DEVELOPING ENHANCED BITUMEN USING LOW-DENSITY POLYETHYLENE AND STYRENE-BUTADIENE-STYRENE POLYMER

[1]Asim Mushtaq*, [2]Nabiha Syed, [3]Amina Israr, [4]Muhammad Taqi, [5]Syed Muhammad Umair, [6]Asad Munir Khan, [7]Muhammad Abdullah

Polymer and Petrochemical Engineering Department, NED University of Engineering & Technology, Karachi City, Sindh 75270, Pakistan

Contact: [1]engrasimmushtaq@yahoo.com*, [2]nabihasyed@neduet.edu.pk, [3]ameenaisrar@neduet.edu.pk, [4]muhammadtaqi08@gmail.com, [5]umairowais1996@hotmail.com, [6]asadmunirkhan@outlook.com, [7]abdullah96chauhan@gmail.com

ABSTRACT: *Road surface conditions in Pakistan is getting worst day by day, problems like thermal cracking, rutting, and traffic-induced stress resistance increased in various forms. Working with polymer modified bitumen is a good solution to this end a lot of work with different polymers had either done or in the pipeline. The advantage to polymer modification of bitumen offers improvements in durability and performance, an extenuation of pavement distress, and ease life cycle costs when compared to hot mix asphalt or unmodified bitumen surface dressings. The aim is to use Styrene-Butadiene-Styrene (SBS) and Low-Density Polyethylene (LDPE) for polymer modifications. This project examines the effect of blending thermoplastic polymers, namely Low-Density Polyethylene (LDPE) and Styrene-Butadiene-Styrene (SBS) in conventional 60/70 graded bitumen, at various plastic compositions. The plastics were mixed and blended with the bitumen with a shear mixer at a temperature of 180^{o}C-190^{o}C. The rheological parameters penetration, softening point and the ductility tests result were a quite impressive change in terms of improvement in mechanical and physical properties of enhanced polymeric blend bitumen. This enhanced bitumen will show improved performance in hot climatic conditions, enhance its hardness and leaving it vulnerable to cracks and exhibit lower binder adhesion in road pavement.*

Key Words: Bitumen; Blending; Low-Density Polyethylene; Styrene-Butadiene-Styrene; Road surface

1. INTRODUCTION

A polymer is a large molecule with high molecular weight composed of repeat units of low molecular weight known as a monomer. The polymer can be made by two processes namely Addition Polymerization and Condensation Polymerization. There are natural and synthetic polymers with different properties such as toughness, viscoelasticity, and its ability to form glassy and semi-crystalline structures [1]. Polymers are assorted in various classification, based on how they join together or how their molecules are arranged. The thermoplastics are the most widely used polymers as they can be reshaped and can be reused again. They remoulded at elevated temperature and they retain that shape upon cooling. In thermoplastics, the chains are concorded with the intermolecular forces, which allow the thermoplastics to be remoulded. Some examples of common thermoplastics are polyethylene, polystyrene, polyamide, polyvinyl chloride and so forth [2]. The thermosets mostly have highly cross-linked, this enables them to have higher physical and mechanical properties, but on the other hand, they show reduced elasticity and elongation. One major disadvantage of thermoset is that it can neither be recycled nor reshaped on heating. It retains the shape once it is cured. It degrades upon heating instead of softening for reuse. Examples of thermosets are epoxy resins, phenolic resins. Elastomers are rubbery materials and they are lightly cross-linked, this enables them to have higher elongation, increased flexibility and elasticity. Elastomers have the ability to recover their original shape even after being elongated to great extents. Common examples are natural rubber (polyisoprene), butadiene rubber, polychloroprene rubber [3].

Bitumen is a sticky and highly viscous mixture of heavy hydrocarbons that are obtained from the bottom in crude oil fractionation. They comprise aliphatic and aromatic, saturated and unsaturated compounds with almost 150 carbon atoms. Technically, it is a byproduct of the residue that is desolated after the more desired parts of the crude oil are extricated [4]. Bitumen constitutes a mixture of a highly condensed polycyclic aromatic hydrocarbon. Bitumen generally contains about 80 wt. % carbon, 10 wt. % hydrogen, 6 wt. % sulfur, little amount of nitrogen and oxygen along with a few traces of metals. Bitumen properties can be enhanced by the addition of different materials or by applying different methods. A major application of bitumen is in making roads, by adding different aggregates to bitumen. This mixture is called asphalt. However, this is a bit ambiguous because in some countries bitumen is also called asphalt [5].

Polymers do not chemically consolidate or change the chemical nature of the bitumen being altered. Some bitumen may expect modifiers like polymer to meet low and high-temperature desires. Polymers utilized for bitumen alteration are long chained hydrocarbon molecules that improve the properties of flawless bitumen. Contingent upon the wide monomer variation of desired properties can be achieved. Polymer modified bitumen can offer enhanced execution over traditional bituminous binders, yet are monetary contemplations ought to be ordinarily taken to ensure their higher cost [3].

The history of pavements emulsions and its application in road development start in the early piece of the twentieth century. These days, the utilization of polymer adjusted asphalt, either natural or synthetic, utilized by analysts and makers to enhance the execution of asphalt, were patented schedule in 1843 [2]. The utilization of polymer adjusted bitumen was recorded by Texas Department of Highway and Public Transportation in June 1982 where it was utilized in a situation of a seal coat on an area of State Highway 327 close Silbee; they utilized styrene-butadiene copolymer for a situate coat. Test ventures were in progress in Europe in the 1930s, and neoprene latex started to be utilized as asphalt modifier in North America in the 1950s [4]. At the end of the 1970s, Europe was in front of the United States in the utilization of adjusted bitumen because the European utilization of contractors, who gave guarantees, inspired a higher enthusiasm for bringing down life-cycle costs even at more noteworthy starting expenses. The preliminary expenses for polymer altered bitumen restricted its utilization in the US. In the mid-1980s, new polymers were delivered and European advancements started to utilize them in the US. In the meantime, the predominance of a long haul monetary viewpoint in the nation expanded. In Australia, the present National Bitumen determination incorporates aides and particulars concerning polymer altered bitumen [1, 3-5].

There is no synthetic change in the mix of polymer added substances or the adjustment in chemical nature of the bitumen being altered, a part of being available inside the bitumen. The polymers will change the physical properties as the softening point and brittleness of the bitumen. Flexibility or versatile recuperation can likewise be moved forward. This will enhance the properties of the bitumen blend in which the polymers are included. These criteria are essential in a blend as to issues, for example, wheel track rutting at high temperatures and exhaustion breaking at low temperatures because of the weakness of the blend [6]. The way the added additive/polymer as a rule impacts the bitumen attributes is by dissolving into certain segment portions of the bitumen itself, a conceal interfacing blend of the polymer is made by spreading out long-chain polymer molecules through the bitumen. Given the thermoplastic idea of the polymers, a few polymers will separate into their constituent sub-atomic molecules at the high temperatures, amid blending and lying and recombine into their polymer chains at bringing down temperatures that is encompassing temperatures. What must be discovered practically speaking is the level of alteration that happens, and whether the level of change accomplished in the general characteristics of the bituminous blend merits having, and is it cost effective [7, 8].

Polymer enhances asphalt an item produced using asphalt emulsion that has been altered with polymer emulsion. A few strategies can be utilized to deliver polymer altered bitumen emulsion. The mixing strategy to include polymer has essential has a vital impact on the polymer arrange circulation and will influence the execution of polymer altered bitumen emulsions. The system incorporates wet procedures, dry procedures and solution phase [9].

The incorporation of polymers in bitumen by mechanical blending or synthetically response is referred to as polymer change, as appeared in Figure 1. Polymer modification is present of a more noteworthy intrigue and has been broadly utilized amid the most recent 40 years, and various research articles have been published since the 1970s. Different explored polymers are ethylene-butyl acrylate (EBA), polyethylene (PE), ethylene vinyl acetate (EVA), polypropylene (PP) and thermoplastic elastomers are styrene-ethylene/butylene-styrene (SEBS), styrene-isoprene-styrene (SIS) and styrene-butadiene-styrene (SBS) are utilized [2, 3, 9].

Bitumen enhancement by various additives deals an essential answer to conquering the presence insufficiencies of bitumen accordingly, enhance the general properties and execution of bituminous blends. A standout amongst the above all utilized polymeric added substances for alteration of bitumen is LDPE and SBS. Both enhance the properties of bitumen like rutting opposition, flexible reactions, and low-temperature splitting obstruction. The SBS and LDPE acknowledged universally for a change of bitumen binder. In any case, the SBS and LDPE changed bitumen regularly indicates unstable thermodynamically nature when put away at high temperature which prompts prompt phase separation. Furthermore, SBS and LDPE altered bitumen tend to degrade long polymeric chain to small atoms on introduction to UV light, oxygen and heat [7, 10].

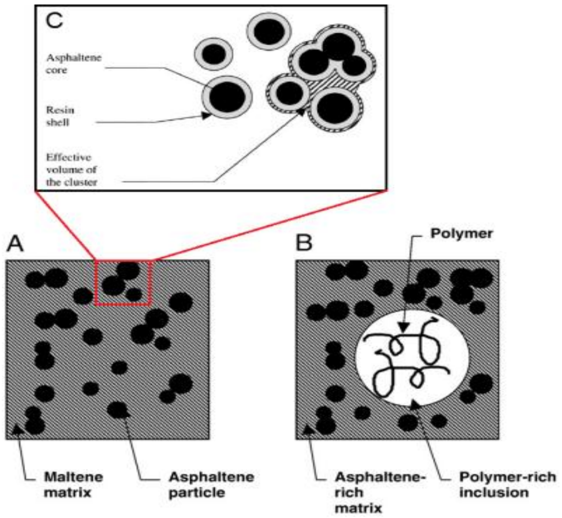


Figure 1. The incorporation of polymers in bitumen.

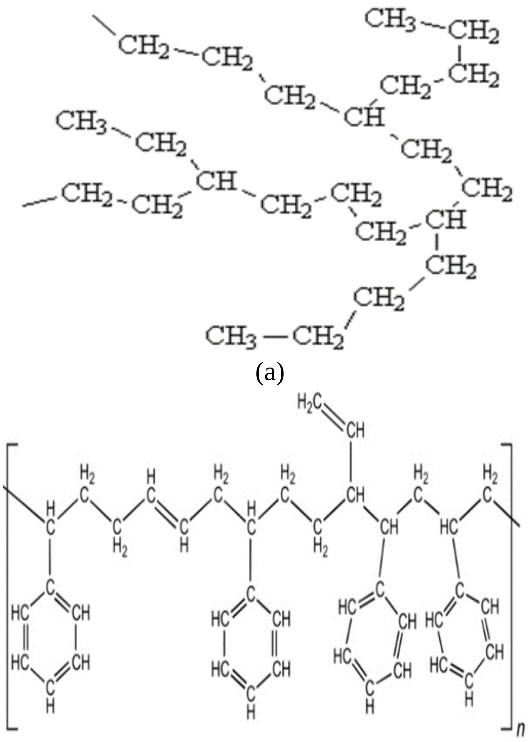
Moreover, cost and creation limit of the SBS and LDPE polymers depends especially on the oil raw petroleum. The adequacy substitute of SBS by any materials can decrease this reliance and cost as well as contribute an incredible degree to the supportability improvement. Such a perception has prompted a look into consideration for enhancing different properties. The compatibility of bitumen changed using new arrangements of added substances and different polymers with varying chemistry. The majority of polymeric modifiers other than styrene–butadiene–styrene (SBS) can be arranged as polymers, for example, polyethylene terephthalate (PET), polyvinyl chloride, ethyl vinyl acetic acid derivation polyoctenamer, polyethylene, styrene-butadiene elastic [11]. Natural rubber elasticity is the main factor of rubber that increases flexibility in the road. Its heat sensitivity limits it to the cold bituminous mixture and improves resistance to cracking and rutting in new pavements [12, 13].

Ethylene vinyl acetate modified binders reveal dispersed polymer particles in a continuous bitumen blend. Morphology (binding) increases and storage stability reduces by an increase in the EVA concentration. EVA binders tend to show fewer changes in elastic recovery yet losing ductility and elastic recovery at a more prominent rate [13]. Styrene-butadiene rubber has low-temperature ductility, improved elastic recovery increased viscosity and improved adhesive and cohesive properties of the pavements.

2. MATERIALS AND METHODOLOGY

2.1. Material Selection

The polymers used in this study are styrene-butadiene-styrene (SBS) and low-density polyethylene (LDPE) for modifying 60/70 graded bitumen. The waste polymer LDPE and SBS were purchased from General Tyre and Rubber Company Limited, Pakistan. The chemical structure of LDPE and SBS are given in Figure 2. LDPE has high impact resistance (doesn’t break easily), waterproof (absorbs moisture), and can stand up too many hazardous materials. SBS has a wide variety over physical and chemical properties. SBS has resistance to fatigue cracking, resistance to low-temperature cracking, resistance to permanent deformation, resistance to reflective cracking and mutually resists aging of bitumen. Bitumen is a highly viscous liquid, a black sticky form of crude. Bitumen that we have used in our experiments was natural that is free from polymers. In this study 60/70 graded Bitumen that was bought from National Refinery Limited, Pakistan. So, it is highly recommended to use low-density polyethylene and styrene butadiene styrene for the core production of polymer modified bitumen.



(a)

(b)

Figure 2. The chemical structure (a) LDPE (b) SBS

2.2. Process Selection

In this research, the bitumen is modified with a polymer using the Dry process. When the experiment starts with the wet process, it was found that there were many chances of stuck solid particles in the pan, non-homogenous dispersion in the sample. It found difficulties in figuring out whether the polymer melts or not. So, the selection of dry process on the basis that stability on average is quite better in a dry process, the flow is more and density also differs with a small amount which can be overcome by increasing stability [9]. As studied earlier that LDPE and SBS show attractive qualities even at high temperatures, hence threaten of being degradation is settled. Since polymers are used in the solid form. Therefore, the technique is using for the modification of Bitumen through the polymer is blending, that is polymer modifier is directly added to the bitumen. To use the dry process of directly mixing polymer in hot bitumen and heat it to the process temperature that is 130^{o}C.

2.3. Sample Preparation

The preparation of six samples was made for each kind of polymer with increasing weight percentage starting from 1 wt. % to 6 wt. % incorporated in Bitumen and the total weight was kept 200 grams for each sample. The sample is not directly made with the addition of polymer. To prepare the sample first, take Bitumen in the pan heated until it melted, sprinkled powdered polymer over the bitumen. Then stirred it mechanically with stirring machine at 200 rpm, stirring was continued for 30 min. After preparation polymer modified bitumen sample was then poured, into different jars according to their testing preferences and are used for testing.

2.4. Characterization of Polymer Modified Bitumen:

2.4.1. Softening Test

A softening point indicates the temperature at which the bitumen achieves a particular degree of softening under the specifications of the test. ASTM D-36 method and Ring and Ball apparatus are used to conduct this test. The standard ball and ring apparatus in which 2 steel balls, each having 9.5mm diameters and 3.5 grams weighing. Brass rings were used, the rings shall be tampered and shall conform to the depth 6.4 mm, 15.9 mm inside diameter at bottom, 17.5 mm inside diameter at the top and 20.6 mm outside diameter. A thermometer is placed, capable of reading temperature up to 0^{o}C to 250^{o}C. The above materials were kept in a water bath that should be heat resistant glass vessel diameter not less than 85mm in and 120 mm in depth. A stirrer was used to ensure uniform temperature at all times throughout the water bath.

A brass ring along with the test sample of bitumen is suspended in liquid like glycerin or water at a given temperature. At first, we heated the material to its melting temperature so that to fill the rings that are placed on a tray. A steel ball of a fixed mass is placed on the bitumen sample and the liquid medium is heated at a rate of 5^{o}C per minute. Temperature is noted when the softened bitumen touches the metal plate which is at a definite distance below. The temperature at which the balls passes through the rings is known as the softening point of bitumen. Usually, higher softening point shows low susceptibility temperature and is favoured in hot climates.

2.4.2. Penetration Test

It measures the softness or hardness of bitumen by determining the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. Bureau of Indian Standards (BIS) had standardized the equipment and ASTM D-5 method is used [14]. The standard penetration apparatus in which a metal or glass cylinder flat-bottomed container essentially with the dimensions for penetration below 225, the diameter is 55mm and internal depth is 35mm. For penetration between 225 and 350, the diameter is 70mm and internal depth is 45mm. At first, we melted the sample so that to fill the metal cylinder up to the required limit and left until cooled. The penetrometer consists of a needle assembly with 100g of total weight and a device for releasing and locking in any position as shown in Figure 3. The needle was first; washed, cleaned, and dried before using, then adjusted so that to make the contact of the needle with the sample would be done. The pointer is brought to zero to ensure that there is no gap left between the needle and the sample. We measured the distance penetrated after five seconds of the release of the needle. Three determinations were made in order to record the average depth of the sample. The depth in tenths of mm is measured as their penetration. The bitumen is softened to a pouring consistency, stirred thoroughly and poured into containers at a depth of at least 15 mm more than the expected penetration. The test ought to be led at a predetermined temperature of 25^{o}C. It might be noticed that penetration value is affected by any error concerning the size of the needle, weight placed on the needle and test the pouring temperature.

Figure 3. Softening test of enhanced polymeric bitumen.

2.4.3. Ductility Test

The ductility test defines the distance in centimeters to which it will elongate when a bituminous material before breaking, is pulled at a specified speed and temperature [15]. The testing method ASTM D-113 was used for determining the ductility of the sample that we prepared including a testing machine, made up of brass mould, thermometer and a thermostat water bath, 10-liter capacity and maintained within the definite temperature conditions that are room temperature in our case. The sample is first heated to its melting temperature to assemble the sample into the mould accordingly and then left for cooling under room temperature. The brass mould containing specimen was then placed in the water bath containing salt and was kept under specified temperature condition for about 85-95 minutes. The specimen is pulled at a constant rate in the water bath. While the test was being conducted, we ensured that water must be above the level where the specimen was placed. The distance in centimeters through which the material fractures known as ductility [9]. The ductility of bituminous material evaluated by the separation in centimeters to which it will reach out before breaking when two ends of standard briquette test of material are pulled isolated at a foreordained speed and demonstrated temperature.

3. RESULTS & DISCUSSION

The results from various characterization conducted on bitumen, bitumen/SBS and bitumen/LDPE waste blend are discussed to reveal the effect of waste on softening point, ductility, and penetration.

3.1. The softening point of Enhanced Polymeric Bitumen

Softening test results of styrene-butadiene-styrene and low-density polyethylene shows that by increasing the weight percentage of polymer in bitumen enhances its properties to soften at a given temperature as shown in Figure 5. This means that a bitumen modified with styrene-butadiene-styrene and low-density polyethylene will show lower temperature susceptibility and will show improved performance in hot climatic conditions. Figure 4 demonstrates that the increments of softening point as the level of polymer waste increment. It was found that when SBS and LDPE content 1 wt. % in bitumen, the softening point is 47.50ºC and 45.50ºC respectively. When SBS and LDPE are taken at 6 wt. % in bitumen, the softening point comes to up to 59.50ºC and 54.75ºC respectively.

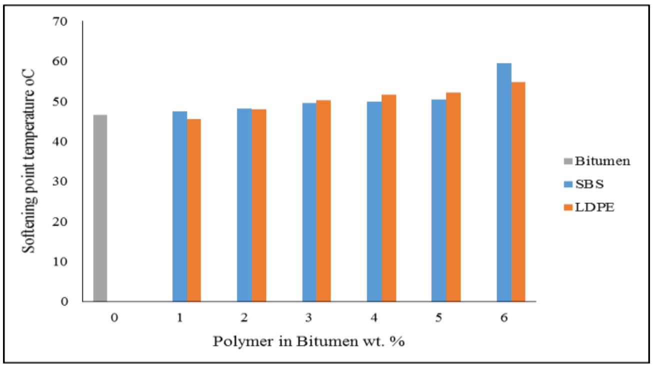


Figure 4. The softening point of Enhanced Polymeric Bitumen

Table (1): Weight percentages of Styrene-Butadiene-Styrene and Low-Density Poly Ethylene in bitumen with their mean temperatures

Polymer	Polymer in Bitumen wt. %	Temperature T1 (ºC)	Temperature T2 (ºC)	Mean Temperature (ºC)
SBS	0	46.25	46.50	46.573
	1	48.00	47.00	47.50
	2	48.00	48.50	48.25
	3	49.00	50.00	49.50
	4	49.50	50.50	50.00
	5	50.00	51.00	50.50
	6	58.00	61.00	59.50
LDPE	1	46.00	45.00	45.50
	2	47.50	48.50	48.00
	3	49.00	51.50	50.25
	4	52.50	51.00	51.75
	5	51.50	53.00	52.25
	6	55.00	54.50	54.75

It indicates that when the softening point is expanding, there will be a decrease in susceptibility at high temperature. Table 1 shows the weight percentages of styrene-butadiene-styrene and low-density polyethylene in bitumen along with their mean temperatures obtained. This wonder demonstrates that the resistance of the binder, impact the heat is expanded and was decreasing its inclination to soften in the hot climate [12]. With the expansion of SBS and LDPE, the altered binder will be less susceptible to the progressions of temperature [16, 17].

3.2. Penetration Result of Enhanced Polymeric Bitumen

Figure 5 illustrates the effect of SBS and LDPE concentration in bitumen on penetration. Penetration results of both the polymers that are styrene-butadiene-styrene and low-density polyethylene exhibit greater penetration resistance when the weight composition of both polymers are increased in the bitumen. This means that the penetration resistance of polymer modified bitumen increases with the increasing weight percentages of both of these polymers.

The penetration depth decreased as the composition increases up to 6 wt. % of SBS and LDPE. It illustrates that polymers composition increasing has a substantial effect on the penetration value. It was observed that when the SBS and LDPE increased from 1 wt. % to 6 wt. %, decrease the penetration value from 13.79 to 5.53 mm and 13.24 to 7.16 mm respectively.

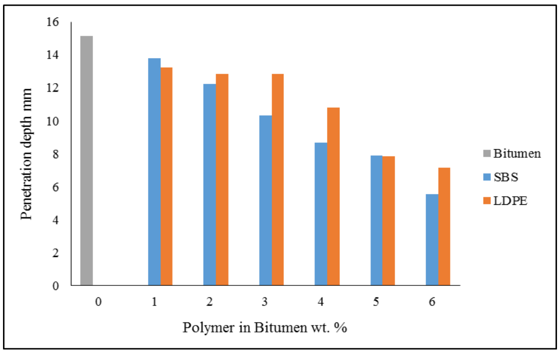


Figure 5. Penetration result of Enhanced Polymeric Bitumen

Table (2): Weight percentages of Styrene-Butadiene-Styrene and Low-Density Poly Ethylene in bitumen with their mean depths

Polymers	Polymer in Bitumen wt. %	Depth D1 (mm)	Depth D2 (mm)	Depth D3 (mm)	Mean Depth (mm)
SBS	0	15.01	15.31	15.14	15.15
	1	13.37	13.89	14.01	13.79
	2	12.22	12.08	12.45	12.25
	3	10.06	10.20	10.74	10.33
	4	9.03	9.43	7.61	8.69
	5	7.81	7.86	8.03	7.90
	6	5.85	6.00	4.74	5.53
LDPE	1	13.15	13.1	13.49	13.24
	2	12.7	12.41	13.39	12.83
	3	12.83	12.53	13.15	12.83
	4	9.74	11.57	11.14	10.81
	5	7.83	7.89	7.76	7.83
	6	7.12	7.15	7.23	7.16

Table 2 shows the weight percentages of styrene-butadiene-styrene and low-density polyethylene in bitumen along with their mean depths obtained. It implies that SBS and LDPE has a drastically impact increasing the stiffness of polymers in a binder resulting in the penetration value decreased. It resisted the deformation due to this binder is less susceptible [18]. So, a road pavement of bitumen modified with these polymers will enhance its hardness [11, 16].

3.3. Ductility Result of Enhanced Polymeric Bitumen

It is an empirical test which determines the cohesive strength of bitumen and its capability to stretch. Ductility test of Styrene-Butadiene-Styrene and Low-Density Polyethylene show that by increasing the weight percentages of both the polymers, its ductility is reduced as shown in Figure 6. After the experimental results indicate that the ductility values of modified bitumen decreased with increasing the percentage of added SBS and LDPE modifier up to 6 % by weight. The ductility was seen to decrease from 57.3 cm for 1 wt. % SBS to 22.4 cm for 6 wt. % of SBS binder. The ductility was seen to decrease from 60.9 cm for 1 wt. % LDPE to 35.5 cm for 6 wt. % of LDPE binder.

The ductility esteem implies the property by which bitumen can exist in a thin film without breaking. The present outcomes demonstrate that the binder turns out to be more brittle with increasing SBS and LDPE composition. This might be because of the inconsistency of the mix, which prompts phase separation. Thereby leaving it vulnerable to cracks and exhibit lower binder adhesion in road pavement [2, 5, 8].

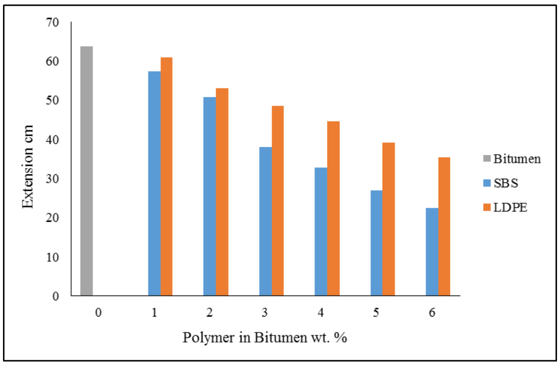


Figure 6. Ductility result of Enhanced Polymeric Bitumen.

Table (3): Weight percentages of Styrene-Butadiene-Styrene and Low-Density Poly Ethylene in bitumen with their mean extension

Polymers	Polymer in Bitumen wt. %	Extension (cm)
SBS	0	63.8
	1	57.3
	2	50.7
	3	38.1
	4	32.8
	5	26.9
	6	22.4
LDPE	1	60.9
	2	53.1
	3	48.5
	4	44.6
	5	39.2
	6	35.5

Table 3 shows the weight percentages of styrene-butadiene-styrene and low-density polyethylene in bitumen along with their mean extensions obtained. Consequences of Hadidy and Yi-Qiu consider demonstrated the binders which had been changed with EVA and LDPE had a higher softening point which implies they were more impervious to deformation. Ductility results were at the minimum range up to 6 wt. % LDPE, EVA and the toughness of bitumen enhanced since the rate loss of weight diminished [4 , 6, 12]. It tends to be inferred that expansion of SBS and LDPE in the asphalt blend enhanced the execution of blend in both high and low-temperature zone. However, if finer particles are used in the modification of bitumen, then this problem can be overcome.

4. CONCLUSION

The investigation planned to use the waste materials that are SBS and LDPE waste for mass scale usage. An endeavour was made to measure the stabilization of the bitumen with SBS and LDPE waste in the shredded frame by performing characterization like softening point, ductility and penetration tests. The present stabilization process is exceptionally powerful in controlling environmental pollution because the waste materials were totally reused with no antagonistic effect on nature. This investigation likewise empowers the mass scale usage of SBS and LDPE. The consequences of the investigation demonstrated that the adjusted blend have a superior outcome compared with the non-altered blend. By adding SBE and LDPE to the bitumen, a superior binding among binder and aggregates was gotten. It is seen that the entrance estimations of base bitumen diminish on the increment of the SBS and LDPE composition. The outcomes likewise demonstrate that the expansion of SBS and LDPE makes the changed bitumen harder and more reliable than base bitumen which results in a change in the rutting obstruction of the blend. It is seen that the ductility of base bitumen diminishes with the expansion of SBS and LDPE. For the most part, SBS and LDPE plastic waste enhance the execution of bitumen when it was included in bitumen. It tends to use the enhance execution of the road asphalt which additionally decreases the rutting impact.

ACKNOWLEDGEMENT
The authors would like to acknowledge the Department of Polymer and Petrochemical Engineering, NED University of Engineering & Technology, Karachi, Pakistan for supporting this research work.

REFERENCES

[1] Zhu, J., Birgisson, B. and Kringos, N., "Polymer modification of bitumen: Advances and challenges", *European Polymer Journal*, **54** 18-38 (2014).
[2] Sienkiewicz, M., Borzędowska-Labuda, K., Wojtkiewicz, A. and Janik, H., "Development of methods improving the storage stability of bitumen modified with ground tire rubber: A review", *Fuel Processing Technology*, **159** 272-279 (2017).
[3] Aziz, M.M.A., Rahman, M.T., Hainin, M.R. and Bakar, W.A.W.A., "Alternative Binders for Flexible Pavement", *ARPN Journal of Engineering and Applied Sciences*, **11** (20): 11868-11871 (2016).
[4] Kalantar, Z.N., Karim, M.R. and Mahrez, A., "A review of using waste and virgin polymer in the pavement", *Construction and Building Materials*, **33** 55-62 (2012).
[5] Yadav, A. and Chandrakar, R., "Construction of plastic roads: An effective way to utilize wastes", *International Research Journal of Engineering and Technology*, **4** (11): 650-652 (2017).
[6] Formela, K., Sulkowski, M., Saeb, M.R., Colom, X. and Haponiuk, J.T., "Assessment of microstructure, physical and thermal properties of bitumen modified with LDPE/GTR/elastomer ternary blends", *Construction and Building Materials*, **106** 160-167 (2016).
[7] Karahrodi, M.H., Jazani, O.M., Paran, S.M.R., Formela, K. and Saeb, M.R., "Modification of thermal and rheological characteristics of bitumen by waste PET/GTR blends", *Construction and Building Materials*, **134** 157-166 (2017).
[8] Salas, M.Á., Pérez-Acebo, H., Calderón, V. and Gonzalo-Orden, H., "Bitumen modified with recycled polyurethane foam for employment in hot mix asphalt", *Ingeniería e Investigación*, **38** (1): 60-66 (2018).
[9] S.Varun, Reddy, D.S.S., Mohan, S.M., Naidu, M.V. and Srikantha, M.K., "Experimental Study on Characterization of Bitumen Mixed with Plastic Waste", *International Journal of Engineering Science and Computing*, **6** (8): 2867-2873 (2016).
[10] Padhan, R.K. and Gupta, A.A., "Preparation and evaluation of waste PET derived polyurethane polymer modified bitumen through in situ polymerization reaction", *Construction and Building Materials*, **158** 337-345 (2018).
[11] Ramarad, S., Khalid, M., Ratnam, C.T., Chuah, A.L. and Rashmi, W., "Waste tire rubber in polymer blends: A review on the evolution, properties and future", *Progress in Materials Science*, **72** 100-140 (2015).
[12] Abdullah, M.E., Ahmad, N.A., Jaya, R.P., Hassan, N.A., Yaacob, H. and Hainin, M.R., "Effects of Waste Plastic on the Physical and Rheological Properties of Bitumen", *IOP Conference Series: Materials Science and Engineering*, **204** 012016 (2017).
[13] García-Morales, M., Partal, P., Navarro, F.J., Martínez-Boza, F.J. and Gallegos, C., "Processing, rheology, and storage stability of recycled EVA/LDPE modified bitumen", *Polymer Engineering & Science*, **47** (2): 181-191 (2007).
[14] Lanjewar, A.A., Deshmukh, D.G.M. and Mishra, A., "Parametric Study on Waste Plastic Utilization in Bitumen", *International Research Journal of Engineering and Technology*, **3** (10): 1123-1129 (2016).
[15] Fernandes, S.R.M., Silva, H.M.R.D. and Oliveira, J.R.M., "Developing enhanced modified bitumens with waste engine oil products combined with polymers", *Construction and Building Materials*, **160** 714-724 (2018).
[16] García-Morales, M., Partal, P., Navarro, F.J. and Gallegos, C., "Effect of waste polymer addition on the rheology of modified bitumen", *Fuel*, **85** (7-8): 936-943 (2006).
[17] Naskar, M., Chaki, T.K. and Reddy, K.S., "Effect of waste plastic as modifier on thermal stability and degradation kinetics of bitumen/waste plastics blend", *Thermochimica Acta*, **509** (1-2): 128-134 (2010).
[18] Hınıslıoglu, S., "Use of waste high density polyethylene as bitumen modifier in asphalt concrete mix", *Materials Letters*, **58** (3-4): 267-271 (2004).