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Performance evaluation of flexible pavement using polyethylene terephthalate (PET)

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K E Y W O R D S

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Hot Mix Asphalt

Natural Aggregates

Polyethylene Terephthalate

Rutting

A B S T R A C T

In this study, the benefits and feasibility of incorporating Polyethylene Terephthalate (PET) into Flexible pavement were evaluated. The study aims to identify new ideas on recycling plastic wastes and thereby improving overall sustainability. The Samples were prepared by adding PET with an increasing concentration level along with optimum asphalt content with a percentage by weight of 3.5%, 4.0%, 4.5%, 5.0%, 5.5% and 6%. Multiple tests were conducted on Natural aggregates including Resistance to degradation of aggregates by Abrasion and Impact, Specific Gravity and Abrasion of coarse aggregates, and Impact Value of Aggregates. Similarly, the tests conducted on asphalt include the specific gravity of semi-solid bituminous material, the ductility of bituminous material, the flash point and softening point of asphalt, and the penetration grade of bituminous material. Rutting potential of the optimum asphalt, Plastic mix Was evaluated by increasing the frequency of load cycles from 0 to 5000 cycles. Furthermore, the effect of asphalt and plastic content on the density, Flow, voids, and stability were also analysed. It was found that the addition of PET resulted in improved stability by more than 50% specifically 52%, while 70% improvement was observed in flow characteristics of Hot Mix Asphalt. However, a slight change in density was observed. The sample also showed a reduction in rut depth by more than 40% of the mix.

1. Introduction

The demand for construction materials is increasing due to urbanization and massive population growth. For this reason, it's crucial to create newer designs of pavements and construction that are resilient, sufficiently durable to withstand stress, and necessitate fewer upkeep and alterations. Waste materials can also be used to make this improvement, making it both affordable and environmentally friendly [1].

Due to the irresponsible and unrestricted use of plastics, a massive surge of plastic waste has been noticed in the past few decades. This has created an urgent need to find effective ways of recycling Plastic waste. The improper disposal of plastic waste leads to its accumulation in landfill sites. These landfill sites contribute to ocean garbage patches or sometimes if incinerated result in various environmental degradations [2].

The worldwide consumer demand for PET is primarily driven by its application in synthetic fibers and plastic bottles. Nevertheless, PET's non-biodegradable nature results in its persistence in the environment for prolonged periods, posing challenges in terms of proper disposal [3]. Meanwhile, PET bottles generate more than 100 times as many dangerous emissions into the air and water as making of glass containers of the same size [4].

An encouraging solution to address these challenges involves incorporating plastic wastes into Flexible Pavement, which not only enhances the pavement's performance but also helps mitigate environmental concerns [5]. Polymers as additives, have gained considerable attention in the fields of road construction. Among these polymers, PET is extensively used to coat the aggregates in asphalt mixtures. The Coating ensures a strong bond between aggregates and enhances surface roughness, making PET a preferred choice due to its advanced engineering properties when combined with asphalt [6].

Numerous studies have been carried out to examine the usage of plastic waste in asphalt compositions for elastic floors. Reusing discarded Plastic can also help to considerably lessen the problem of disposing of waste, concerns about pollution, improved performance, and lower road construction costs. The use of waste Plastic in the asphalt mixture has been shown to improve engineering characteristics like martial stability, water resistance (retention measure Stability, as plastic is hydrophobic), and crack propagation resistance (indicated by the indirect tensile strength of the modified Asphalt Mix as per ASTM D6931-17). This method of modification also improves the Asphalt mixes' binding qualities and lengthens the lifespan of the road.

Approximately 95% of the asphalt mixture is composed of aggregate. Continuous usage of this substance is endangering its natural resources, especially since Flexible Pavement is one of the most popular types of pavement in the world. Therefore, recycling this material can provide sustainable construction, lower the demand for natural resources, and minimize the cost of building a road while also protecting the environment. To reduce waste and generate asphalt with better engineering qualities than traditional mixes, waste Plastic is added to the mix [7].

It is crucial to exercise caution when selecting waste materials for pavement construction, especially in the asphalt surface layer. Recycled materials should only be used selectively so as not to compromise the pavement's structural integrity or functionality. To offer the necessary characteristics including strength and durability within an affordable manner, the composition of the asphalt mix must be carefully chosen, with the right proportions to allow for irreversible deformation and fracture [8].

During the production process, the PET fibres or fragments were added to the asphalt mixture in the shredded or granular form. This method is referred to as Polymer-modified asphalt. PET fibres can enhance the resilience to stress and durability of asphalt mixtures [9].

Rutting is one of the most common issues with pavement. Frequent crossings by large axle-load vehicles cause it to happen. Rutting is the overtime deformation of the wheel route along the road caused by wear and tear. So, because of the fibres' increased stability and stiffness, PET-modified asphalt resists rutting better. In general, PET with asphalt has the potential to be stronger, more durable, and sustainable; its use could lead to more environmentally friendly and robust road infrastructure. We can lessen the negative effects of construction on the environment and encourage a more resource- and circular-conscious methodology by integrating PET into Flexible Pavement [10].

Melted plastic bottle trash is coated on the aggregates used in flexible pavements in one approach, and melted plastic garbage is substituted for asphalt cement in another method. The study's conclusions showed that, in comparison to plastic-modified asphalt, bituminous asphaltic concrete made with plastic-coated aggregates might make better use of plastic waste. However, the Plastic-modified Asphalt exhibited slightly better stability, although the difference was minimal. Overall, asphalt produced using both methods demonstrated superior properties compared to traditional asphalt [11].

Similarly, in the dry process, the aggregate is modified by coating it with PET Plastic polymers to generate a newer raw material for Flexible Pavement [12]. PET proves to be an excellent modifier due to its ability to facilitate smooth mixing at relatively low temperatures. PET further exhibits favorable properties, such as the absence of gas production at temperatures between 130 and 180˚C, and its easy softening at 130˚C. Its binding properties are also commendable, making it a suitable binder that can be combined with other binders like Asphalt to enhance binding capacity [13].

The combination of Plastic with Asphalt and hot aggregates results in a high-quality coat that exhibits improved shear strength, better resistance, smoother surface, and superior performance over time. Introducing Plastic waste into pavement production reduces Plastic shrinkage, and drying shrinkage, and enhances abrasion and slip resistance. The incorporation of Plastic combined with Asphalt and aggregates leads to better pavement performance, reducing voids, moisture absorption, grooves, and pothole formation. PET possesses unique characteristics that enhance the flexibility of pavements. Its adequate tensile strength and elasticity make it suitable for resisting cracks and deformations under heavy traffic loads. By blending PET with other substances, such as Asphalt, the resulting composite material can increase strength and resistance, extending the pavement's lifespan [14].

The objective of this work is to assess the performance and feasibility of incorporating PET into flexible pavement as an asphalt-wearing course. The volumetric properties were examined and found to improve with the addition of PET. The stability, flow, and density were all found better as compared to controlled samples. The stability and flow characteristics were found to be enhanced by more than 52% and 70% respectively. Rutting susceptibility is one of the major problems that occur due to repeated traffic loads. The addition of PET also increases the rutting susceptibility of the asphalt mix. The PET mix reduced the rut resistance nearly by 50%. That is the major aim that has been achieved through the result of this study. This not only reduces the burden on natural resources but is also a step towards sustainability.

2. Experimental Program

2.1 Materials

The natural aggregates utilized in the preparation of samples were tested and sieved by the standard test parameters. Similarly, the PET bottles were acquired, cleaned, and shredded which were then used with asphalt in percentages of 3%, 6%, 9%, 12%, and 15%. The waste PET bottles were sourced from the waste around the city.

2.2 Sample Preparation

To prepare the Marshal specimens, the aggregates were sieved to the specified size, as shown in Fig. 1, and then washed and dried in an oven. The graduation requirements for the aggregates, as per NHA specification, are presented in Table 1. For each asphalt content level and waste Plastic utilization level, three Marshall Mix samples were prepared, as shown in Fig. 2. The scheme of the specimen prepared is presented in Table 2. There were six (06) mix types, Mix Types were designated M-I as mix type I, and M-VI as mix type VI respectively. M-I was utilized for calculating the OAC and served as a Controlled Sample. While other mix types from M-II to M-VI were used to study the behaviour of PET in the asphalt mix. A total of 42 samples belonged to M-I of which half of them were compacted and the rest were un-compacted. On the contrary, the rest of the mix types except M-I, specimens were prepared on OAC with the addition of PET. The M-II specimens were prepared with 3.0%. For every mix type, an addition of 3.0% of PET was designed. So, the last mix type M-VI specimens have 15.0% of PET. A total of seventy-two (72) Marshall specimens were prepared. These controlled specimens were made using natural aggregates and conventional asphalt. All the mix types and number of samples are described in Table 2.

Fig. 1. Sample Of Aggregates of Different Sieve Sizes

Table 1

Particle Size Distribution used in Study

Sr.	Sieve Size (in)	Mass Retained (gm)	Mass Retained (%)	Cumulative Mass Retained %	Cumulative Passing (%)
1	1	0	0	0.0	100
2	3/4	60	5	5.0	95
3	3/8	384	32	37.0	63
4	4	246	21	57.5	42.5
5	8	162	14	71.0	29
6	16	246	21	91.0	8.5
7	200	42	4	95.0	5
8	Pan	60	5	100.0	0

Fig. 2. Molds for Marshal Testing

Table 2

Testing scheme of marshall samples

S. No	PET (%)	Mix Type	AC (%)	Compacted	Total	Un-compacted	Total	Total Samples
1	-		3.0	3		3		
2	-		3.5	3		3		
3	-		4.0	3		3		
4	-	M-I	4.5	3	21	3	21	42
5	-		5.0	3		3		
6	-		5.5	3		3		
7	-		6.0	3		3		
8	3	M-II	opt	3		3		
9	6	M-III	opt	3		3		
10	9	M-IV	opt	3	15	3	15	30
11	12	M-V	opt	3		3		
12	15	M-VI	opt	3		3		
Total								72

To examine the behavior of optimum samples both controlled and optimum PET samples. Two Types of samples were prepared designated as optimum Controlled Specimen OCS and optimum PET Specimen OPS. OCS were prepared on OAC and are controlled one while, the OPS were prepared on optimum PET content. Both types of samples were prepared for both the test Marshall and Rutting resistance tests. The testing scheme is presented in Table 3. Three (03) Marshall and rutting samples for each set of mix types were prepared. A total of Six (06) Marshall and the same set of rutting samples were prepared to examine the behavior of rutting and other volumetric properties on optimum asphalt and optimum PET content.

Table 3

Testing scheme of rutting susceptibility test

Mix Type	AC	PET %	Marshall	Rutting
OCS	opt	-	3	3
OPS	opt	Opt	3	3

For the mixture preparation, the aggregates and asphalt were placed inside the oven after proper proportioning at a temperature of 160oC for 2 hours, as shown in Fig. 3(a) and 3(b). After which the asphalt was added to aggregates and the mixture was blended thoroughly on a hot plate. This mixture, of coated aggregates with asphalt, is then placed back in the oven for another 2 hours. The same process was repeated for all the specimens in this study.

Fig. 3. (a) Oven For Heating and Drying, **(b)** Sample Being Dried in Oven

2.3 Tests and Standards

The compaction of specimens is carried out on the Roller Compactor, as shown in Fig. 4(a) and 4(b). The mold containing a mixture of asphalt and aggregates is removed from the oven and is filled into three layers into the mold and each layer is compacted by applying 25 blows using the tamping rod. Afterwards, a compaction hammer is used to apply 75 strikes on each side of a sample and the sample is then left at room temperature for 24 hours.

Fig. 4. (a) Sample During Compaction, **(b)** Roller Compactor

For the un-compacted samples, the prepared sample is left to dry for 24 hours, weighed, and placed on the Rice test apparatus. The Sample is then submerged in water. ASTM D2041 was followed to find out the Maximum Theoretical Specific Gravity (Gmm). Similarly, for the stability and flow test, the weight of samples was recorded in dry, submerged, and saturated dry conditions. After that, the samples were submerged in a 60°C water bath for 30 minutes. Both the stability and flow characteristics were evaluated independently using the Marshall apparatus as per ASTM D6927-15. The percentage of voids was calculated using Eq. 1.

$$V_a = \left[1 - \frac{G_{mb}}{G_{mm}}\right] \text{x } 100 \quad (1)$$

where,

V_a = Void Fraction

G_{mm} = Theoretical Max. Specific Gravity

G_{mb} = Bulk Dry Specific Gravity

The mixture's bulk dry specific gravity is the specific gravity including the air voids which is calculated by Eq. 2.

$$G_{mb} = \left[\frac{w_d}{W_{ssd} - W_{sub}}\right] \quad (2)$$

where,

Wd = Dry weight of compacted sample

Wssd = Saturated surface dry weight of sample

Wsub = Submerged weight of sample

Similarly, the highest specific gravity of the hot mix asphalt mixture that can theoretically be achieved without air gaps is given by Eq. 3.

$$G_{mm} = \left[\frac{A}{A+D-E}\right] \quad (3)$$

where,

A = Mass of dry sample

D = Mass of lid and bowl with water @ 25oC

E = Mass of lid, bowl, sample and water @ 25oC

Table 4 provides the details about testing standards being adopted for the tests of aggregates along with the apparatus utilized. Table 5 gives the test, its standard, and the apparatus for the test conducted binder being used in this study.

Table 1

Test of aggregates

Test	Standard	Apparatus
Resistance to degradation of aggregates by Abrasion and Impact	ASTM: C131-89	Los Angeles Abrasion Machin
Specific Gravity and Abrasion of coarse aggregates	ASTM: C127-88	Balance Sample container, Wire Basket of 3.55mr Water Tank.
Impact Value of Aggregates	BS: 812 part 112	Cylinder, Impac Testing Machine Temping Road, Sieve, Balance

Table 2

Test of asphalt

Test	Standard	Apparatus
Penetration Grade of Bituminous Material	ASTM: D5-86	Penetrometer, Water Bath, Penetration Needle Sample Container, Thermometers, Transfer Dish
Flash Point of Asphalt	ASTM: D92-78	Clevel and Open Cup Apparatus
Softening Point Of Asphalt	ASTM: D36-8	Ring And Ball Apparatus
Specific Gravity Of Semi-Solid Bituminous Material	ASTM: D70-76	Pyknometer Bottle Beaker, Water Bath Thermometer
Ductility Of Bituminous Material	ASTM: D113- 86	Ductilimeter, Mold Water Bath, Thermometer

3. Results and Discussion

The Tests for Asphalt and Aggregates were performed in the Transportation Engineering Laboratory at NED University. The results of the tests performed on aggregates are shown in Table 6. All tests were under the limits specified by NHA. Similarly, Table 7 shows the results of tests conducted on asphalt, and the obtained properties of asphalt. The properties of the binder were also under the limits as per NHA regulations. All the results obtained are within the recommended range of the National Highway Authority (NHA) both for aggregates and asphalt.

Table 3

Comparison of standard tests conducted on aggregates and recommended values

Tests	Natural Aggregates	Recommended Value
BSG	2.69	2.5-3
BSG (SSD)	2.71	2.6-2.8
BSG (Apparent	2.73	2.5-2.8
Absorption (%)	0.53	< 3
LA Abrasion (%)	25	< 30
Impact Value (%)	17.8	< 35

Table 4

Comparison of standard tests conducted for determination of asphalt properties and recommended values

Tests	Results	Recommended Value
Softening Point (oC)	42.5	30-80
Penetration Valu (0.1mm)	66.2	25-200
Flash Point (oC)	230	> 200
Specific Gravity (kg/m3)	0.98	0.97-1.02

To determine volumetric properties such as air voids, density, flow, and stability at various percentages of asphalt were presented. Table 8 presents the volumetric properties of the Un-compacted samples. The compacted samples were also prepared on the same percentages of binder starting from 3.5% to 6.0% of the binder by the weight of samples. These samples provide the value of Maximum Theoretical Specific Gravity (Gmm). The Gmm value was further utilized in finding out the Air Voids (%). The table 9 also explained the percentage of binder addition starting from 3.5% to 6.0% as per the weight of the samples as per the Marshall Mix Design Method. In response, all the volumetric properties were observed on all percentages of binder. The air void percentage will be utilized to find out the OAC. The OAC further extends to find out optimum stability, flow, and density.

Table 5

Volumetric properties of un-compacted samples

S.No	Percentage Asphalt	Average Dry Weight (A) (Kg)	Average Saturated Weight (B) (kg)	Average Submerged Weight (C) (Kg)	Average Gmm
1	3.5%	1.55	12	12.85	2.21
2	4.0%	1.58	12	12.85	2.17
3	4.5%	1.5	12	12.85	1.69
4	5.0%	1.55	12	12.65	1.80
5	5.5%	1.55	12	12.90	2.38
6	6.0%	1.53	12	12.78	2.07

Table 9

Volumetric properties of compacted samples

S.no	Percentage Asphalt	Average Height (mm)	Average Dry Weight (A) (kg)	Average Saturated Weight (B) (kg)	Average Submerged Weight (C) (kg)	Average Stability (kgf)	Average Flow (in)	Average Gmb
1	3.5%	70.16	1218.80	1235.92	699.00	1138.75	19.4	2.27
2	4.0%	67.39	1201.85	1214.81	685.95	1415.00	15.3	2.28
3	4.5%	71.06	1263.45	1273.20	711.70	1093.75	17.2	2.25
4	5.0%	68.97	1227.15	1234.25	691.05	1540.50	9.2	2.26
5	5.5%	69.15	1229.05	1236.25	692.51	1527.25	13.1	2.26
6	6.0%	70.21	1233.05	1240.35	688.52	1079.75	11.2	2.24

Similarly, to study the behavior of addition on PET, it was added to the binder. The plastic content was added at varied percentages i.e., 3% to 15% at 3% interval. These PET contents were added at OAC (4.25%) as an additive material. To evaluate the effect of plastic content on the stability and the flow. The volumetric properties of the Un-compacted samples containing PET are given in Table 10. The volumetric properties of OAC with the variegated percentage of PET of compacted samples are given in Table 11.

Table 10

Volumetric properties of compacted samples at OAC with variegated PET %

S.no	Opt Asphalt + % PET	Average Height (mm)	Average Dry Weight (A) (kg)	Average Saturated Weight (B) (kg)	Average Submerged Weight (C) (kg)	Average Stability (kgf)	Average Flow (in)	Average Gmb
1	4.25%+3%	69.33	1200.73	1211.9	680.10	1842.83	10.7	2.26
2	4.25%+6%	68.19	1202.73	1211.9	684.36	3114.50	5.3	2.28
3	4.25%+9%	69.57	1211.60	1221.6	689.93	2898.67	8.3	2.28
4	4.25%+12%	70.53	1204.80	1217	679.81	2656.33	14.0	2.24
5	4.25%+15%	69.51	1214.26	1225.6	687.32	2267.67	18.0	2.26

Table 11

Volumetric properties of un-compacted samples at OAC with variegated PET %

S.no	Opt Asphalt + % PET	Average Dry Weight (A) (kg)	Average Saturated Weight (B) (kg)	Average Submerged Weight (C) (kg)	Average Gmb
1	4.25%+3%	1.500	12	12.825	2.23
2	4.25%+6%	1.450	12	12.775	2.15
3	4.25%+9%	1.525	12	12.85	2.26
4	4.25%+12%	1.525	12	12.85	2.26
5	4.25%+15%	1.525	12	12.825	2.19

The rutting test of controlled Hot Mix Asphalt and HMA with plastic is conducted by using a wheel tracker. The obtained results of the rutting specificity of different mixes at OAC are shown in Table 12. It can be observed that the HMA containing plastic content has less depth as compared to the Controlled HMA. The rut depth of PET modified sample was approximately 45% less than the controlled specimen. The graphical representation of rutting behavior can be observed in Fig. 5.

Table 6

Rutting specificity of different mix at optimum asphalt content (Average Rut depth)

Load Cycles (No.)	Rutting Depth (mm)	
	Controlled	Opt. PET
0	0.00	0.00
500	2.87	1.40
1000	3.36	1.85
1500	4.00	2.50
2000	4.56	2.75
2500	5.22	3.00
3000	5.87	3.20
3500	6.20	3.45
4000	6.38	3.51
4500	6.50	3.60
5000	6.70	3.70

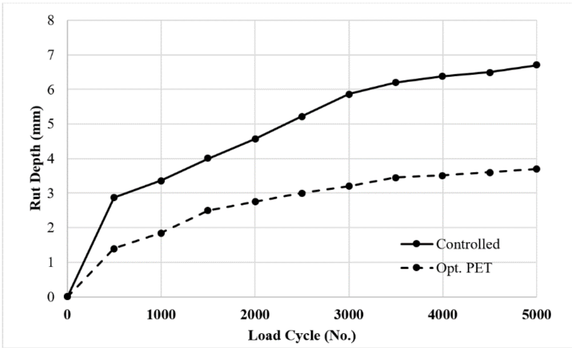

Fig. 5. Graphical Representation of Rutting Specificity Of Different Mix At OAC

Similarly, the performance of flexible pavement improves due to the addition of a PET binder as shown in Table 13. This table shows that the PET sample made at OAC and optimum PET content enhanced the stability by more than 100% as compared to controlled samples. The flow value also decreases by 70%. However, it has little effect on density. The rutting resistance of optimum PET-modified specimens also provides a better result. The controlled samples have a maximum rut of 6.7 mm while the specimen prepared by PET-modified binder increased the rut resistance by a great extent to 45%.

Table 13

Performance of flexible pavement – volumetric and rutting susceptibility

	Stability (KgF)	Flow (in)	Density (Kg/m3)	Max Rutting Depth (mm)
Controlled	1400	17	2257	6.7
Opt. PET	2960	10	2276	3.7

Fig. 6 shows the relation between the different asphalt content against the Air voids, stability, density, and flow. (a) This shows the inverse relation, as the asphalt content fills the voids resulting in decrement in air voids. The OAC is selected at 4.25% based on the value of air voids, according to standards. (b) With the increase in AC percentage, its stability also increases. Because asphalt acts as a binder that holds the aggregate, providing greater resistance to deformation under load. But it starts decreasing after reaching OAC. The stability at 4.25% asphalt content is around 1400 and is acceptable. (c) Shows that with the increase of AC percentage density also increases but at a certain point it starts decreasing. (d) It shows that the flow decreases upon increment in AC %. High asphalt content increases the stiffness and viscosity of the mixture, making it less susceptible to excessive deformation or movement.

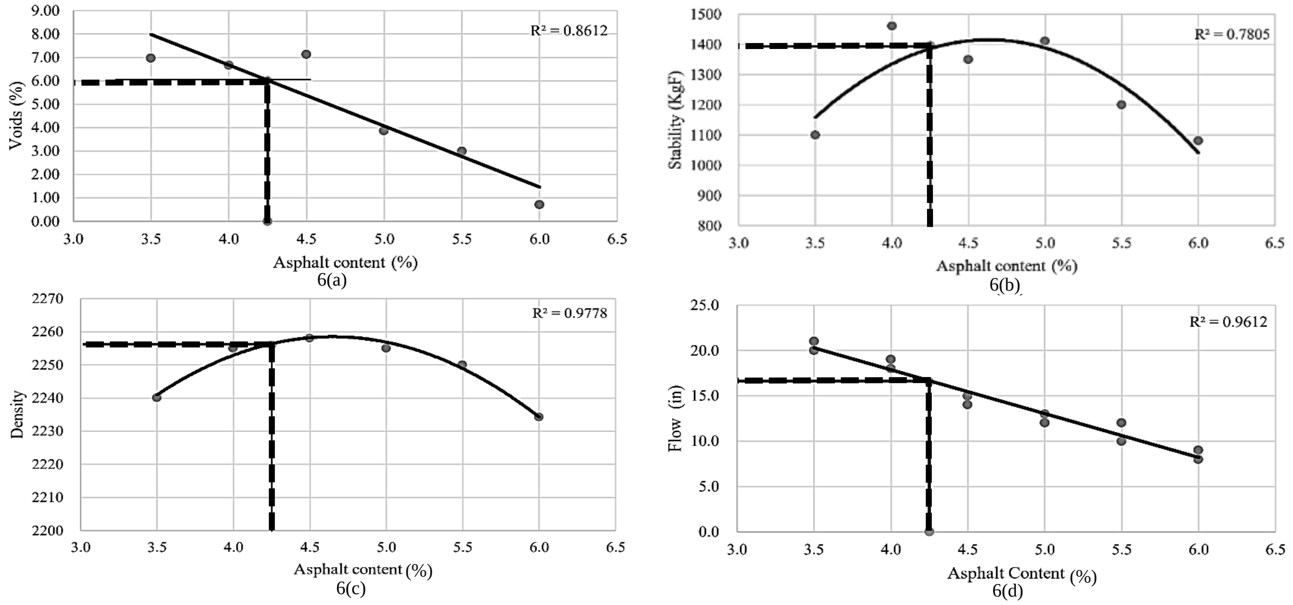

Fig. 6. Relation Between Different Asphalt Content With (a) Air Voids, (b) Stability, (c) Density, (d) Flow

Similarly, Fig. 7 shows the relation between the OAC with the addition of PET in different percentages against the Air voids, stability, density, and flow. (a) Shows a similar inverse relation between the plastic content and the air voids due to the filling of air voids. (b) With an increase in PET percentage, its stability also increases. At opt Plastic content the stability almost becomes double, because more asphalt with Plastic provides better bond and strength so provides greater stability. But at a certain point, it starts decreasing with a further increment in PET percentage. (c) The density increases with the increment in PET percentage, but upon further increment, density starts to decrease due to the lighter weight of PET. (d) Shows the direct relation between PET percentage and flow, the flow would linearly increase upon an increase in the OAC with PET percentage.

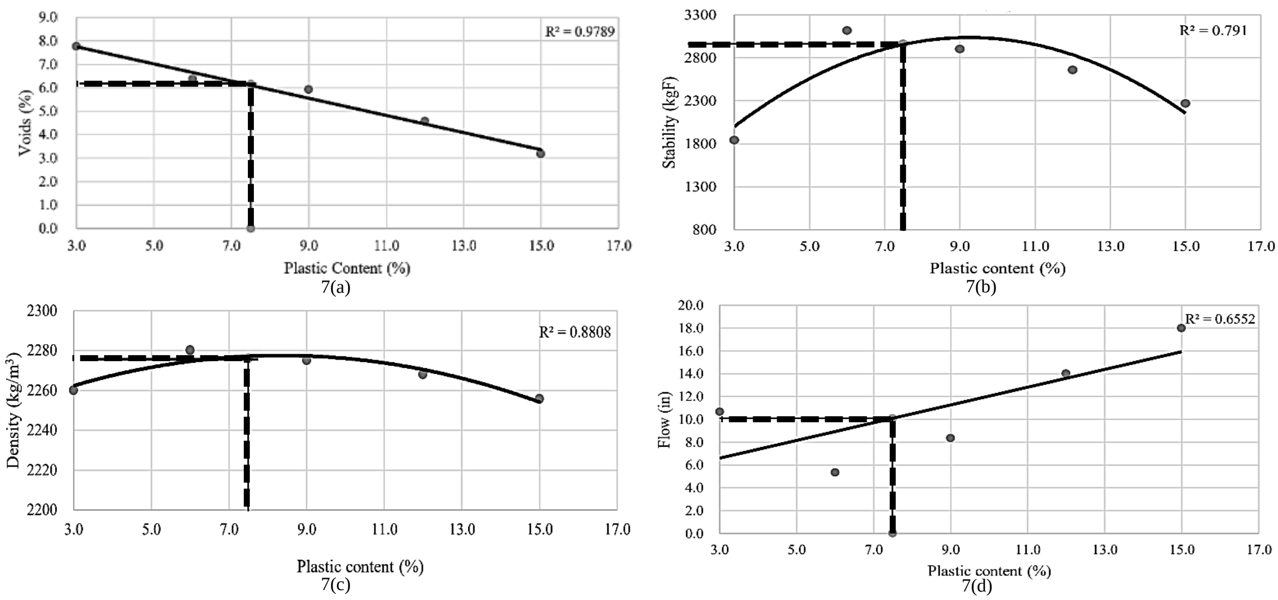

Fig. 7. Relation between OAC with different PET Percentages with (a) Air voids, (b) Stability, (c) Density, (d) Flow

4. Conclusion

This study examines the properties of a mixture made of neat asphalt (controlled specimens) and PET-modified asphalt. The volumetric properties of the mixture along with rutting susceptibly were examined during the entire course of the study for both types of mixes. Firstly, OAC was drawn from the controlled sample. After finding the OAC, the behavior of PET as a binder was examined. Based on the study following conclusion can be drawn:

- The incorporation of Polyethylene Terephthalate (PET) into Hot Mix Asphalt enhanced nearly all the volumetric properties by more than 50%. The PET-modified specimen will not only increase the stability by 52% but also decrease the flow values by 70% as compared to the controlled sample made of neat asphalt.
- The study further extends to find out the rutting potential for both types of samples i.e., neat binder samples (controlled) and PET-modified samples. The rutting susceptibility test was performed on the Wheel Tracking Device. The result showed that the PET-modified samples showed approximately 50% more resistance to load as compared to the controlled one.
- The study presented states that, PET would be one of the resources that may be utilized as substitutive material in road construction. The utilization would not only lessen the burden on natural resources but also open the sustainable use of PET by recycling it.

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