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Performance Evaluation of Modified Bitumen Using EPS-Beads for Green and Sustainable Development of Polymer Based Asphalt Mixtures

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Abstract: The increasing cost of virgin content, decreasing resources, and growing plastic waste has shifted the research momentum towards green and sustainable road pavements. Hence, in recent years, the various researcher has worked out on the utilization of different types of plastic wastes in asphalt concrete by replacing it with binder content. Under this premise, this study examines the effect of Expanded Polystyrene Beads (EPS) as a replacement to the binder at seven different dosages ranging from 5% to 50%. The bitumen of 60/70 grade was utilized in this study. The fresh properties of polymer modified bitumen was checked and compared with that of conventional specimens. The mechanical properties of all specimens were investigated in terms of Marshall Stability properties. The results indicated that adding of PEB improves the stability of modified asphalt concrete. Furthermore, the addition of EPS by substituting bitumen content could be a promising way to reduce the environmental impact of bitumen and will also help in economic infrastructure development.

Keywords: sustainability; green and sustainable asphalt concrete; Expanded Polystyrene Beads (EPS); mechanical properties

1. Introduction

Roads are among the most commonly used constructive elements that are using the highest tonnage of materials around the globe i.e., about 91.9% of these roads are constructed in Europe with bituminous mixes, resulting in an increased demand for bitumen, a residue obtained after distillation of petroleum product [1]. The extraction and consumption of bitumen return 0.048 kg CO_2/ kg to the environment, a quite significant value, taking into consideration the need for 43.7 tonnes of bitumen for just 1 km of roadway, which indicates a carbon footprint of 2.13 tonnes [2]. The increased use of plastic materials aligns with this fact worldwide, because of their versatility and contributing a massive quantity of plastic waste that is produced each year [1]. All this scrap, equivalent to 25.8 Mt/year in Europe, has been reused, renegotiated, as well as shifted near landfills [3]. The goal of conscientious countries is to reduce the amount delivered into landfills and to reuse such products as well as reduce the use of virgin plastics [4]. Under these contexts, this research was established to study the potential replacement of bitumen with plastic waste to lessen the adverse effect of the former on the atmosphere. In this study expanded polystyrene beads (EPS) were recommended and used as a modifier because of its thermoplastic behavior and low temperature of glass point [5] and belong to a family of amorphous polymers as well as most used polymer all over the world [3].

The additives can be mixed into a bituminous mixture in two ways: wet process and dry process. The process involves the earlier mixing of the emulsifier with bitumen as a modified binder for its later application. This method involves the crushing of the material that is to be used in very small sizes and carefully blended with heated bitumen to ensure proper homogenous mixing. So in the existing literature for utilization of polymers such as the end of life tires (ELT), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polymerizing Vinyl Chloride (PVC), polypropylene (PP), Polyethylene terephthalate (PET), acrylonitrile butadiene styrene (PET), silicon resin polymers [4,6–9]. In the case of dry mixing, the modifier is introduced and transferred to the mixer with aggregates and pure bitumen (unmodified). Hence, the bitumen is not directly modified by this method. The dry method makes it possible to apply high levels of supplements to bitumen, which will contribute to making it more potentially cost-effective [10]. This method is much less evolved than the wet way even with its technical advantages [11–13].There are several investigations and studies relevant to the application of expanded polystyrene beads(EPS) in various areas are available such as buildings and structures, recycled polystyrene, geotechnics, acoustic emissions, or lightweight concrete [14–17][18][19].

This research has been designed to study the application of EPS as bitumen modified for the development of flexible pavement as a major replacement to binder content for sustainable utilization of waste material for development of a polymer based durable pavement.

2. Materials and Methods

2.1. Experimental Framework

The experimental work was conducted for the present study as summarized in the flow chart as shown in Figure 1.

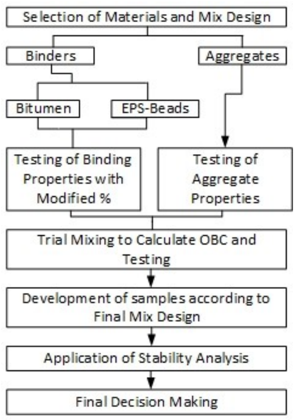


Figure 1. Flow Chart of Research Methodology**.**

2.1.1. Bitumen

Bitumen with a penetration value of 60–70 was used in both modified (binder + EPS) and unmodified (pure binder) samples. Expanded polystyrene beads (EPS) was blended with pure bitumen. In this study, some basic tests of bitumen blended with EPS were performed such as penetration, ductility, and softening temperature as per the American Society for Testing and Materials (ASTM) standard. The basics tests of the pure binder are listed in Table 1, for comparative analysis of results using ASTM specifications [20].

Table 1. Basics tests of Bitumen with their standards.

Analyzed Properties	Units	Limit	Test Method
Density @25 °C	Kg/m³	1010–1060	ASTM D70 OR D3289
Penetration @25 °C	Mm/10	60–70	ASTM D5
Softening point	°C	49–56	ASTM D36
Ductility @25 °C	Cm	100 min	ASTM D113
Loss of heating	Wt %	0.2 max	ASTM D6
Flash Point	°C	232 min	ASTM D92
Solubility in Trichloroethylene	Wt%	99.0 min	ASTM D2042
Viscosity @60 °C	P	2000+/–400	ASTM D2171
Viscosity @135 °C	cst	300 min	ASTM D2170

2.1.2. Aggregates

In this study, an aggregate of size ranging from 10 to 20 mm was used for the preparation of modified and unmodified asphalt specimens. The performance characteristics of the aggregate used have been extensively tested in compliance with ASTM and BS standards [21] as presented in Table 2.

Table 2. Physical properties of aggregate used.

Type of Test	Test Methods	Result	Specifications
Aggregate Impact Test	BS812: Part3	22.53%	Less than 27%
Los Angeles Abrasion Test	ASTM: C131	28%	Less than 35%
Aggregate Crushing Test	BS812: Part3	21.14%	Less than 30%
Water Absorption Test	ASTM: C127	1.77%	Less than 2%
Specific Gravity (Aggregate)	ASTM:C127	2.26	2 to 3

2.1.3. Expanded Polystyrene Beads (EPS-Beads)

Polystyrene $(C_8 H_8)_n$ is also called as polyvinyl resin. Polystyrene (PS) is an extended organic compound and widely used in foodservice industries. Structurally, it is linked with a phenyl array to each specific atom of carbon. Styrene is derived from the compound of polyvinyl resin by radical chemical reactions of vinyl [22]. Similarly, expandable polystyrene (EPS) is steam-heated styrene in raw beads, allowing it to expand [22]. It is widely used in many concrete applications especially in the making of concrete blocks as well as in geotechnical engineering because it is light and cool [14,23]. It is a new type of additives that can be used in road construction because of its potential beneficial properties i.e., adhesive properties, large surface area. The physical features [24] of EPS used during the research are shown in Table 3.

Table 3. Physical properties of EPS-Beads**.**

Physical Properties	Average Value
Diameter	2 mm to 5 mm
Adhesive bond strength	0.165 MPa
Density	12 kg/m³
Softening point	70 °C
Ignition temperature	285 °C
Color	White

2.2. Sample Preparation Process

Expanded polystyrene beads were added in bitumen and replaced at five different dosages (10%, 20%, 30%, 40%, and 50%) by the wet method. In this method, bitumen was heated first at 160 to 170 °C and then EPS was added into hot bitumen corresponding to each selected percentage by weight of binder content. This substitution was done by removing the same quantity of bitumen by weight of binder content in grams corresponding to each selected percentage substituted by EPS. Before the preparation of blended asphalt samples, trial samples were prepared with pure bitumen to find the optimum percentage of the binder about the standard. The EPS materials were mixed with hot bitumen to make it homogenous.

The aggregates used were heated at a temperature of about 150 to 170 °C. All the ingredients were blended for almost 4 extra minutes. This method was chosen as it allows bitumen to be directly mixed with EPS and to compare the results of both modified and unmodified core samples effectively in a precise way. The sieve analysis was performed for the mixed aggregate as shown in Figure 2.

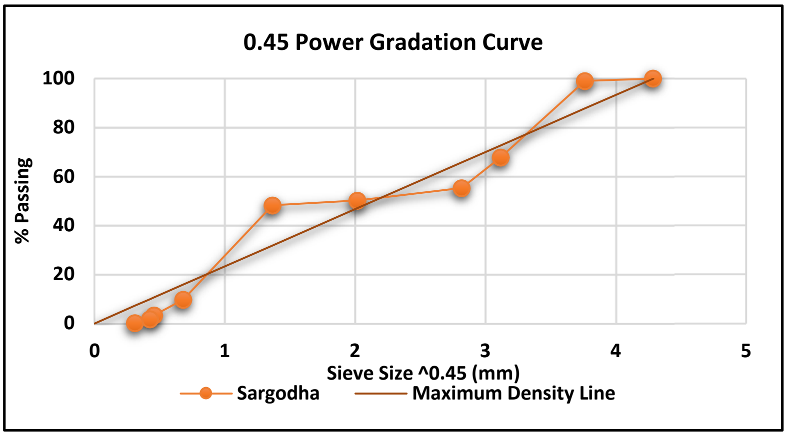


Figure 2. Gradation curve of used aggregate for asphalt mixtures**.**

3. Results and Discussions

This research has been divided into two stages. In the first stage all fresh properties of pure and EPS- modified bitumen were comprehensively analyzed for better comparative analysis of the results. In the second stage, Marshall stability analysis was performed for the EPS-modified mixture and compared with control samples.

3.1. Performance Analysis of EPS-Modified Bitumen

In the first stage of the present study, all the fresh properties of EPS-modified and pure bitumen were investigated for the study of comparative performance with reference to control samples to explore the effects of EPS effectively. The EPS was introduced into hot bitumen up to 50% or partially by replacing bitumen content, respectively. Based on fresh results, it was concluded that the penetration value of modified bitumen was decreased as the percentage of EPS increases when compared to pure bitumen of 60–70 grade. Similarly, the ductility value of modified bitumen was within limit with reference to standard value >75 cm up to 30% replacement then at 40% replacement, its value was slightly decreased. The softening value of EPS modified bitumen increases with an increase in the percentage of EPS content which indicates that it could be the best option to used EPS modified bitumen in hot climate conditions for the construction of flexible pavement. The results of EPS- modified were presented along with results of pure bitumen as presented in Table 4.

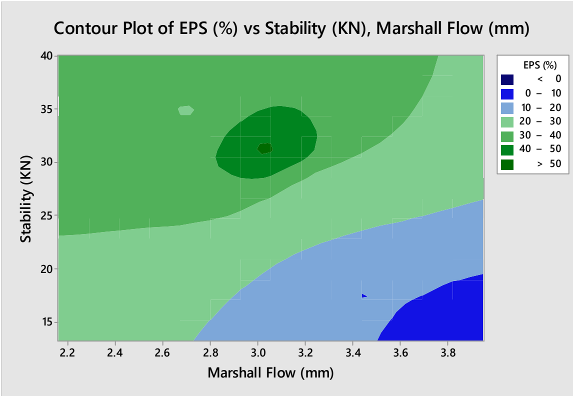
Table 4. Physical properties of EPS-modified bitumen**.**

Sample	Composition	Penetration	Ductility	Softening Point
		(25 °C,100 g,5 s)	25 °C	°C
Test Method		**ASTM: D5-97**	**ASTM: D113**	**ASTM: D36**
Units		**0.1 mm**	**0.1 cm**	**1 °C**
M 1	100 % B + 0% M	68.1	95	50
M 2	90 % B + 10% M	59.4	90	56
M 3	80 % B + 20% M	52.5	79	62
M 4	70 % B + 30% M	42.0	73	68
M 5	60 % B + 40% M	36.9	67	74
M 6	50 % B + 50% M	45.3	75	79
Standard	**Pure Bitumen**	**60–70**	**>75**	**40–55**
Remarks		**>60 are ok**	**>75 are ok**	**Higher than level**

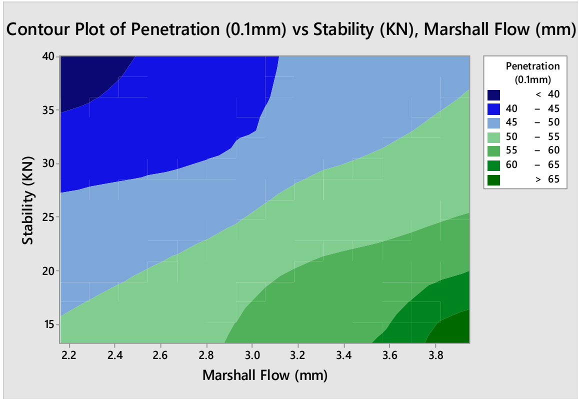
3.2. Marshall Stability Analysis of EPS-Modified Mixtures

The Stability analysis was performed for comparative performance analysis of both modified and unmodified asphalt concrete. For this purpose, three samples on each percentage of EPS content were cast according to standards, and then average values were taken for better results analysis. The results indicate that with an increasing percentage of EPS content, the stability value increases up to 40% replacement and afterward decreases. The optimum binder content (OBC) was 7%. The increase in stability value can be due to enhanced bonding properties between aggregate and modified bitumen (EPS % + pure bitumen). Based on stability analysis, it can be concluded that the addition of EPS up to 40 % showed satisfactory performance as compared to conventional asphalt mixtures. The relationship between stability and flow values of modified asphalt concrete and EPS- beads percentage is presented in the contour plot as shown in Figure 3a. The darker regions in the contour plot in the form of a growing ridge surface show higher stability in the upper left to the middle of the graph. As the response increases, it appears darker.

It can be concluded that the flow value decreases with increasing EPS content up to 40% replacement. The flow value of the control specimen with OBC of 7% was 3.95 mm which complies with the standard range (2–4 mm). It was observed in earlier studies that flow value cannot give true reflection regarding the permanent deformation of flexible pavement. Therefore, to predict its behavior further research study, need to be carried out on other tests such as repeated load axial test and wheel tracking test, etc. The decrease in flow may be due to this reason as the percentage of EPS increases, the bitumen becomes harder. In conclusion, the flow value tends to decrease with an increase in the percentage of EPS up to 40% in binder content.



(**a**)



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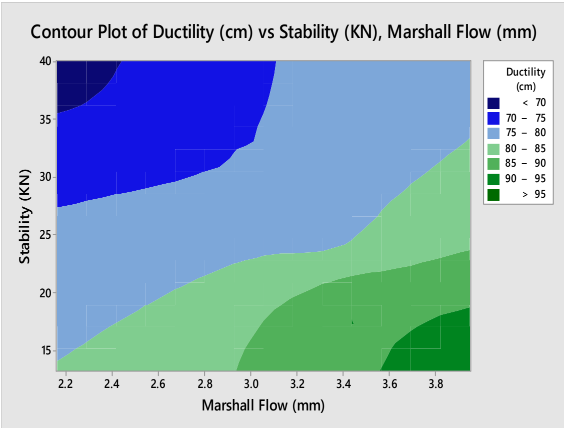
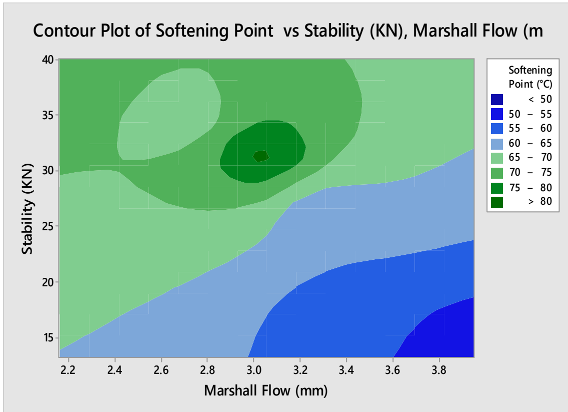


(**c**)



(**d**)

Figure 3. Comparative performance analysis for (**a**) EPS-Beads (%) vs stability (KN) and flow (mm); (**b**) penetration (0.1 mm) vs stability (KN) and flow (mm); (**c**) ductility (cm) vs stability (KN) and flow (mm); (**d**) softening point (0.1 mm) vs stability (KN) and flow (mm).

The relationship between stability and flow value was shown in Figure 3b that results due to EPS- beads contents respectively. In this plot, the higher penetration values be a darker region in the right lower part of the plot which shows the relationship between stability and flow that results under high penetration values. Similarly, the relationship among both stability and flow and the ductility value of EPS-modified asphalt concrete can be seen in Figure 3c which indicates that with an increase in ductility (response), the stability increase but flow will decrease at the same time. This relationship can be noted in the form of a ridge running from the upper left and lower right of the graph. Also, the contour plot of the softening point against stability and flow can be observed in Figure 3d. Observe the relationship between the surface outline as well as the shape of the contours plot which indicates that as the softening point increases, the stability increase and flow value decrease at the same time and can be seen in the lower right corner of the contour map in the form of valleys. In conclusion, the stability values of EPS-modified bitumen were increased due to an increase in their penetration and softening point but leads to a decrease in ductility and flow values.

4. Conclusions

The present study aims to explore the potential benefits by the utilization of expanded polystyrene beads in road construction. Based on experimental work, this study derived the following main conclusions.

- Based on results obtained from Marshall stability tests, the stability of asphalt concrete containing EPS was improved with varying percentages of EPS up to 40 % replacement but afterward, there was a slight drop was observed in their stability values at 50% replacement.

- The flow values were remained within a range of up to 40% with an increase in EPS percentage according to ASTM specifications. It is clearly shown that EPS increased the overall performance of asphalt concrete observed in the case of both fresh and mechanical properties. Higher values of softening points recommended that it could be used in hot climate conditions in road construction as it showed strong resistance against permanent deformation.
- It can be concluded that the use of EPS in road construction will not only offer green and sustainable as well as a cheaper transport system. Also, their effectiveness in term of social and environment are promising by reducing the demand for virgin bitumen.

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Conflicts of Interest: The authors declare no conflict of interest.

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