Evaluation of the Properties of Hot Mixed Asphalt Modified by Plastic Waste

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Abstract

Plastics are convenient to use, however they are not environmentally friendly because they are non-biodegradable. As the population grows, so does the amount of plastic waste in municipal solid waste. Plastic waste is becoming a huge concern since it is designed to withstand a variety of circumstances such as light, heat, chemicals, pathogens, and other factors in order to be useful in a variety of applications. One of the most practical and economical ways to dispose of waste plastic is to use it as a binder for Bitumen, which may be used to pave roads. The studies are carried out by mixing varying percentages (3, 6, 9 & 12)% of waste plastic with bitumen to see how it affects the properties of the bitumen. In comparison to conventional bitumen, the mixture had higher binding properties, stability, density, and water resistance. It also showed an improvement in fire point and flash point, indicating that it can withstand high temperatures. By replacing some bitumen with waste plastic, which is less expensive than bitumen, the entire construction cost can be reduced.

Keywords—Aggregates, Flexible Pavement, Plastic Modified Bitumen, Waste Plastic

1 Introduction

Pakistan produces between 30 and 48 million tonnes of solid waste per year. Solid waste production, on the other hand, is predicted to be growing at a rate of 2% to 3% each year. In the main urban regions, 77 thousand tonnes of waste are created every day, with 70 percent to 80 percent of this material being collected for suitable disposal. According to a report on solid waste management published by the United Nations Development Program (UNDP) in 2016, Pakistan's plastic waste ranks fourth among all solid waste collected [1].

Pakistan imported USD 76 million worth of bitumen in 2018. As a result, the utilization of plastic waste from road pavement provides a major import substitution opportunity, resulting in significant foreign exchange savings. Payment data for Bitumen imports in US Dollars for the year 2018 was PKR 11,959,315,712 and USD 76,248,509, respectively, against 195,509 metric tonnes. Direct savings of at least 10% were achievable, and the same savings rate is possible owing to a greater road construction mix [2].

Modified bitumen was first used in practical applications in the 1930s. Several Western European countries attempted to employ this material for experimental asphalt concrete pavement plots during the time. The first modifying ingredient was natural rubber. The early findings of using modified bitumen were promising since the road surfaces were able to sustain high traffic.

In 1970s, there was a renewed interest throughout modified bitumen in Western Europe. This time, the material performed admirably in the device for surface treatment and asphalt mixture production. The early 1980s saw a surge in modified bitumen research by US experts, who gratefully drew on the knowledge of their European counterparts. The number of modifications that have been applied is growing. Rubbers, thermoplastic resins, sulfur, rubber granules, organic-manganese compounds, and thermoplastic rubbers are

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being utilized to improve the performance properties of oil bitumen [3].

The results of Adela et. al. [4] were positive, indicating that the changed asphalt mixtures performed better. In addition, waste plastic can be utilized to partially replace coarse aggregate in concrete mixes. Plastic waste output has been expanding globally, posing major health and environmental risks. Garg et. al. [5] reported that many studies are being carried out to see how best to use this waste to turn it into wealth. Giri et. al. [6] reported that recycling and waste reuse are critical for long-term sustainability in the transportation construction industry. Gade et. al. [7] were of the view that recycling plastics for road construction, as well as environmentally responsible disposal of plastic waste, is a cost-effective method of preventing early road deterioration. Recycling plastics for road construction, as well as environmentally responsible disposal of plastic waste, is a cost-effective method of preventing early road deterioration.

Asare et. al. [8] investigated the idea of using plastic wastes as plastic-coated aggregates to replace around 10% of asphaltic road materials. Mishra & Gupta [9] used specimens with waste plastic content of (5 , 7 , 9, 11, 13, and 15)% by weight of optimal bitumen content and bitumen content ranging from 4 percent to 6 percent with an increase of 0.5 percent by weight of aggregates. Rohit Sai et. al. [10] reported that the properties of modified bitumen and bituminous mixes, in general, were improved by a binder for bituminous macadam created by blending waste plastic in 5–16 percent (by weight of optimum bitumen). Khursheed, et. al. [11] reported that plastic waste is incorporated into bituminous mixes. Increases user satisfaction and reduces accidents by increasing durability and resilience to deformation and water-induced damage.

Ye Huang [12] reported that recycled plastics can be used as a binder modifier or as an alternative to aggregates. Vasudevan [13] found that in comparison to conventional bitumen, the use of waste plastic in bitumen improves binding properties. It enhances the characteristics of bitumen by increasing the Softening Point and decreasing the Penetration Value, resulting in increased durability. Small amounts of bitumen (about 5-10% by weight of bitumen) improve the stability, strength, fatigue life, and other desired attributes of bituminous mixes, resulting in better pavement lifespan and performance. Justo [14] according to the manufacturer, adding 8.0 percent processed plastic to modified bitumen saves 0.4 percent bitumen weight or approximately 9.6 kg bitumen.

Resin identification coding (RIC) was created by the plastic trade organization in 1988, and it was inducted into the American Society for Testing Materials in 2010. It's essentially a number or code located on the bottom of plastic containers. Recycling of plastic waste has been much easier as a result of the adoption of these numbers since the identification of recycling containers and locations has become much easier. It was also made easy to sort plastic waste by simply printing the resin number at the time of printing. Resin numbers for various kinds of plastic are shown in Table 1 [15]. In today's society, waste plastic disposal is a major issue. These plastic products impose drastic threats on the human being environment and sound us generally sand, stones and bitumen are conventionally used in the construction of flexible roads but the availability of this material is degrading day by day, and the by-product of crude oil (bitumen being used as a binding material proved to be costly and unfriendly to the environment. In this concern, scientists are trying to develop alternative materials for road construction. Pollution and disposal problems might be greatly minimized if these waste materials could be reused successfully in road construction. The possible use of these waste materials in the development of low-volume roads across the country may cause an increase in the economic rate of the country.

Recent research on the use of waste plastic in road construction has shown some promise in this regard. Modified bitumen is quickly becoming one of the most essential components of flexible road construction. Modified bitumen has improved characteristics for road construction, and waste plastic is used in this process to help reduce pollution.

This material is important to our future. Despite its use, poor management of plastic waste is a source of frustration. There is not a way to get rid of plastic waste. As a result, the plastic product must be recycled rather than ending up in landfills. These issues can be addressed by plastic recycling. As a result, one method of disposing of plastic waste as crumb rubber into the road for bitumen modification has evolved throughout time. The proper inclusion of such waste in bitumen enhances road quality, life, and reduces road construction costs. The objective of this study is to lessen the environmental problems caused by discarded plastic. The goal of this research is to improve marshal stability and flow value. This research also seeks to substitute plastic waste with bitumen to save roughly 10kg on road-building costs. Its objective is to establish how long it will be able to withstand weather conditions.

S.No.	Acronym	Description
1	PS	Polystyrene
2	PP	Polypropylene
3	LDPE	Low density polyethylene
4	PVC	Polyvinyl chloride
5	HDPE	High-density polyethylene
6	PETE	Polyethylene terephthalate
7	Others	Miscellaneous types of plastic

TABLE 1: Resin numbers for different types of plastic [15]

2 Experimental Procedure

Waste plastic bags were collected from roadways, garbage trucks, dumpsites, and compost plants, as well as rag pickers and waste buyers. Household plastic, such as empty milk bags and used plastic bags, was also collected for the project's work. The collected plastic waste was separated according to thickness requirements. For the next step, polyethylene with a micron size of 60 microns or less is usually utilized. Less micron plastic is easily mixed with the bitumen at higher temperatures (160°C-170°C). It can be de-dusted or washed if necessary. The collected plastic was cut into small pieces as much as possible. The plastic bits were sieved twice, once through a 4.75mm sieve and then again through a 2.36mm sieve. Bitumen was first heated to around 160°C-170°C, which is its melting temperature. Pieces were gently put to the heated bitumen, which was around 160-170°C. For around 20-30 minutes, the mixture was manually mixed. During that time, the temperature was maintained at around 160-170°C. Penetration, ductility, fire point, and flash point tests, softening point test, and Marshall Stability and flow value tests were all carried out using polymer-bitumen combinations of various compositions.

2.1 Raw Materials & Test Area

2.1.1 Bitumen

Bituminous materials, often known as asphalts, are widely utilized in road construction due to their outstanding binding and water-proofing properties, as well as their inexpensive cost. Bituminous materials include bitumen, a black or dark-colored solid, and viscous cementitious materials, which are mostly high molecular weight hydrocarbons produced from petroleum or natural asphalt distillation, have adhesive properties, and are soluble in carbon disulfide [16].

Bitumen modifiers are additives or mixtures of additives that can improve the characteristics of bitumen and bituminous blends. Modified bitumen is bitumen that has been treated with certain additives. Depending on the needs of extreme climate changes, polymer modified bitumen (PMB)/crumb rubber modified bitumen (CRMB) should be utilized exclusively in wearing courses. IRC: SP: 53-1999 contains the complete requirements for modified bitumen. It should be mentioned that the performance of PMB and CRMB is highly reliant on temperature control during construction. Bitumen of grade 60/70 for all conventional and modified mixes were used. Bitumen was in fresh condition with good color (black).

2.1.2 Aggregates

Aggregates were collected from Ring road Chowk, Peshawar KPK. The aggregate was 1 inch down. The nominal size of aggregate was 9mm (Type 2). Samples were taken in grams of aggregate for performing different tests. Different physical properties of coarse aggregate were found out and also performed gradation of NHA CLASS-B.

2.1.3 Waste Plastic

The word "plastic" originated from the Greek word "plastikos," which means "suited for molding." This refers to a material's malleability, or plasticity, throughout the manufacturing process, which allows it to be cast, pressed, or extruded into a variety of shapes, such as films, fibers, plates, tubes, bottles, boxes, and much more [17].
Waste plastic was collected from the local dumpsite and it is under pabbi TMA site which is composed of low-density polyethylene (LDPE) and high-density polyethylene (HDP) but this research is on LDPE so that's is why LDPE (waste shopping bags) were collected from the dumpsite.

2.2 Testing Procedure

Preliminary testing on bitumen and aggregates and principle tests are the two types of tests that were carried out.

2.2.1 Preliminary Tests on Bitumen

All preliminary testing is carried out in accordance with AASHTO guidelines. Penetration, flash and fire point, ductility, softening point, maximum specific gravity, and bulk specific gravity are all preliminary testing.

2.2.2 Principle Tests

The influence of plastic on the job mix formula (JMF) of bituminous concrete is evaluated using principle experiments.

Sample Preparation: Asphalt samples were created according to a predetermined gradation to determine Marshall Stability and flow in the Marshal Apparatus, as well as density measurement, as described later in the chapter. For modified asphalt samples, LDPE waste was substituted with bitumen acquired from a local dumpsite. Plastic was replaced with 3%, 6%, 9%, and 12% (by weight) with bitumen for sample replacement.

Following the calculations, 1200 gm of normal aggregate was used to produce a control sample, and the optimum binder content was determined. Asphalt mixes with various Bitumen content of (3.5, 4, 4.5, 5, and 5.5) % were prepared and evaluated. The optimum binder content for the control sample was determined to be 4

At 105°C, the aggregate was completely dry. The OBC-required amount of bitumen was collected and preheated in the oven. The aggregate, which included plastic, was heated to 160°C. Both the aggregate and the binding material were manually combined in the mixing pan until the aggregate was coated with the binding material. On a hot electric plate, a cleaned mold was pre-heated. Marshall Mold had a diameter of 10.16 cm and a height of 7.62 cm, as well as an extension collar and a base plate. The asphalt sample received 75 strikes from a specific hammer. The compaction hammer weighed 4.536 kilograms and had a height of 45.72 centimeters. The specimen in the mold was flipped over and 75 blows were delivered on the opposite side. After that, the asphalt sample was carefully removed from the mold and set on a level surface to cool. The sample was then stored at room temperature for 24 hours. The sample was subsequently evaluated in a marshal stability device after 24 hours. This study used a total of 90 samples that were prepared and evaluated, with three samples prepared for each percentage, and then took its average.

Marshall Stability & Flow Test (AASHTO T-245): The maximum load supported by the bituminous mixture when force is applied at a rate of 5.08 cm/minute is known as its stability. Mix's loading is raised until it reaches its maximum value. When the load stops increasing, the peak value is recorded and the load is discharged. During the application of the loading flows, the asphalt mixes. A dial gauge is used to record the plastic flow in 0.25mm increments. The load was applied at a regular rate during the Marshall testing. For each mixture, the maximum load and flow were measured.

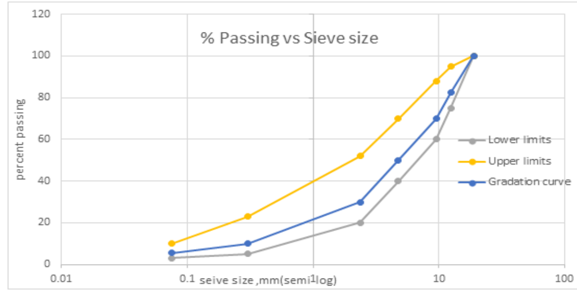

Fig. 1: Gradation curve of NHA Class-B

3 Test Results & Analysis

3.1 Results & Analysis of Preliminary Tests on Bitumen

According to the findings of the grade penetration test, bitumen of grade 60/70 is appropriate for the test area of Nowshera Industrial State, Bara Banda, Nowshera, KPK. The preliminary test results for the selected bitumen are listed in Table 2. The softening point test, flash and fire point test, ductility test (in terms of rupture distance), average maximum specific gravity, and average bulk specific gravity of bitumen tests all confirmed that the selected bitumen was grade 60/70.

3.2 Results & Analysis of Preliminary Tests on Aggregates

According to the findings of the sieve analysis, the aggregates of class B are suitable for the test area of Ring Road in Peshawar, KPK. The preliminary test results for the selected aggregates are listed in Table 3. The findings of the aggregates tests for specific gravity, water absorption, Los Angeles Abrasion, impact value, and crushing value all corresponded to the class B of the chosen aggregates.

3.3 Results & Analysis of Sieve Analysis of Class B Aggregates

For aggregate gradation, National Highway Authority (NHA) class B standards were utilized, as well as NHA (2017) specifications for dense graded surfaces. According to this, the aggregate's nominal maximum size is 19mm. The chosen mix is displayed in Table 4 and the gradation curve is shown in Figure 1.

3.4 Results & Analysis of Principle Tests

The optimum asphalt content of bitumen as determined by Marshall Mix design was 4.30%, 4.35%, 4.42%, and 4.50%. Asphalt mixtures were prepared by mixing aggregates with binder samples at optimum

SNO	Test Description	Specification	Conventional Bitumen	Modify Bitumen (12%)	Recommended Range
1	Softening Point	ASTM D36-06	49°C	80°C	47 min
2	Flash and Fire Point	ASTM D 92	321°C	338°C	250 min
3	Penetration	ASTM D5	68 mm	54 mm	60-70
4	Ductility	ASTM D113	100+	100+	>100

TABLE 2: Summary of results of bitumen tests

S.No.	Test Description	Specification	Results (%)	Recommended Range
1	Fractured particles	ASTM D5821	100	90% (min)
2	Flakiness	ASTM D4791	5	10% (max)
3	Elongation	ASTM D4791	08	10% (max)
4	Los angles abrasion	ASTM C131	15	15% (max)
5	Water absorption	ASTM C127	1.02	2% (max)

TABLE 3: Summary of results of aggregates tests

Sieve size	Sieve Power 0.45 Gradation	NHA Class-B Specification Ranges		Retained Percent	Percent Passing for Selected Blend
		Lower	Upper		
3/8	3.76	100	100	0.00	100
½	3.12	75	90	17.50	82.5
¾	2.75	60	80	12.50	70
#4	2.02	40	60	20	50
#8	1.47	20	40	20	30
#50	0.58	5	15	20	10
#200	0.31	3	8	4.50	5.5
Pan				5.5	

TABLE 4: NHA Specification (Class-B)

binder content (OBC). The trial mixes were prepared by using a standard hammer of 4.5 lbs weight. The trial mixes were subjected to 75 blows and an 18-inch height of fall was maintained during preparation.

To achieve consistent results, modified asphalt mixtures. In all types of mixtures, three different percentages of modified plastic bitumen and conventional bitumen (0, 3 percent, 6%, and 9% by weight of bitumen) were employed, as well as four different bitumen contents (4.30 percent, 4.35 percent, 4.42 and 4.5 percent).

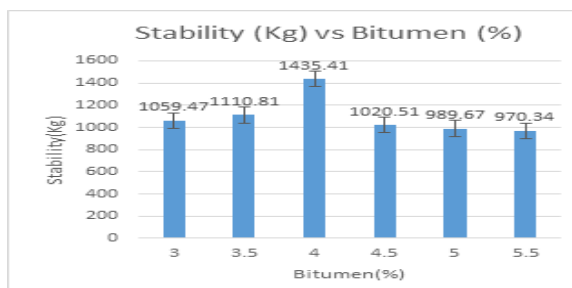

Fig. 2: Conventional mix stability vs. Bitumen

3.4.1 Conventional Bitumen Stability Vs. Bitumen Graph

Marshall Stability curves: For Marshall Specimens, the graphical representation of the stability curve for variation in the percent of plastic at optimum bitumen content. At 12% plastic, the highest stability obtained in plastic specimens is 1611.5 Kg.

>Marshall Stability Curves: The increase in stability value as the plastic percentage is increased might be attributed to a reduction in the percent air spaces in the specimen, which is required for a bituminous mix design. At the optimum content of bitumen, bituminous mixtures with different percentages of plastic exhibited maximum stability of 1611.5 at 12 percent, with an ascending trend up to 12 percent.

Marshall Flow value curves (mm): For Marshall Specimens, the graphical illustration of the flow value curve for variation in the percent of plastic at optimum bitumen content. The flow value increased, and the flow curve generally follows a linear trend as bitumen content increases. The flow value was increasing, however, the proportion of air voids produced was reducing as the plastic was increased.

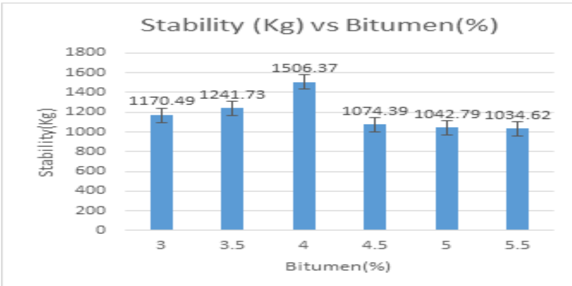

Fig. 3: Plastic modify mix stability vs. Bitumen

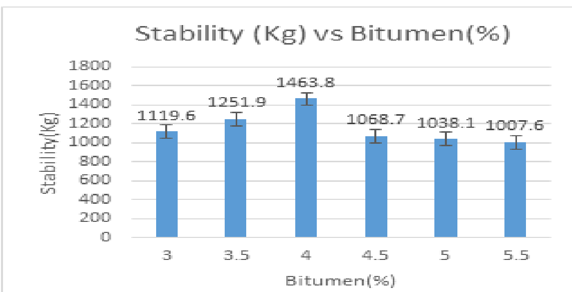

Fig. 4: 6% plastic modify mix stability vs. Bitumen

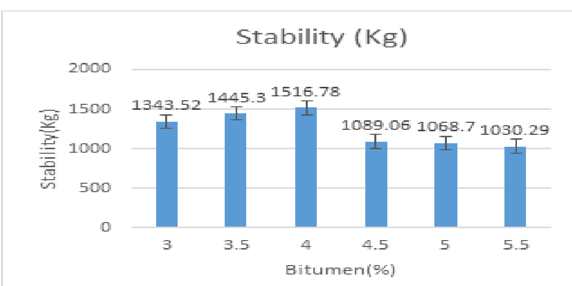

Fig. 5: 9% plastic modify mix stability vs. Bitumen

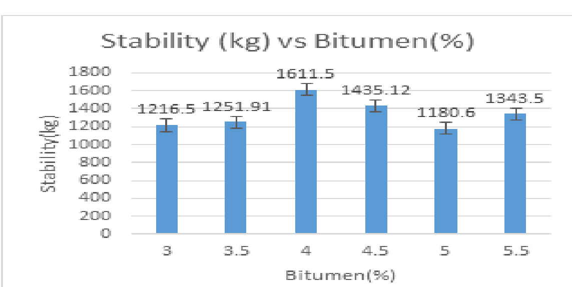

Fig. 6: 12% plastic modify mix stability vs. Bitumen

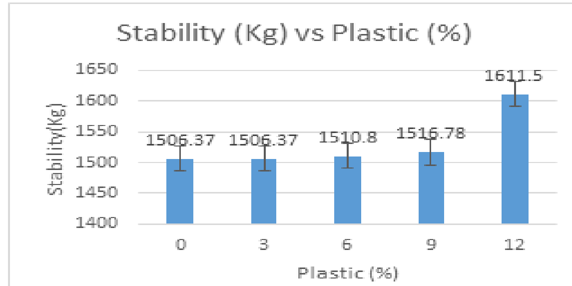

Fig. 7: Stability (Kg) vs. Plastic (%)

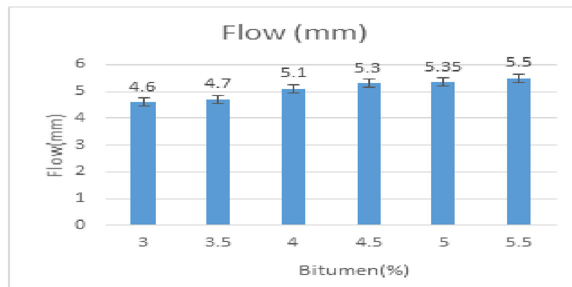

Fig. 8: Conventional mix flow vs. Bitumen

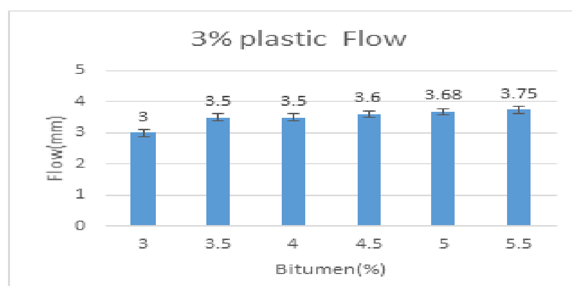

Fig. 9: 3% plastic modify mix flow vs. Bitumen

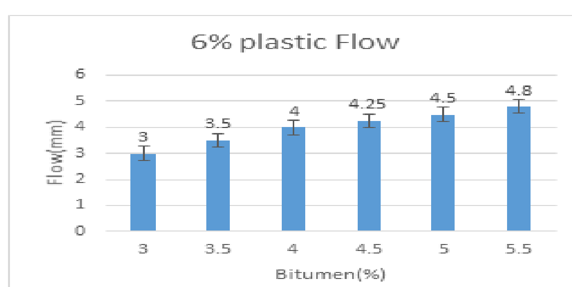

Fig. 10: 6% plastic modify mix flow vs. Bitumen

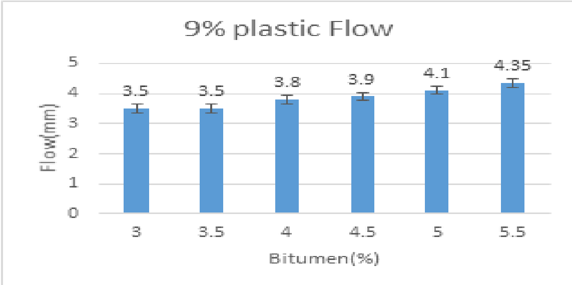

Fig. 11: 9% plastic modify mix flow vs. Bitumen

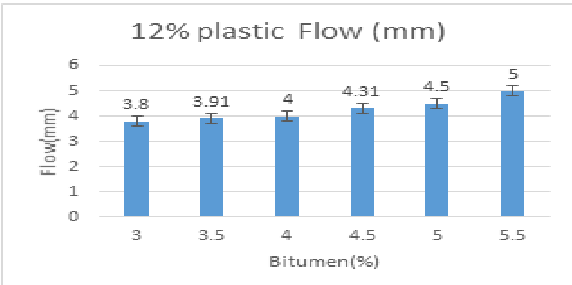

Fig. 12: 12% plastic modify mix flow vs. Bitumen

4 Density of Asphalt Samples

The theoretical maximum density of Trail Mix was calculated. In graphs 13-18, the average results of conventional and modified mixtures are shown. The increasing percentage of plastic in the asphalt mix results in a lesser density of asphalt mix. It is very much evident from the comparison that as the plastic content is increasing the density is decreasing as shown in the graphs. The density at 12% is less as compared to conventional samples.

5 Cost Estimation and Economy Incorporated

5.1 Cost Estimation

In the wet process, waste plastic is used to modify bitumen, whereas, in the dry process, waste plastic is utilized to cover aggregates. Waste plastic collection

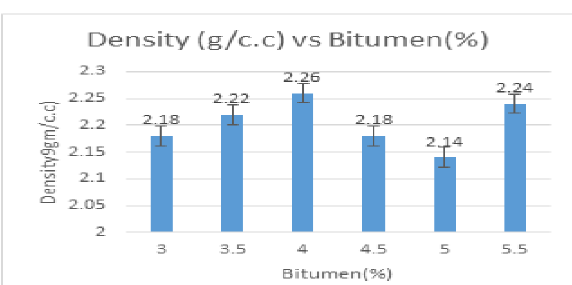

Fig. 13: Conventional mix density vs. Bitumen

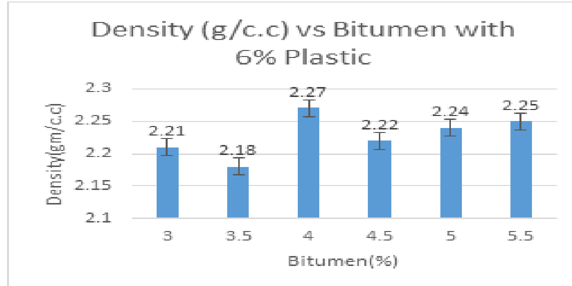

Fig. 14: 3% plastic modify mix density vs. Bitumen

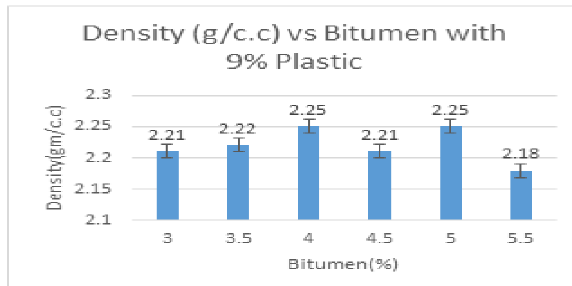

Fig. 15: 6% plastic modify mix density vs. Bitumen

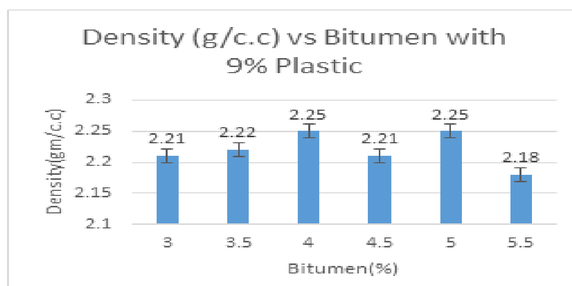

Fig. 16: 9% plastic modify mix density vs. Bitumen

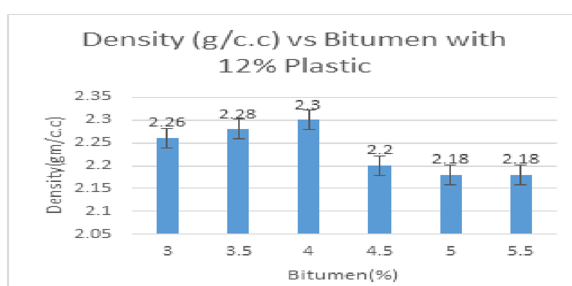

Fig. 17: 12% Plastic modify mix density vs. Bitumen

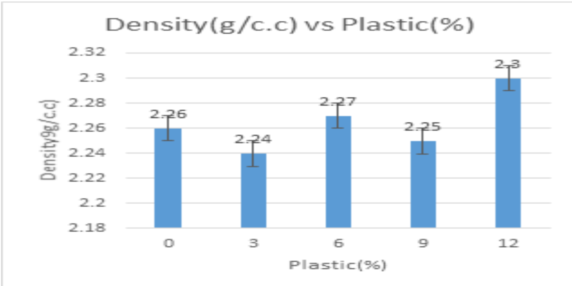

Fig. 18: Density (g/c.c) vs. plastic (%)

in Pakistan is normally done by a large network of persons participating at various levels. As a result, there is a distinct economy there.

Roads, on the other hand, are more widely utilized than any other method of transportation, including trains, planes, and canals, and are the most convenient and economical routes of transportation. However, the condition of the roadways is deteriorating daily. As the availability of new technology grows, so does the expense of upgrading. Natural resources are being depleted. As a result, any strategies for increasing road conditions while also saving money are welcome. Bitumen and aggregates are examples of natural resources that are required. The use of this innovative technology for road improvement has shown to be both beneficial and economical, saving thousands of billions of rupees. With the state and quality of roads deteriorating by the day, there are several chances for road improvement, both in terms of quality and cost-effectiveness. Some of the information about road construction are given below.

- Assuming the cost of plastic waste (collection, segregation, and processing) = Rs. 5 per Kg
- Bitumen cost per drum (200 kg) = Rs.20000
- Bitumen cost per kg = Rs.100
- Bitumen cost per ton = Rs.100, 000
- In Pakistan, roads are usually built with a standard width of 3.75 meters.
- Consider 1 Km length road
- It takes 10 tons of bitumen to pave one kilometre of road,
- Bitumen cost per km = Rs.1, 000,000
- According to the test results in the literature studied, the optimum percentage of bitumen plastic is about 10% (By percent wt of bitumen)
- Total quantity of bitumen required = 9 tons
- Total quantity of bitumen required = 1 ton
- Bitumen cost for 9 tons = Rs. 900,000
- Plastic Waste Costs = Rs. 5,000
- Total cost of bitumen and plastic = Rs.905, 000
- Total savings = 1,000,000 – 905, 000 =Rs. 95,000 per Km

$$\%Saving = \frac{95000}{1000000} * 100 = 9.5\% \quad (1)$$

6 Results & Discussion

The penetration value dropped as the percentage of polymer increased. This illustrates that polymer enhances the hardness of bitumen. The penetration values of the blends decrease as the percentage of polymers and the kind of polymer utilized increases. Bitumen's ductility was reduced when plastic waste was added to it. Polymer molecules reacting with bitumen might be causing ductility loss. The flash and fire points increased as the amount of polymer increased. A polymer bitumen blend road surface is less susceptible to fire. This indicates that the blend is more water-resistant. This might be due to the improved binding properties of the polymer bitumen mix. The softening point of the bitumen was improved by adding plastic waste. As the proportion of plastic waste added increases, the softening point increases. The chemical composition of the polymers introduced may have an impact on the softening point. There will be less bleeding throughout the summer because the softening point has increased. On the one hand, bleeding causes higher friction for moving cars, while on the other hand, bleeding causes slippery conditions when it rains. The polymer-bitumen combination significantly reduces both of these negative situations.

7 Conclusion

The following conclusions were drawn after completing a detailed laboratory experiment on aggregates and bitumen with and without combining polymers.

- The properties of the bituminous concrete mixture can be increased even more by including waste plastic.
- Use of waste plastic the addition of 12% by weight of aggregate to bituminous mixes improves their volumetric properties, resulting in better performance of bituminous concrete mixture with plastic waste than the control mix (without plastic waste).
- The modified bitumen has a lower penetration value and a higher softening point than regular bitumen.
- The penetration and ductility of the bitumen binder will be reduced by using plastic.
- Plastic increased the melting point of the bitumen hence enabling the asphalt to sustain higher temperatures

- Plastic roads would be a blessing for Pakistan's hot and humid climate, as they would be long-lasting and environmentally friendly, allowing the earth to be free of all types of plastic waste.
- It helps to save the bitumen hence significantly reducing the overall cost
- Modified bitumen is a preventative measure that will eventually lead to a cure. In the long term, it will save us millions of rupees.
- The cost of bitumen is reduced by 9.5%. This modest investigation not only makes good use of waste non-biodegradable plastics, but it also gives us a better pavement with greater strength and a longer lifespan.

8 Recommendations

- Some additional key steps must be considered to refine and to further enhance the research work
- Superpave mix design method must be used to explore the limitations of the MBP
- Those lab tests must be conducted that gives a close indication of its field performance In light of the findings, it is recommended that the reuse of plastic waste be encouraged since this would reduce the pressure on landfills and conserve our important agricultural land.

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