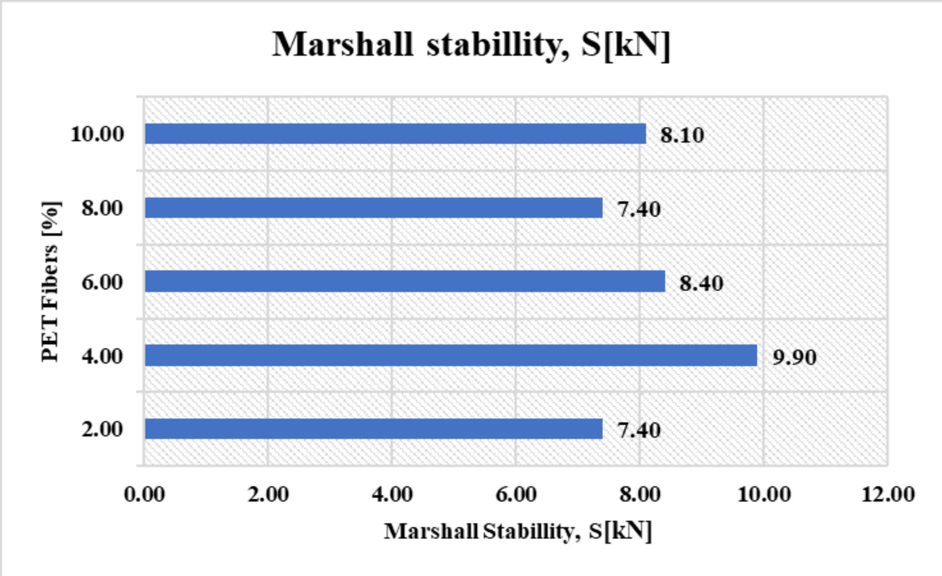

Fig. 9 – Marshall stability values for BADPC 22.4 – specimen with PET fibres.

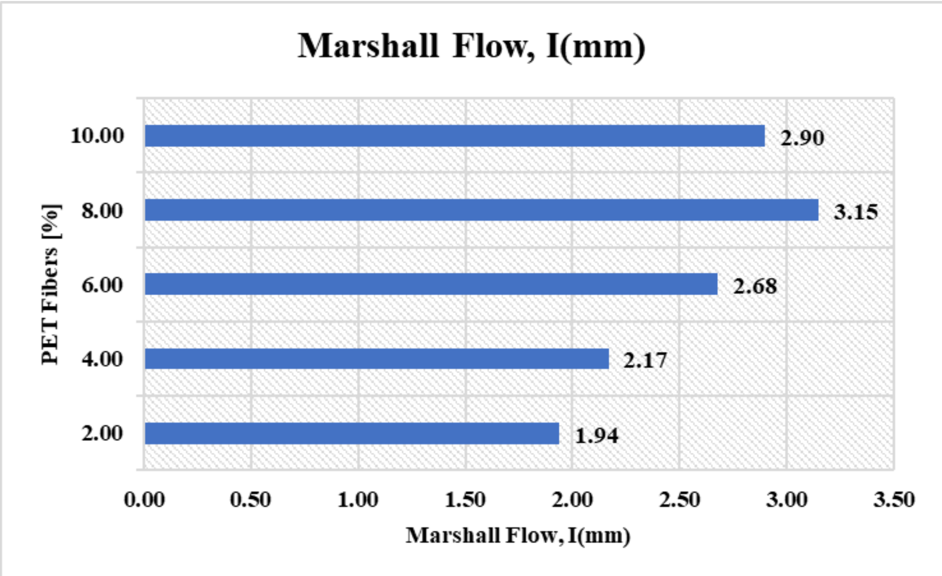

Fig. 10 – Marshall Flow values for BADPC 22.4 – specimen with PET fibres.

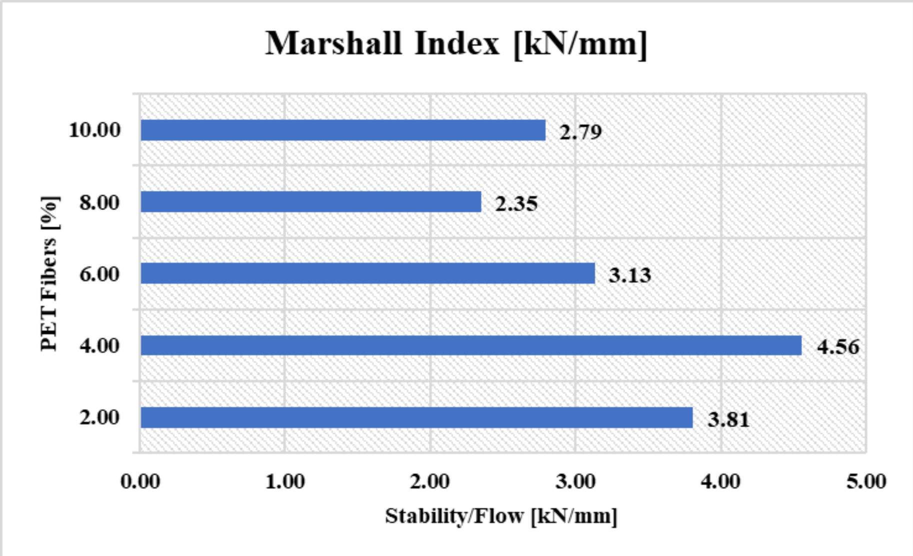

Fig. 11 – Marshall Index values for BADPC 22.4 – specimen with PET fibres.

Table 8
Physico - mechanical characteristics determined through testing on Marshall cylinders – according to AND 605/2016

Type of asphalt mixture	Stability at 60℃ (kN)	Marshall Flow (mm)	Marshall Index (kN/mm)
Open bituminous concrete	5.0.....15	1.5....4.00	1.2

4. Conclusions

Incorporating plastic waste, specifically PET (polyethylene terephthalate) bottles, into asphalt mixtures is an inventive approach that is attracting growing interest globally and nationally, aimed at decreasing the volume of plastic pollution and enhancing the quality of road infrastructure. In the laboratory were made recipes for asphalt mixture BADPC 22.4 control specimens and specimens made with PET fibers with quarry aggregates brought in: Filler - Hoghiz, Brasov County, Bitumen 50/70 - Almatar, Buzău County, Natural Sand - Tupilați, Neamt County, Crushing gravel - Citadin, Iași County.

After sieving, the granulometric curve for BADPC 22.4 falls within the limits imposed by AND 605.

The mixture BADPC 22.4 designed in the road laboratory of the Faculty of Civil Engineering and Installations, Iași, are composed of: filler (5.00%), natural sand 0-4 mm (15.00%), crushing sand 0 - 4 mm (15.00%), crushing gravel 4 - 8 mm (14.00%), crushing gravel 8 - 16 mm (18.00%), crushing gravel 16 –

22.4 mm (33.00%). Thus, specimens were taken from the control asphalt mixture and the asphalt mixture made with PET fibers.

As a result of determination of the asphalt mixture density, of water absorption and Marshall stability the optimal bitumen percentage, for which the Marshal Index had the highest value, was 4.60%. For the optimal bitumen content, PET fibers were added in proportions of 2%, 4%, 6%, 8%, and 10%.

The optimal fiber percentage for reinforcing the asphalt mixture, which resulted in the best Marshall Flow [kN/mm] ratio, was 4.00% PET fibers. Additionally, favorable results were also obtained for other percentages of PET fibers. Due to the positive outcomes achieved so far, further static and dynamic tests will be conducted. For example, the optimal percentage of fibers for reinforcing the asphalt mixture, which yielded the best S/I [kN/mm] ratio for the AB 22.4 asphalt mix, was found to be 4.00% PET fibers, relative to the optimal bitumen content of 4.60%.

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UTILIZAREA FIBRELOR PET – POLIETILEN TEREFTALAT (RECIPIENTE DIN PLASTIC) ÎN COMPOZIȚIA MIXTURII ASFALTICE TIP BADPC 22,4

(Rezumat)

Utilizarea deșeurilor din plastic în construcții reprezintă o soluție inovatoare pentru reducerea impactului ecologic al acestor materiale. Printre cele mai utilizate tipuri de plastic reciclate în domeniul construcțiilor se numără polietilen tereftalatul (PET), datorită durabilității, greutății reduse și disponibilității sale. În industria construcțiilor, deșeurile din plastic și PET-urile sunt integrate fie în alcătuirea betoanelor de ciment, fie în mixturile asfaltice, contribuind la îmbunătățirea performanțelor mecanice și a sustenabilității acestor materiale. În betonul de ciment, adăugarea fibrelor de PET poate îmbunătăți rezistența la fisurare, durabilitatea și flexibilitatea, reducând în același timp necesitatea utilizării materialelor convenționale. În cazul mixturilor asfaltice, PET-ul este utilizat sub formă de fibre sau agregate reciclate, având rolul crește performanța drumurilor și la extinderea duratei lor de exploatare. În cadrul acestui studiu, au fost realizate experimente pe mixtura asfaltică BADPC 22,4. În prima etapă, s-a determinat conținutul optim de bitum, iar pentru acest conținut, mixtura asfaltică a fost ranforsată cu fibre de PET în proporții de 2%, 4%, 6%, 8% și 10%, pentru a analiza influența acestora asupra caracteristicilor fizico-mecanice ale materialului.