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Experimental Investigation on Bituminous Mix Design with the Use of Plastic Waste Rubber

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Abstract: The rising demand for durable and high-performance pavements has led to the exploration of polymer-modified bitumen to overcome conventional asphalt's limitations. This study investigates the effects of incorporating different polymers—including Ethylene-Vinyl Acetate (EVA), Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE), and Ethylene-Propylene-Diene Monomer (EPDM)—on the physical and mechanical properties of bituminous mixes. The primary objective is to enhance asphalt performance under varying environmental and loading conditions, addressing issues such as rutting, thermal cracking, and premature aging. The research follows a systematic experimental approach involving standard tests such as the Marshall Stability Test, Los Angeles Abrasion Test, and Aggregate Impact Test. Bituminous mixtures were prepared with varying bitumen contents, and their behaviour was analysed in terms of stability, flow, density, voids, and binder content. Results indicate that polymer modification significantly improves the structural integrity and fatigue resistance of asphalt mixes, making them more suitable for modern road traffic demands. This study concludes that adding selected polymers at 5%, 10%, 15%, 20%, and 25% enhances the performance of asphalt pavements and contributes to sustainable road construction by enabling waste polymers. The findings support the adoption of polymer-modified bitumen in infrastructure development for improved longevity and cost-efficiency.

Keywords: Polymer Modified Bitumen; Asphalt performance Marshall Stability Test.

I. INTRODUCTION

The need for pavements that are good in performance has grown in response to changes in traffic conditions, such as increasing volume, heavier loads, and tire pressure. Asphalt cement with reduced low-temperature cracking and high-temperature rutting properties is necessary for high-performance pavements. When exposed to freezing temperatures, it becomes brittle. and soft in hot weather, asphalt loses some of its exceptional technical properties when subjected to a broad range of loads and weather conditions. Hence, asphalt is often fortified with polymers to enhance its mechanical properties. It is becoming more vital to mix asphalt with almost insoluble polymers to provide an uneven material that can fulfill performance demands. One common word for how asphalt and polymer interact microstructurally is morphology. An assortment of polymers, including thermoplastics (such as ethylene-vinyl acetate, HDPE, LDPE, and EPDM) and elastomers (such as styrene-butadiene-styrene, styrene-isoprene-styrene, and styrene-butadiene random copolymers), have been used in asphalt mixes. Asphalt has a long history of usage, dating back 5,000 years, as a binding and protecting substance. Entre Rios, northwest India, and Iran were the first sites of record-keeping. The Egyptians utilized bitumen for building and waterproofing purposes. The actual reason for the lengthy period between bitumen's widespread use in ancient times and its widespread use now remains a mystery. Even the Romans had trouble making good use of it while building roads.

II. LITERATURE REVIEW

" Ming Huang and Weidong Huang (2016) are said to have said. Blend design may downplay its significance, but one of the most crucial blend outline factors is its wear life, which may be enhanced by recuperating impact. Nine modified black-top mixes and two basic black-top blends are subjected to a weakening experiment in the evaluation. The most common three event scenarios in blend configuration handling—a high-temperature performance evaluation, a volume configuration target, and a four-point bowing bar weariness test—were considered for the exhaustion exhibitions; the results can guide the choice of black-top in design applications. Results also show that black-top mixes using styrene-butadiene-styrene and piece elastic have excellent restorative effects. In addition, the test results were used to produce a segment scatterplot, which provides a control for the altered black-top mix configuration.

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Erol Iskender and Atakan Aksoy (2012), were presumed that "The motivation behind this review is to think about research facility and field exhibitions for thick evaluated black-top blends. The control street asphalt area was built in the Black Sea Coast Highway. Marshall indistinguishable control tests delivered in a research facility and center specimens taken from wearing courses before the movement opened were utilized. Three diverse dampness molding techniques were connected to control lab and center examples. Mechanical properties of tests were assessed with circumferential pressure, backhanded strain quality, and rehashed crawl tests. Backhanded elasticity test results were about for research facility blends were discovered, 1.22 and 1.30 circumstances more as per field tests at 10 °C and 20 °C separately. Marshall tests gave a higher modulus for all control and molded blends. Rehashed crawl test comes about additionally demonstrated the distinction between research center and field test execution. Research center examples ensured their auxiliary uprightness alongside the test span and did not indicate tertiary crawl. It is closed from this review research center specimens state explicitly higher execution as indicated by the center field tests."

Serkan Takin (2008) presumed that "Polypropylene strands have been widely utilized as a part of structural building applications for a long time. These filaments are utilized as part of concrete as a three-dimensional optional support. Because of grip between polypropylene filaments and bitumen, the reinforcing component in black-top cement is in some way or another diverse. Using the optimal bitumen content, this review produced black-top solid samples using polypropylene filaments. The Marshall solidness values increased, and the stream values decreased significantly for fiber-strengthened samples. Additionally, the instances' fatigue life was extended. The positive effect of polypropylene filaments is shown by the alteration of black-top solid's characteristics. Great resistance to rutting, a postponed tiredness life, and reduced reflection splitting are all characteristics of the fiber-fortified black-top mix. So, polypropylene strands significantly refine the black-top blend's properties.

Sinan Hınıslıoğlu and Emine Agar (2004) performed this review to look at the potential of using several types of plastic waste, such as High-Density Polyethylene, into black-top cement as polymer additives. While subjected to several mixing circumstances in terms of duration, temperature, and HDPE content, covers that had been changed with the material were evaluated for their stream, Marshall Quotient, and Marshall Stability. The fasteners utilized in Hot Mix Asphalt (HMA) were made by combining AC-20 with 4-6% and 8% HDPE, respectively, at temperatures of 145-155 °C and 165 °C for 5-15 and 30 minutes of mixing time, depending on the density of the appropriate bitumen material. Marshall Quotient (imperviousness to disfigurement) and Marshall Stability (quality) values significantly increase in HDPE-altered black-top solid. For Marshall Stability, stream, and Marshall Quotient (MQ), the optimal mixing conditions were a temperature of 165°C for 30 minutes with 4% HDPE. The MQ was 50% higher than the control combination. Trash HDPE-changed bituminous folios, due to their strength and high Marshall Quotient, provide better resistance to irreversible distortions; they also help disperse plastic waste and ensure that nature will be preserved.

S. Takin *et al* (2011) presumed that "This part talks about the physical and mechanical conduct of polypropylene fiber-strengthened altered black-top blends. The part first surveys a general prologue to the polypropylene adjustment of black-top cement. At that point, dry premise adjustment with polypropylene filaments and weakness life change of black-top cement are talked about. Wet premise adjustment of black-top with polypropylene strands and rehashed crawl conduct of bituminous cement are presented next. The use of simulated neural systems for the expectation of Marshall test consequences of polypropylene changed thick bituminous blends is additionally researched. At that point, a novel approach using shape-shifting arrangements and parametric reviews to foresee the strain aggregation of polypropylene-changed Marshall examples in rehashed crawl tests is proposed. Assurance of ideal polypropylene fiber adjustment of black- top cement and the important mechanical and optical tests to satisfy this point are likewise used. At long last, decisions and a short editorial on likely future patterns are presented."

III. OBJECTIVES / AIMS

- Studying the effects of various polymers on bitumen performance in order to improve asphalt mixtures' strength and longevity; these polymers include EVA, HDPE, LDPE, and EPDM.
- To learn about the flow values, density, Marshall Stability, air voids, voids in mineral aggregates, and voids filled with bitumen, as well as other mechanical characteristics of bituminous mixes.
- Why determine the optimal bitumen composition for asphalt mixes using the Marshall Mix Design Way. This will ensure that the mixtures have high-performance attributes and last a long time.
- Determine if modified bitumen can be used to surface roads, taking into account factors such as temperature and loading conditions.
- To verify that the aggregates used in the mix meet the required standards for road building by comparing their impact and abrasion values.

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IV. RESEARCH METHOD / METHODOLOGY

Literature review
Material selection
Sample preparation
Mix design proportion
Laboratory testing
Optimal mix identification
Environmental impact assessment
Data analysis
Report writing

V. MATERIALS USED

Aggregates; it's that possess the desired qualities of strength, hardness, toughness, and soundness are selected. Crushed stone aggregates and sands of angular particles are considered to produce high-quality mixes. The grading of the aggregate is also chosen carefully; open grading with mixing sizes is not preferred as they produce inferior mixes.

Higher maximum sizes can produce greater stability and are therefore preferred, consistent with the thickness of the pavement. Based on experiments Ministry of Surface Transport (MOST) has recommended the following two gradations for a superior bituminous concrete pavement:

Coarse Aggregates The coarse aggregate shall consist of crushed rock, crushed gravel or other hard material retained on a 2 36 mm sieve. It shall be clean, hard, durable, and have a cubical shape, free from dust and soft organic and other deleterious substances. The aggregate should preferably be of low porosity

Fine aggregate shall consist of crushed or naturally occurring mineral material, or a combination of two, passing 2.36 mm sieve and retained on 0 075 mm sieve No natural sand will be allowed in the binder and wearing courses and no more than 50 percent natural sand will be allowed in the base courses The fine aggregate shall be clean, hard, durable, dry and free from dust and soft organic and other deleterious substances Fine aggregate shall have a sand equivalent value not less than 50 when tested under the requirement of IS: 2720 Part 37. The plasticity index of the fraction passing the 0.425 mm sieve shall not exceed 4 when tested by IS: 2720**.**

Filler shall consist of finally divided mineral matter such as rock dust, hydrated lime, or cement approved by the Engineer. The use of hydrated lime is encouraged because of its very good anti-stripping and antioxidant properties.

Bitumen BS group Bitumen Grade VG 30 is a standard viscosity grade Bitumen usually used as a paving Bitumen suitable for road construction and other industrial purposes. Bitumen VG-30 is one of the grades in high demand, and oxidation of vacuum bottom in the distillation tower is used to produce it. This grade of Bitumen is mainly used for hot mix, especially in a moderate climate. 80/100 Penetration Grade Bitumen is a medium-soft grade of bitumen, widely used in Indian road construction, especially in regions with a moderate climate.

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Plastic Waste Rubber

Source and Type:

- Derived from waste rubber products, primarily discarded vehicle tires
- Mechanically shredded and processed into crumb rubber
- Sometimes combined with plastic waste polymers (like LDPE, HDPE, EVA, EPDM)
- **Ethyl-Vinyl-Acetate (EVA):** A combination of ethylene and vinyl acetate, with vinyl acetate typically ranging from 10 to 40 percent by weight. EVA copolymers are generally considered non-toxic and offer improved gloss, pliability, and softness.
- **Low-Density Polyethylene (LDPE):** A thermoplastic ethylene monomer. LDPE is flexible and durable, available in opaque and transparent varieties, with weaker intermolecular forces compared to HDPE.
- **High-Density Polyethylene (HDPE):** A thermoplastic polyethylene with a high strength-to-density ratio. HDPE is used in pipes, plastic bottles, and geomembranes due to its superior strength.
- **Ethylene-Propylene-Diene (EPDM):** An elastomer with several uses, closely related to ethylene propylene rubber. EPDM rubber is a terpolymer comprising ethylene, propylene, and a diene component.
- **Styrene-Butadiene-Styrene (SBS):** A synthetic rubber with both elastic and rigid plastic characteristics. SBS is an ideal bitumen modifier for achieving elasticity and flexibility in cold weather.

VI. EXPERIMENTAL ANALYSIS

The Following tests were conducted to determine the physical properties of aggregates

- Specific gravity
- Water absorption
- Aggregate impact test
- Aggregate crushing test
- Shape test
- Los-Angeles's abrasion test
- Aggregates are the **main load-carrying** component in bituminous mixes
- Tests were performed to evaluate their **strength, durability**, and **suitability** for road construction
- ALL TESTS CONDUCTED AS PER **IS: 2386** AND **MORTH SPECIFICATIONS**
- the bituminous mixes with modified binders in comparison with the unmodified bitumen.
- The performance of the bituminous mixes under loading is evaluated using a rut wheel tester under varying temperature and material states.
- The experimental analysis of bituminous mix design involves systematically testing and evaluating.
- the properties and performance of different bituminous mixtures to determine the optimal mix proportions for durability, stability, and cost-effectiveness.

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1. **Penetration Test**: Measures the hardness or softness of bitumen by the depth it penetrates under specific conditions.
2. **Softening Point Test**: Determines the temperature at which bitumen softens.
3. **Flash Point Test**: Finds the temperature at which bitumen produces flammable vapours.
4. **Ductility Test**: Measures the ability of bitumen to stretch without breaking.
5. **Specific Gravity and Density**: Checks the weight about its volume.
6. **Viscosity Test**: Assesses flow characteristics at certain temperatures.

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VII. RESULTS & DISCUSSION

TABLE 7.1 SIEVE ANALYSIS RESULT

Sieve Size	Permissible limit	Aggregate% % in Sieving	1200g Aggregate% %	30kg Aggregate in %
19mm	100	100%	0g	0kg
13.2mm	90-100	95%	60g	1.8kg
9.5mm	70-88	79%	192g	5.8kg
4.75mm	53-71	62%	204g	6.2kg
2.36mm	92-58	50%	144g	4.4kg
1.18mm	34-48	44%	72g	2.2kg
0.6mm	26-38	32%	144g	4.4kg
0.3mm	18-28	23%	108g	3.3kg
0.15mm	12-20	16%	84g	2.6kg
0.07mm	4-10	7%	108g	3.3kg

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Aggregate test results

Table 7.2 Aggregate Test results

S. No	Properties tested	Test results	Specification
1	Specific gravity test	**2.6** **2.8**	**2.5-3.0** **2.5-3.0**
2	Water absorption	1.06	Max 2&
3	Stripping value	98%	Min 95%
4	Impact test	7.85	Max 24%
5	Los Angeles test	20.63	Max 30%

Determination of Softening Point Test of Bitumen: -

The grade of bitumen on which tests are performed is VG-30. Method of test according to IS 1205-1978.

Table 7.3 Test on Bitumen

Sr no	Test name	Obtained value	Permissible value
1	Penetration test	37mm	50 mm
2	Ductility test	78 cm	50 cm
3	Softening point test	52°c	35 to 70
4	Stripping value test	5%	Max 25%

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Table 7.4 Test on Bitumen with plastic rubber

% of Plastic Waste/Test	5%	10%	15%	20%	25%
Penetration test	35	33.5	34	33	34
Ductility test	79cm	82cm	84cm	85cm	54cm
Softening point	54°C	55°C	56°C	57°C	57°C

Table 7.5 Calculation of average values

S.no.	**Bitumen %**	**VMA**	**VA**	**VFB**
1	4.0	15.819	7.243	54.187
2	4.5	13.641	6.266	54.168
3	5.0	11.935	5.318	55.248
4	5.5	11.694	4.805	58.446
5	6.0	11.439	3.754	66.998
6	6.5	10.699	2.558	75.933
7	7.0	9.142	2.162	77.729

Table 7.6 Average Bitumen content percent Vs Stability Value, Kg

Sample No	**Bitumen content Percent**	**Stability Value, kg**
Average	4.0	705.67
Average	4.5	820.00
Average	5.0	916.33
Average	5.5	849.00
Average	6.0	800.67
Average	6.5	769.67
Average	7.0	669.33

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Table 7.7 Calculation of average values

% of bitumen	% of Plastic	% of aggregates	Stability reading	Correction factor	Corrected stability kg/kn	Flow mm division	Average Flow	Stability Avg
6% 0% plastic	0%	94%	340	1.00	1075	5.2	4.92	1224
			350	1.00	1107	6.3		
			330	1.14	1190	5.4		
			440	1.00	1392	4.2		
			430	1.00	1360	3.5		
4.7% 5% Plastic	3.6%	95.3%	420	1.00	1328	4.2	3.3	1476
			490	1.04	1612	4.4		
			420	1.00	1328	2.3		
			480	1.04	1578	2.5		
			330	1.47	1534	3.1		
5.4% 10% plastic	7.2%	94.53%	480	0.89	1349	3.2	3.16	1382
			460	1.00	1453	4.1		
			480	0.96	1455	2.3		
			580	1.00	1327	2.8		
			520	1.00	1327	3.4		
5.1% 15% plastic	10.8%	94.9%	490	0.93	1232	5.5	3.38	1293
			470	0.96	1169	3.4		
			420	1.00	1422	3.2		
			430	1.00	1358	2.5		
			450	1.00	1422	2.3		
4.8% 20% Plastic	14.4%	95.2%	460	0.93	1353	3.2	3.16	1288
			360	0.96	1093	2.3		
			460	1.09	1585	4.5		
			460	0.96	1396	3.5		
			360	0.89	1013	2.3		
4.5% 25% plastic	18.0%	95.5%	480	0.96	1152	4.5	4.4	1215
			570	1.00	1169	2.5		
			570	1.09	1274	5.5		
			560	0.86	1029	4.4		
			560	1.00	1453	3.3		

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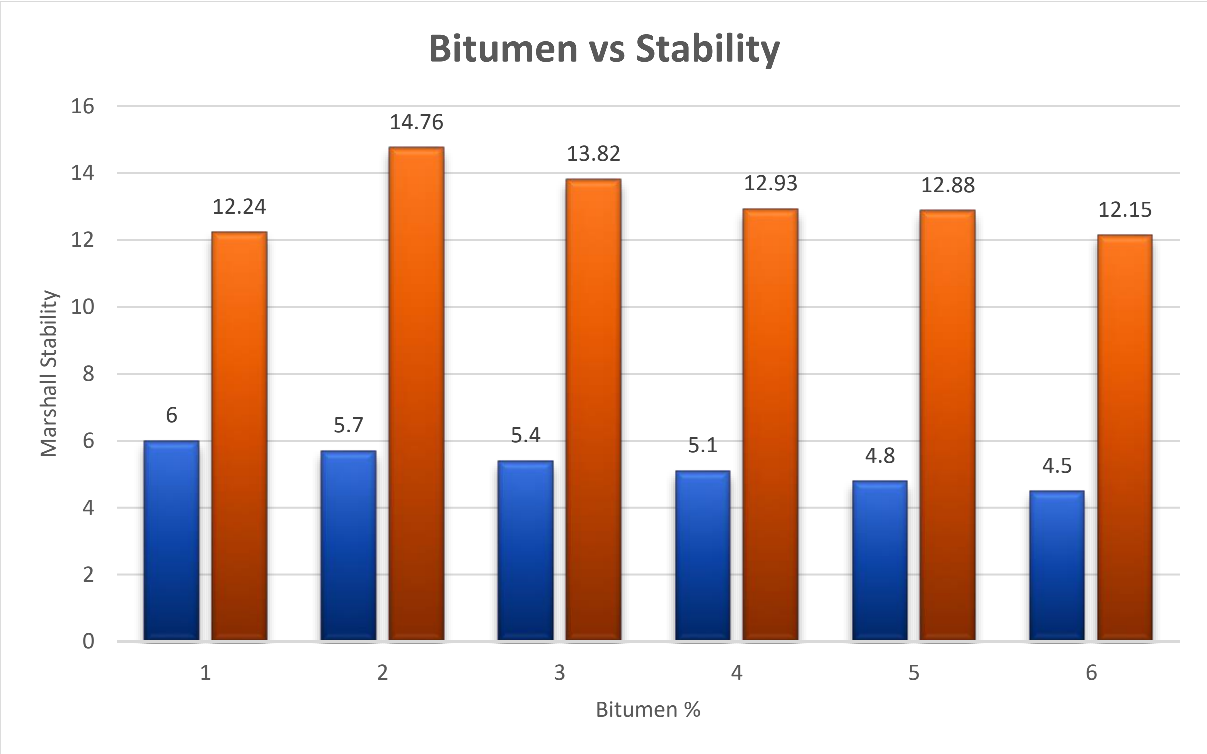
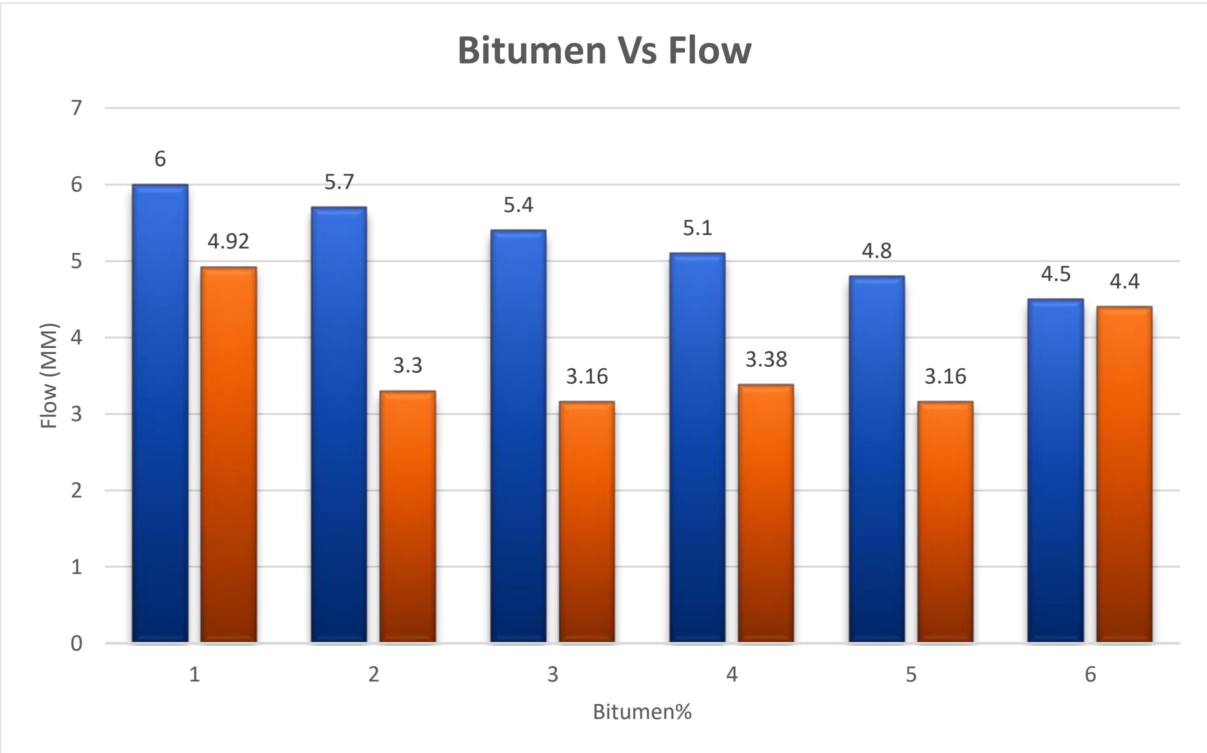


Graph 7.1



Graph 7.2

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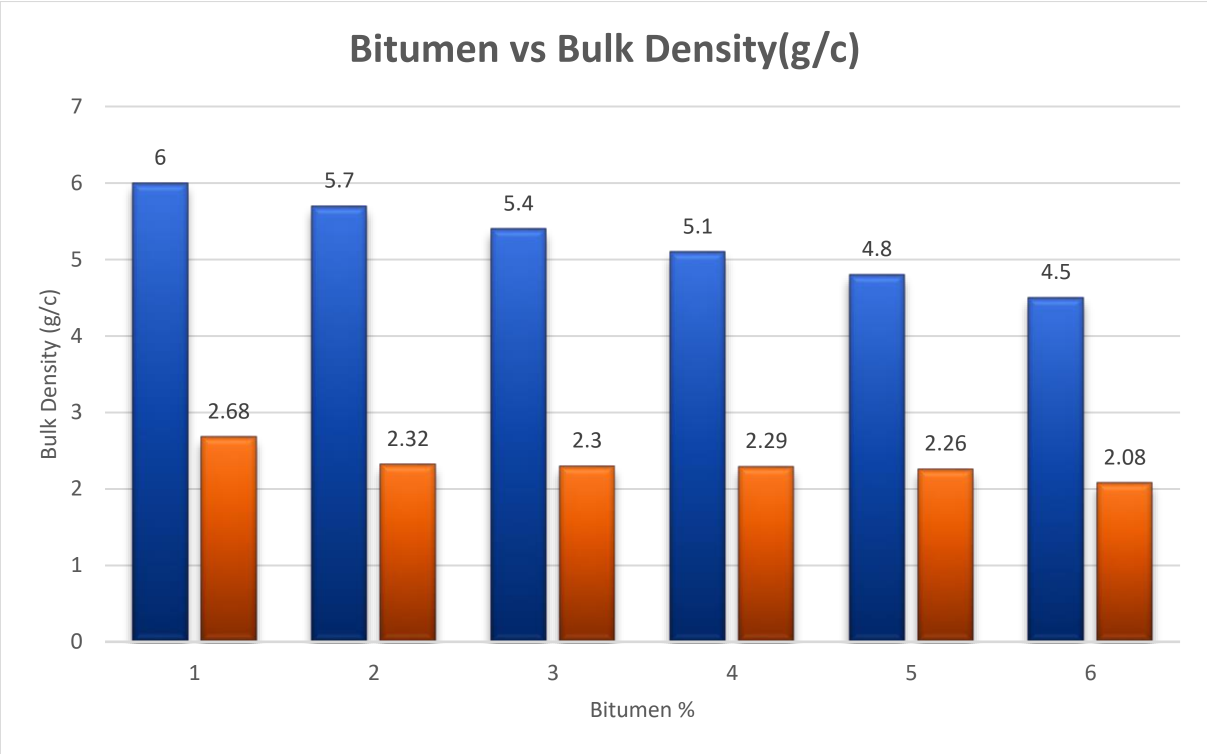

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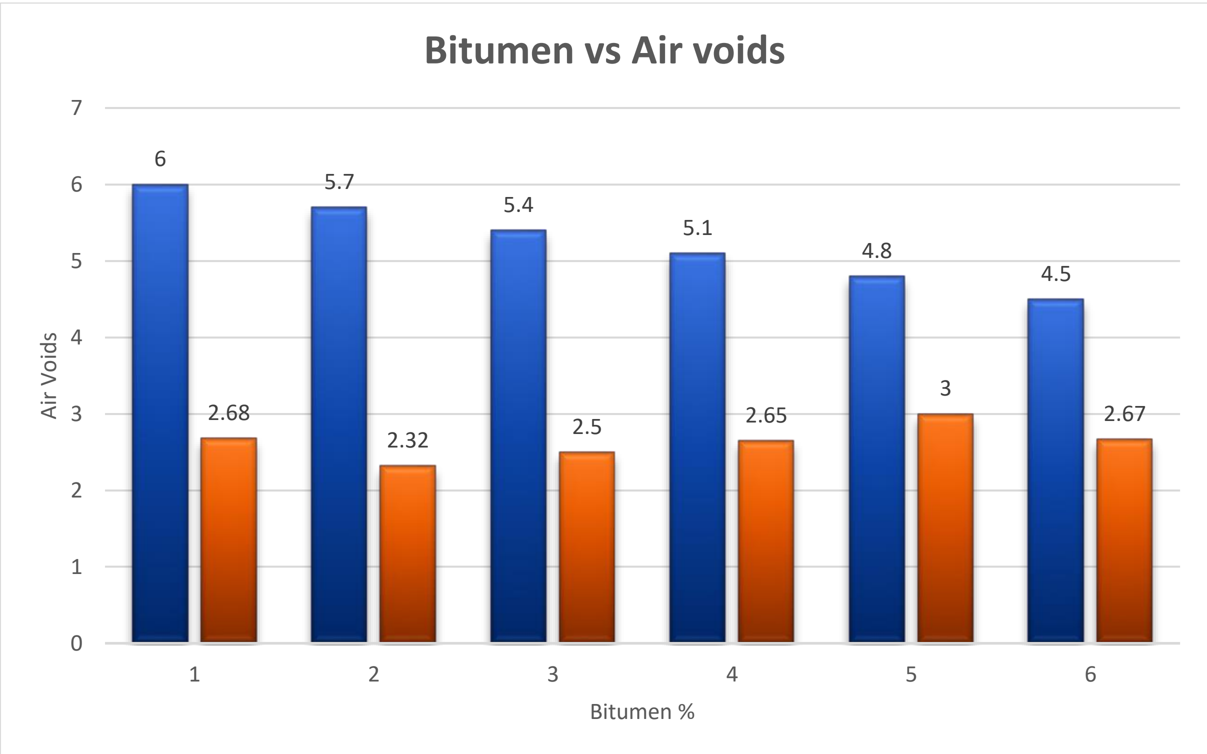

Graph 7.4

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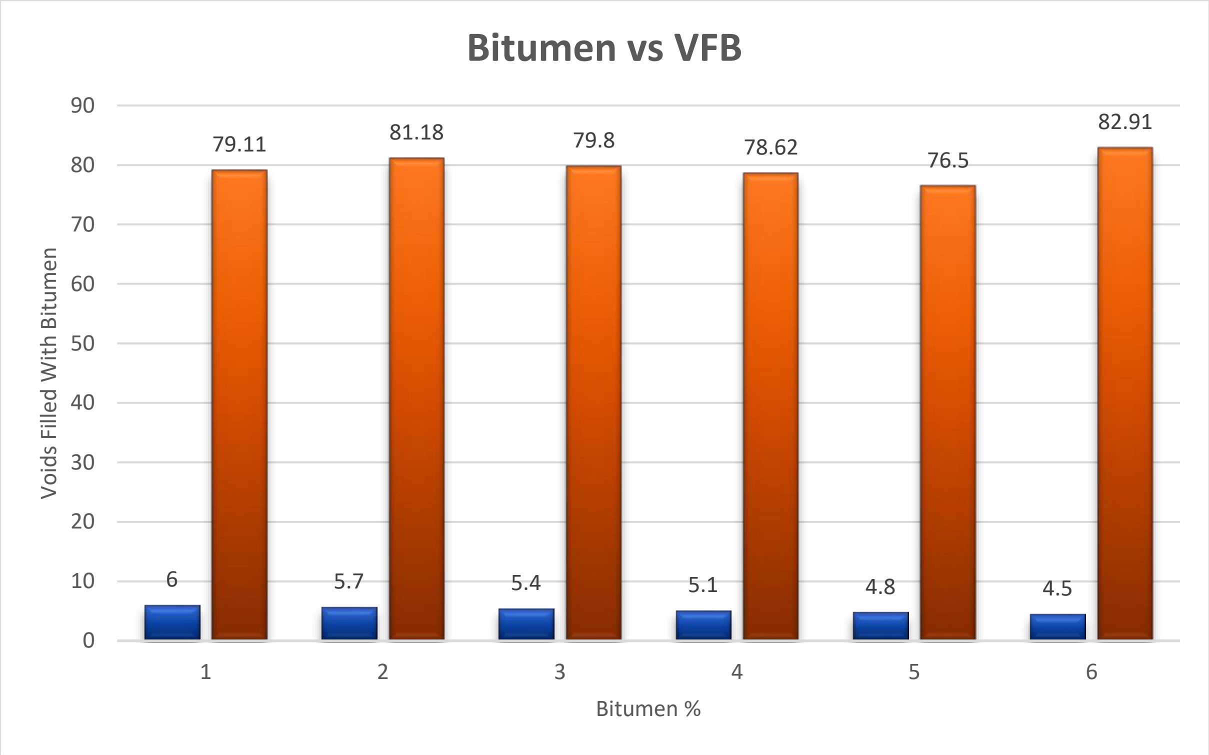
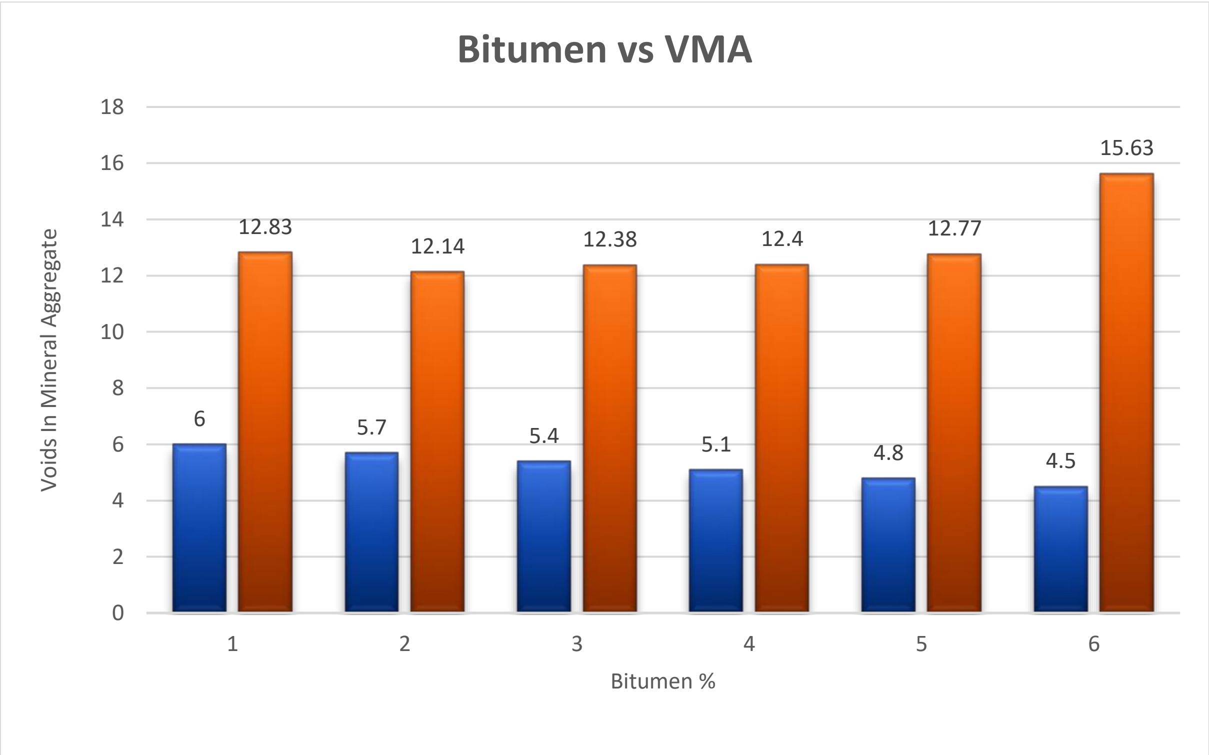


Graph 7.5



Graph 7.6

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VIII. CONCLUSION / SUMMARY

The following findings were derived from the aforementioned tests: -

1. The greatest average stability value of 1476 kg/kn was achieved in the Marshall Test on a bituminous mix that included 5% plastic waste. The related values for average flow were 3.3 mm, percent air voids were 2.32%, Vma was 12.14%, and Vfb was 81.18%.
2. A penetration value of 33 mm was found in the 2 Marshall Test, which is within the allowed limit, when the bituminous mix was tested with 20% plastic waste.
3. The bituminous mix containing 20% plastic waste had a better ductility value of 85 cm in the third Marshall Test.
4. Laboratory performance is the basis for these outcomes.
5. Our research has yielded promising results regarding the incorporation of plastic waste into bituminous mixtures. The Marshall Test revealed that a 5% plastic waste addition achieved the highest average stability value of 1476 kg/kn, with favorable flow (3.3 mm), air voids (2.32%), Vma (12.14%), and Vfb (81.18%) values.
6. Further testing demonstrated that bituminous mixes containing 20% plastic waste exhibited acceptable penetration values (33 mm) within permissible limits. Additionally, these mixes displayed superior ductility values of 85 cm in the third Marshall Test, indicating enhanced flexibility and durability.
7. These laboratory findings suggest significant potential for plastic waste utilization in road construction, offering both environmental benefits through waste reduction and improved performance characteristics in the resulting bituminous mixtures.

IX. RECOMMENDATIONS

Based on our comprehensive analysis, incorporating plastic waste into bituminous mixes offers significant benefits for road construction. The optimal plastic waste content appears to be between 5% and 10%, where we observe peak stability values, reduced flow (indicating better rutting resistance), and favorable volumetric properties.

The addition of plastic waste increases the softening point of bitumen, making it more resistant to high temperatures, while maintaining adequate ductility for flexibility. This suggests roads constructed with plastic-modified bitumen would perform better in varying climate conditions. Furthermore, this approach provides an environmentally sustainable solution for plastic waste management while potentially reducing long-term road maintenance costs

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