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Study of Characteristics of Bitumen and Aggregate with Use of Plastic Waste

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Abstract

Plastic is everywhere and its use in different forms is increasing day by day despite of discouragement from government. Plastic waste disposal is a global issue since they are non-biodegradable and toxic in burning. Plastic pollution threatens food quality, human health, sanitation, eco-system and contributes to climate change. The usage of plastic waste in elements (bitumen and aggregate) used in road construction was the main objective of this study. With use of appropriate plastic waste in building of road would not only reduce material cost but also contributes in solving plastic waste management issue. Nepal being a developing country with low Gross Domestic Product (GDP) where most of the districts are still deprived of good flexible pavement networks, plastic modified roads could be a value engineering and economic solution. The paper highlights by which method plastic waste can be used effectively in road construction by performing different experimental tests reflecting the characteristics of bitumen and aggregate on addition of plastic. The study has determined the penetration, softening point, ductility values of bitumen and impact and abrasion values of aggregate in addition to different percentage of plastic waste. According to the study, bitumen's penetration and ductility value drop with increasing plastic content, making it better suited for usage in warmer climates, but its softening point rises, ensuring a stronger resistance to flow in services. Comparably, when in aggregate plastic content rises, both its AIV value and its LA abrasion value fall, enhancing the aggregate's toughness and ability to endure greater wear and tear.

Keywords: Plastic, Bitumen, Aggregate, Penetration, Softening point, Ductility, Toughness, Abrasion, Plastic Modified Bitumen (PMB), Plastic Modified Aggregate (PMA)

1. Introduction

According to research conducted in Kathmandu, Nepal, approximately 4,700,000 to 4,800,000 plastic bags are used daily in the city, contributing to the 16 percent of urban waste comprised of plastic, equivalent to 2.7 tons of daily plastic garbage production (Molden, Julliand and Johannessen, 2018). This immense plastic waste issue is not limited to Kathmandu but has global consequences, with an estimated 9.1 billion tons of plastic produced by humans so far, much of which negatively impacts nature, ecosystems, and living beings (Molden, Julliand and Johannessen, 2018). Compounding the problem is the fact that plastic takes an estimated 500 years to biodegrade, posing long-lasting environmental challenges and affecting future generations (Molden, Julliand and Johannessen, 2018). Additionally, a significant amount of plastic waste enters river systems and ultimately finds its way into the global ocean ecology, exacerbating the global ecological crisis (Molden, Julliand and Johannessen, 2018). Considering the state of the world today, even if plastic consumption is becoming unhealthy for both the present the next generation, it cannot be fully prohibited (Ayalon et al., 2009). However, the use of plastic in pavement construction is becoming more and more popular nowadays since it performs better than regular pavement and can be used to recycle plastic trash, which was once thought to be a threat to environmental health (Devi, Stephen and Mini, 2013). Plastic waste that consists of only Low-Density Polyethylene (LDPE) [carry bags, sacks, milk pouches, bin lining, cosmetic and detergent bottles] or High-Density Polyethylene (HDPE) [carry bags, bottle caps, household articles etc.] or Polyethylene Terephthalate (PET) [drinking water bottles, food packaging] could be used in road construction (Ministry of Railways GOI, 2019). PET type i.e., drinking water bottles were used in our study. For Nepal, the plastic road would be beneficial. Durable and environmentally friendly plastic roads are

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of greatest benefits in hot, severely humid climates (Singh and Yadav, 2016). Additionally, this will assist in reducing the amount of plastic trash in our country and world, leading to decrease in the global carbon footprint and controlling global warming.

2. Research Questions

At the end of this study answers to following questions were expected:

- Will the use of plastic waste in bitumen and aggregate be effective?
- How will the usage of plastic affect the physical properties of bitumen?
- How will the usage of plastic affect the physical properties of aggregate?

3. Research Objective

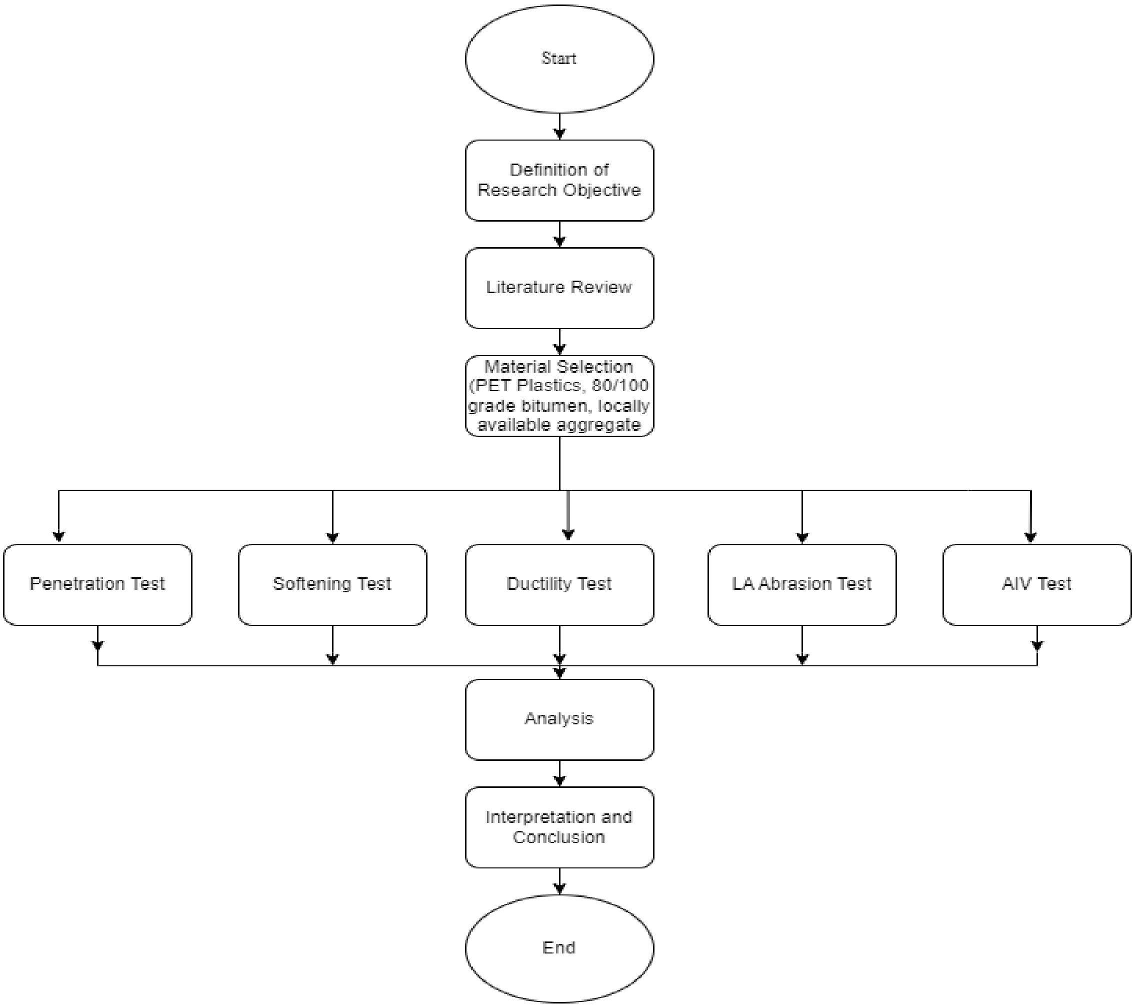
The main objective of this research is to study the change in physical characteristics of two important components used in road construction, namely bitumen and aggregate, when a particular amount of plastic trash is added to them.

4. Literature Review

Various papers and literature were reviewed regarding the use and characteristics of plastic modified bitumen and aggregate. Tunde, Alaro and Adewale, (2020) developed models for the trend of variation of the classification, strength and safety compliance properties with respect to increasing percentage of Polyethylene Terephthalate (PET). Reclaimed asphalt pavement is the material that is milled or removed from an existing asphalt pavement and then recycled for use in new asphalt mixes. Giustozzi et al., (2015) compared properties of polymer-modified hot mix asphalt with fiber-reinforced warm-mix asphalts with high amount of Reclaimed asphalt pavement (RAP). Use of plastics in asphalt mix not only reduces the amount of plastic waste ending up in the landfills but also it enhances the properties of the pavement mix. A study by (E. Ashouri Taziani E. Toraldo and Giustozzi, 2017; Behnood and Modiri Gharehveran, 2019) concluded that the use of plastic modified bitumen binder increases the rut resistance of the asphalt. Study by (Abdullah et al., 2017) states that the PET waste proportions of 8%, 10% by weight of bitumen content were found to be more resistant to deformation than conventional sample. Study by (M. S., Ahmad and S.A., Ahmad, 2022) concludes that addition of 8% plastic has the highest resilient modulus, creep modulus and overall highest value properties of asphalt mixture. Study by (Hake, Damgir and Awsarmal, 2020) claims that replacing certain % volume of bitumen and aggregate by plastic waste would reduce project cost and plastic being sound insulator would minimize the noise pollution of traffic roads (Kumar and Allah Khan, 2020). But using plastic wastes in asphalt mix also comes with its own problems and challenges. Other studies have highlighted several challenges with use of plastic-modified bitumen binder in asphalt concrete. Plastic is a persistent material and plastic contamination in the environment is a topic of growing concerns. Studies by (Järlskog et al., 2020; Pramanik et al., 2020) have identified contamination of stormwater and groundwater by microplastic due to use of plastic modified asphalt. RAP makes use of fact that asphalt concrete is reusable and recyclable, but the study by (Rodríguez-Fernández et al., 2020) points out that the current 100% recyclability of asphalt could be hindered by the addition of waste material. Our study aims to bridge the research gap that exists in comparison of the rheological properties including softening point, penetration, ductility, LA abrasion, AIV value test, of locally used bitumen and aggregate in the Kathmandu valley, due to varying percentage of plastic wastes (PET).

5. Methodology

Experimental research design was employed to study the change in characteristics and behavior of bitumen and aggregate on addition of plastic. Various tests that define the physical properties of bitumen and aggregate were carried out experimentally in laboratory. The work flow of the study is as shown in Figure 1.



5.1. Materials Used

Following materials were used in our study:

- Bitumen (Grade = 80/100)
  Bitumen of grade 80/100 being normally used in road construction of Kathmandu valley was used in our study which was obtained from local construction material suppliers.
- Aggregate
  Aggregates used normally in road construction meeting the specifications of SSRBW, DOR (Standard Specifications for Road and Bridge Works) were used in our study which were obtained from local construction material suppliers.
- Plastic waste: Used drinking water bottles

Polyethylene Terephthalate (PET) type plastic i.e., used drinking water bottles were used which were collected from home, college and restaurants as shown in Figure 2. As seen in Figure 3, these bottles were cut into small pieces (approximately 1cm*1cm) for PMB and 2.36 to 4.75mm for PMA according to (Ma et al., 2021), to facilitate simple mixing with bitumen and aggregate.

Figure 2. Used Plastic Bottles

5.2. Plastic Modified Bitumen (PMB)

Firstly, the used water bottles were cut in small pieces. The bitumen was thus heated not more than (120 to 140) ºC and pieces of plastics were added to bitumen by its weight and stirred well with the help of mechanical stirrer until the temperature reached 260ºC according to (Ma et al., 2021). The plastic should be mixed well without any solid residue left. Similarly, the samples with 0%, 2%, 4%, 6%, 8%, 10% plastic were prepared and following tests were performed in plastic modified bitumen:

- Penetration Test
- Softening Test
- Ductility test

All above tests were performed following the guidelines of IS: 1201 – 1978 to IS: 1220 – 1978.

5.3 Plastic Modified Aggregate (PMA)

Firstly, the used water bottles were cut in small pieces of size 2.36 to 4.75mm. The aggregate was thus heated and pieces of plastics were added to hot aggregate by its weight and stirred well with the help of mechanical stirrer until 260℃. The plastic should be mixed well around the aggregate surface uniformly. Similarly, the samples with 0%, 0.5% and 1% plastic were prepared (as greater amount of aggregate is required to perform its test less percentage by weight of plastic were used in this case) and following tests were performed in plastic modified aggregate:

- LOS Angeles Abrasion (LAA) Test
- Aggregate Impact Value (AIV) Test

All above tests were performed following the guidelines of Indian Standard CODE IS 2386 (Part IV) – 1963.

6. **Result and Discussions**

The experimental test findings of PMB and PMA are summarized below:

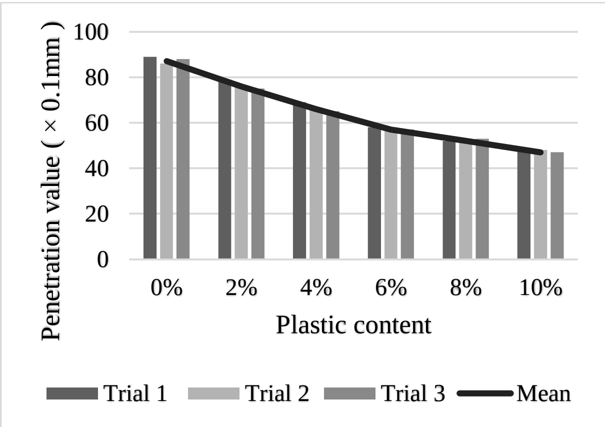
6.1. Penetration Test

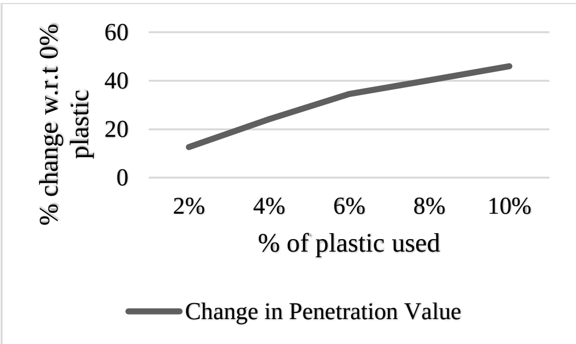
It measures the grade or hardness of the bitumen by measuring the depth in tenths of millimeter will penetrate vertically in five seconds. The data obtained from penetration test of bitumen at various plastic content is shown in Table 1.

Table 1. Penetration value at various plastic content

Plastic Content	Penetration Value (× 0.1 mm)			
	Trial 1	Trial 2	Trial 3	Mean
0%	89	86	88	87
2%	79	76	75	76
4%	69	66	65	66
6%	58	58	57	57
8%	52	53	53	52
10%	48	48	47	47

The mean of three trials of penetration value for each 0%, 2%, 4%, 6%, 8% and 10% plastic content are obtained as 87, 76, 66, 57, 52 and 47 respectively which is in decreasing order. The One – Way ANOVA test from R software was carried out and the F Statistic was determined to be 352.67 with P-value of 1.031 e-10, signifying the penetration value of the PMB decreases with increase in plastic content as illustrated in Figure 3 and Figure 4 shows the change in penetration value with respect to 0% plastic content.





Hardness of bitumen is increased with increase in plastic content as penetration value decreases by 12.64%, 24.14%, 34.48%, 40.23% and 45.97% accordingly for 2%, 4%, 6%, 8%, 10% plastic compared to 0% plastic as illustrated in Figure 4. According to Indian Standards the 0% bitumen sample falls in A90 and S90 bitumen grade with 10% bitumen sample falls in A45 and S45 bitumen grade with others in between suggesting addition of plastic waste makes PMB stiffer and more suitable to use in warmer places.

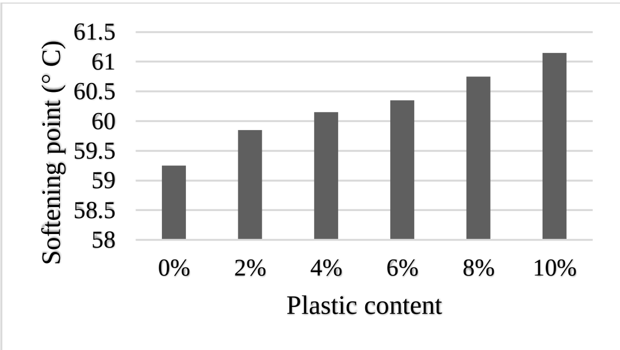
6.2. Softening Test

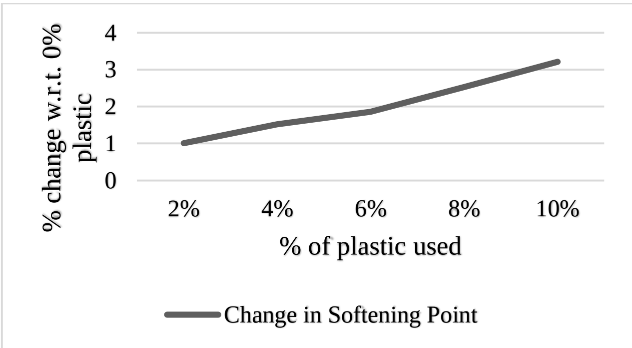
It measures the consistency of bitumen. This test shows the temperature at which bitumen attains certain viscosity. It is usually determined using ring and ball apparatus. As the temperature rises, bitumen starts to soft, and attains certain fluidity sufficient enough to be applied on the road surface. The data obtained from softening test of bitumen at various plastic content is shown is Table 2.

Table 2. Softening Point at Various Plastic Content

Plastic Content	Softening Point (° C)		
	Trial 1	Trial 2	Mean
0%	59.2	59.3	59.25
2%	59.8	59.9	59.85
4%	60.1	60.2	60.15
6%	60.3	60.4	60.35
8%	60.7	60.8	60.75
10%	61.1	61.2	61.15

The mean of softening point for each 0%, 2%, 4%, 6%, 8% and 10% plastic content are obtained as 59.25° C, 59.85° C, 60.15° C, 60.35° C, 60.75° C and 61.15° C respectively which is in increasing order. The One – Way ANOVA test from R software was carried out and the F Statistic was determined to be 537.6 with P-value of 1.12 e-13 signifying the softening point of the PMB increases with increase in plastic content as illustrated in Figure 5 and Figure 6 shows the change in softening point with respect to 0% plastic content. According to (IS 73:2013), all the bitumen samples fall on the VG-40 Bitumen viscosity grade.





Softening point of bitumen is increased with increase in plastic content by 1.01%, 1.52%, 1.86%, 2.53% and 3.21% accordingly for 2%, 4%, 6%, 8%, 10% plastic compared to 0% plastic as shown in Figure 6. Addition of plastic shows a mild increase in softening value of bitumen from 59.25° C at 0% plastic content to 61.15° C at 10 % plastic content and with increase in softening point temperature susceptibility decreases ensuring higher resistance to flow in services.

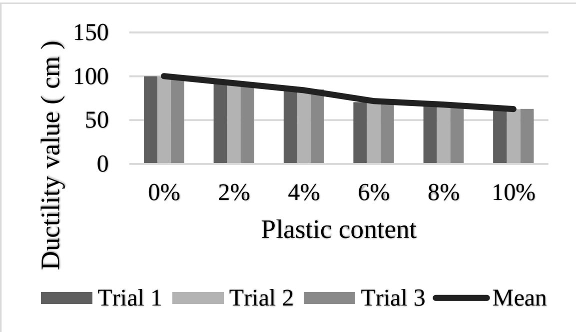
6.3. Ductility Test

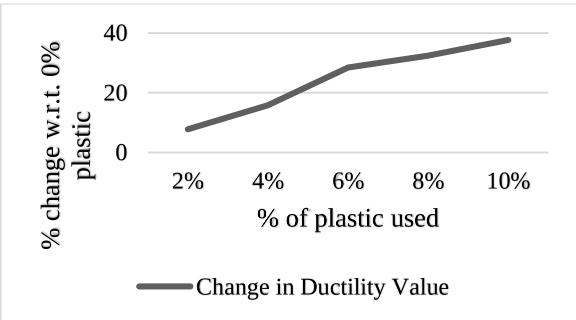
It measures adhesive property of bitumen and its ability to stretch. Ductility test on bitumen measures the distance in centimeters to which it elongates before breaking when two ends of standard briquette specimen of material are pulled apart at a specified speed and specified temperature. The data obtained from ductility test of bitumen at various plastic content is shown is Table 3.

Table 3. Ductility value for varying plastic content

Plastic Content	Ductility Value (cm)			
	Trial 1	Trial 2	Trial 3	Mean
0%	100	100	100	100
2%	91.2	92.6	92.8	92.2
4%	83.8	84.1	84.8	84.2
6%	70.5	71.8	72.6	71.6
8%	66.2	67.9	68.8	67.6
10%	62.1	62.5	62.6	62.4

The mean of ductility value for each 0%, 2%, 4%, 6%, 8% and 10% plastic content are obtained as 100cm, 92.2cm, 84.2cm, 71.6cm, 67.6cm and 62.4cm respectively which is in decreasing order. The One – Way ANOVA test from R software was carried out and the F Statistic was determined to be 998.96 with P-value of 2.887 e-15 signifying the ductility value of the PMB decreases with increase in plastic content as illustrated in Figure 7 and Figure 8 shows the change in ductility value with respect to 0% plastic content.





Ductility of bitumen is decreased with increase in plastic content by 7.8%, 15.8%, 28.4%, 32.4% and 37.6% accordingly for 2%, 4%, 6%, 8%, 10% plastic compared to 0% plastic as illustrated in Figure 8. Significant reduction in ductility value is seen on addition of polymer to the binder i.e., ductility decreases by 37.6% on 10 % of plastic addition thus higher PMB having less ductility can be used in hot climate.

6.4. LOS Angeles Abrasion (LAA) Test

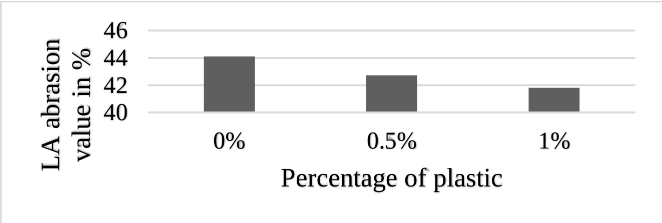
The Los Angeles Abrasion Test is widely used as an indicator of the relative quality of aggregates. It measures the degradation of standard gradings of aggregates when subjected to abrasion and impact in a rotating steel drum with an abrasive charge of steel balls. 5 kg of the sample was taken for grading B and the abrasive charge was chosen as per IS: 2386 (PART IV) - 1963 (4) i.e., 11 number of steel balls for Grading B.

$$\text{LA Abrasion Value}=\frac{W1-W2}{W1}\times 100 \qquad \text{(Equation 1)}$$

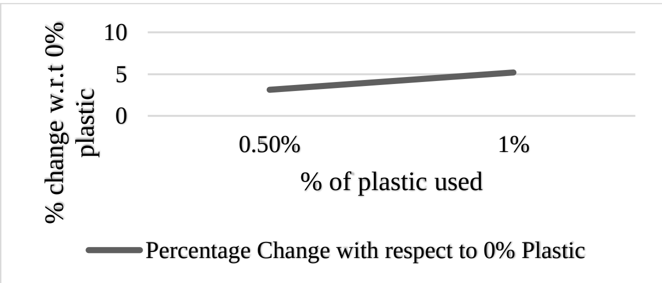
where,
W1= Original weight of the sample in gm, W2= Weight of aggregate retained on 1.70mm IS sieve in gm
Loss of weight= (W1-W2)
The data obtained from LA abrasion test of aggregate at various plastic content is shown is Table 4.

Table 4. LA Abrasion value for varying plastic content

Plastic Content	W1 (gm)	W2 (gm)	LA Abrasion Value in %	% change w.r.t 0% plastic
0%	5000	2796	44.10	-
0.5%	5000	2864	42.72	3.13
1%	5000	2910	41.80	5.22



The mean of LA abrasion value for each 0%, 0.5% and 1% plastic content are obtained as 44.10%, 42.72% and 41.80% respectively which is in decreasing order signifying the abrasion value of the PMA decreases with increase in plastic content as illustrated in Figure 9 and Figure 10 shows the change in LA abrasion value with respect to 0% plastic content. According to (AASTHO, 2019), aggregate with LA values given in Table 4 all being ≤ 50% can be used in base course layer of flexible pavement.



The LA abrasion value for 0% plastic is 44.10% which decreased to 42.72% and 41.80% for 0.5% and 1% plastic addition. This means only 42.72% and 41.80% of test aggregate is affected by the abrasive action in LA machine which was previously 44.10% in original sample indicating PMA can withstand more wear and tear due to friction and environmental changes as well as vehicular motion compared to normal aggregate.

6.5. Aggregate Impact Value (AIV) Test

The aggregate impact test value is a measure of resistance to sudden impact or shock, which may vary from its resistance to gradually applied compressive load. The Aggregate impact value (AIV) was calculated as:

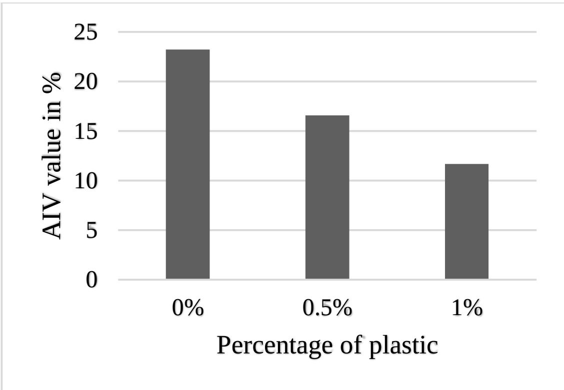
$$\text{AIV} = \frac{W2}{W1} \times 100 \qquad \text{(Equation 2)}$$

Plastic Content	W1 (gm)	W2 (gm)	AIV Value in %	% change w.r.t 0% plastic
0%	336	78	23.21	-
0.5%	326	54	16.56	28.65
1%	326	38	11.65	49.81

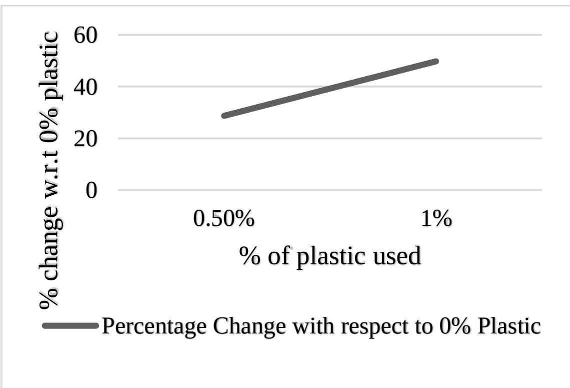
where,
W1= Net weight of test sample, W2 = Net weight of sample passing 2.36 mm IS Sieve

The data obtained from AIV test of aggregate at various plastic content is shown is Table 5.

Table 5. AIV value for varying plastic content



The mean of AIV value for each 0%, 0.5% and 1% plastic content are obtained as 23.21%, 16.56% and 11.65% respectively which is in decreasing order signifying the AIV value of the PMA decreases with increase in plastic content as illustrated in Figure 11 and Figure 12 shows the change in AIV value with respect to 0% plastic content.



AIV value of control specimen was 23.214%. It reduced to 16.564% for 0.5% plastic and 11.656% for 1% plastic. According to standards in (AASTHO, 2019), the 0% plastic content sample having AIV < 30% is acceptable to use in wearing course whereas the 0.5% and 1% sample AIV being >10% and ≤20% lies is very strong category. This shows that the toughness of the aggregate was increased to face the impact on use of plastic.

7. Conclusion

Based on the results obtained from laboratory tests with varying proportion of plastic waste it can be concluded that with the use of plastic waste in bitumen, its penetration value decreases, making it harder and stiffer than the non-modified bitumen, and a lower penetration grade makes PMB less susceptible to softening in warmer temperatures. Similarly, the softening point of PMB rises, making it more suitable to be used in warmer places, and the increase in softening point decreases the temperature susceptibility, indicating improved resistance to thermal cracking. Furthermore, the addition of polymers to bitumen also makes it more ductile, which contributes to better resistance against rutting, which is the formation of depressions in pavement surfaces due to repeated traffic loads. In the case of aggregate, the use of plastic decreases its AIV value, enhancing its resistance to sudden shocks and impacts of wheel load in pavement making PMA more stable and resilient construction material to be used in places with heavy traffic loads. The decrease of LA abrasion value of PMA makes it more resistant to abrasion indicating better durability over time, enhanced strength and improved wear resistance.

The PMA can be used in different layers of pavement i.e. base, subbase and surface layer. The PMB can be used in the surface layer of the flexible pavement. PMB could be used in layers like prime coat and tack coat but further tests should be done to determine the effect of plastics on binding capacity and water resistance of the bitumen binder.

The use of plastic waste in bitumen and aggregate is effective in terms of enhancing their physical characteristics but in terms of strength, cost and optimum quantity of plastic waste to be used in construction additional study and research is further needed.

8. Limitations and Future Studies

Some limitations of our study and suggestions for future studies are:

- The study only focuses on the potential use of PMA and PMB in flexible pavement, but future studies are necessary to determine its potential use in rigid pavement.
- Only 3 tests for PMB and 2 tests for PMA were performed which is insufficient to fully suggest its use in modern road construction. Further tests like Marshall Stability tests are recommended for future studies.
- Statistical significance test of the result for PMB were carried out but for PMA they could not be performed due to low sample sizes (Sample size of 1), using larger sample size and performing statistical significance test of the result is suggested for future studies.

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