Polymer Pathways: A sustainable approach to plastic waste disposition

Vías de polímeros: un enfoque sostenible para la eliminación de residuos plásticos

Caminhos dos polímeros: uma abordagem sustentável para a disposição de resíduos plásticos

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Summary. - Pakistan is a land filled with natural resources, but gradually due to depletion of these, the country aims to benefit use from different materials that can serve the intended purpose with the minimal cost. Our country annually generates 3.3 million tons of plastic waste. The plastic waste disposal is one of the most threatening challenges to all major metropolitan areas around the world. If not sorted out immediately, it might degrade in the environment for many years. This study proposes the use of waste PET bottles in road construction. The main objective is to analyse and compare the properties of plastic-mixed bitumen roads over non-plastic mixed bitumen roads. Shredded plastic bottles were mixed with bitumen in different ratios (0%, 6%, 8% and 10%) to enhance the stability and durability of roads. Different tests like Marshall stability, penetration, ductility, and softening tests were performed in the laboratory. The results showed that bitumen with 8% plastic has a low flow value. Also, the plastic modifier to bitumen increases the density of the mixture which improves the structural performance of the asphalt pavement. There is an increase in the softening point which illustrates that plastic modified bitumen roads can withstand hot weather more effectively than traditional bitumen roads This addition of plastic in bitumen will be a boon for Pakistan's road industry.

Keywords: Polyethylene terephthalate (PET), asphalt, binder, Marshall stability, waste plastics, aggregates, bitumen, optimum binder content.

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Resumen. - *Pakistán es un país repleto de recursos naturales, pero debido a su agotamiento gradual, el país busca aprovechar el uso de diferentes materiales que puedan cumplir su propósito con un costo mínimo. Nuestro país genera anualmente 3,3 millones de toneladas de residuos plásticos. La eliminación de estos residuos es uno de los desafíos más importantes para las principales áreas metropolitanas del mundo. Si no se gestiona de inmediato, podría degradarse en el medio ambiente durante muchos años. Este estudio propone el uso de botellas de PET desechadas en la construcción de carreteras. El objetivo principal es analizar y comparar las propiedades de las carreteras con asfalto mezclado con plástico frente a las de asfalto mezclado sin plástico. Se mezclaron botellas de plástico trituradas con asfalto en diferentes proporciones (0 %, 6 %, 8 % y 10 %) para mejorar la estabilidad y durabilidad de las carreteras. Se realizaron diversas pruebas de laboratorio, como pruebas de estabilidad Marshall, penetración, ductilidad y ablandamiento. Los resultados mostraron que el asfalto con un 8 % de plástico tiene un bajo índice de fluidez. Además, el modificador plástico del asfalto aumenta la densidad de la mezcla, lo que mejora el rendimiento estructural del pavimento asfáltico. Hay un aumento en el punto de ablandamiento que ilustra que las carreteras de betún modificado con plástico pueden soportar el clima cálido de manera más efectiva que las carreteras de betún tradicionales. Esta adición de plástico al betún será una bendición para la industria vial de Pakistán.*

Palabras clave: *Tereftalato de polietileno (PET), asfalto, aglutinante, estabilidad Marshall, residuos plásticos, áridos, betún, contenido óptimo de aglutinante.*

Resumo. - *O Paquistão é um país repleto de recursos naturais, mas, devido ao esgotamento gradual desses recursos, o país busca se beneficiar do uso de diferentes materiais que possam atender aos propósitos pretendidos com o mínimo custo. Nosso país gera anualmente 3,3 milhões de toneladas de resíduos plásticos. O descarte de resíduos plásticos é um dos desafios mais ameaçadores para todas as principais áreas metropolitanas do mundo. Se não forem tratados imediatamente, podem se degradar no meio ambiente por muitos anos. Este estudo propõe o uso de garrafas PET na construção de estradas. O objetivo principal é analisar e comparar as propriedades de estradas com mistura de plástico e asfalto em comparação com estradas com mistura de asfalto sem plástico. Garrafas plásticas trituradas foram misturadas com asfalto em diferentes proporções (0%, 6%, 8% e 10%) para aumentar a estabilidade e a durabilidade das estradas. Diferentes testes, como estabilidade Marshall, penetração, ductilidade e amolecimento, foram realizados em laboratório. Os resultados mostraram que o asfalto com 8% de plástico apresenta baixo valor de fluidez. Além disso, o modificador plástico no asfalto aumenta a densidade da mistura, o que melhora o desempenho estrutural do pavimento asfáltico. Há um aumento no ponto de amolecimento, o que ilustra que estradas de asfalto modificado com plástico podem suportar climas quentes de forma mais eficaz do que estradas de asfalto tradicionais. Essa adição de plástico ao asfalto será uma bênção para a indústria rodoviária do Paquistão.*

Palavras-chave: *Tereftalato de polietileno (PET), asfalto, ligante, estabilidade Marshall, resíduos plásticos, agregados, betume, teor ideal de ligante.*

1. Introduction. - In research, it has been found that plastic waste can sustain on earth surface for about 4500 years without being changed or decomposed [1]. Plastic is a vital substance, and it is present everywhere in various forms, from synthetic fishing nets to single-use items like water bottle and trash bags. Currently, 400 million tonnes of plastic waste produces every year, and it is observed that plastics are not biodegradable and are unaltered under the surface of earth for about a period of 4500 years. The manufacturing of plastics has grown exponentially since 1950, rising from 2 metric tonnes in 1950 to 322 metric tonnes in 2015. Global manufacturing reached an astounding 8.3 metric billion annually as of 2017. Around 36 metric million tons of plastic waste is generated in the United States every year [2]. It is approximated that by 2050 a billion metric tons of plastics is consumed and present in landfills. The plastic is a threat to biosphere. Why? The answer to this statement lies in the properties of plastic itself. Plastics are very much flexible, handy, cheap, lightweight and durable so once they have been used, they can’t easily be disposed even they take centuries to be decomposed completely [3].

Landfilling is a conventional approach to deal with plastic waste but due to lack of space for landfills, it was no longer a justified solution. An alternative to landfilling is incineration of plastic waste but it was also an ineffective solution due to the release of noxious fumes which are unhealthy to the environment [2]. The best and productive solution for the disposal of waste plastic is to reuse it. In this way the need for the production of plastic reduces and it will circulate around the surroundings, hence reduces the health risks. Steps have been taken to reuse plastic waste in different sectors including clothing accessories, transportation and construction [4]. Researchers found that plastic- bitumen mixed pavements are more flexible than the ordinary asphalt pavements. When water gathers over the asphalt pavements, it penetrates and create depressions known as potholes decreasing the strength and the life of roads and bridges. On the contrary, plastic increases the strength and durability of roads when it is added to the bituminous mix. It also increases the slip resistance and lowers the cost of the construction [1].

Plastic is a flexible synthetic polymer that can be heated and moulded into different shapes. It is cheap, strong, formable, lightweight and corrosion resistant. On the basis of physical properties, it is classified as thermoplastic or thermosetting plastic. Thermoset plastics are formed by the process of irreversible polymerization. They do not soften upon heating once they have moulded. Examples of widely used thermosets are vulcanized rubber, polyurethane foams and phenolic resins. On the contrary, thermoplastics undergo multiple heating and cooling cycles and becoming soft and hard during these cycles. Atoms and molecules in thermoplastics consist of long and short carbon chains that work independently. This structure makes these materials non-biodegradable due to their resistance to degradation or hydrolytic cleaving of chemical bonds. A common example of thermoplastics is polyethylene terephthalate (PET) in clothing fibers and in packaging of beverages and foods [5], [6], [7].

PET or Polyethylene terephthalate is the most used and recyclable plastic in the world. It is used to package 70% of carbonated soft drinks, fruit juices and bottled water. It is flexible, colorless and translucent polymer. It has a good tensile strength and chemical resistance. In South Asia only, the consumption of PET by the six largest countries is to almost double from 886,000 tons in 2018 to 1.52 million tons in 2030 [8]. Due to its good creep resistance and low moisture absorption, it is suitable to be used in asphalt pavement [9], [10]. The plastics can reduce thermal susceptibility to bitumen, such as rutting in warm temperatures and fatigue cracking in cold temperature [8]. Plastic waste can be added to the bitumen either by wet or dry process. The dry process is considered to be simple and economical while the wet process involves a higher investment and machinery. Hence, it is not commonly used [11]. In the wet process, plastic waste is made into powder form and then add to the hot bitumen before the aggregates are mixed. The temperature range for this method is preferably 155ºC to 165ºC. On the contrary, dry process involves the shredding of waste plastic. These plastics are coated over pre-heated aggregates. The bitumen is heated to 160ºC and get mixed with plastic coated aggregates [12], [13]. A study reported a marked improvement in various parameters such as Marshall stability and tensile strength for the outputs of dry process in comparison to that of wet process [11].

The use of plastic-modified bitumen in roads construction is indeed a great idea which has been adopted by many countries in order to solve the problem of plastic waste disposal and to increase the lifetime of their roads. The United Kingdom government had invested £23 million into plastic roads technologies. A Ghana based plastic recycling company produced pavement blocks from waste plastic that have been approved by Ghana’s Ministry of Science and

Technology and have been used to construct a road in Accra. Moreover, Netherlands have also built a 30-meter cycle path in the Zwolle municipality [14], [15]. India was also one of the biggest promoters of PET modified roads. Many other countries including China and Ethiopia have been working under this idea to enhance their roads quality [16]. The authorities in Pakistan also took initiatives to build plastic modified roads across the country. Pakistan's first plastic road under the "World Without Waste" program was completed in December 2021 at F-Park and Ataturk Avenue, Islamabad, using almost 8 tons of polyethylene terephthalate recycled plastics. Over 2.5 tons of discarded lubricant bottles were recycled for the construction of 730 feet long and 60 feet wide road on which a multinational firm is located in Karachi. The discarded lubricant's plastic bottles were incorporated in the construction of the asphalt road using the dry process method, reducing plastic waste [17]. More projects regarding plastic modified bitumen roads are under operation in the province of Sindh and Punjab [18].

The increasing use of plastic and its disposal has become a worldwide issue which needs to be resolved by taking some effective measures. This study shows a comparative analysis between plastic modified bitumen and non-plastic bitumen roads. It highlights the mechanical properties and usefulness of PET modified roads and listed all the results that have been obtained from the experiments performed. It focused on the need of a sustainable action that makes the true use of plastic wastes instead of their elimination. For the present study, we use waste PET bottles as a plastic modifier. Around 100 bottles were crushed to a size of 2-4mm in a crusher machine and then1 sieved thorough 4.5mm sieve.

2. Methodology. - The optimized bituminous mix's binder content was optimized using the Marshall mix design. In addition, the same procedure was used to optimize three other plastic types. The amount of bitumen needed in the bituminous mix to produce fully coated aggregates, sealed air gaps, and increased durability is known as the optimal binder content. The Marshall Testing Machine was used to conduct this test. The specimens with 2.5%, 3%, 3.5%, 3.9%, 4.6%, 5.5%, and 7% asphalt by weight of aggregates, were made using standards ASTM D1559-89 and AASHTOO standard, T245-82.

Approximately 1200 grams of aggregates are heated to 160-185°C. The first trial involves heating bitumen to 130-150°C and adding 2.5% bitumen by weight to the aggregates. The heated aggregates and bitumen were completely mixed at a temperature of 150–160°C. The mixture is then placed in a prepared mold and crushed using a rammer with 75 blows on both sides at a temperature of 130-150°C. The produced mixture is then placed into the Marshall Testing Machine. The Design Criteria or the Marshall Method Table I were used to determine the optimal binder content for heavy traffic surface and base mixes.

Marshall Method Mix Criteria	Surface and Base Mix					
	Light Traffic		Medium Traffic		Heavy Traffic	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Compaction, no. of blows at each end of the specimen	35		50		75	
Stability, (lb.)	500	-	750	-	1500	-
Flow (0.01 inch)	8	20	8	18	8	16
Percentage of air voids	3	5	3	5	3	5
Percentage of voids in mineral aggregate (VMA) for 3/4″size	14	-	14	-	14	14

Table I. - Design Criteria of the Marshall Method.

After determination of optimal binder content of bitumen, a mixture consisting solely of virgin bitumen as well as PET was prepared. Different percentages of plastic were chosen and analyzed for each modified mix. Two different processes i.e. wet process and dry process can be used. However dry process was used as it is more economical and does not require any extra effort to preheat the plastic. To begin, an asphalt sample core with 4% plastic content was to be made. This process involves the heating of aggregates having 12.5mm dimensions at 170ºC. About 100 waste PET bottles were crushed to a size of 2-4mm size in a crusher machine and then sieved thorough 4.5mm sieve. These aggregates are then coated by hot shredded plastic. Grade 60/70 bitumen which confirms to the ASTM standards is then mixed with plastic coated aggregates. A digital scale is used to measure the sample weights, and an industrial grade mixer is used to uniformly mix the contents.

The following procedure is applied on the sample.
a. Heating the sample in a special apparatus to obtain a cylindrical shape as per the standards.
b. Then the sample is left in the oven for 4 hours.
c. The asphalt molds are then air cooled at room temperature.
All The above steps are repeated with varying content of plastic by weight of bitumen (0%, 6%, 8% and 10%).

As shown in Figure I, each sample was labelled according to its plastic content, and each has a diameter of 100mm and a height of 64mm as per AASHTO standards.

Once the samples cool, the bitumen quality tests were to be applied. At first, the Marshall Stability Test was to be performed. This test estimates the maximum load that a bitumen sample can bear under standard testing temperature of 60ºC. It was performed by Marshall Testing Machine Figure IV. Along with the MS, density, stability and flow determination, stability and penetration, ductility and softening of the cores were checked in Figure V.

The density of the specimen can be determined by weighing it in air and clean water at room temperature and the difference between the two gives the density value called Density Determination. Another test value that can be measured from Marshal Stability tester is the Stability and Flow determination. The flow value is the vertical deformation when the maximum load is applied to the specimen.

After stability, the penetration, ductility and softening of the sample cores were to be checked. This test determines the consistency of bitumen materials by measuring the depth (in units of one tenth of mm) to which a standard needle will penetrate under specific condition of load, duration and temperature. The weight of the standard needle assembly is 100 gm. The needle penetrates in the sample for a duration of 5 seconds at 25ºC and is used for the purpose of grading. The softer the bitumen the greater will be the penetration. ASTM Standard D5-86 and AASHTO standard T49-68. The penetration sample is shown in the Figure I.

Figure I. Penetration Sample.

Another major factor is Ductility; expressed as a distance in centimeters to which a standard briquette of bitumen can be stretched before the thread breaks. This test helps to determine the asphalt's flexibility and its resistance to cracking in cold weather conditions, as shown in Figure II.

Figure II. Ductility Sample.

Softening point is the temperature at which the sample attains a particular degree of softening under specified conditions. The apparatus used for this test is known as ring and ball apparatus. It was conducted to assess the temperature susceptibility and suitability of asphalt mixtures in specific climates and weather conditions, especially in hot weather. Figure III.

Figure III. Softening Point Sample.

Figure IV. Marshall Tester.

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Figure V. Sample Core.

3. Results and Discussions. - The laboratory results for both virgin mix and modified plastic specimen, as well as the impact of plastic are discussed below in Table 2.

% of bitumen by wt. of mix	Unit wt. (pcf.)	% Air voids	Flow in 1/100 inch	Stability, Lbs.	% VMA
2.5	137.5	15.2	6	1000	20
3	142	10	7	2350	16.7
3.5	145.5	7.6	8	2700	15.6
3.9	147.5	5.5	11	2750	14.9
4.6	148	3.7	16.5	2000	15.3
5.5	147.5	2.8	30	1250	16.1
7	146	2	44	400	17.6

Table II. Experimental Results for Optimum Binder Content.

According to the Marshal mix design, the trial findings for optimum binder content are determined where the best value of stability occurs, and the air voids are within acceptable limits (usually between 3% and 8%). The graph shows that when the binder content increases, air voids decrease. These details better compaction and performance however values below 3% can restrict the expansion of asphalt binder during temperature fluctuations, causing potential cracking and instability [19]. There is an increase in the stability value with the percentage of bitumen up to 3.9% where it peaks at 2750 lbs. Although there is an increase at flow value with the increase in binder, reaching a maximum at 4.6, but the stability begins to decline. Also, the minimum % VMA is at 3.9% bitumen content but within the acceptable range. On comparison with the stability and flow values; it is concluded the optimum bitumen binder content is 3.9%. This is also consistent with [20]. The results of tests performed to find optimum bitumen content are listed in Table II.

When plastic is added, the mixture's viscosity decreases, and its Marshall Stability value rises until it reaches its ideal content. However, the increased friction between the mixture's various particles causes the MS value to drop after the optimal content. The use of different kinds of plastic, varying volumes of bitumen, and a variable mixing technique are the causes of the variation in the ideal percentages that has been noticed as shown in Figure VI.

Figure VII shows the effect on flow value with varying percentage of plastic in asphalt mixture. As seen, flow value decreases while adding plastic to the bitumen. Plastic increases the viscosity and stiffness of the bitumen, and the mixture become less susceptible to deformation, especially under high temperature conditions. As shown, bitumen with 8% plastic has a low flow value. This decrease in flow value indicates greater resistance to rutting, which is a common problem in asphalt pavements. Further, as shown in Figure VIII, density increases with plastic content up to 8% and thereafter decreases. Thus, the addition of plastic modifiers to bitumen increases the density of the bitumen mixture which improves the structural performance of the asphalt pavement. Similarly, the stability of the mixture increases with plastic content up to a certain value i.e. 8% and thereafter decreases as shown in Figure IX. According to the data, there exists an ideal range for the binder content that maintains acceptable flow values while optimizing stability. Hence, the optimum plastic content was found to be 8%.

All the reading taken from the penetration test are listed in Table II. Each sample was tested thrice to get the average penetration value. Figure X; illustrates the effect of plastic concentration on penetration. The penetration depth decreases as the amount of plastic increases up to 8% and thereafter increases. This explains that the asphalt mix has the greater stiffness, durability and resistance to rutting at 8% plastic content. The results of ductility test are listed in Table III. The distance the specimen stretched before breaking was measured and recorded as its ductility value.

As shown in Figure XI, ductility increases with plastic content up to 8% and decreases afterwards. This means that the bitumen modified with 8% plastic have greatest elongation or elasticity before it fails. The results of softening test are listed in table 4. In this test, when either of the two balls touched the base of the cylinder, the temperature was measured and recorded as the softening point of the given bitumen sample.

It is shown in Figure X that the softening point increases with plastic content up to 8% and thereafter decreases. This increase in the softening point illustrates that plastic modified bitumen roads can withstand hot weather more effectively than traditional bitumen roads.

According to the data, there exists an ideal range for the binder content that maintains acceptable flow values while optimizing stability [21].

Figure XII highlights the superiority of plastic-mixed bitumen sample over non-plastic bitumen sample. It is less susceptible to softening in hot weather, hence, reducing the risk of rutting and pothole formation. It remains flexible at lower temperatures, reducing the risk of cracking and deformation. It enhances bitumen’s resistance to wear and tear, resulting in more durable roads. Furthermore, reusing plastic waste contributes in a sustainable environment and reduces the maintenance time and cost. Therefore, in order to enhance asphalt's overall qualities, this amount of plastic modification is advised. It is significant to remember that using modified asphalt in construction might result in pavement structures that are more resilient and long-lasting.

Specimen	Optimum binder %		Marshall Stability (lbs)	Flow value in 1/100 inch	Density (PCF)
	bitumen %	plastic %			
1	100	0	1926.84	22	2.23
2	96	4	2647.75	21	2.25
3	94	6	3105.21	24	2.25
4	92	8	3430.39	23	2.26
5	90	10	2438.31	26.5	2.19

Table III. Experimental Results.

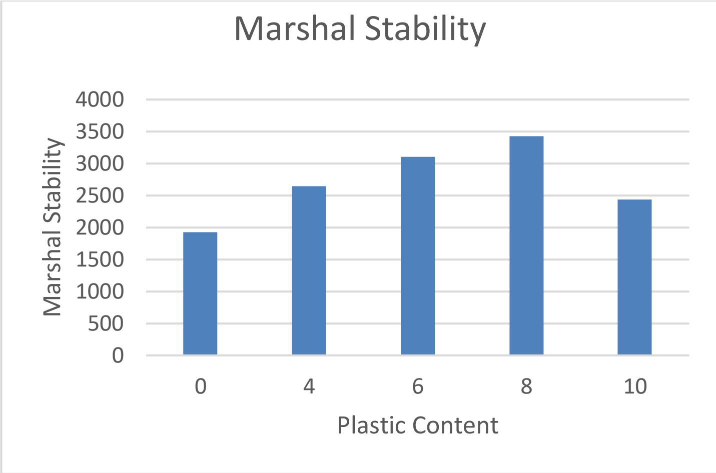

Figure VI. Experimental Results of Marshal Stability.

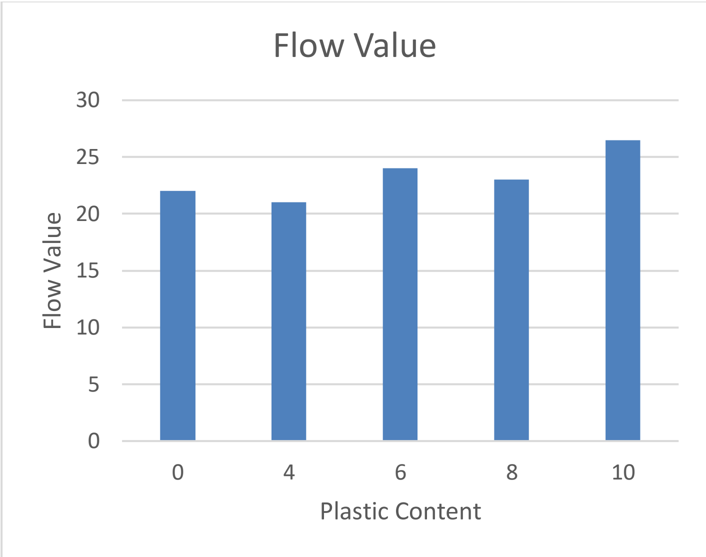

Figure VII. Experimental Results of Flow Value.

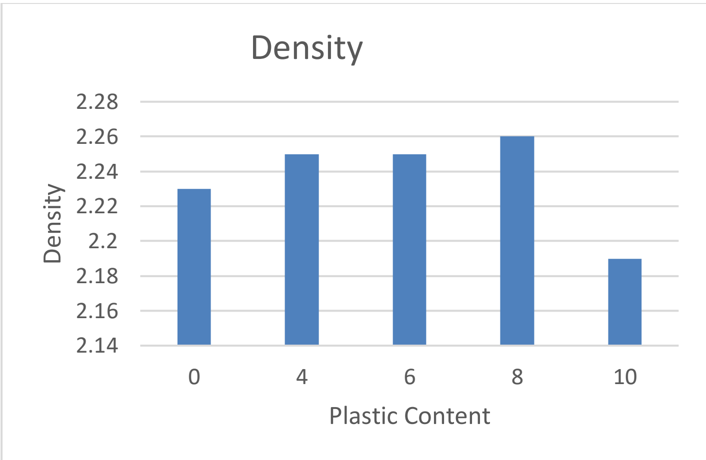

Figure VIII. Experimental Results for Density.

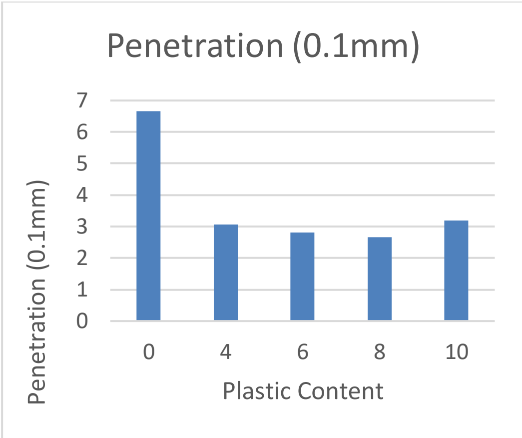

Figure IX. Experimental Results of Penetration.

Specimen	Plastic %	Ductility (cm)
1	0	108
2	4	110
3	6	112
4	8	115
5	10	110

Table IV. Experimental Results of Ductility.

Specimen	Plastic %	Softening point (ºC)		
		Ball 1	Ball 2	Average
1	0	45	46	45.5
2	4	60	61	60.5
3	6	62	61	61.5
4	8	62	63	62.5
5	10	60	61	60.5

Table V. Experimental Results of Softening.

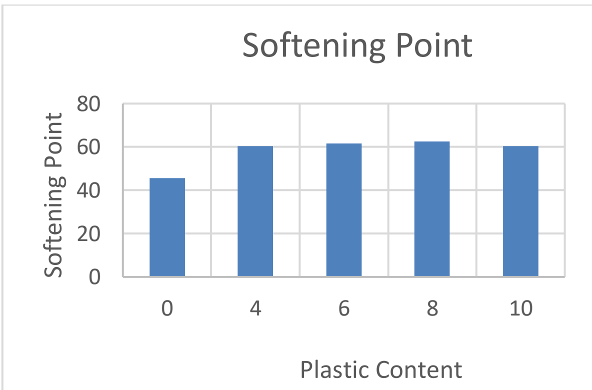

Figure X. Experimental Results for Softening Point.

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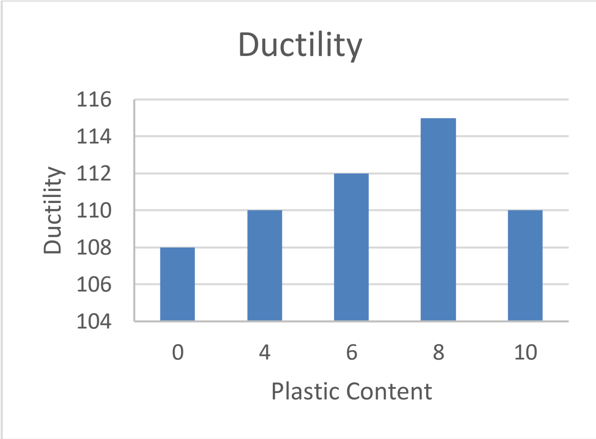

Figure XI. Experimental Results for Ductility.

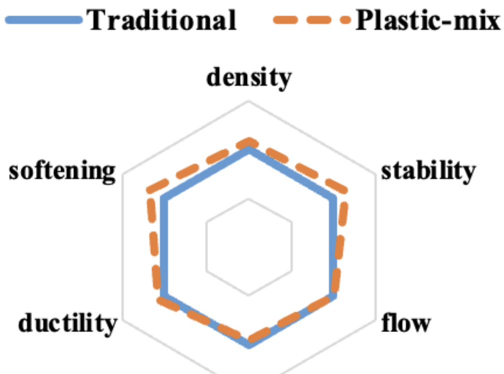

Figure XII. Performance indicators of Traditional vs Plastic Bitumen-modified.

3.1. Statistical Analysis. - A correlation analysis was performed amongst the Plastic content and various properties like Ductility, Marshal Stability, Penetration and Softening Point. The results are discussed below:

1. There is a moderately positive association between ductility and plastic content, indicating that ductility tends to rise in tandem with plastic content. This relationship may not be consistent across samples, though, as it is not statistically significant ($p > 0.05$).
2. The moderate positive correlation between Plastic content and Marshal Stability indicates that higher plastic content is associated with higher Marshal Stability values, but this rise in Marshal Stability is only valid till 8% of plastic content, however it reduces at 10% plastic content.
3. According to a strong negative association, penetration drops as plastic content rises, meaning that more plastic materials are less permeable.

		Ductility	Marshal Stability	Penetration	Softening Point
Plastic	**Pearson Correlation**	0.589	0.576	-0.796	0.817
	P-VALUE	0.296	0.31	0.107	0.091
	n	5	5	5	5

Table VI. Experimental Results of Statistical Analysis.

4. Economic Analysis of Plastic Bitumen Road for Pakistan.

4.1 Pakistan's Bitumen Import Cost. - Approximately, Pakistan imported bitumen of about $ 3 million in the year of 2023, increasing cost of bitumen per year shown in Figure X. Roads made from plastic waste give an opportunity to reduce the amount of bitumen use for the road construction and eventually reduce the import cost of bitumen annually. The details of 2023 bitumen import cost approx. in USD $ 45,814.70K and the total tonnage was about 207240 metric ton from the world [22]. By using plastic waste in roads, we can approx. reduce 10% cost of bitumen import and will be able to build more sustainable and eco-friendly roads network.

4.1.1 Cost Estimation of Plastic Waste Processing. - Use of plastic waste for road construction, in the bituminous mixture is 6% to 8% of weight of bitumen. Cost of waste plastic shreds in kilogram is between Rs.85/kg to Rs.90/Kg [23].

S.NO	PARTICULARS	APPROX RATE (Rs./kg)
1	Waste plastic	1
2	Collection of plastic	2
3	Transportation	2
4	Cleaning and shredding	2
5	Labor charges	3
6	Machinery charges (electricity and maintenance)	2
	Total	**Rs. 12 / kg**

Table VII. Per kilogram waste plastic processing cost.

4.2 Cost Estimation and Comparison of Conventional Roads and Plastic Roads

4.2.1 Material Costing. - For the cost comparison initially take the standard of construction of 1-kilometre road of and width of 3.7 m [23].

• Bitumen cost per kg is Rs.119 per kg.

• Surface area of road which will be covered by bitumen is given as Road surface area = Road length x width of road = 1000 meters x 3.7 meters = 3700m2.

• Gravels chips cost = Rs.12,000 to Rs 13,000 per 1 brass (2.83 m3)

• The volume of bitumen required for all types of roads surface is 0.98 kg to 1.10 kg per m2 [22].

4.2.2 Pure Bitumen Seal Coated Roads Cost Estimation. -Now for the comparison analysis first evaluate the estimated cost required for the construction and seal coating of aggregate with pure bitumen. We have taken the standard of 1 kilometer road of width 3.7 meters [20].

• Total volume of bitumen required for road coating Bitumen = (road surface area) x (bitumen required per m2)
= 3700 m2x 1 kg/m2 = 3700 kg

• Gravel chips volume required for road.

• Gravel volume = (road surface area) x (Gravel chips layer thickness) = 3700 m2x 0.005m (5mm) = 18.5 m3

• Pure bitumen cost for road coating.

• Total Bitumen cost = (total bitumen volume) x (cost of bitumen per kg) = 3700 kg x Rs.119 /kg = Rs. 440,300/ km

• Total cost of gravels or aggregate is given as

Total Gravel cost = (total volume of Gravels) x (rate of Gravel)
= 18.5m3 x (13,000 / 2.83 m3) {1 brass = 2.83}
= 18.5 x 4,593
= Rs.84,970 / km

• Total cost of the pure bitumen coated road is estimated as
Total cost of bitumen road = (total cost of bitumen) + (total cost Gravel)
= Rs.440,300 + Rs. 84,970
= Rs.525,270 (approx.).

4.2.3 Costing Evaluation Result. - Hence the total cost for the construction of 1 km and width of 3.7 m road is approximately estimated as Rs.525, 270. It should be considered that it is estimated cost of the material that is required for the construction of roads it does not include the cost of labor, machinery and traveling.

4.2.4 Modified Plastic Bituminous Mixture Road Cost Estimation. - The use of plastic shredded waste in bituminous mixture of road is 6% to 8% of weight of bitumen. For cost estimation again consider the construction of road of 1 kilometer having width of 3.7 meters.
• Cost of shredded plastic waste is Rs 85. /kg to Rs.90/kg
• Total volume required of waste shredded plastic for aggregate coating is Total shredded plastic volume = (total bitumen volume) x (% of plastic) = (3700 kg) x (8%) = 296 kg

• Total cost of shredded plastic required for road is
Total shredded plastic cost = (total plastic volume) x (rate per kg)
= 296 kg x RS.90/kg = Rs.26, 640 /km.

• Total cost of bituminous mixture with shredded plastic can be estimated as.
Total cost of mixture = (cost of bitumen after plastic addition) + (Shredded plastic cost)
= [(3700 kg – 296 kg) x119] + Rs.26,640 = Rs. 431,716/km

• Total cost of plastic road can be estimated as.
Total cost of plastic road = (plastic/bitumen mixture cost) + (Gravel cost)
= Rs.431,716 + Rs 84,970. = Rs. 516,686 / km

4.3 Costing Evaluation Result. - Hence the cost estimation for plastic road is calculated as Rs. 516,686 /km. It does not include the labor, machinery and travelling cost. We have taken the standard of 1-kilometer road having a width of 3.7 meters. The reduction is cost with plastic shredded particulate in the bituminous mixture can be approximately calculate as 4% to 6% as compared to pure bitumen road construction.

4.3.1 Bitumen Cost Reduction. - The cost of bitumen is also reduced by using plastic in the road mixture as plastic replaces the amount of bitumen uses for affective coating of the aggregate, the reduction in cost can be calculated as.
• Bitumen cost (conventional road) = 3700 kg x Rs.119/kg = Rs. 440,300/kg
• Modified Plastic bitumen cost = [(3700 kg – 296 kg) x 119] = Rs. 405,076
• Cost reduction = Rs.440,300 – Rs.405,076 = Rs.35,224/ km

Hence a cost reduction of Rs.35, 224 is saved in bitumen mixture by using shredded plastic as an additive in the bituminous mixture for road construction shown

4.3.2 Overall Road Construction Cost Analysis. - From the above calculation we have derived some of the major cost reduction by using shredded plastic waste in the bituminous mixture. The reduction in cost for construction of road per kilometer can be calculated as:

• Cost reduction = (cost of pure bitumen road) – (cost of modified plastic bitumen)
= Rs. 525,270-516,686
= Rs. 8,584 /km

The findings of this study show that using waste plastic in road construction can be a smart and eco-friendly solution for Pakistan. By mixing shredded plastic into bitumen, it can reduce the number of traditional materials needed, which helps lower costs and makes roads stronger and more durable. This approach not only helps tackle the serious issue of plastic waste in the environment but also supports the building of better roads that can withstand wear and tear. As Pakistan adopts these innovative practices, it opens the door to a cleaner future where waste is reused effectively. Overall, this method can lead to significant savings and contribute to a healthier planet for everyone.

5. Future Recommendations. -

a. Further studies should investigate the potential leaching of harmful chemicals from plastic additives into soil and waterways. As some plastics can release toxic substances when heated, understanding these risks is crucial for ensuring the safety of road construction practices.

b. Many studies so far have been conducted using several other forms of plastics like PET, LDPE and HDPE. Further material like Polypropylene (PP) or Polystyrene (PS) to assess their suitability in the asphalt mix.

c. Further research can incorporate detailed analysis on microstructure of plastic-bitumen sample. This was not conducted in this study due to limitations of resources.

d. Further studies with bigger sample sizes may offer more conclusive insights into this relationship, as the correlation approaches significance but falls short of traditional standards.

6. Conclusions. - This research explored the use of waste PET bottles in asphalt mixtures, highlighting the environmental and economic benefits of incorporating plastic into road construction. Following conclusions could be interpreted from the results.

a. In our study, we created five sample cores with varying plastic content: 0%, 4%, 6%, 8%, and 10%. The results showed that asphalt with 8% plastic content by weight of Optimum Binder Content (OBC) exhibited the highest Marshall Stability, with values of 3430.29 lbs.

b. Also the value of ductility and softening point at 8% plastic content is maximum. This increase in the softening point illustrates that plastic modified bitumen roads can withstand hot weather more effectively than traditional bitumen roads

c. Additionally, using plastic in bitumen not only improves road performance but also leads to substantial cost savings. For instance, roads made with plastic-modified bitumen can reduce overall construction costs by approximately 4% to 6% compared to traditional methods. This innovative approach not only helps manage plastic waste effectively but also supports the development of stronger, more resilient road networks.

d. By adding waste plastic to asphalt, we can significantly reduce the amount of plastic that ends up in landfills and oceans, promoting more sustainable practices.

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Author contribution:

1. Conception and design of the study

2. Data acquisition

3. Data analysis

4. Discussion of the results

5. Writing of the manuscript

6. Approval of the last version of the manuscript

EAJ has contributed to: 1, 2, 3, 4, 5 and 6.

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