Performance evaluation of hot mix asphalt using textile waste

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ABSTRACT – REZUMAT

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Polyester (PET) is used in asphalt binder to improve the sustainability and performance of the road. Modification of asphalt has become a serious demand these days due to performance requirements caused by significant traffic and heavy vehicles. Asphalt alone cannot bear the stresses. The Marshall Mix design method is used for testing treated and untreated asphalt samples. The properties of all asphalt samples were compared. The best combination of asphalt and PET for best performance is based on the study of PET content used in the mix of PET/Asphalt, i.e., 0%, 2.5%, 5%, 7.5%, and 10%. The following tests were performed on the asphalt samples for various aspects of performance: stability test, flow test, air voids, voids filled with asphalt (VFA), voids in mineral aggregate (VMA), and OAC. Polyester waste is utilized in road construction which has been proved helpful to improve the performance of conventional road construction and provide reliability in a sustainable approach. An asphalt grade of 60/70 was taken for evaluation.

Keywords: *asphalt, marshal mix design method, polyester fibre waste, road construction, sustainability*

Evaluarea performanței amestecului fierbinte de asfalt utilizând deșeuri textile

Poliesterul (PET) este utilizat în liantul de asfalt pentru a îmbunătăți durabilitatea și performanța carosabilului. Modificarea asfaltului a devenit o cerere serioasă în aceste zile, din cauza cerințelor de performanță impuse de trafic și de vehiculele grele. Asfaltul nu poate suporta solicitările. Metoda de proiectare Marshall Mix este utilizată pentru testarea probelor de asfalt tratate și netratate. Au fost comparate proprietățile tuturor probelor de asfalt. Combinația cea mai performantă de asfalt și PET se bazează pe studiul conținutului de PET utilizat în amestecul de PET/Asfalt, respectiv 0%, 2,5%, 5%, 7,5% și 10%. Următoarele teste au fost efectuate pe probele de asfalt pentru diferite aspecte ale performanței: test de stabilitate, test de debit, goluri de aer, goluri umplute cu asfalt (VFA), goluri în agregate minerale (VMA) și OAC. Deșeurile de poliester sunt utilizate în construcția drumurilor, ceea ce s-a dovedit util pentru a îmbunătăți performanța construcției de drumuri convenționale și pentru a oferi fiabilitate într-o abordare durabilă. S-a evaluat gradul de asfalt de 60/70.

Cuvinte-cheie*: asfalt, metoda de proiectare Marshall Mix, deșeuri de fibre de poliester, construcție de drumuri, durabilitate*

INTRODUCTION

There are several challenges being faced by all developed and developing countries among which high productivity and economic fight are major challenges. High productivity has not only increased the need to meet economic competitiveness, but safe and efficient transportation has also become a necessary requirement for the delivery of goods. To achieve the economic requirement, vehicle manufacturers are now moving towards the manufacturing of larger vehicles and containers which are applying high stresses, pressure, and axle load for the delivery of huge production to the market. The increase in the traffic, high axle load, high-temperature rutting, low temperature cracking and medium temperature fatigue are contributing to the deterioration and decomposition of conventional asphalt pavement sooner than the predicted time. For this purpose, it is important to make new pavement designs and construction that are durable and strong enough to bear stresses and require less maintenance and modifications. This modification can be done by using waste materials so that it could be cost-effective as well as sustainable for the environment by utilizing the waste as a substitute for binder in road construction [1].

A network of roads has been spread all over the world. In Pakistan Transportation by road is widely used; almost 91% of transportation takes place by road. So, it is necessary that the road should be safe, sustainable, and reliable. Heavy vehicles (trawlers and trucks which have high tons of weight) and huge amounts of traffic are applying different stresses on the road, which not only deteriorate the roads but also consume a large amount of asphalt. Therefore, an additive should be added to asphalt which can give the necessary requirements that are; should be strong enough, fatigue resistant and could bear high stresses [2]. Asphalt concrete (AC) is a composite material consisting of aggregate, asphalt binder and air void. AC is used for road construction that meets different stresses, loads and different environmental conditions that affect its durability. So, different studies showed that adding some of the additives in asphalt can alter its properties like strength, fatigue behaviour and several engineering properties. The additives containing organic polymers and fibres that are used with hot mix asphalt for the construction of road pavements would be able to enhance their mechanical strength, reduce thermal susceptibility, change visco-elastic response and increase resistance to rutting [3–6]. However, not all the fibres can be used because of their limited availability and high costs [7]. The addition of polymer fibres in the pavements is the most innovative way which not only reduces the damaging problems but also improves the service life of the pavement. Also, this is the best way to utilize the waste of polymer fibres. This addition can lead to an increase in the service life of the pavement and reduce the maintenance requirement which is needed in conventional asphalt concrete pavements. Thus, the cost factor is also reduced by decreasing the quantity of asphalt and making the pavement more durable. Using polyester fibres is an innovative technique that is widely adopted all over the world as filler material to produce polyester-reinforced concrete (PFRC) and that can be used in pavement quality concrete (PQC) [2].

Asphalt shows different behaviours under different conditions, temperatures and other materials that are added to asphalt to improve its properties. Asphalt is known as viscoelastic material in nature that shows good viscosity behaviour at different temperatures and with different polymers [2]. Different modifications have been made to the asphalt mixture, but research work has shown that only polymer and fibres could obtain such tremendous effects on the asphalt pavements. Polymers have good strength and sustainability so their addition in asphalt is considered as an important modification in all the research work [8]. The synergetic behaviour of asphalt and the additives are strongly dependent on fibre type and structure. It would be crucial to compare fibre properties along with the mechanism that is being selected for the modification in asphalt design [7]. Both wet and dry processes can be used to add a polymer to asphalt mix: In the wet process, heated asphalt is mixed with heated polymer first, they then mix with aggregates. In the dry process, polymer particles are blended with heated aggregates or to be applied on aggregate by coating first, they then mixed with asphalt. Both methods have different effects on the properties of asphalt [9, 10].

Serfass and Samanos used the wet method and concluded after testing asphalt/polyester composite, that resistance to ageing, shear, flexure and tension have been improved. It also has a very low effect of water on it [11].

Asma reported that modified asphalt is highly resistant to stress, disruption, and water damage due to the multi-directional reinforcing function of polyester fibres. The bitumen film (mixed with polyester) becomes thick and adheres to the aggregate more firmly, giving it more strength than conventional asphalt mix [12]. According to the research carried out by Qunshan, different fibres (Polyester, Cellulose, and mineral fibres) were used out of which the only polyester is proved to be the best modifier for asphalt in terms of fatigue property [13]. Xu investigated the polyester fibre effect on fatigue life of asphalt by dry process. Different percentages were used. i.e., 0%, 0.2%, 0.35% and 0.5% were used in his research. A bending fatigue test was performed at 20°C. Fatigue life has increased significantly by using polyester fibres due to the binder stabilization on the surface of aggregate [7]. Anurag performed an indirect tensile strength test of asphalt mixtures, roofing polyester waste fibres were used as additives. Properties of tensile strength as well as Marshall stability, void content and unit weight of Asphalt mixture were improved [14]. Shaopeng found that polyester/asphalt composite could increase the viscosity of asphalt binder and the cycle number to fatigue failure by 3.6 times. The optimum fibre content of 0.30% on the weight of the total mixture was found [8]. Hasan, used different contents of Polypropylene fibres (0.10%, 0.20%, 0.30% and 0.40%) to be mixed with asphalt. Marshall Properties, indirect tensile strength, temperature susceptibility and resistance to moisture damage were studied on the developed fibre/asphalt composites. The results showed improved tensile strength, resistance to plastic flow and resistance to moisture damage of all composts compared to pure asphalt [15].

Peng, studied the effect of the addition of different polymers in asphalt using a dry process. He concluded that the addition of polyester in bitumen would prevent bleeding of asphalt caused by high temperatures in summer. Polyester is able to keep the bitumen film in a very stable state. This happens because polyester provides extra space for the expansion of bitumen, this can prevent bleeding and give sufficient high-temperature stability to the road. The study also shows a decrease in rutting depth and an improvement in the shear resistance of the asphalt mixture [16]. Essawy added polyester and polypropylene fibres from industrial waste, it was found that using polymer can reduce temperature susceptibility. Polypropylene was preferred over polyester because polyester fibre toughens the PMA sample [17]. Sabagh et al. studied stearyl acrylate and methyl methacrylate and styrene modified asphalt composites. They concluded that those HMA polymers were showing exceptional performance as compared to ordinary asphalt mixture after a series of tests performed on some chemical and physical properties [18]. Nura Usman used recycled PET fibre to make asphalt composite, using a dry method to add the PET fibres to the mixture. Resilience Modulus was tested on PET fibre modified composite samples in comparison to control samples. Research results revealed there was a significant increase in resilience modulus at low temperatures [19]. Afroz Sultana utilized plastic waste to make asphalt composite by the wet method. The waste consists of polypropylene, low-density polyethylene and high-density polyethylene fibres. The test includes Marshall Stability to be performed on PMA sample and controlled sample. The research not only revealed better performance for asphalt concrete but also proved to be a cost-effective process [20]. Joohari et al. studied the effect of polypropylene (PP) fibre as a replacement of filler on asphaltic concrete performance. Marshall Mix design was used to obtain the optimum binder content and the compressive strength of the samples produced was determined. The study revealed that PP fibre as filer showed impressive improvement in terms of Marshall stability, flow and compressive strength as compared to the conventional bituminous mixture [21].

In light of the above findings deduced from experimental studies, it is clear that the addition of polyester to the asphalt to make asphalt composite can increase its many properties and extend its lifetime, requiring low maintenance. In this study, the addition method for polyester in asphalt used is the wet method by substituting approach to make the process cost-effective and sustainable by substituting asphalt binder by polyester in certain ratios. The main objective of this research is to minimize the deterioration in the conventional asphalt pavement by adding a certain percentage substitution of waste polyester as an asphalt binder and to evaluate the optimum amount of polyester on the weight of asphalt against best performance. After the modification of asphalt with polyester, the comparison is done between conventional and modified asphalt pavements through different tests such as stability test, flow test and specific gravity test. The other objective of this study is to reduce cost utilizing cost-effective PET waste and reduce the amount of asphalt used.

METHODOLOGY

This study comprises of making samples of flexible pavement using polyester waste by using the wet method. Polyester is added with asphalt in different ratios on the basis of the weight of asphalt, which are 0%, 2.5%, 5%, 7.5% and 10% respectively. For this purpose, 150 samples were made in which 90 of them were compacted and the rest were non-compacted. Asphalt also utilized was made in different weight fractions with respect to the weight of the aggregate samples which are 3.5%, 4%, 4.5%, 5%, 5.5%, 6%. All the samples were tested in a Marshall Test apparatus to evaluate the performance of asphalt/polyester composites in comparison to samples without polyester.

MATERIALS

Asphalt

For making Marshall Specimen three components are essential, which include asphalt, aggregate, and polyester. The asphalt used in this study is 60/70 grade with specifications given in table 1.

Table 1

ASPHALT AND BITUMINOUS PROPERTIES

Properties	Bituminous	Asphalt
Softening point (ºC)	49-56	43.75
Penetration value at 25ºC (Desi-mm)	-	64.92
Penetration grade	60–70	60/70
Fire flash point (ºC)	232	130
Specific gravity (Kg/cm^3)	1.01–1.06	0.99
Ductility at 25ºC (cm)	100	-
Loss of heating (%)	0.2 (max)	-
Drop in penetration after heating (%)	20 (max)	-
Solubility in trichloroethylene (%)	99	-
Spot test	Negative	-

Polyester fibre

As part of this research, polyester fibre waste with the following properties was used (table 2).

Table 2

PROPERTIES OF WASTE POLYESTER FIBRE

Polyester Properties	Values
Specific gravity	1.40
Tenacity (g/d)	3.5–7.0
% Elongation at break (%)	15–45
Moisture regain (%)	0.4–0.8
Shrinkage in Boiling Water (%)	0–3
Elastic recovery (%)	93 at 5%
Glass transition temp (ºC)	80
Softening temp (ºC)	230–240
Melting point (ºC)	260–270
Effect of sunlight (%)	70–80 tenacity at long exposure
Resistance to weathering	Good

Preparation of Marshall sample

Marshall Specimen were prepared following the standard procedure AASHTO T 245. The mixture was prepared using the sieved aggregate and asphalt grade 60/70 as mentioned earlier. The aggregate was preheated to 150°C then heated with asphalt at 175°C to get the desired viscosity. Asphalt was added to the aggregate samples up to the required weight and mixed thoroughly as pre-planned ratios. The preheated mould assembly was positioned on the mould holder of the marshal mix compaction machine. The mixture was poured into the mould in three layers. Each layer was spaded 25 times at the interior portion of the mix using a tamping rod. Once filled 75 blows were applied using a compaction hammer. The mould was then reversed and reassembled, and 75 blows were applied on the reversed side.

Table 3

TESTS PERFORMED ON AGGREGATES		
Test	**Standard**	**Apparatus**
Resistance to degradation of aggregate by abrasion and impact	ASTM: C131-89	Los Angeles Abrasion Machine
Specific gravity and absorption of coarse aggregate	ASTM: C127-88	Balance, sample container, a wire basket of 3.55 mm, Water tank
Impact value of aggregate	BS: 812 Part 112	Cylinder, impact testing machine, temping rod, sieve, balance

Table 4

TESTS PERFORMED ON BITUMINOUS MATERIAL		
Test	**Standard**	**Apparatus**
Penetration grade of bituminous material	ASTM: D5-86	Penetrometer, Penetration needle, sample container, water bath, Transfer dish, thermometers
Flash and fire point of bitumen	ASTM: D92-78	Cleveland open cup apparatus
Softening point of bitumen	ASTM: D36-8	Ring and ball apparatus
Specific gravity of semisolid bituminous material	ASTM: D70-76	Pycnometer bottle, beaker, Water bath, Thermometers
Ductility of bituminous material	ASTM: D113-86	Ductilimeters, Mould, Water bath, thermometer

Samples were taken out of the mould after 24 hours using a sample extractor. Tables 3–6 show different tests performed on aggregates and bituminous mix, including resistance to degradation, specific gravity and absorption and impact, penetration grade, flash and softening temperature, and ductile property.

Table 5

SPECIFIC GRAVITY AND ABSORPTION TEST ON AGGREGATES		
Parameters	**Natural Aggregates**	
	1/2”	3/4"
A	1998.9	2996.0
B	2013.1	3015.0
C	1257.9	1881.5
BSG	2.646	2.643
BSG_{SSD}	2.665	2.660
$BSG_{Apparent}$	2.720	2.688
Absorption %	0.710	0.643

Table 6

L.A. ABRASION AND IMPACT TEST ON AGGREGATES	
Parameters	**Natural Aggregates**
L.A. Abrasion %	28.3
Impact value	15.8

RESULTS AND DISCUSSION

The bituminous aggregate mixture without polyester is considered as control/reference sample. Modified samples were made by the addition of polyester to bituminous aggregate in 2.5%, 5%, 7.5% and 10% respectively on the weight of the mix.

Effect on air voids and density

The air voids percent indicates the basic physical characteristic of bituminous asphalt mix. Figure1, *a* shows that air voids are gradually decreased with the addition of polyester at a certain level. It can be noticed that there is a very little bit of variation in air voids within band 0–5%. But between 5% and 7.5%, there is a noticeable change that occurred in the air voids %. The air voids are decreased from 5% to 7.5% and increased from 7.5% to 10%. At a 10% polyester/mix ratio the asphalt content is getting low caused by more air voids observed. Figure 1, *b* shows the variation in density with the increase in polyester content in all Marshall Samples. The results show that the density is decreased with the increase in polyester content because polyester is lighter than asphalt. In the current research the asphalt content decreases with the increases in polyester content, this explained the reason for decreased density. At the stage when polyester content reaches 10% the density is abnormally increased.

Effect on VMA and stability/flow

VMA indicates the portion of voids in a compacted asphalt aggregate specimen which not occupied by the aggregate. VMA is expressed as a percentage of the total volume of a mixture. The graph obtained for VMA as shown in figure 2, *a* is the opposite of density. There is a very less significant change in VMA percentage in samples with polyester/mix ratios of 0%, 2.5% and 5%. VMA percentage significantly decreases in samples with polyester content from 7.5% to 10%. This is because there was very low optimum asphalt content in those samples as compared to 0%, 2.5% and 5% PET containing samples which have a high value of optimum asphalt content. Asphalt fills the spaces between the aggregates, causing the low amount of asphalt and a higher percentage of polyester, VMA decreases. The linear curves in figure 2, *b* shows a direct relation between stability/flow and polyester at a certain level. It is observed from the stability/flow graphs, that stability/flow is increased with the increase of polyester content in the Marshall Mixture. The increasing trend is observed from samples with PET content of 0% to 7.5%, but there is a noticeable decrease in the linear curve of stability/flow at 10% PET modified sample. This is due to the reason that asphalt provides good adhesion and strength to the bituminous mixture. This explained the reason that in the sample containing 10% polyester the amount of asphalt is very low compared to 0%, 2.5%, 5% and 7.5% PET-containing samples, due to which stability/flow is increased to 7.5% and decreased after. It means that only a certain amount of PET can be substituted in place of asphalt in flexible pavements to have increased stability/flow than the conventional bituminous mixture. It is also observed from figure 2, *b*, that excessive increment in PET content in a mixture can result in a significant decrease in stability/flow of the bituminous mixture.

Optimum Asphalt Content (OAC)

By using the results of air voids (figure 1, *a*), the optimum asphalt content is determined. According to National Highway Authority (NHA) specifications, air voids in flexible pavement must be in the range of 4% to 6%. In this research, the optimum asphalt content for control/reference, as well as modified bituminous PET samples, is measured against 5% air voids, according to the NHA specifications. The theoretical values of Density, VMA, Stability and Flow were then obtained at Optimum Asphalt Content. According to figure 3, the OAC decreases with the increase in PET content in the mixture. After calculating the OAC against 5% air voids, the samples were prepared at OAC and tested, comparisons are made between results from the theoretical and experimental values in terms of physical properties which are Density, Stability, VMA and Flow.

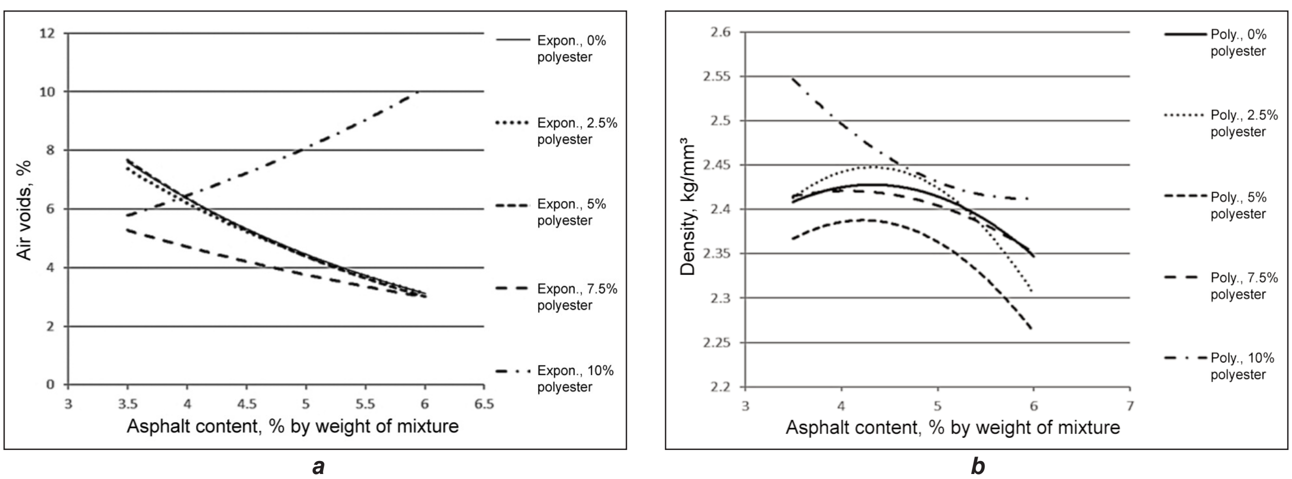


Fig. 1. Graphical representation of: *a* – percentage of air voids for different polyester level; *b* – density values for different polyester level

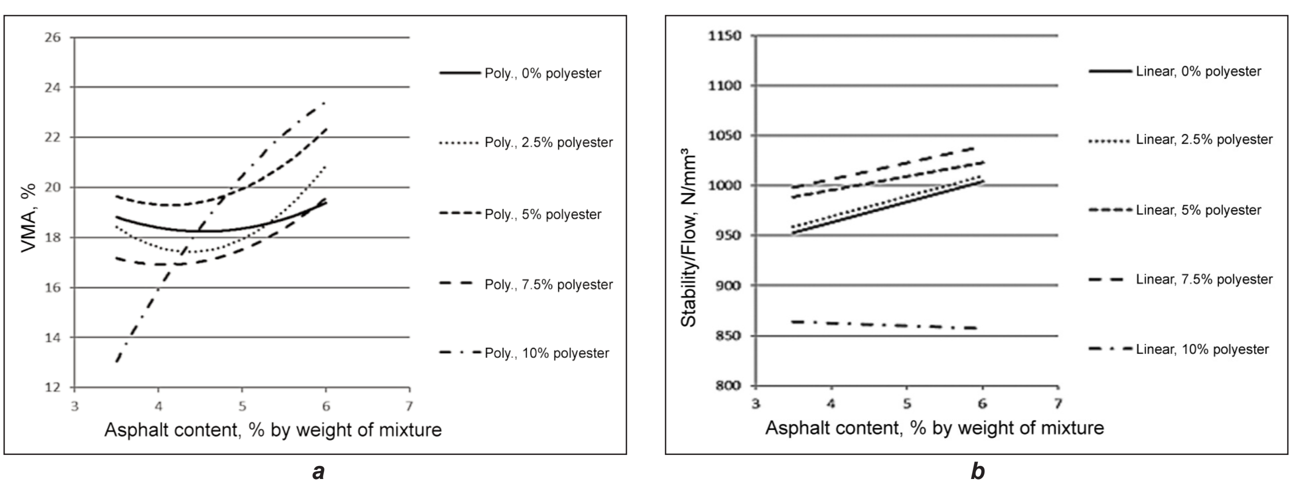


Fig. 2. Graphical representation of: *a* – VMA values for different polyester level; *b* – Stability/Flow values for different polyester level

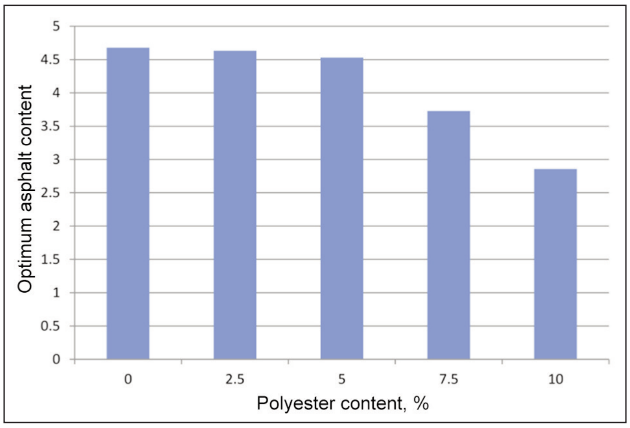


Fig. 3. Optimum asphalt content for different percentages of polyester

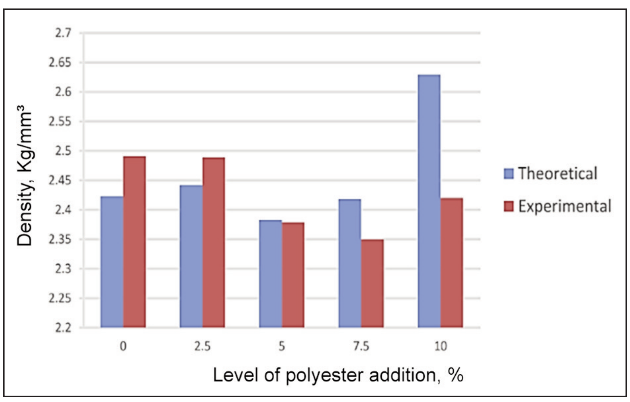
The values of VMA, Density, Stability and Flow corresponding to OAC were evaluated using experimentally recorded data at each level of PET/mix ratios, shown in figures 4 and 5. It can be seen that the difference between theoretical and experimental values is about 16%, and almost all theoretical and experimental values are similar with little variation.

Based on the research results of the tested samples of Marshall Mix, it can be found that:

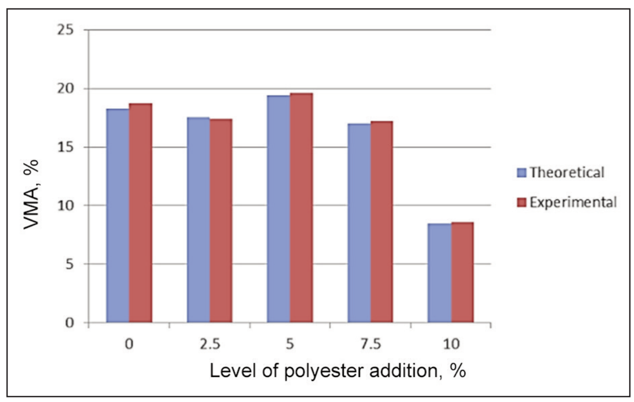
- There is very little change in VMA percentage from 0% to 5%, but a significant decrease in VMA percentage from 7.5% to 10% because of the low asphalt content.
- The modified bituminous mixture requires less asphalt content for absorption and binding as compared to the conventional bituminous mixture.
- The highest stability at optimum asphalt content with 5% air voids can be achieved at 7.5% PET content.
- The flow is also increased with the increase in the PET content at optimum asphalt content.
- The use of PET fibres provides a proper consideration of reduction in PET waste as well as a considerable reduction in the use of asphalt, which not only reduces the production cost but also provides stability to the flexible pavement and enhances its life cycle. The increased stability also ensures low maintenance costs, thus making flexible pavements more durable, sustainable, and economical.

CONCLUSIONS

The generation of waste plastics is increasing day by day. The addition of polyester shows adhesion property in its molten state. Polyester will increase the melting point of the bitumen. Hence, the use of polyester waste for pavement is one of the best methods for easy disposal of polyester. The use of innovative technology not only strengthened road

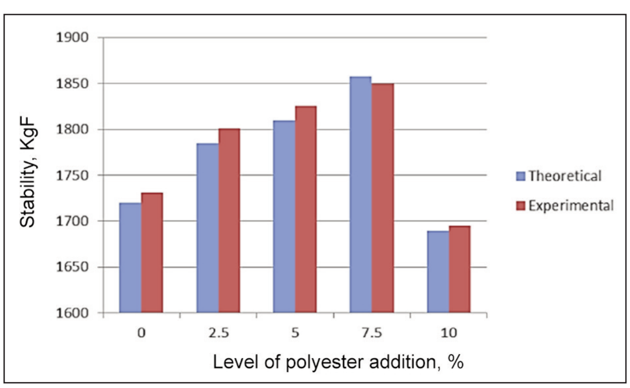


a

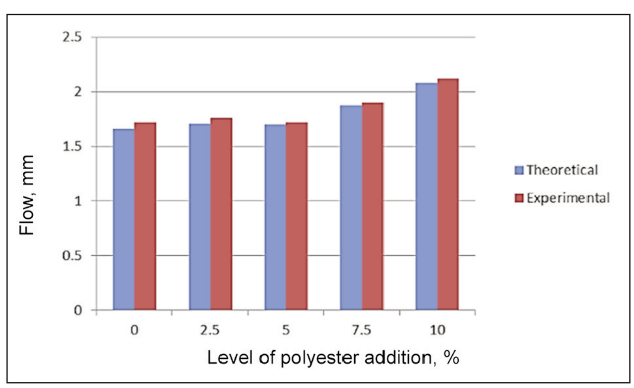


b

Fig. 4. Graphical representation of: *a* – theoretical and experimental data of density at OAC; *b* – theoretical and experimental data of VMA at OAC



a



b

Fig. 5. Graphical representation of: *a* – theoretical and experimental data of stability at OAC; *b* – theoretical and experimental data of flow at OAC

construction but also increased road life. Results of all the Marshall Mix design tests performed on control (conventional) and modified samples (PET asphalt mixture) show positive effects in terms of strength, flow, stability, and sustainability. The addition of PET also reduces the Optimum Asphalt Content (OAC) significantly. This reduction in OAC directly reduces the cost of Asphalt, and proves to be economical, sustainable and also suitable because of the use of polyester waste. The addition of polyester also increases the service life of flexible pavement due to the synergetic properties of polyester and asphalt. Polyester mixed with bitumen and aggregates can provide better performance on the roads. The polyester mixed with aggregates reduces the voids and moisture absorption. This results in the reduction of ruts without pothole formation. The modified flexible pavements can withstand heavy traffic and are more durable than conventional flexible pavement.

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