

Use of Plastic Waste in Bituminous Concrete

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ABSTRACT: The situation of the present way of life makes a complete restriction on the utilization of waste plastic impossible, despite the fact that waste plastic poses a serious threat to both present and future generations. Waste plastics, littered by both domestic and industrial sectors, were found to be a source of raw material for flexible pavements. Waste plastics, mainly used for packing, are made up of PE, PP and PS; their softening point varies between 110°C and 140°C and they do not produce any toxic gases during softening. Bituminous mixes are most commonly used for road pavements. With the increase in traffic volume, bituminous road pavements are expected to provide more strength. The use of waste polyethylene for road construction as a partial replacement of bitumen can increase the strength of flexible pavement and will also be beneficial for the environment. In the present work, procedures were developed to utilize plastic waste in pavement design. LDPE plastics from carry bags were utilized in blends for experimental work. Plastic content of 5%, 10%, and 15% was used as substitution of bitumen. This project focused on increasing the Marshall Stability using LDPE plastic waste. The results show that 10% LDPE plastic content gives the maximum Marshall Stability of 16.68 kN. Subsequently, it is an efficient and environmentally advantageous approach for development of plastic blend bituminous pavement.

KEYWORDS: Bituminous Concrete, LDPE Plastic Waste, Marshall Stability, Marshall Flow, Flexible Pavement, Dry Process.

I. INTRODUCTION

Plastic is the most widely used material in the present times. It is light in weight, moisture resistant, flexible, and very inexpensive. These qualities increase our propensity towards plastic, hence making its use very common. Today, plastic is used in every vital sector of the economy, ranging from agriculture to automobile, electronics, construction, etc. But this plastic ultimately becomes waste. It forms the major portion of the total municipal solid waste (MSW). Tons of plastic wastes which include polyethylene's, cups, bags, etc. are discarded every year, polluting land, rivers, seas, and oceans. Plastic is a non-biodegradable material, and it has been found that it can remain on earth for about 4500 years without showing any signs of degradation.

It is estimated that approximately 10 thousand tons per day (TPD) of plastic waste is generated, i.e., 9% of 1.20 lacs TPD of MSW in India. The plastic waste constitutes two major categories: (i) Thermoplastics and (ii) Thermosetting plastics. Thermoplastics constitute 80% and thermosetting constitutes approximately 20% of total post-consumer plastic waste generated in India. The thermoplastics are recyclable plastics which include Polyethylene Terephthalate (PET), Low Density Polyethylene (LDPE), Poly Vinyl Chloride (PVC), High Density Polyethylene (HDPE), Polypropylene (PP), and Polystyrene (PS).

Studies have shown that plastic waste after proper processing can be used in the construction of bituminous pavements. Such pavements show enhanced properties and increased life spans, thus making road construction economical while solving the environmental problem simultaneously. Nearly 50 to 60% of the total plastics are consumed for packing. The use of waste plastic in bituminous construction with addition in small doses of about 5–10% by weight of bitumen helps in substantially improving the Marshall stability, strength, fatigue life, and other desirable properties of bituminous mix.

II. LITERATURE SURVEY

Mahabir Panda and Mayajit Mazumdar (2002) reported that reclaimed polyethylene obtained from low-density polyethylene carry bags can be blended with asphalt cement to form modified binder in the laboratory using a high-speed mechanical stirrer rotating at about 3,000 rpm for about 20 minutes. The optimum quantity of reclaimed polyethylene by weight of binder was observed to be 2.5%.

R. Vasudevan et al. (2007) studied the utilization of waste polymers for flexible pavement. They found that Los Angeles Abrasion values of plastic-coated aggregate decreased with increasing plastic percentage (37% without plastic, 32% with 1% plastic, and 29% with 2% plastic). The penetration value decreased to a very low value with the addition of waste plastics to bitumen. More than 3% addition of waste plastics resulted in hard polymer modified bitumen with very poor viscoelastic properties.

R. Vasudevan et al. (2011) developed a technique to dispose of waste plastics in an eco-friendly way for construction of flexible pavement using the dry process. The samples showed higher Marshall Stability values in the range of 18–20 kN, and the load-bearing capacity of the road was increased by 100% with no pothole formation.

Utibe J. Nkanga et al. (2017) reported that using reengineered bituminous mix with the addition of plastic waste (PE, PS) at 5% to 15% by weight helps improve Marshall stability, flow, bulk density, strength, and fatigue life of the bitumen.

Azmat Shaikh et al. (2017) observed that Marshall Stability value increases with plastic content, and the Marshall Flow value decreases upon addition of polythene, i.e., resistance to deformation under heavy wheel loads increases.

Dr. S. L. Hake et al. (2019) found that the Marshall Stability of modified semi-dense bituminous concrete mixes with waste plastic showed 1.6% higher values compared to neat mixes, and the Air Voids showed 8.1% lower values. The use of plastic waste in bituminous mixes increases the life of the road and reduces maintenance expenditure.

Prakhar Duggal et al. (2020) used the dry mix process with VG-30 bitumen and found that utilization of altered bituminous concrete mix with expansion of processed waste plastic of around 5–10% by weight of bitumen enhances the fatigue life, quality, and other properties, ultimately improving the life span and performance of flexible pavement.

III. METHODOLOGY

[1] Tests on Aggregate

Impact Test (IS: 2386-1963, Part-4)

The aggregate impact test was conducted to determine the resistance of aggregate to sudden impact or shock. In this test, the aggregate sample was taken in a measuring cylinder and compacted by giving 25 blows with a tamping rod. The compacted aggregate was then placed in the impact testing machine and subjected to 15 blows of a standard hammer. The material passing through 2.36 mm sieve after the test was weighed and the aggregate impact value was calculated. The total weight of dry sample taken (W_1) was 344 gm and the weight of portion passing 2.36 mm sieve (W_2) was 68 gm. The Aggregate Impact Value was calculated as $(W_2/W_1) \times 100 = 19.76\%$, which is within the acceptable limit of 30% for bituminous concrete, confirming that the aggregate is suitable for use in pavement construction.

Crushing Test (IS: 2386-1963, Part-4)

The aggregate crushing value test was conducted to determine the resistance of aggregate to crushing under a gradually applied compressive load. The aggregate sample was filled in a cylindrical mould in three layers, each layer being tamped 25 times. A load of 40 tonnes was then applied gradually over a period of 10 minutes using a compression testing machine. The crushed material was then sieved through a 2.36 mm sieve and the weight of material passing through was recorded. The total weight of dry sample taken (W_1) was 2887 gm and the weight of portion passing 2.36 mm sieve (W_2) was 617 gm. The Aggregate Crushing Value was calculated as $(W_2/W_1) \times 100 = 21.37\%$, which is within the acceptable limit of 30%, indicating that the aggregate possesses sufficient strength for use in bituminous concrete pavement.

Los Angeles Abrasion Test (IS: 2386-1963, Part-4)

The Los Angeles Abrasion test was conducted to determine the hardness and resistance of aggregate to wear and abrasion due to traffic loads. The aggregate sample of 5000 gm was placed in the Los Angeles Abrasion testing machine along with steel balls and the drum was rotated for 500 revolutions. After the test, the material was sieved through a 1.7 mm IS sieve. The weight of material retained on 1.7 mm sieve (W_2) was 4218 gm and the loss in weight ($W_1 - W_2$) was 782 gm. The Los Angeles Abrasion Value was calculated as $((W_1 - W_2)/W_1) \times 100 = 15.64\%$, which is well within the acceptable limit of 30%, confirming that the aggregate is hard and durable and suitable for use in bituminous pavement construction.

**[2] Tests on Bitumen
Penetration Test**

The penetration test was conducted to determine the hardness or consistency of bitumen by measuring the depth in tenths of a millimetre to which a standard needle penetrates vertically into a sample of bitumen under known conditions of loading, time, and temperature. The bitumen sample was poured into a container at a pouring temperature of 100°C and allowed to cool for 30 minutes at room temperature (35°C) and then for 30 minutes in a water bath. A standard needle was applied to the surface of the bitumen sample with a load of 100 gm for 5 seconds at 25°C. Three observations were recorded with initial dial readings of 0, 79, and 161, and final dial readings of 79, 161, and 229 respectively, giving penetration values of 79, 82, and 68. The mean penetration value was found to be **76.33**, which confirms that the bitumen used is of VG-30 grade and suitable for pavement construction in the given climatic conditions.

Ductility Test (IS: 1206-1958)

The ductility test was conducted to measure the distance in centimetres to which a standard briquette of bitumen can be stretched before the thread breaks. The bitumen sample was poured into a briquette mould at a pouring temperature of 100°C and was cooled for 30 minutes at room temperature and then for 30 minutes in a water bath maintained at 25°C. The briquette was then pulled apart in the ductility machine at a rate of 50 mm per minute. Two briquette samples were tested and the ductility values obtained were 66 cm and 62 cm respectively. The ductility values confirm that the bitumen has adequate flexibility and binding properties required for pavement construction.

Flash and Fire Point Test (IS: 1209-1978)

The flash and fire point test was conducted to determine the temperature at which bitumen gives off vapours that momentarily catch fire (flash point) and the temperature at which it sustains burning for at least 5 seconds (fire point). The bitumen sample was poured into the Pensky-Martens cup at a pouring temperature of 100°C and was heated at a controlled rate. A small flame was passed over the surface of the bitumen at regular temperature intervals. Two observations were recorded. The flash point values were found to be 220°C and 223°C, and the fire point values were found to be 224°C and 226°C respectively. These values are well above the mixing and laying temperatures, confirming that the bitumen is safe to use during the construction process.

[3] Sieve Analysis

Sieve analysis was conducted to determine the particle size distribution of the aggregate used in the bituminous concrete mix. The aggregate sample was passed through a set of IS sieves arranged in descending order of size, and the mechanical sieve shaker was used to ensure uniform and efficient separation of particles. The weight of material retained on each sieve was recorded and the percentage passing was calculated. The grading adopted in this study corresponds to **Grading 1 (19 mm nominal aggregate size)** as per the bituminous concrete pavement specifications with a layer thickness of 50 mm. The sieve analysis results confirmed that the aggregates used in this study meet the required grading specifications for bituminous concrete pavement as per MORTH standards. Based on the sieve analysis, the composition of the mix was finalized with coarse aggregate ($W_1 = 456$ gm), fine aggregate ($W_2 = 636$ gm), filler material ($W_3 = 48$ gm), and bitumen content of 60 gm (5% of total mix = 1200 gm).

[4] Mixing Method – Dry Process

The **Dry Process** was adopted for incorporating plastic waste into the bituminous mix in this study. In the dry process, the waste plastic is first collected from various sources such as carry bags, packaging materials, etc. The collected plastic waste is then segregated to remove plastics like polyvinyl chloride (PVC) and flux sheets, which cannot be used due to safety concerns. The segregated plastic waste is then thoroughly cleaned to remove any residual substances such

as food particles, as most of the plastic waste collected has been used for packaging. After cleaning, the plastic waste undergoes the process of shredding, which reduces it to the correct size of 2–4 mm thickness.

In the mixing procedure, the aggregates are first dried in a hot oven and then heated to a temperature of around 160°C–170°C. The shredded plastic waste is then added to the hot aggregates, and after 30–40 seconds, a uniform coating of plastic over the aggregates is observed, giving them an oily appearance. This polymer-coated aggregate (PCA) serves as a better raw material for bituminous pavement construction. Hot bitumen at a temperature of around 155°C–163°C is then added to the polymer-coated aggregates and the mixture is thoroughly mixed before laying. This temperature is carefully regulated to ensure strong binding between the plastic-coated aggregates and bitumen. The road laying is carried out at a temperature of 110°C–140°C. The dry process was preferred over the wet process because it requires lower investment, simpler equipment, and helps to dispose of 80% of waste polymers in an eco-friendly manner. Care was taken throughout the process to ensure that temperatures did not exceed 180°C, beyond which thermal degradation and release of harmful gases may occur.

[5] Marshall Test Procedure

The Marshall Test was conducted to determine the Marshall Stability and flow values of the bituminous concrete mix. The Marshall test specimens were prepared by taking a total mix weight of 1200 gm, consisting of aggregates of different sizes as per the grading requirement, filler material, and bitumen at the required percentage. The aggregates were heated to 160°C–170°C in a hot oven and the required amount of bitumen was weighed and heated to the mixing temperature of 155°C–163°C. The aggregates and bitumen were thoroughly mixed together to ensure uniform coating of all aggregate particles. For specimens with plastic waste, the shredded LDPE plastic was first added to the hot aggregates before the addition of bitumen following the dry process. The prepared mix was then placed in a Marshall mould (diameter 101.6 mm and height 63.5 mm) and compacted with **75 blows on either side** of the specimen using a Marshall compaction hammer as per MORTH specifications for bituminous concrete (BC) surface course.

After compaction, the specimens were allowed to cool and were then extracted from the mould. The dimensions and weight of each specimen in air and in water were recorded to calculate the bulk density of the specimen. The specimens were then immersed in a water bath maintained at 60°C for 30 minutes prior to testing. The Marshall Stability test was then conducted by placing the specimen in the Marshall Stability testing machine and loading it at a constant rate of 50 mm per minute until failure. The maximum load carried by the specimen was recorded as the Marshall Stability value (kN), and the deformation at the point of failure was recorded as the Marshall Flow value (mm). A correction factor was applied to the Marshall Stability value based on the volume of the specimen to obtain the corrected Marshall Stability value. The volumetric properties of the mix, namely the percentage air voids (Vv), voids in mineral aggregate (VMA), and voids filled with bitumen (VFB), were also calculated using the bulk density and theoretical specific gravity of the mix.

The theoretical specific gravity (Gt) of the mixture was calculated using the formula:

$$G_t = 100\% / [(W_1/G_1) + (W_2/G_2) + (W_3/G_3) + (W_4/G_4)]$$

Where W_1 , W_2 , W_3 , and W_4 are the percentage by weight of coarse aggregate, fine aggregate, filler, and bitumen respectively, and G_1 , G_2 , G_3 , and G_4 are their corresponding specific gravities ($G_1 = 2.68$, $G_2 = 2.65$, $G_3 = 2.50$, $G_4 = 1.02$). The bulk specific gravity (G_m) was determined from the weight of specimen in air (W_m) and weight in water (W_w) as $G_m = W_m / (W_m - W_w)$. The percentage air voids was calculated as $V_v = [(G_t - G_m) / G_t] \times 100$. The volume of bitumen (V_b) was calculated as the percentage of volume of bitumen to the total volume of specimen. The voids in mineral aggregate (VMA) was calculated as $VMA = V_v + V_b$, and the voids filled with bitumen (VFB) was calculated as $VFB = (V_b / VMA) \times 100$.

To determine the optimum bitumen content, Marshall specimens were prepared with bitumen contents of 4.5%, 5.0%, and 5.5% without any plastic addition. The bitumen content giving the maximum Marshall Stability, satisfactory Marshall Flow, and volumetric properties within the MORTH design requirements was selected as the optimum bitumen content. Subsequently, to study the effect of LDPE plastic waste, specimens were prepared using the optimum bitumen content with LDPE plastic additions of 5%, 10%, and 15% by weight of bitumen, and the Marshall properties and volumetric properties of each mix were evaluated and compared with the conventional mix (0% plastic).

IV. EXPERIMENTAL RESULTS

1) Results of Tests on Aggregate and Bitumen

The physical and mechanical properties of the aggregates and bitumen used in this study were evaluated through a series of standard laboratory tests before proceeding with the mix design. The results of the aggregate tests revealed that the Aggregate Impact Value was 19.76%, the Aggregate Crushing Value was 21.37%, and the Los Angeles Abrasion Value was 15.64%, all of which are well within the permissible limits of 30% as specified for bituminous concrete pavement. These results confirm that the aggregates used in this study are hard, strong, durable, and suitable for use in bituminous pavement construction.

The bitumen tests conducted on VG-30 grade bitumen showed that the mean penetration value was 76.33 (at 25°C), the ductility values were 66 cm and 62 cm for the two briquette samples, the flash point ranged between 220°C and 223°C, the fire point ranged between 224°C and 226°C, and the softening point was 57°C. All the bitumen test results confirmed that the VG-30 grade bitumen used in this study satisfies the standard specifications and is suitable for use in bituminous concrete pavement construction under the given climatic conditions

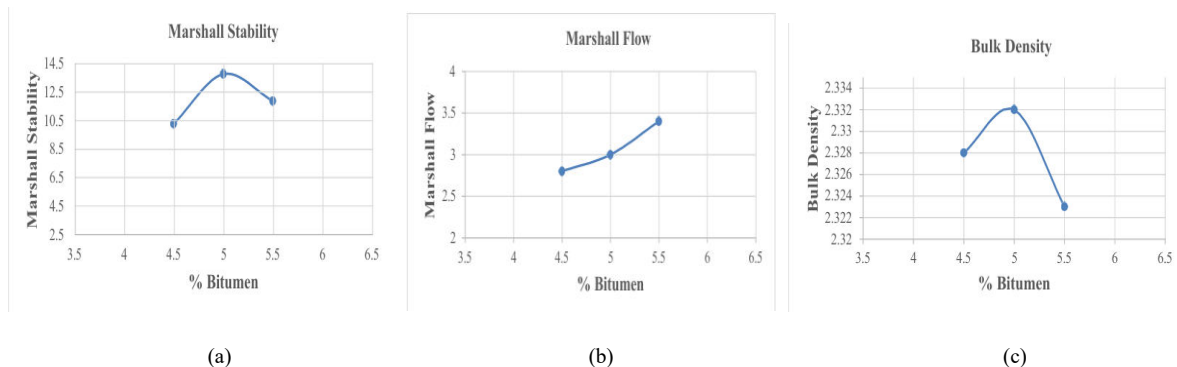
2) Optimum Bitumen Content Determination

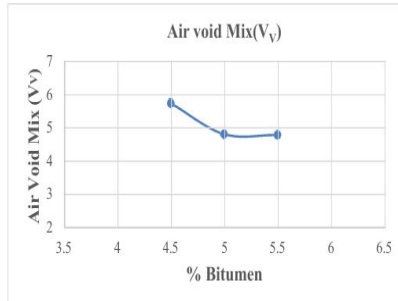
To determine the optimum bitumen content, Marshall specimens were prepared with bitumen contents of 4.5%, 5.0%, and 5.5% without any plastic addition, and the Marshall Stability, Marshall Flow, Bulk Density, Air Void Mix, and Void Filled with Bitumen values were evaluated for each bitumen content. The results obtained from the Marshall test for different bitumen contents are presented in Table 10.

From the experimental results, it was observed that the Marshall Stability value increased from 10.29 kN at 4.5% bitumen content to a maximum of 13.78 kN at 5.0% bitumen content, and then decreased to 11.88 kN at 5.5% bitumen content. The Marshall Flow value increased gradually from 2.80 mm at 4.5% bitumen content to 3.00 mm at 5.0% bitumen content and further to 3.40 mm at 5.5% bitumen content. The Bulk Density of the specimens increased from 2.328 gm/cm³ at 4.5% bitumen to a maximum of 2.332 gm/cm³ at 5.0% bitumen and then decreased to 2.323 gm/cm³ at 5.5% bitumen content. The Air Void Mix decreased from 5.74% at 4.5% bitumen to 4.81% at 5.0% bitumen and remained nearly constant at 4.79% at 5.5% bitumen content. The Void Filled with Bitumen (VFB) increased from 64.25% at 4.5% bitumen to 70.38% at 5.0% bitumen and further to 72.23% at 5.5% bitumen content. Based on the analysis of all Marshall properties and volumetric characteristics, the optimum bitumen content was determined to be 5.0%, as it gives the maximum Marshall Stability of 13.78 kN, a Marshall Flow of 3.00 mm within the acceptable range of 2–4 mm, Air Void Mix of 4.81% within the acceptable range of 3–6%, VFB of 70.38% within the acceptable range of 65–75%, and VMA of 16.24% satisfying the MORTH design requirements. All values at 5.0% bitumen content satisfied the MORTH design specifications for bituminous concrete surface course.

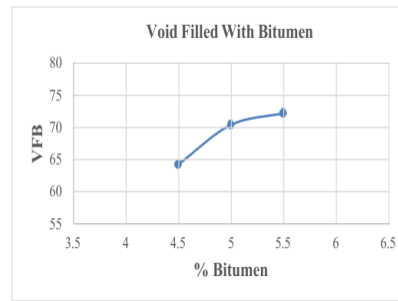
Sl no	Bitumen Content	Bulk Density	Air void Mix (Vv)	Vol.of Bitumen(Vb)	VMA	VFB	Marshall Stability	Marshall Flow
1	4.50	2.328	5.74	10.32	16.06	64.25	10.29	2.80
2	5.00	2.332	4.81	11.43	16.24	70.38	13.78	3.00
3	5.50	2.323	4.79	12.46	17.25	72.23	11.88	3.40

Marshall test results for 0% plastic





(d)

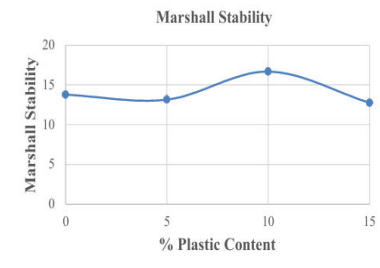


(e)

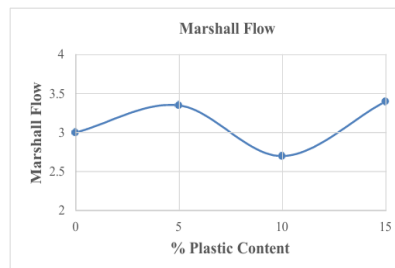
3) Effect Of LDPE Plastic Waste on Marshall Stability

After determining the optimum bitumen content as 5.0%, LDPE plastic waste was incorporated into the bituminous concrete mix at three different percentages — 5%, 10%, and 15% by weight of bitumen — using the dry process. Two samples were prepared for each plastic content and the average values were considered for analysis. The results of the Marshall test for different LDPE plastic contents are presented in Table 11. From the experimental results, it was observed that when **5% LDPE plastic waste** was added to the bituminous concrete mix, the Marshall Stability value slightly decreased from 13.78 kN (0% plastic) to an average of **13.15 kN**. This marginal decrease may be attributed to the non-uniform distribution of plastic at lower percentages and slight increase in air voids from 4.81% to 6.43%. The VFB also decreased from 70.38% to 62.65%, slightly below the acceptable range, indicating that at 5% plastic content, the mix properties are not fully optimized. When **10% LDPE plastic waste** was added to the bituminous concrete mix, the Marshall Stability value significantly increased to an average of **16.68 kN**, which represents an increase of **21.16%** compared to 5% plastic content and an increase of **17.38%** compared to the conventional mix with 0% plastic content. This significant improvement in Marshall Stability at 10% LDPE plastic content can be attributed to the better binding and interlocking effect of plastic-coated aggregates with bitumen, which results in a stronger and more stable mix. The Marshall Flow value at 10% LDPE plastic content decreased to **2.70 mm**, which is within the acceptable range of 2–4 mm, indicating increased resistance to deformation under heavy wheel loads. The Bulk Density increased to **2.369 gm/cm³**, the Air Void Mix decreased to **4.47%** within the acceptable range of 3–6%, and the VFB was **70.17%** within the acceptable range of 65–75%. The VMA was **14.96%**, satisfying the MORTH design requirements for 19 mm nominal aggregate size. All the volumetric properties at 10% LDPE plastic content satisfied the MORTH design specifications, confirming that 10% is the optimum plastic content for the bituminous concrete mix. When **15% LDPE plastic waste** was added to the bituminous concrete mix, the Marshall Stability value decreased to an average of **12.76 kN**, which is lower than the conventional mix (0% plastic) as well as the 10% plastic mix. The Marshall Flow value increased to **3.40 mm** and the Air Void Mix increased to **6.50%**, which is at the borderline of the acceptable range. The VFB decreased to **60.14%**, which is below the acceptable range of 65–75%, indicating that at 15% plastic content, the mix becomes less workable and the binding between plastic-coated aggregates and bitumen becomes less effective due to excessive plastic content. These results suggest that beyond 10% LDPE plastic content, the properties of the bituminous mix deteriorate rather than improve.

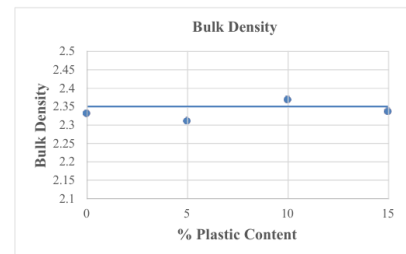
Sr. No.	% Plastic Content	Bulk Density	Air void Mix(VV)	Vol. of Bitumen(Vb)	VMA	VFB	Marshall Stability	Marshall Flow
1	0	2.332	4.81	11.43	16.24	70.38	13.78	3
2	5	2.316	6.23	10.81	17.04	63.43	12.48	3.3
3	5	2.306	6.63	10.76	17.39	61.87	13.83	3.4
Average	5	2.311	6.43	10.78	17.21	62.25	13.15	3.35
4	10	2.359	4.87	10.45	15.32	68.21	17.36	2.6
5	10	2.379	4.07	10.54	14.61	72.14	16.00	2.8
Average	10	2.369	4.47	10.49	14.96	70.17	16.68	2.7
6	15	2.335	6.60	9.80	16.40	59.75	12.00	3.5
7	15	2.340	6.40	9.82	16.22	60.54	13.52	3.3
Average	15	2.337	6.50	9.81	16.31	60.14	12.76	3.4



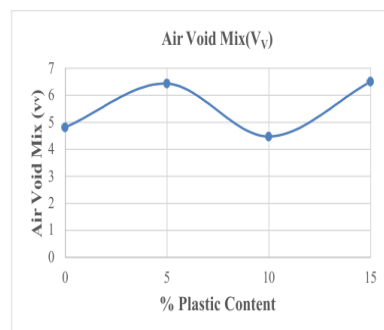
(a)



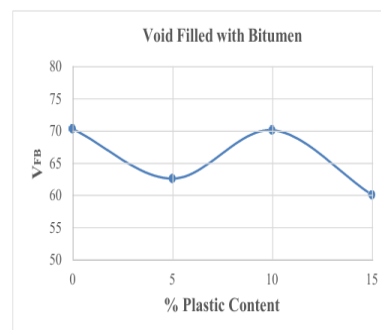
(b)



(c)



(d)



(e)

V. CONCLUSION

The present study investigated the feasibility of utilizing Low-Density Polyethylene (LDPE) plastic waste as a modifier in bituminous concrete mixes for flexible pavement construction. Based on the laboratory investigations and Marshall Stability analysis, it was observed that the incorporation of waste plastic significantly influences the performance characteristics of the bituminous mix. The conventional mix exhibited an optimum Marshall Stability of 13.78 kN at 5% bitumen content, whereas the modified mixes showed varying performance with different plastic contents. The results revealed that the addition of LDPE plastic waste up to 10% by weight of bitumen improved the Marshall Stability, bulk density, and deformation resistance of the mix. The maximum Marshall Stability of 16.68 kN was obtained at 10% LDPE content, representing an increase of approximately 17.38% compared to the conventional mix. Furthermore, the Marshall Flow value decreased at the optimum plastic content, indicating enhanced resistance to rutting and permanent deformation under traffic loading. However, further increase in plastic content beyond 10% resulted in a reduction in stability, suggesting that excessive plastic adversely affects the bonding characteristics of the mix. The study demonstrates that waste plastic can be effectively utilized in bituminous concrete through the dry process without affecting the standard requirements of pavement construction. The use of LDPE plastic waste not only improves pavement performance and durability but also contributes to sustainable waste management by reducing the environmental burden associated with plastic disposal. Therefore, the incorporation of 10% LDPE plastic waste in bituminous concrete is recommended as an optimum and environmentally friendly solution for the construction of durable and sustainable road pavements.

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