

## Research Article

# Effectiveness Evaluation of Shredded Waste Expanded Polystyrene on the Properties of Binder and Asphalt Concrete

Rocksana Akter  and Rain Man Raja 

*Department of Civil Engineering, Dhaka University of Engineering & Technology, Gazipur 1707, Bangladesh*

Correspondence should be addressed to Rain Man Raja; [raja\\_ce@duet.ac.bd](mailto:raja_ce@duet.ac.bd)

Received 22 February 2022; Accepted 28 June 2022; Published 1 August 2022

Academic Editor: Masoomeh Mirrashid

Copyright © 2022 Rocksana Akter and Rain Man Raja. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The disposal of massive amounts of waste, particularly nondecaying waste, is now a major issue for both developed and developing countries. One of the most sustainable solutions to this problem is to recycle garbage into valuable items. Expanded polystyrene, which is manufactured in large quantities, is one of these waste materials. This is being used globally as packaging material, construction material, and household appliances. The waste expanded polystyrene (EPS) is necessary due to its biodegradability, and aesthetically, it has a great negative impact on the environment. The goal of this research would be to see how shredded waste EPS affects the characteristics of asphalt and asphalt concrete. For this, four separate serial asphalt concrete samples were made with varying amounts of shredded expanded polystyrene waste (0.25, 0.50, 0.75, and 1% by the weight of the total aggregate) and five different percentages of asphalt (4.0, 4.5, 5.0, 5.5, and 6.0% by the weight of the total aggregate). In this study, 60/70 grade bitumen was used. Modified asphalt concrete properties were examined and compared with those of the standard specimens. The penetration, ductility, softening point, flash point, and fire point of the asphalt will all be affected by the addition of EPS plastic waste. The optimal asphalt content of the conventional specimen was 5.1 percent, and different percentages of EPS with OAC were applied. The mechanical properties of all specimens were studied in terms of Marshall properties after Marshall specimens were created with regard to OAC by adding EPS. It has been discovered that applying a 0.5% addition produces improved results than other methods. Simultaneously, as the EPS percentage increased, the stability value increased by approximately 82.61% compared to the traditional mix.

## 1. Introduction

With the rapid growth of traffic and the harshness of the weather, finding ways to extend pavement service life whilst lowering the cost of maintenance has become a need. As a result of its enhanced performance over typical asphalt concrete (AC) mixtures, using modified asphalt concrete (AC) mixtures for roadway construction has received a lot of attention [1, 2]. A number of additives, such as polymers, latex, fibers, and a variety of chemical additives, can improve the performance of asphalt mixtures [3, 4]. Because of their capacity to improve AC mixture stiffness, viscoelastic behavior, and durability at various temperatures, polymers are among the most widely used asphalt modifiers [5–8]. Polymer-modified binders have been shown to increase

adhesion and cohesion characteristics, routing resistance, heat cracking, fatigue loss, stripping, and temperature sensitivity while also lowering the life cycle [4, 9]. Lushingua et al., as cited in [10], discovered that chemically modifying bitumen with polydimethylsiloxane (PDMS)-silicone oil might improve the compatibility and storage durability of modified asphalt binders.

One of the most enduring and prevalent difficulties in the modern world is the effective and sustainable management of plastic garbage. Since the beginning of large-scale plastic production in the 1940s [11], the production of plastic solid waste has been rapidly increasing. In Dhaka, Bangladesh, it was also revealed that 4635.52 tons of solid waste was produced every day, with plastic accounting for 137.57 tons [12]. As a result, the city is being despoiled by

vast volumes of plastic rubbish. Furthermore, this disposal would damage our ecosystem due to its toxicological and intransigent contaminants [13]. Scientists and researchers are looking for new and sustainable ways to reuse/recycle plastic garbage to lessen its detrimental impact on the environment, as a result of the exponential rise in plastic production and the resulting increase in plastic waste. El-Saikaly [14] used waste plastic bottles (WPB) as an additive and suggested that WPB might be used as a modifier for asphalt mixes to improve both waste management and mix performance. In China, Ding et al. [15] recognized the feasibility of using recycled asphalt mixture in the pavement base to address a number of pressing issues such as land occupation, resource overconsumption, and pollution. Polystyrene (PS) is a form of plastic that is commonly used in everyday life. Extruded polystyrene (XPS) and expanded polystyrene (EPS) are two forms of PS. Similarly, EPS is raw styrene that has been steam-heated to allow it to expand [16]. Because it is light and cool, it is widely employed in many concrete applications, particularly in the production of concrete blocks and in geotechnical engineering [17, 18]. Anwar et al. [19] investigated the effects of EPS as a binder replacement at seven different dosages ranging from 5% to 50%. They concluded that adding EPS to modified asphalt concrete improves its stability. Listiani and Ayu [20] used EPS plastic waste as an asphalt replacement material in the asphalt concrete wearing course (AC-WC) layer with three volume substitution variations: 10%, 20%, and 40%. The wet process is used to combine EPS plastic trash with asphalt. The wet process is used to combine EPS plastic waste with asphalt. They concluded that adding EPS plastic waste to asphalt will change the properties of the asphalt and asphalt concrete. Because of its potential positive features, such as adhesive properties and vast surface area, it is a novel form of additive that can be employed in road construction.

The most effective way to eliminate too much solid waste accumulation in metropolitan regions, according to [21], is to execute waste material re-use. The use of reprocessed materials in road pavements is now seen as not just a sustainable solution but also as an interesting choice for improving service performance [22]. Various investigations are carried out on the feasibility of utilizing waste plastic as a construction material, especially in developing countries. However, there is a limited attempt to use waste EPS as a road construction material. So, this study took an opportunity to use EPS to improve the properties of asphalt and asphalt concrete mixture.

## 2. Material Properties

Different types of materials such as stone chips as aggregate, stone dust as filler, asphalt as a binder, and EPS as an additive are used in this study. Descriptions of these materials are given below.

*2.1. Aggregate.* Aggregate qualities have a significant impact on the strength, workability, and economics of asphalt concrete. Locally available aggregates have been used in this

TABLE 1: Physical properties of aggregate.

Test name	Test standard	Result (%)	Standard value
LAA	AASHTO T 96	15.67	$\leq 30$
AIV	BS 812: part 112:1992	14.98	$\leq 25$
ACV	BS 812: part 110:1992	23.45	$\leq 30$
EI	BS 812: section 105.2:1990	17.62	$\leq 30$
FI	BS 812: section 105.1:1990	11.60	$\leq 30$
SG (CA, FA)	AASHTO T 85	2.78, 2.72	—

study and purchased locally from the supplier. Tables 1 and 2 show the physical properties of aggregate particles and gradation.

Gradation refers to the particle size distribution of stone aggregate. The particle size distribution is determined using sieve analysis. Stone aggregates were screened using an ASTM-recommended sieve of 3/4 inch to #200 in this study. Table 2 shows the aggregate and filler combined gradation.

*2.2. Mineral Filler.* The filler in asphalt concrete has a massive effect on its characteristics. Conventionally, cement, stone dust (hereafter referred to as SD), and lime are used as fillers in subtropical monsoon climatic regions [23]. Locally available cement was used as a filler in this study, and the specific gravity was found to be 3.09 by testing in our laboratory. Kar et al. [24] indicated that the specific gravity of cement, stone dust, and fly ash is 3.1, 2.7, and 2.2, respectively.

*2.3. Asphalt Binder.* Asphalt is a semisolid hydrocarbon product produced from refining crude oil. The asphalt of grade 60/70 penetration was used in this experiment. This bitumen is collected from a local distributor. Table 3 shows the properties of used asphalt.

*2.4. Waste Expanded Polystyrene.* Nonmodified EPS foams feature a cellular nanostructure with EPS-based confined membranes and a density of less than  $50 \text{ kg/m}^3$  [22]. In this study, EPS was used as an additive material which was collected from waste packaging. They are crushed into pieces manually, and sieve analysis was performed. In this study, stone aggregates were screened by ASTM specified sieve 3/4 inch to #4 and aggregate passing through sieve 3/4" and retained on #4 sieve are taken into analysis. The waste expanded polystyrene was used at 0.25%, 0.50%, 0.75%, and 1% by the weight of the total aggregate. The photo views of waste EPS are shown in Figures 1 and 2.

## 3. Test Scheme and Experimental Works

This research involves a number of steps in its experimental investigation. Characterization of materials for EPS plastic waste, asphalt (60/70), and aggregate is carried out at the start of the study. In the second step, the physical properties of asphalt/bitumen (such as specific gravity, ductility, flash point, fire point, softening point, and penetration) were

TABLE 2: Selected combined gradation of aggregate and filler.

Coarse aggregate (CA) = 52%, fine aggregate (FA) = 42%, and mineral filler (MF) = 6%				
Sieve size	% passing	Specified limit (AASHTO T 27)	Cumulative % retained	% used
3/4"	100	100	0	0
1/2"	97.38	90–100	2.62	2.62
3/8"	78.66	76–90	21.34	18.72
#4	59.44	44–74	40.56	19.22
#8	48	28–58	52	11.44
#40	33.3	8–27	66.7	14.7
#80	16.92	5–17	83.08	16.38
#200	6	5–8	94	10.92
#200 (retained)			100	6
			Total	100

TABLE 3: Test results of physical properties of asphalt binder.

Test name	Test standard	Test value	Standard value
Penetration grade	ASTM D 5-86	63	60–70
Softening point	ASTM D 36-70	48°C	30°C to 157°C
Specific gravity	ASTM D 70-76	1.02	0.97 to 1.02
Ductility	ASTM D 113-86	100+	100+
Flash point	ASTM D 92-90	320°C	Minimum 175°C
Fire point	ASTM D 92-90	355°C	Minimum 200°C

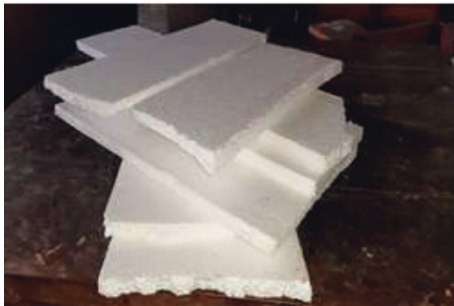


FIGURE 1: Waste expanded polystyrene.



FIGURE 2: Shredded waste expanded polystyrene.

examined by combining EPS plastic waste in various proportions (0.25%, 0.50%, 0.75%, and 1% by the weight of the total aggregate) with bitumen using the wet method and comparing them with the nonmodified bitumen properties. The author Suroso also added plastic to the hot asphalt and mixed until homogeneous by using the wet method [25]. Subsequently, in the third phase, 27 cylindrical test

specimens were constructed in accordance with the Marshall test requirements following the AASHTO guideline for medium traffic load [26]. The specimen size was considered to be 101.6 mm (dia) × 63.5 mm (height) by applying 50 blows on each side of the cylindrical casing for different asphalt concentrations (4 to 6%). The specimen compositions are listed in Table 4, and Marshall tests were performed on each specimen in accordance with ASTM D1559 [27].

The spherical Marshall specimens were squeezed on the lateral surface at a continuous rate of 50.8 mm/min until the maximum force (failure) was obtained. Following that, the Marshall characteristics of unmodified (control mix) asphalt concrete were evaluated, and the optimum asphalt content (OAC) was estimated. The Marshall characteristics of AC were then determined by adding various ratios of EPS to it without modifying the OBC and comparing them to non-modified AC. Figure 3 depicts an outline of the study's sequential work.

#### 4. Results and Discussion

This investigation was divided into 2 parts. For a better comparative examination of the results, all fresh properties of pure and EPS-modified asphalt were carefully evaluated in the first stage. Marshall stability analysis was done on the EPS-modified mixture in the second stage, and the results were compared to control samples. The acquired results are given in detail in the following.

##### 4.1. Effect of Waste EPS on the Physical Properties of Asphalt.

The physical properties of modified asphalt with different percentages are shown in Figure 4 through Figure 5. The variation in the penetration value of modified asphalt is

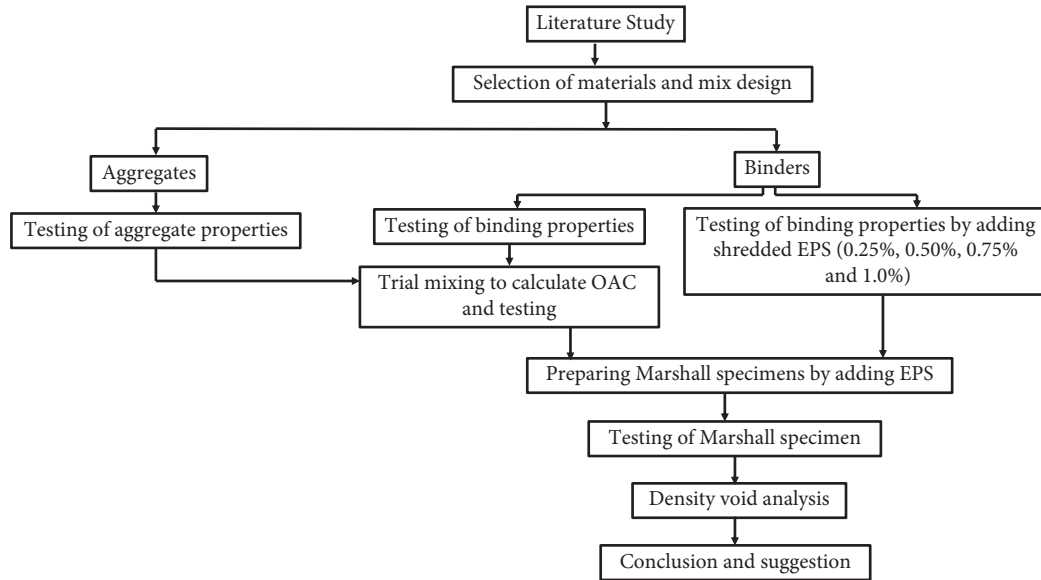


FIGURE 3: Marshall properties for control specimens.

TABLE 4: Composition of specimens.

Number of specimens containing	
Control mix: total = 15	Modified mix: total = 09
3 (EPS-0%, binder-4%)	3 (EPS-0.75%, binder-OBC%)
3 (EPS-0%, binder-4.5%)	3 (EPS-0.5%, binder-OBC%)
3 (EPS-0%, binder-5%)	3 (EPS-1%, binder-OBC%)
3 (EPS-0%, binder-5.5%)	
3 (EPS-0%, binder-6%)	

shown in Figure 4. The penetration value decreases when increasing the percentage EPS. The penetration value has been decreased when increasing the polymer percentage and also stated that by adding EPS the asphalt has become more viscous and stiffer, which might be beneficial in obtaining a stiffer asphalt penetration value [22]. Listiani and Ayu [20] also found that incorporating EPS plastic waste into asphalt reduces the value of penetration, making the pavement tougher. With the growing amount of EPS plastic waste added, the stiffness (lower penetration value) of the asphalt will increase. The pavement will be more resistant to deformation if the asphalt stiffness is increased. Furthermore, as the amount of EPS plastic waste added grew, the softening point value increased as well. As a result, the asphalt will be less susceptible to fluctuations in temperature. These characteristics will be linked to the earlier discussion of asphalt stiffness. According to another study, the penetration value of modified asphalt declined as the proportion of EPS grew, when compared to pure bitumen of 60-70 grade. They also concluded that the softening value of EPS-modified bitumen improved as the percentage of EPS content increased, indicating that using EPS-modified asphalt for the construction of flexible pavement in hot temperature conditions would be the best alternative [19].

The ductility of the mixture decreases with the increased quantity of EPS, as shown in Figure 6. Modified asphalt is less ductile than the control sample and has a lower ability to

stick aggregate together and coat aggregate [28]. The value of softening point increases when increasing the waste EPS in the asphalt, as shown in Figure 7. This may be for the leak of homogeneity in the modified asphalt binder. It is possible to conclude that the waste plastic EPS enhances the asphalt softening temperature and improves its high-temperature stability.

Figure 5 shows the variation of flash and fire point values for conventional and modified asphalt. As can be seen, the flash and fire point values increased as WEPS content increased. The EPS added asphalt shows a higher value than conventional asphalt. This is because the hardened asphalt also requires a higher temperature to achieve the flash and fire point.

**4.2. Marshall Properties for Control Specimens.** The results of the Marshall test for the control mix have been presented in Figure 8. All the properties such as stability, density, air void, voids in mineral aggregate (VMA), and voids filled with asphalt (VFA) show the standard trend.

**4.3. Effect of EPS on the Marshall Properties of Asphalt Concrete.** The Marshall specimens with modified asphalt were made to investigate the performance of asphalt concrete. All the specimens were made with optimum asphalt content. The optimum asphalt content was calculated to be 5.1% with the help of stability, density, and air void (%) curves by following the asphalt institute manual series [29]. All the properties are shown in Figure 9 through Figure 10. The relationship between stability and waste EPS is shown in Figure 9. It shows that as the percentage of EPS is increased, the stability value gradually goes up. The density of the modified asphalt mixture increases with the increase of EPS %, as shown in Figure 11. Stability value is co-related with the specimen density. It was observed that the stability increased with increased density. When the stability value is

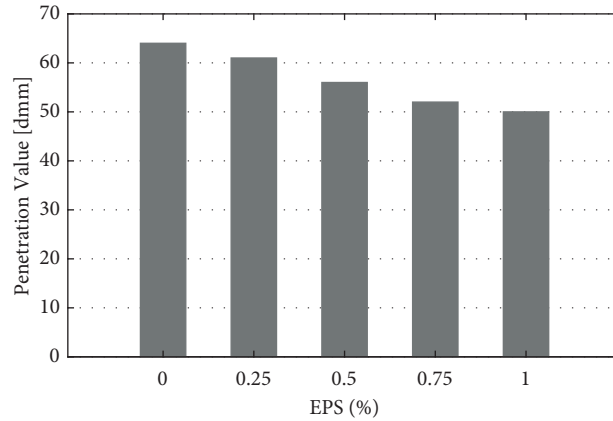


FIGURE 4: Experimental scheme.

too significant, the asphalt mixture becomes too stiff and far less stable. In a prior investigation, the authors discovered that when the penetration and softening point of EPS-modified asphalt increased, the ductility and flow values decreased. According to Marshall stability test results, the stability of AC-containing EPS was increased with varying percentages of EPS substitution up to 40%, but after that, a little decline in their stability values was noted at 50% replacement [19].

The flow values decrease when increasing waste EPS, as shown in Figure 12. The flow value is related to the flexibility of the mix. This is due to the fact that harder and more viscous samples show a lower flow value. Figure 13 shows the air void (%) graph for modified asphalt mixtures. The air void (%) has been decreased with increasing EPS content for all cases. This is because when the EPS is applied to a mixture, it fills the void of the mixture.

Figure 14 shows the voids in mineral aggregate (%) of the Marshall specimen at different EPS contents. The VMA values of all specimens decrease as the EPS content increases up to higher content. This is why when EPS and binder are combined, the aggregate soaks the binder first, followed by the binder filling the vacuum in the mix. As a consequence, the VMA value has dropped. Figure 10 shows the relationship between voids filled with asphalt and EPS. It can be seen from the figure that the values of VFA for all EPS contents have been increased when increasing the EPS content. This is because with increasing EPS more voids are filled with it.

From the above circumstances, it is evident that the use of waste EPS gives better results as compared to the control mix. Also, the higher percentage of EPS content gives the lower values of flow value, air void %, VMA, and higher values of stability, density, and VFA. It is also seen that all the values are within the specified limit with the exception of VFA (%). These values are slightly more than the maximum specified value.

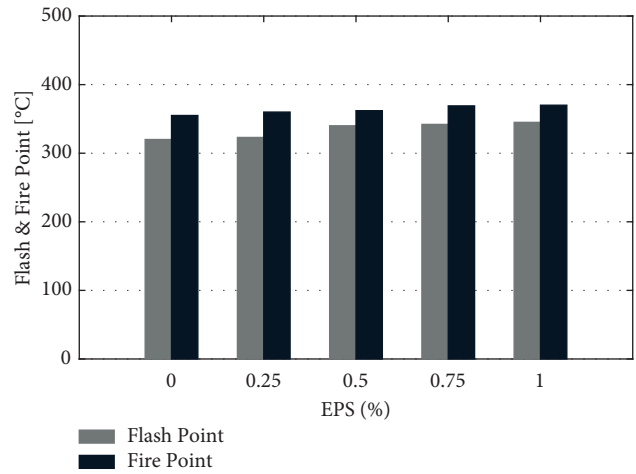


FIGURE 5: Variation of penetration value.

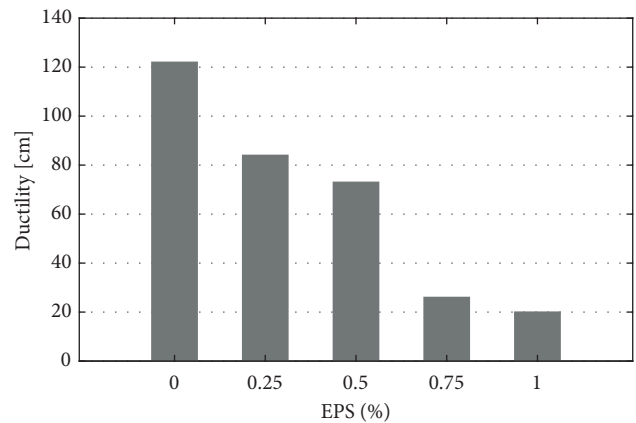


FIGURE 6: Variation of flash and fire point values.

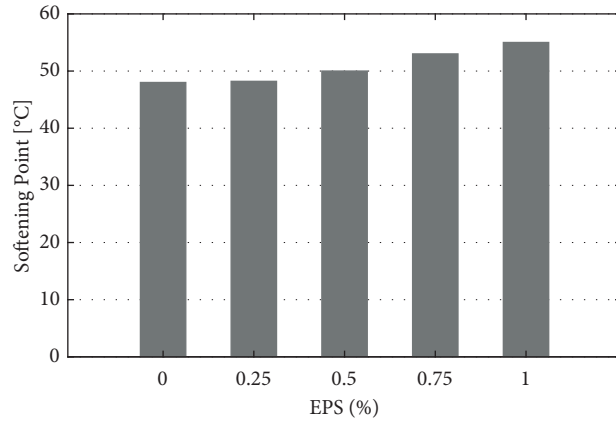


FIGURE 7: Variation of ductility value.

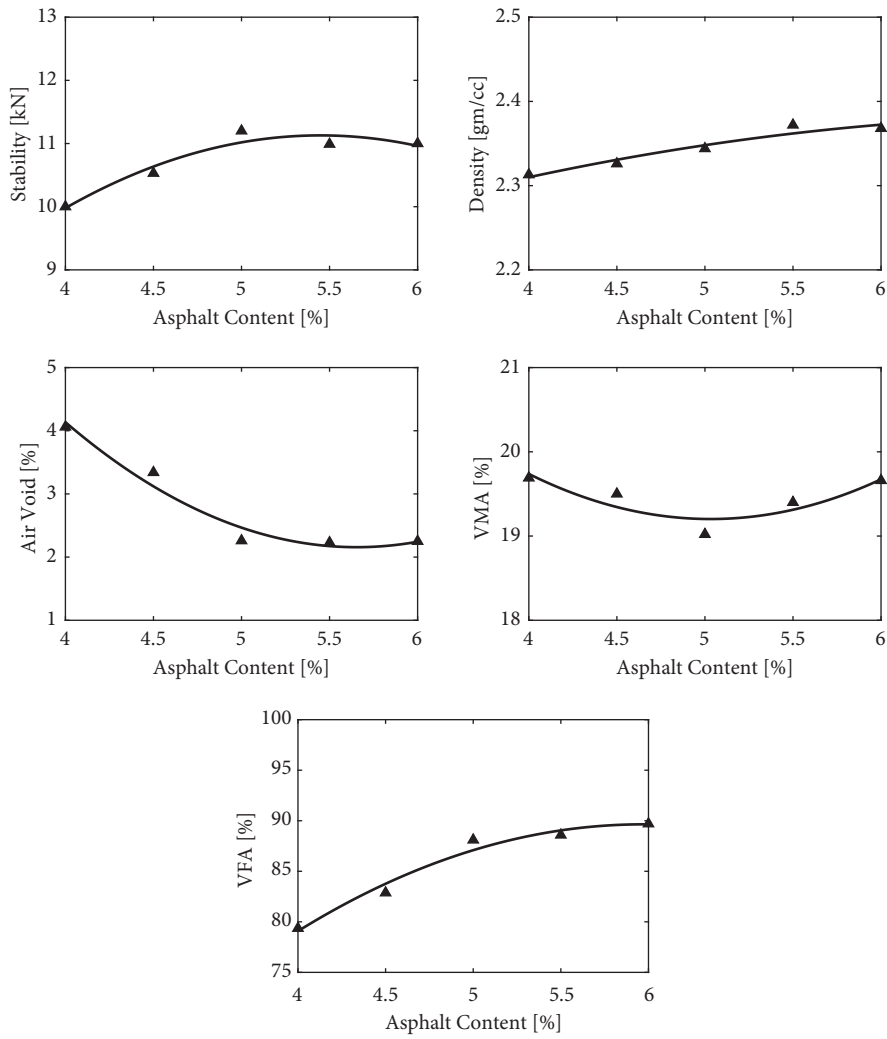


FIGURE 8: Variation of softening point value.

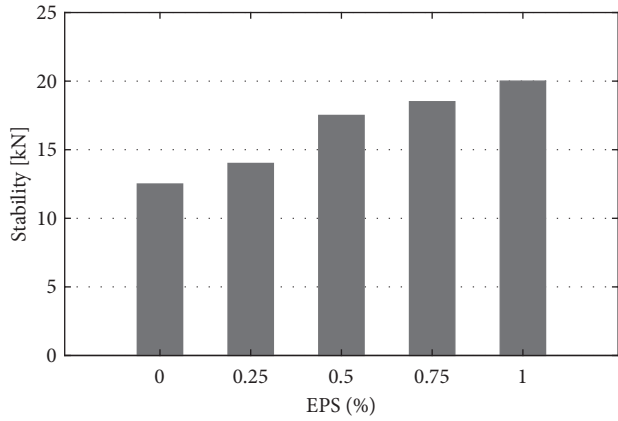


FIGURE 9: Relationship between stability and EPS.

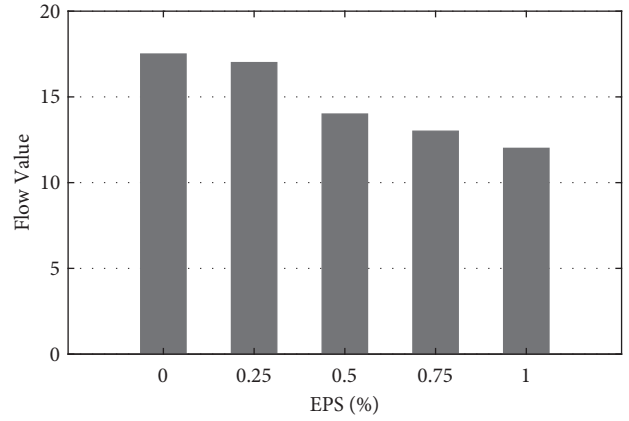


FIGURE 12: Relationship between flow value and EPS.

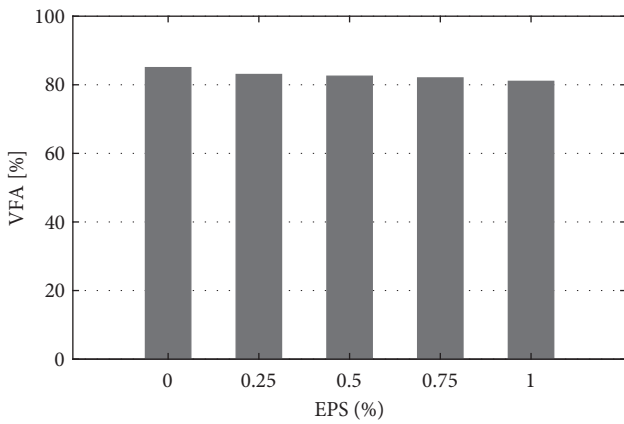


FIGURE 10: Relationship between VFA and EPS.

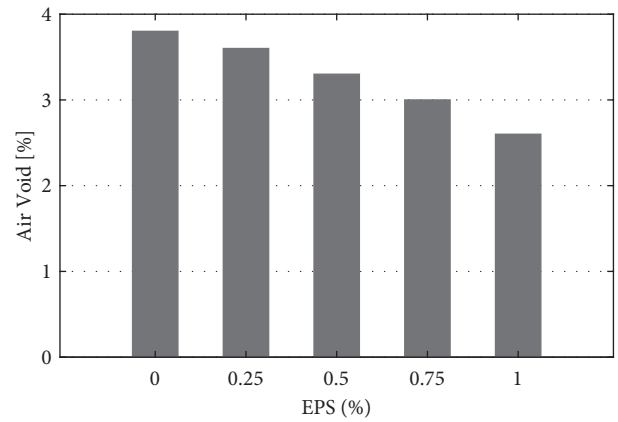


FIGURE 13: Relationship between air void and EPS.

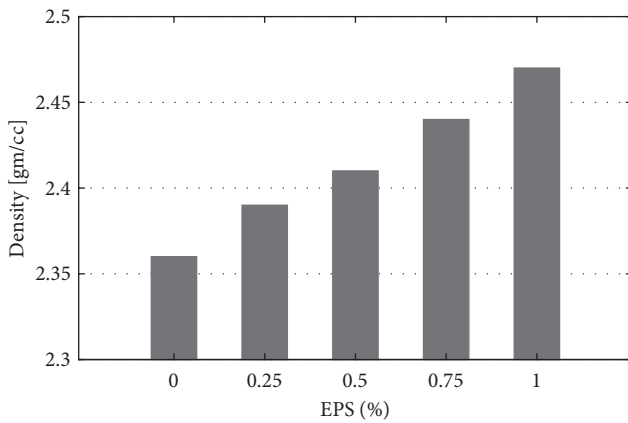


FIGURE 11: Relationship between density and EPS.

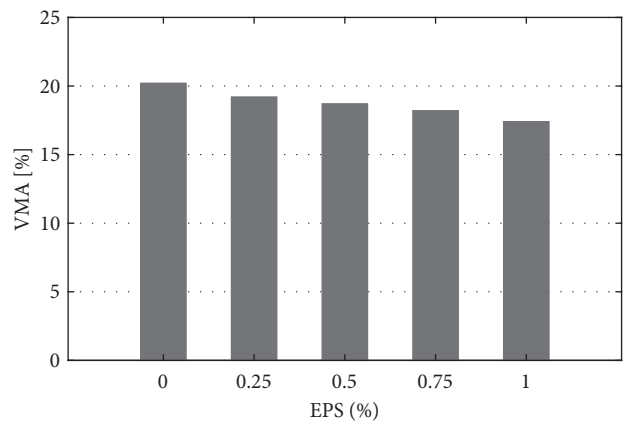


FIGURE 14: Relationship between VMA and EPS.

## 5. Conclusion

The purpose of this study was to look into the potential benefits of using expanded polystyrene in road construction. The following primary results were drawn from the experimental work in this study.

- (i) It was observed that the addition of 1% EPS in asphalt shows the minimum ductility. But this point shows the maximum softening point, flash point value, and fire point value.
- (ii) The maximum value of Marshall stability of a modified mix with EPS is increased approximately 82.61% compared to the conventional mix.
- (iii) The modified asphalt and asphalt concrete with 0.75% shows better results than others with the exception of ductility value and VFA (%). But at 0.50% EPS, all the values are within the specified limits. So, the optimized percentage of EPS is 0.50%.

Subsequently, it is claimed that mixing EPS with the asphalt concrete mixture produces an effective outcome than the conventional mix and enhances the mixture characteristics as the amount of EPS increases. In our research, it can be seen that 0.5% EPS added asphalt concrete mixture shows improved performance over the others. The usage of EPS in road construction would result in a more environmentally friendly, long-lasting, and cost-effective mode of transportation. Furthermore, by minimizing the demand for raw bitumen, its efficacy in terms of society and the environment is promising. Finally, it can be concluded that using EPS in asphalt concrete mixtures not only enhances the properties of asphalt concrete but also decreases the environmental solid waste disposal problem.

## Data Availability

The experimental data used to support the findings of this study are included within the article.

## Disclosure

This study was performed as part of the job, as a researcher, and faculty member of the Department of Civil Engineering, Dhaka University of Engineering & Technology, Gazipur 1707.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## References

- [1] A. Mehrara and A. Mehrara, "Evaluation of permanent deformation of unmodified and SBS modified asphalt mixtures using dynamic creep test," *Construction and Building Materials*, vol. 23, no. 7, pp. 2586–2592, 2009.
- [2] I. Hafeez, M. A. Kamal, M. W. Mirza, Barkatullah, and S. Bilal, "Laboratory fatigue performance evaluation of different field laid asphalt mixtures," *Construction and Building Materials*, vol. 44, pp. 792–797, 2013.
- [3] S. Abd Taih, "The effect of additives in hot asphalt mixtures," *Journal of Economics and Sustainable Development*, vol. 15, no. 3, pp. 131–150, 2011.
- [4] M. T. Shbeeb and L. Shbeeb, "The use of polyethylene in hot asphalt mixtures," *American Journal of Applied Sciences*, vol. 4, no. 6, pp. 390–396, 2007.
- [5] A. Baldi-Sevilla, J. P. Aguiar-Moya, A. Vargas-Nordbeck, and L. Loria-Salazar, "Effect of aggregate-bitumen compatibility on moisture susceptibility of asphalt mixtures," *Road Materials and Pavement Design*, vol. 18, no. sup2, pp. 318–328, 2017.
- [6] M. Garcia and A. Garcia, "Factors affecting hydraulic conductivity of asphalt mixture," *Materials and Structures*, vol. 50, no. 2, p. 116, 2017.
- [7] X. Zhang, G. Zou, S. Wang, and D. Wang, "Evaluating the resistance to reflective cracking of asphalt mixtures in South China," in *Proceedings of the 23rd Annu. South. African Transp. Conf. SATC 2004 Get*, pp. 243–248, Recognit. Importance Transp, Pretoria, South Africa, July, 2004.
- [8] M. Sánchez and J. A. Sánchez, "Estimation of asphalt concrete fatigue curves - a damage theory approach," *Construction and Building Materials*, vol. 22, no. 6, pp. 1232–1238, 2008.
- [9] Y. Becker, M. P. Méndez, and Y. Rodríguez, "Polymer modified asphalt," *Vision Tecnológica*, vol. 9, no. 1, pp. 40–50, 2001.
- [10] N. Lushinga, L. Cao, and Z. Dong, "Effect of silicone oil on dispersion and low-temperature fracture performance of crumb rubber asphalt," *Advances in Materials Science and Engineering*, vol. 2019, Article ID 8602562, 12 pages, 2019.
- [11] S. M. Al-Salem, P. Lettieri, and J. Baeyens, "Recycling and recovery routes of plastic solid waste (PSW): a review," *Waste Management*, vol. 29, no. 10, pp. 2625–2643, 2009.
- [12] S. K. R. I. Enayetullah, A. H. M. M. Sinha, I. Hossain et al., "Composition of Plastic Waste and Market Assessment of the Plastic Recycling Sector in Dhaka City," *Waste Concern Consult*, 2006.
- [13] E. Aminudin, M. F. M. Din, Z. Mohamad, Z. Z. Noor, and K. Iwao, "A review on recycled expanded polystyrene waste as potential thermal reduction in building materials," *Int. Conf. Environ. Ind. Innov.*, vol. 12, pp. 113–118, 2011.
- [14] M. A. El-Saikaly, "Study of the Possibility to Reuse Waste Plastic Bags as a Modifier for Asphalt Mixtures Properties (Binder Course Layer)," MSc Thesis, The Islamic University of Gaza, 2013.
- [15] L. Ding, J. Zhang, B. Feng, and C. Li, "Performance evaluation of recycled asphalt mixtures containing construction and demolition waste applied as pavement base," *Advances in Civil Engineering*, vol. 2020, Article ID 8875402, 11 pages, 2020.
- [16] R. Kan and A. Kan, "Thermal conductivity and shrinkage properties of modified waste polystyrene aggregate concretes," *Construction and Building Materials*, vol. 35, pp. 730–734, 2012.
- [17] H. Gao, J. Liu, and H. Liu, "Geotechnical properties of EPS composite soil," *International Journal of Geotechnical Engineering*, vol. 5, no. 1, pp. 69–77, 2011.
- [18] M. A. Qurashi, S. A. R. Shah, M. Farhan et al., "Sustainable design and engineering: a relationship analysis between digital destructive and non-destructive testing process for lightweight concrete," *Processes*, vol. 7, no. 11, p. 791, 2019.
- [19] M. K. Anwar, S. A. R. Shah, M. A. Qurashi et al., "Performance evaluation of modified bitumen using eps beads for green and sustainable development of polymer-based asphalt mixtures," in *Proceedings of the The First International Conference on*



- "Green" *Polymer Materials 2020*, p. 36, Spain, November, 2021.
- [20] E. Listiani and S. Ayu, "Evaluation of expanded polystyrene (eps) plastic waste utilization as an asphalt substitution material in asphalt concrete wearing course," *International Journal for research in Applied Science*, no. November, 2015.
- [21] P. K. Gautam, P. Kalla, A. S. Jethoo, and R. Agrawal, "Properties of bituminous mix and binder modified with waste polyethylene terephthalate," *zahra kalantar dissertation submitted in fulfillment of the requirements for the degree of master of engineering science faculty of engineering*, "Construction and Building Materials", vol. 33, no. 5, pp. 1–6, 2012.
- [22] A. Demirboğa and R. Demirboğa, "A new technique of processing for waste-expanded polystyrene foams as aggregates," *Journal of Materials Processing Technology*, vol. 209, no. 6, pp. 2994–3000, 2009.
- [23] M. N. Rahman and M. A. Sobhan, "Use of non-conventional fillers on asphalt-concrete mixture," *International Journal of Innovation and Applied Studies*, vol. 3, no. 4, pp. 1101–1109, 2013.
- [24] J. P. Kar, D. Panda, and Giri, "Influence of fly-ash as a filler in bituminous mixes," *ARPJ. Eng. Appl. Sci.* vol. 9, no. 6, pp. 895–900, 2014.
- [25] T. W. Suroso, "Pengaruh penambahan plastik ldpe cara basah dan cara kering," *Tek. Sipil*, vol. 3, pp. 208–222, 2008.
- [26] American Association of State Highway and Transportation Officials (AASHTO), "AASHTO T 245," *Standard method of test for resistance to plastic flow of asphalt mixtures using marshall apparatus*, AASHTO T 245, Washington DC, USA, 2015.
- [27] ASTM D1559, "ASTM D1559," *Standard test method for resistance of plastic flow of bituminous mixtures using marshall apparatus*, ASTM D1559, Philadelphia, USA, 1989.
- [28] I. M. I. M. Akbar and K. I. Kabel, "Evaluation of the effect of waste polystyrene on performance of asphalt binder," *Advances in Materials*, vol. 8, no. 2, p. 48, 2019.
- [29] Asphalt Institute, *Mix Design Methods for Asphalt Concrete and other Hot Mix Types*, Asphalt Institute, Sixth Edn., 1993.