EXPLORING RHEOLOGICAL CHARACTERISTICS OF BITUMEN-HDPE PLASTIC BLENDS FOR ENHANCING ROAD PERFORMANCE

Dr. D. Koteswara Rao[1], Sajida Sulthana Mohammed[2], Thatavarthi S S P C N Rohith[3] Nandigam Raghava[4], Mohammad Heena[5], Mohammad Ahmed Alisha[6]

[1]Professor, Head of The Civil Engineering Department, OSD To Hon'ble Vice Chancellor, University College of Engineering Kakinada(A), JNTUK, Kakinada, Andhra Pradesh, India
[2]Assistant Professor(C), Department of Civil Engineering, University College of Engineering Kakinada(A), JNTUK, Kakinada, Andhra Pradesh, India
[3,4,5,6] U.G. Final year Students, Department of Civil Engineering, University College of Engineering Kakinada(A), JNTUK, Kakinada, Andhra Pradesh, India

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Abstract – *Due to the escalating traffic volume, there is now a requirement to develop pavements capable of withstanding heavy and extremely heavy traffic loads. This could be attained by increasing the bitumen content, but it is not cost-effective. However, the same effect can be achieved by incorporating marginal materials into the bitumen. The current study investigates the use of HDPE derived from cement bags as a marginal material. Several tests are performed on bitumen-HDPE plastic blends to investigate the rheological characteristics of the composite material. In the current study, HDPE plastic strips from cement bags are shredded and mixed with bitumen to produce plastic modified bitumen (PMB), which also provides an alternative solution for safe plastic disposal that does not harm the environment.*

***Key Words*: HDPE plastic, Bitumen, Flexible pavements, Pot hole patch work, Cement bags, Plastic waste, Polymer.**

1. INTRODUCTION

The advancement of any nation hinges significantly on its infrastructure. Developing and underdeveloped countries alike require substantial investment in road infrastructure to spur economic growth, elevate living standards, and nurture social progress. Nonetheless, it's imperative to guarantee that such investments are sustainable, inclusive, and cater to the requirements of local communities. Enhanced road infrastructure facilitates tourism and trade by facilitating access to remote areas, thereby generating notable benefits for local economies such as heightened tourism income and broader trade connections.

India stands on the brink of a significant leap forward in transportation infrastructure. With the surge in traffic volumes over recent decades, there's a pressing need for more robust and enduring pavements. Innovations in pavement design are emerging to enhance road performance. Among these innovations one is the incorporation of waste HDPE plastic into bituminous roads.

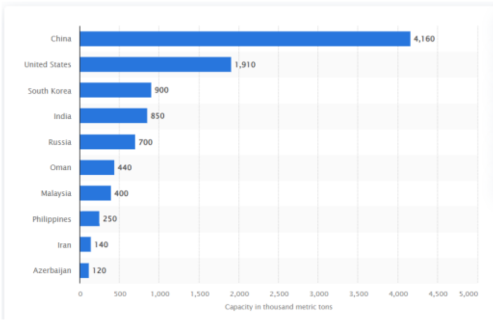
The Government of India has been proactive in advocating for the utilization of plastic waste in road building endeavors. This initiative not only tackles the challenge of plastic waste management but also enhances road quality and longevity.

Incorporating plastic waste into road construction entails blending shredded plastic waste with bitumen, resulting in a modified bitumen mixture utilized in road laying. This approach not only aids in repurposing plastic waste but also enhances road properties, rendering them more resilient to degradation and increasing flexibility [8]. The Ministry of Road Transport and Highways (MORTH) has released guidelines and specifications governing the utilization of plastic waste in road construction, ensuring adherence to quality and safety standards [7].

HDPE, known as High-Density Poly Ethylene, is commonly used in items like bags, cement bags, and pipes. When we dispose of these plastics, it harms the environment. However, reusing this waste HDPE plastic in pavement construction can improve the durability, strength and performance of the pavements.

Plastic is incorporated into bitumen in two ways: the dry process and the wet process. In the dry process, plastic is heated with aggregates. On the other hand, in the wet process, bitumen and plastic are heated separately and then mixed together using a stirrer [6].

Production of High-Density Poly Ethylene (HDPE) worldwide between 2019 and 2021



Source:https://www.statista.com/statistics/1120465/global-high-density-polyethylene-production-distribution-by-region/

1.1 BITUMEN

Bitumen is a viscous, black, and sticky material that is derived from the distillation of petroleum during the refining process. It is a crucial component in the construction of roads, as it binds together the aggregate materials which are commonly used on road surfaces. Bitumen's adhesive nature enables it to effectively bond with aggregate materials, forming a robust surface capable of enduring the weight of vehicles and environmental pressures. Additionally, it offers waterproofing capabilities, safeguarding the underlying road layers from potential water-related deterioration. Bitumen is available in a variety of types and grades. To judge the suitability of these binders, various physical tests have been specified by ASTM, ISI and British Standards Institution.

Properties of Bitumen:

- Bitumen is a hydrocarbon material.
- Bitumen is insoluble in water but soluble in many organic solvents.
- Bitumen is completely soluble in carbon disulphide and carbon tetra chloride.
- Bitumen provides resistance to acids, alkalis, and many types of chemicals, making it highly durable and suitable for pavements.

Table -1: Rheological properties of Bitumen

S. NO	RHEOLOGICAL PROPERTY	GRADE	RESULT
1.	Penetration	VG 30	71.3 mm
2.	Viscosity	VG 30	355 Seconds
3.	Softening point	VG 30	53 ℃
4.	Flash point Fire point	VG 30	186 ℃ 210 ℃

1.2 High-Density Poly Ethylene (HDPE)

HDPE is a versatile type of plastic known for its high strength, durability, and chemical resistance. It is a thermoplastic polymer made from ethylene monomers through polymerization. HDPE plastic is widely used across various industries for a multitude of applications. Its durability makes it ideal for products requiring long-term performance, such as plastic bottles, containers, packaging, cement bags, etc. HDPE plastic has been widely used due to its suitability. However, it offers resistance to degradation and decomposition leading to adverse effects on the environment. Under typical environmental conditions, HDPE can take hundreds to thousands of years to decompose completely.

Properties of HDPE Plastic:

- HDPE has a high density when compared to other polyethylene materials, which contributes to its strength and stiffness.
- HDPE is impermeable to moisture, making it ideal for use in applications where exposure to water or moisture is a concern.
- HDPE demonstrates exceptional impact resistance, particularly in low temperatures, rendering it suitable for applications necessitating toughness and durability.
- It is non-toxic and does not leach harmful chemicals into the environment.
- The melting point of HDPE (High-Density Poly Ethylene) typically ranges from 120°C to 130°C.

Table -2: Properties of HDPE

S. NO	PARAMETERS	RESULT
1.	Density	0.97 g/cc
2.	Softening point	120 °C
3.	Melting point	130 °C

2. REVIEW OF LITERATURE

2.1 Dr. R. Vasudevan et al. (2010) investigated and found that a polymer bitumen blend was found to be a better binder than plain bitumen. The polymer bitumen blend has a higher softening point, a lower penetration value, and suitable ductility.

2.2 Zahra Niloofar Kalantar et al. (2012) stated that many studies on polymer modified asphalt (PMA) mixtures have been conducted for the past two decades. Although the addition of virgin polymers to asphalt to improve its properties over a wide temperature range in paving applications was considered some time ago, recycled polymers added to asphalt have also shown nearly the same result in improving road pavement performance as virgin polymers. This paper provides a review of the use of polymers in asphalt pavement.

2.3 **Dr. Amit P. Gawande et al. (2012)** stated that the quantity of plastic waste in municipal solid waste (MSW) is increasing due to population growth, urbanization, development activities, and lifestyle changes, resulting in widespread littering on the landscape. As a result of its non-biodegradability and undesirable appearance, waste plastic disposal is a threat and has become a major issue worldwide. Because these are not disposed of scientifically, there is a possibility of land and water pollution. This waste plastic partially replaced the conventional material to improve the mechanical properties of the desired road mix.

2.4 **Rishi Singh Chhabra et al. (2015)** explored the importance of sustainability in the global construction industry. They highlighted the growing encouragement to use waste materials in road construction to minimize environmental impact. In the realm of highway infrastructure, various materials and technologies have been developed to assess their suitability for pavement design, construction, and maintenance, with plastics and rubbers being among them. The excessive use of polythene in everyday activities significantly pollutes the environment, as it is non-biodegradable. Therefore, there's a pressing need to utilize waste polythene to address this issue.

2.5 **R Manju et al. (2017)** observed that waste plastic and its disposal pose a significant threat to the environment, causing pollution and global warming. The use of plastic waste in bituminous mixes improves their properties and strength. Furthermore, it will address plastic disposal and various pavement defects such as potholes, corrugation, ruts, and so on. The waste plastic is shredded, coated over aggregate, and mixed with hot bitumen, and the resulting mix is used in pavement construction. This not only strengthens the pavement but also makes it more durable. Titanium dioxide is used as a smoke absorbent material, absorbing the smoke from vehicles. This innovative technology will benefit India's hot and humid climate.

2.6 **Prof. Shashikant S. Manekari et al. (2020)** proved that plastic works well as a binder for bitumen mixtures used in flexible pavements. By limiting the formation of cracks and preventing rainwater infiltration, which otherwise leads to the development of potholes, this effective procedure helps the pavements withstand greater temperatures. These pavements involve less water seepage and better crushing and abrasion qualities. Using plastic bottles and bags during the construction of bituminous roads to improve the material's properties. The Indian government has outlawed the use of plastic because the current state of plastic disposal poses a serious threat. In order to reduce construction costs, an effort has been undertaken to investigate the safe disposal of plastic trash throughout the bituminous road-building process.

3. OBJECTIVE AND SCOPE OF THE PROJECT

- To compare the characteristics of conventional bituminous roads with those of plastic bituminous roads.
- To determine the optimum amount of HDPE plastic (%) to incorporate into the bitumen mixture to achieve the desired strength.
- To decrease the utilization of bitumen by partially replacing it with HDPE plastic waste obtained from cement bags.
- To study the rheological characteristics of bitumen-HDPE plastics blends.

4. MATERIALS

Materials used in the present study are as follows:

4.1 Aggregates

Aggregates are vital in construction as they provide strength, stability, toughness, and durability to various structures and infrastructure projects. It's crucial to carefully select, process, and test aggregates to ensure their quality and performance.

4.1.1 Coarse Aggregates

Coarse aggregates are made up of crushed rock, crushed gravel, or other hard materials. These are the larger aggregates that are retained on a 4.75 mm sieve.

4.1.2 Fine Aggregates

Fine aggregates consist of crushed or naturally occurring mineral material. These are the smaller aggregates that pass through a 4.75 mm sieve. They should be clean, hard, and free from dust and other harmful substances.

4.2 Bitumen

In this study, VG 30 grade bitumen is used, which can be substituted for 60/70 penetration grade. It's particularly suitable for use in hot and rainy weather conditions.

4.3 HDPE Plastic

To examine the rheological properties of bitumen-HDPE plastic blends, empty cement bags are utilized. These bags are shredded into strips measuring 20mm x 3mm in size.

5. METHODOLOGY

5.1 Collection of waste plastic

Waste cement bags are collected from construction sites or from waste buyers.

5.2 Cleaning of plastic

Collected HDPE plastic waste is cleaned and washed if necessary.

5.3 Shredding of plastic

Cleaned HDPE plastic waste in the form of a cement bag is cut into 20mm x 3mm using scissors.

Fig -1: Shredding of HDPE plastic

5.4 Mixing of shredded waste plastic and bitumen

In the present study, shredded bitumen is heated up to its melting point, i.e. 130°C, and the requisite percentage of HDPE plastic is added to the percentage weight of bitumen.

In the next stage, bitumen HDPE plastic mix is added to aggregates, and various tests are carried out for comparative study.

Fig -2: Mixing of shredded plastic and bitumen

6. EXPERIMENTAL INVESTIGATION

6.1 TESTS ON AGGREGATES

6.1.1 AGGREGATE IMPACT VALUE TEST

This test evaluates the toughness of stone or the ability of aggregate to withstand repeated impacts.

6.1.2 AGGREGATE CRUSHING VALUE TEST

It measures the strength of coarse aggregate by assessing its resistance to crushing under a gradually applied compressive load.

6.1.3 LOS ANGELES ABRASION TEST

This test determines the percentage wear due to surface rubbing, which is important for evaluating resistance to wear or hardness, especially in wearing courses.

6.1.4 SPECIFIC GRAVITY TEST

Specific gravity indicates material strength or quality, with lower values suggesting weaker aggregates.

6.1.5 WATER ABSORPTION TEST

This test indicates rock strength, with higher absorption suggesting greater porosity and generally unsuitable aggregates.

6.1.6 FLAKINESS INDEX TEST

The presence of flaky particles is undesirable for road pavement construction.

6.1.7 ELONGATION INDEX TEST

Elongated particles are undesirable for road base construction as they may break down under heavy loads.

6.2 TESTS ON BITUMEN

6.2.1 PENETRATION TEST

This test indirectly determines paving grade bitumen consistency, classifying it based on penetration value.

6.2.2 VISCOSITY TEST

Viscosity measures bitumen flow resistance, with higher viscosity indicating a slower flow rate.

6.2.3 SOFTENING POINT TEST

It indicates the temperature at which bitumen softens, with higher points preferred in warm climates.

6.2.4 FLASH AND FIRE POINT TEST

The Flash and Fire point tests are carried out by using Pensky-Martens closed-cup apparatus. This test determines the lowest temperatures at which bitumen vapor ignites and burns under specified conditions.

6.2.5 MARSHALL STABILITY TEST

This test measures bituminous mixtures resistance to plastic deformation under load, aiding in determining the optimum content of bitumen-HDPE plastic blends.

Fig -3: Filling the Marshall compaction mould with the prepared mixture

Fig -4: Extraction of specimen from the mould

Table -3: Test Results of Bitumen

S. NO	TESTS	IS CODES AS PER IRC	GRADE	PLAIN BITUMEN	PMB (6.5%)	PMB (9%)	PMB (11.5%)	PMB (14%)
1.	Penetration Test (mm)	IS 1203-1978	VG 30	71.3	69.8	67.9	65.4	63.4
2.	Viscosity Test (Seconds)	IS 1206-1978	VG 30	355	362	372	380	385
3.	Softening Point Test (°C)	IS 1205-1978	VG 30	53	55	57	60	62
4.	Flash Point Test (°C) Fire Point Test (°C)	IS 1209-1978	VG 30	186 210	190 215	193 218	197 220	200 224

Table -4: Test Results of Aggregates

S. NO	TESTS	IS CODES AS PER IRC	RESULT	SPECIFICATIONS	REMARKS
1.	Aggregate Impact Value (AIV)	IS:2386 (Part IV)	12.30%	AIV Should not exceed 30% for wearing course	Suitable for wearing course
2.	Aggregate Crushing Value (ACV)	IS:2386 (Part IV)	21.30%	ACV Should not exceed 45% for base course and 30% for surface course	Suitable for base course and surface course
3.	Los Angeles Abrasion	IS:2386 (Part IV)	8.20%	Value should be less than 30% for bituminous concrete	Suitable for base course in bituminous concrete
4	SPECIFIC GRAVITY a)Coarse Aggregate b)Fine Aggregate	IS:2386 (Part III)	2.73 2.45	2.6 to 2.9 2.2 to 2.6	Lies within range
5.	Water Absorption	IS:2386 (Part III)	0.55%	Should be less than 0.6%	Lies within range
6.	Flakiness Index	IS:2386 (Part I)	12.75%	Flakiness Index should not exceed 25% for bituminous concrete	Suitable for bituminous concrete
7.	Elongation Index	IS:2386 (Part I)	33.70%	Elongation Index greater than 15% are undesirable but suitable for construction	Used for construction

Table -5: Marshall Test Results for finding optimum Bitumen content (%)

S.NO	BITUMEN CONTENT(%)	BULK DENSITY	Vv(%)	Vb(%)	VMA(%)	VFB(%)	STABILITY (Kg)		FLOW (mm)
							MEASURED	CORRECTED	
1	4	2.22	8.26	8.71	16.97	51.33	520	499.2	2.3
2	5	2.23	6.69	10.84	17.53	61.84	667.5	667.5	5.4
3	6	2.25	4.66	13	17.66	73.61	780	780	7.1
4	7	2.26	3	15.09	18.09	83.42	820	820	8.3
5	8	2.25	2.17	17.01	19.18	88.69	380	380	8.5

Table-6: Marshall Test Results for finding optimum Plastic content (%)

S.NO	PLASTIC CONTENT(%)	BULK DENSITY	Vv(%)	Vb(%)	VMA(%)	VFB(%)	STABILITY (Kg)		FLOW (mm)
							MEASURED	CORRECTED	
1	6.5	2.205	5	13.8	18.8	73.4	365	379.6	2.4
2	9	2.215	4.48	13.5	17.98	75.08	675	702	3.3
3	11.5	2.224	4.01	13.19	17.2	76.69	830	946.2	5.1
4	14	2.222	3.64	12.87	16.51	77.95	420	436.8	6.6

7. RESULTS AND DISCUSSIONS

- After performing the standard tests on the VG 30 grade bitumen and HDPE plastic modified bitumen, the results thus obtained are listed in **Table -3**.
- After performing the standard tests on aggregates, the results thus obtained are listed in **Table -4.**
- Marshall test results thus obtained for VG 30 grade and HDPE plastic modified bitumen are listed in **Table -5** and **Table -6** respectively.
- The penetration value of bitumen decreases with an increase in HDPE plastic content. This suggests that hardness increases with an increase in HDPE plastic content.
- The viscosity value of bitumen increases with an increase in HDPE plastic content.
- The softening point of bitumen increases with an increase in HDPE plastic content. A higher softening point helps in the construction of pavements in warmer climate regions.
- The flash and fire points of bitumen increases with an increase in HDPE plastic content.
- From **Chart -1**, the Marshall stability value goes on increasing with bitumen content (%) till 7% and decreases with an increase in bitumen content (%). Hence the optimum bitumen content is found to be 7%.
- Using the obtained optimum bitumen content, Marshall tests were conducted by replacing the bitumen with HDPE plastic waste.
- From **Chart -6**, the optimum HDPE plastic content (%) is found to be 11.5%.
- As the HDPE plastic content (%) in the blend increases, voids in mineral aggregates (VMA), volume of air voids (Vv) decreases as a result, strength and durability of bitumen plastic blend increase.
- From **Chart -7**, we can observe that as the plastic content (%) in the bitumen blend increases the flow value monotonically increases. This suggests better flexibility and provides resistance to deformation.

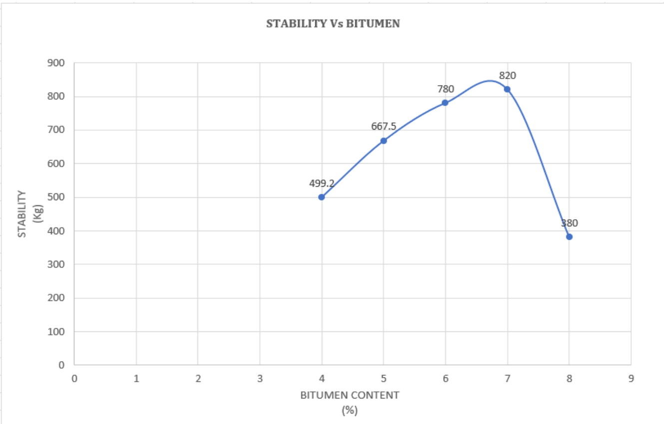


Chart -1: Variation of stability with Bitumen content (%)

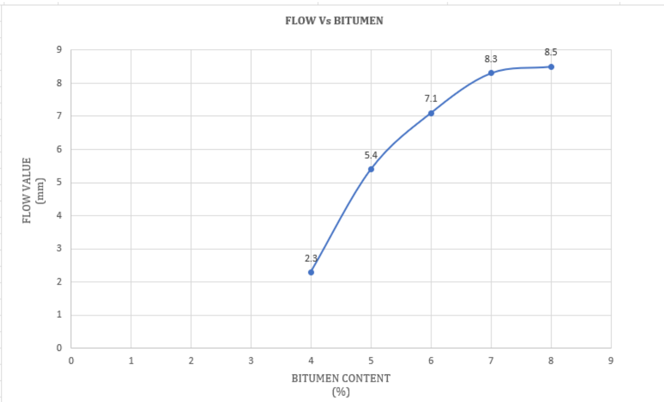


Chart -2: Variation of Flow value with Bitumen content (%)

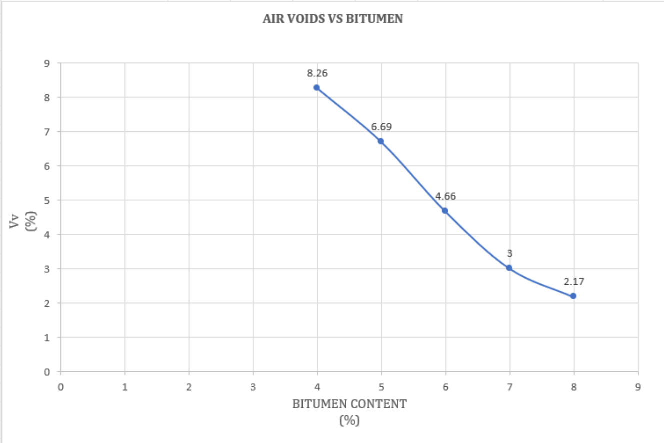


Chart -3: Variation of Air voids with Bitumen content (%)

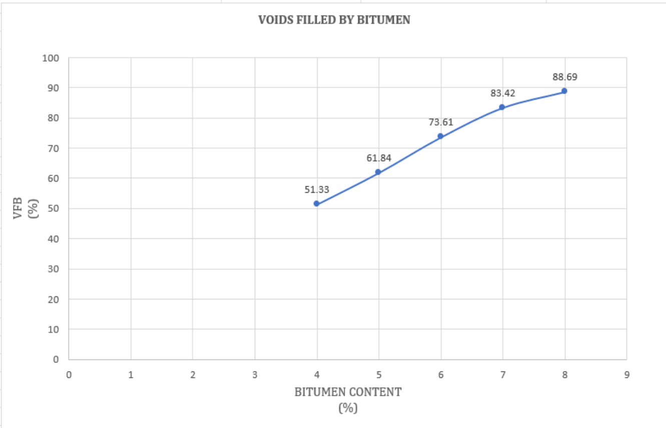


Chart -4: Variation of Voids Filled with Bitumen content (%)

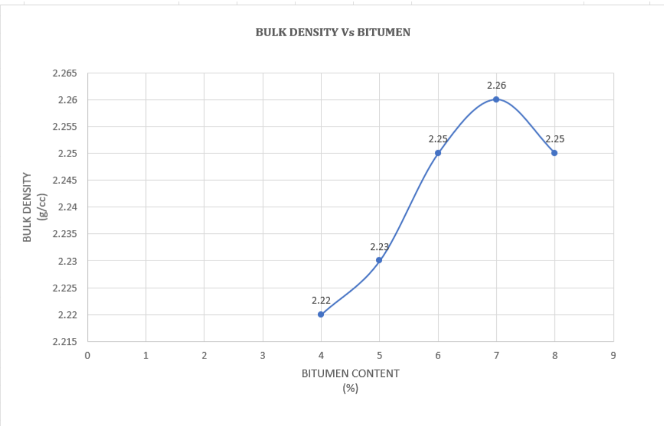


Chart -5: Variation of Bulk Density with Bitumen content (%)

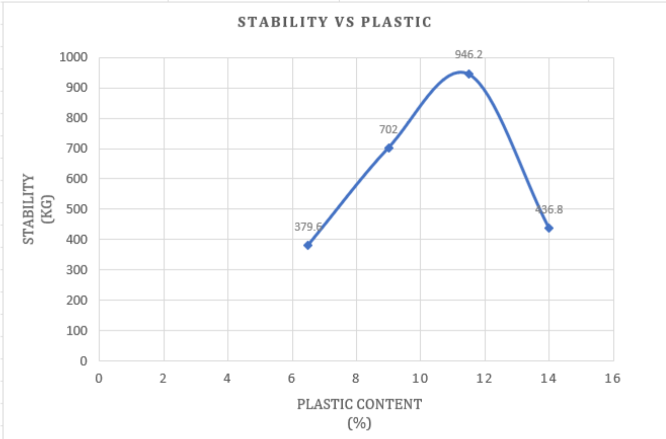


Chart -6: Variation of Stability with HDPE Plastic modified Bitumen (%)

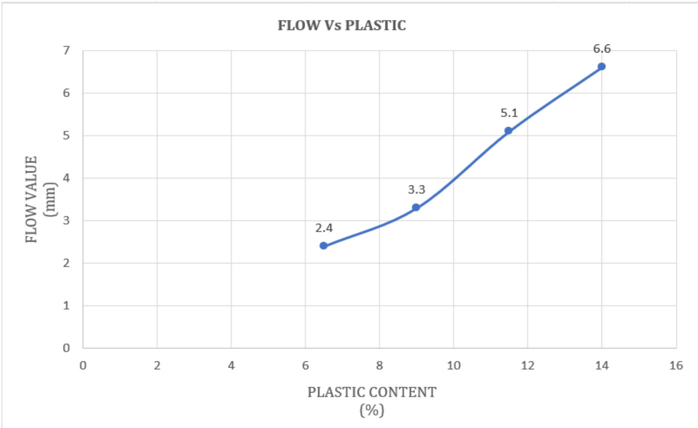


Chart -7: Variation of Flow value with HDPE Plastic modified Bitumen (%)

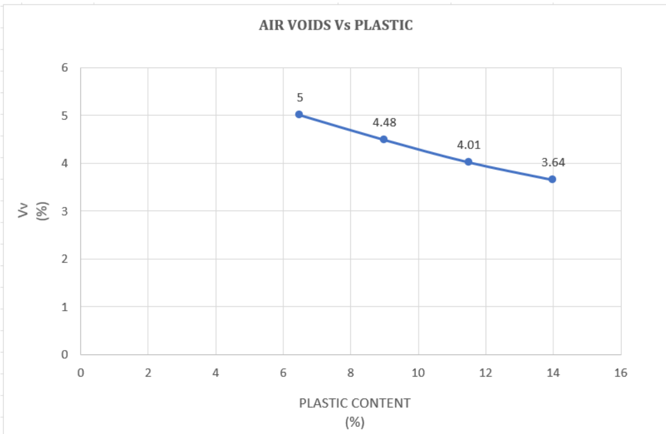


Chart -8: Variation of Air voids with HDPE Plastic modified Bitumen (%)

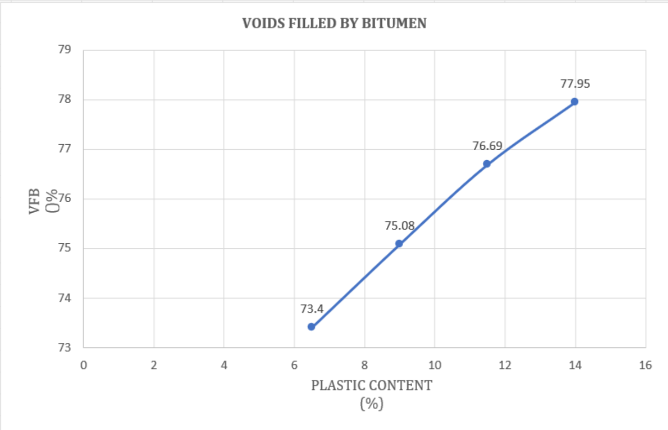


Chart -9: Variation of Voids Filled with HDPE Plastic modified Bitumen (%)

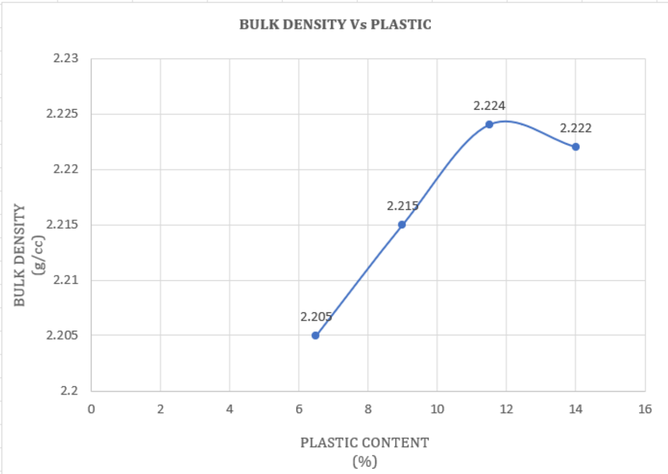


Chart -10: Variation of Bulk Density with HDPE Plastic modified Bitumen (%)

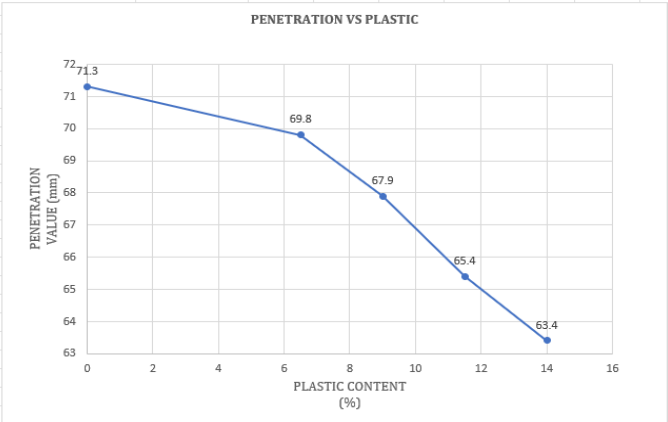


Chart -11: Variation of Penetration value with HDPE Plastic modified Bitumen (%)

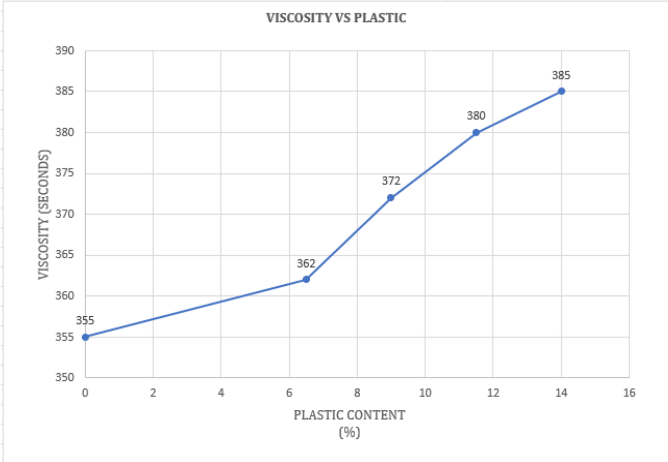


Chart -12: Variation of Viscosity with HDPE Plastic modified Bitumen (%)

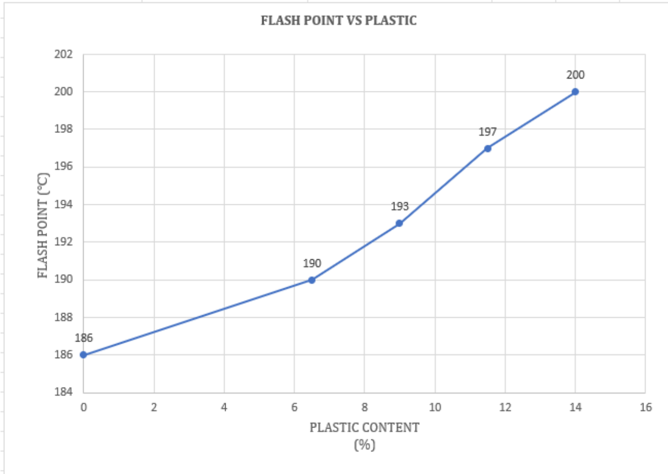


Chart -13: Variation of Flash Point with HDPE Plastic modified Bitumen (%)

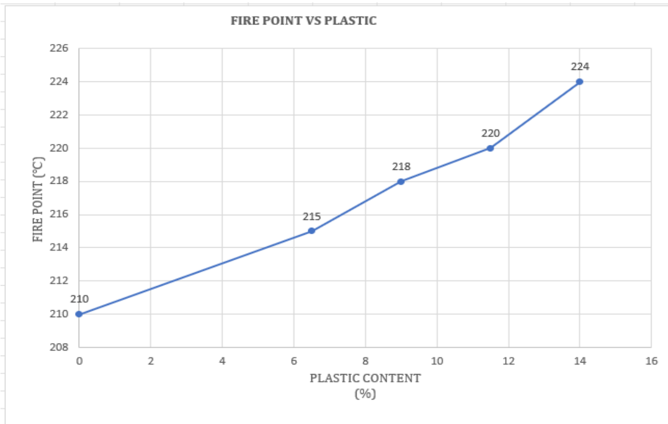


Chart -14: Variation of Fire Point with HDPE Plastic modified Bitumen (%)

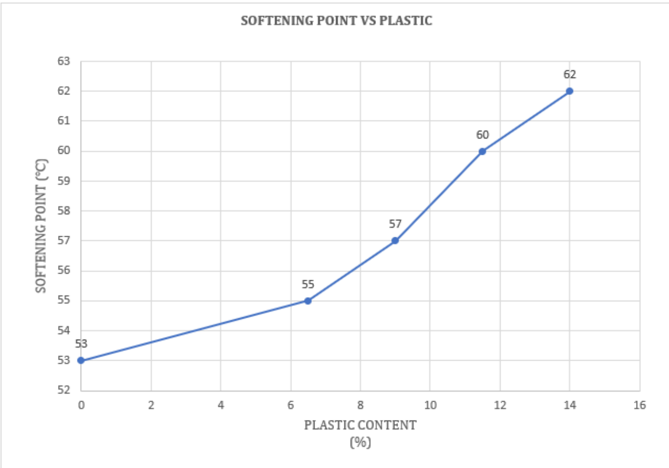


Chart -15: Variation of Softening point with HDPE Plastic modified Bitumen (%)

8. CONCLUSIONS

- Based on the analysis of the results, it can be concluded that partially replacing bitumen with 6.5%, 9%, 11.5%, and 14% of HDPE plastic significantly improves the rheological properties of bitumen.
- However, determining the optimal HDPE plastic content can be done through Marshall stability test charts.
- The optimum HDPE plastic content for enhancing rheological characteristics is found to be 11.5% by weight of bitumen.
- The stability value of plain bitumen at optimum content is 820 Kg, suitable for light and medium traffic as per MORTH specifications.
- In contrast, the stability of HDPE plastic-modified bitumen at optimum plastic content is 946.2 Kg, making it suitable for heavy and very heavy traffic.
- A decrease in bitumen utilization in pavements directly correlates with a reduction in the cost of laying pavement.
- By incorporating an optimal percentage of plastic (11.5% of the bitumen's weight), both the consumption of bitumen and the cost of laying pavements are reduced, resulting in enhanced economic viability.

9. FURTHER SCOPE OF STUDY AND PRATICAL APPLICATION OF RESEARCH

The experimental study can be extended by patching potholes with the modified bitumen HDPE plastic blends to enhance durability, strength, and sustainability compared to conventional mixes. Using bitumen HDPE plastic blends improves road performance and provides resistance to vehicle wear and tear, thereby increasing sustainability compared to conventional pavements. In addition to the rheological properties tested in this study, further available tests are as follows:

- Wet coating test
- Static immersion test
- Water resistance test
- Workability test.

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