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An Experimental Study of the Use of EPS in Bituminous Mixes Prepared with RAP

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Abstract: This study explores the combined use of Reclaimed Asphalt Pavement (RAP) and Expanded Polystyrene (EPS) as sustainable and performance-enhancing materials in Bituminous Concrete Grade-2. With the growing focus on environmentally friendly road construction, the use of RAP helps reduce the consumption of virgin aggregates and bitumen, while also minimizing waste generation and energy use. EPS, a lightweight and recyclable plastic waste, is known to improve the stiffness and thermal resistance of bitumen when used as a modifier.

The experimental program began with the sample being prepared for a control mix with varying binder content. The optimum binder content for the control mix was determined to be 5.65% using the Marshall Method. Subsequently, modified bituminous mixes were prepared by incorporating RAP at 27.5%, 30%, and 32.5%, and EPS at varying contents from 3% to 7%.

Laboratory testing was conducted in accordance with ASTM standards. It included Marshall Stability, Flow Value, Bulk Density, Air Voids, VMA, VFB, and ITS. The results indicated that the inclusion of RAP increased the stability of the mix and reduced the requirement for fresh binder due to the presence of aged bitumen. The addition of EPS resulted in an increase in the softening point and a decrease in the penetration value, indicating improved stiffness and resistance to high temperatures.

Overall, the optimum use of 27.5% RAP and 5% EPS produced bituminous mixes with higher stability, desirable air void content, improved crack resistance, and enhanced tensile strength compared to conventional mixes. The study concludes that RAP and EPS can be effectively utilized in bituminous concrete to lower environmental impact and reduce material costs. These findings support the use of recycled materials in highway construction and highlight the need for further research on the long-term field performance and optimization of RAP–EPS proportions for practical applications.

Keywords: Marshall stability, Indirect tensile strength (ITS), RAP, EPS, Bituminous Concrete

I. INTRODUCTION

Asphalt pavements are widely used across the world, including India, due to their importance in transportation infrastructure and ease of maintenance. The incorporation of reclaimed asphalt pavement (RAP) and other recycled materials in asphalt mixes reduces dependence on virgin resources and minimizes environmental impacts by effectively managing waste

A. RAP (Reclaimed asphalt pavement)

Reclaimed Asphalt Pavement (RAP) is the material obtained by milling or removing existing asphalt pavements during road maintenance, rehabilitation, or reconstruction works. This removed material contains valuable aggregates and aged bitumen, which can be reprocessed and reused in new asphalt mixtures.

B. EPS (Expanded Polystyrene)

Expanded Polystyrene (EPS) is increasingly used in road construction as a lightweight and sustainable material to improve pavement performance and reduce environmental impact. In bituminous mixes, EPS can be added as a modifier to bitumen or as shredded particles, helping to enhance stiffness, thermal resistance, and deformation resistance. Its low density reduces the overall weight of the pavement layer, which is particularly beneficial over weak subgrades and embankments.

II. REVIEW OF LITERATURE

The following is a description of some of the relevant research that is important to this topic's area of study:

[1] Kaya, O. (2023). The study explores using waste Expanded Polystyrene (EPS) to modify asphalt binders as a solution to EPS waste management. As part of this study, a base asphalt binder with a Penetration grade of 70/100 was modified with waste EPS in four different ratios (0%, 1.5%, 3% and 4.5%, by weight of asphalt binder).

[2] Akter, R. et al. (2022). This study tackles waste management challenges by incorporating recycled expanded polystyrene (EPS) into asphalt concrete through the use of varying proportions of shredded EPS and asphalt. Marshall properties were evaluated for all specimens prepared at the optimum asphalt content with varying EPS additions. Results showed that a 0.5% EPS content gave the best performance, with stability increasing by about 82.61% compared to the conventional mix.

[3] Prasittisopin et al. (2022) examined the use of expanded polystyrene (EPS) in cement-based materials for lightweight construction. They discuss challenges like segregation and reduced strength, proposing strategies such as additives and recycled EPS waste to mitigate these issues. Additionally, they address environmental concerns and suggest on-site recycling of aged EPS concrete waste for sustainable applications.

[4] Al-Shamayleh et al. (2022). This study examines the performance of hot-mix asphalt incorporating varying percentages of reclaimed asphalt pavement (RAP). Marshall tests conducted on mixes with varying asphalt contents showed that increasing RAP content improved stability and flow, with the highest stability achieved at 75% RAP.

[5] Yıldızet al. (2021). This study investigates the application of waste expanded polystyrene (EPS) foam as a modifier in bitumen to enhance sustainability. EPS was added at different percentages, and test results showed reduced penetration and ductility with increasing EPS content, indicating stiffer asphalt. The findings suggest that EPS-modified bitumen is suitable for hot regions, with effective modification occurring at additive levels of at least 4%.

[6] Di Wang et al. (2021). The study investigated the impact of combining Warm Mix Asphalt (WMA) technology with recycled rubber asphalt, revealing that incorporating up to 40% recycled RAP into WMA improved low-temperature properties while maintaining fatigue resistance

[7] M. Enieb et al. (2021). This study aims to explore the potential advantages of incorporating Reclaimed Asphalt Pavement (RAP) in asphalt mixtures. The study primarily focuses on the benefits of using RAP in hot mix asphalt (HMA). The results show that incorporating 30% RAP into virgin asphalt mixtures provides the best performance in terms of these key properties.

[8] Murana et al. (2020). This study investigates the use of waste disposable food packs (DFP) as a bitumen modifier to improve hot mix asphalt performance. The best overall performance was achieved at an optimum DFP content of about 6.7%, showing that waste DFP can be effectively used in modified asphalt.

[9] Akbar et al. (2019). This study investigates the use of polystyrene as an additive in asphalt mixes. Results showed that strength increased significantly with polystyrene addition up to 5%, achieving maximum stability of 10.41 KN, after which further addition reduced strength, indicating 5% as the optimum content.

[10] Al-Haydari et al. (2017). This research investigates using waste Expanded Polystyrene (EPS) packaging material in asphalt pavements by testing five EPS percentages (1-5% by weight) of asphalt. Laboratory testing of the physical and mechanical qualities of asphalt pavement mixtures has shown that EPS improves their mechanical performance without changing the asphalt binder.

III. GAPS IN LITERATURE REVIEW

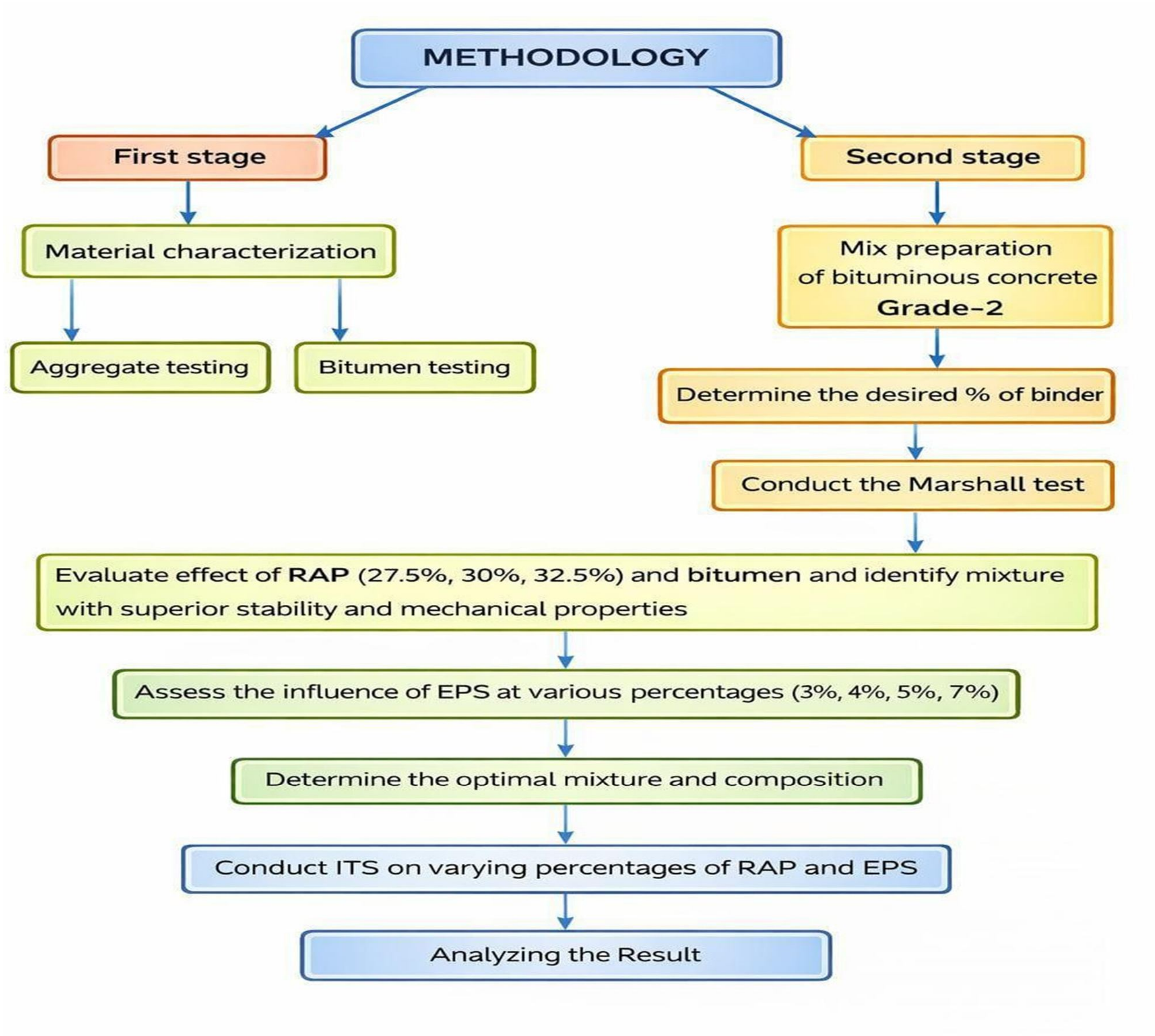
These gaps represent areas where limited or insufficient information is available:

1) Though many studies have explored the effects of various RAP and EPS percentages, the ideal balance between these materials for achieving optimal performance in strength, stability, and environmental benefits is still not well-defined.
2) The suitability of EPS with respect to different binder grades and its influence on grade-specific performance characteristics remains insufficiently investigated.
3) There is a lack of depth in research on the Engineering properties of asphalt mixes with varying ratios of RAP and EPS.
4) More studies are required for different types of mixes, such as DBM, BC, etc.

IV. OBJECTIVE OF THE STUDY

1) To determine the optimum binder content for the control mix of Bituminous Concrete (Grade- 2) prepared without and with varying percentages of RAP.
2) To determine Marshall stability parameters (Stability value, Flow value, Air voids, Volume in Mineral aggregate (VMA), and Volume Filled with Bitumen (VFB)) of Bituminous concrete (Grade-2) with varying RAP and EPS Dosage.
3) To identify the optimum combination of RAP and EPS
4) To determine the Indirect Tensile Strength value of Bituminous concrete Grade-2 at varying EPS and RAP percentages

V. RESEARCH METHODOLOGY



VI. MATERIAL TESTING & RESULT

A. Test on Bitumen

VG-30 Bitumen is used

Table 1: Physical properties of bitumen used

Physical properties	Result	Required as per IS-73 2013
Penetration @ 25°C (0.1mm),100g	53	45 min
Softening Point, °C	62.5	47°C min
Specific Gravity	1.01	0.99 min
Solubility	99.0%	

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B. Test on Aggregate

Table 2: Physical properties of the aggregate used

Physical Properties	Result	Required as per IRC: SP:139-2023
Specific Gravity	2.6	
Impact value, %	16.49%	Max 24%
Elongation Index, %	12.1%	
Flakiness index, %	14.1%	
Combined Flakiness &Elongation index, %	26.2%	Max 30%
Water absorption, %	0.50	Max 2%
Los Angeles Abrasion Value, %	18.1%	Max 30%

C. Test on RAP Aggregate

Table 3: *Physical properties of the RAP aggregate used*

Physical Properties	Result	Required as per IRC: SP:139-2023
Specific Gravity	2.69	
Impact value, %	13.9%	Max 24%

D. Test on Bitumen mix with EPS

Table 4: Physical properties of the bitumen mix with EPS

Parameters	Penetration @ 25°C (0.1mm)	Softening Point°C
VG-30+EPS 3%	30	65
VG-30+EPS 5%	20	69
VG-30+EPS 7%	13	73

VII. RESULT AND DISCUSSION

A. Mix Design of Bituminous Concrete Grade-2 (Control Mix)

Four control bituminous concrete mixes without RAP or EPS were prepared with binder contents of 5.40%, 5.65%, 5.80%, and 5.95% to determine the optimum binder content (OBC) using the Marshall method.

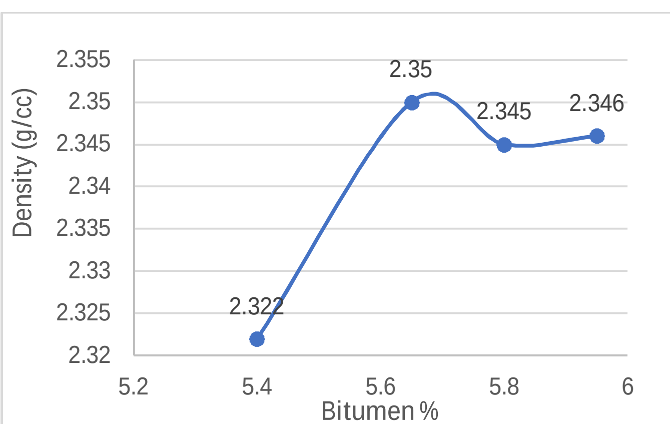

Fig 1: Density v/s Bitumen%

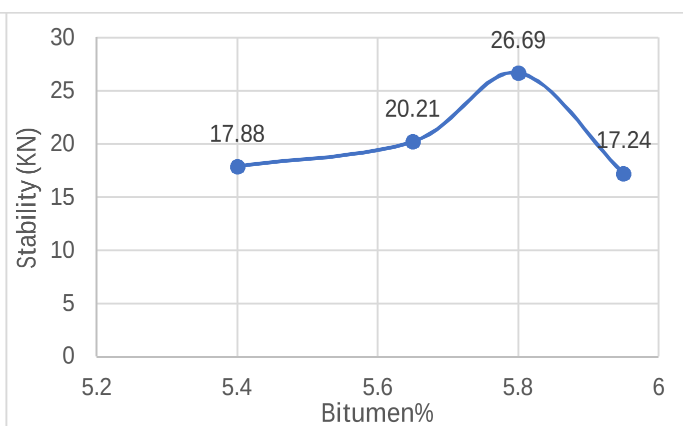

Fig 2: Stability v/s Bitumen

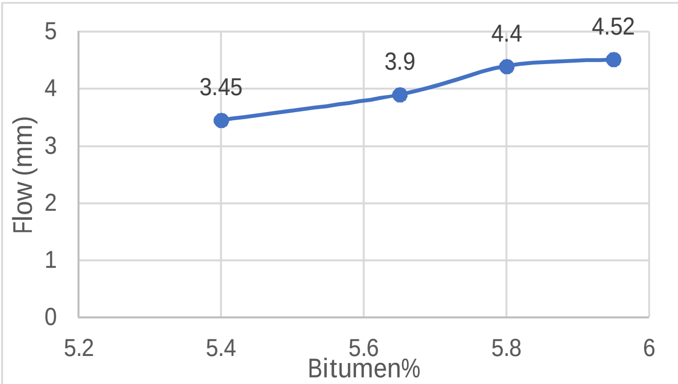

Fig 3: Flow v/s Bitumen%

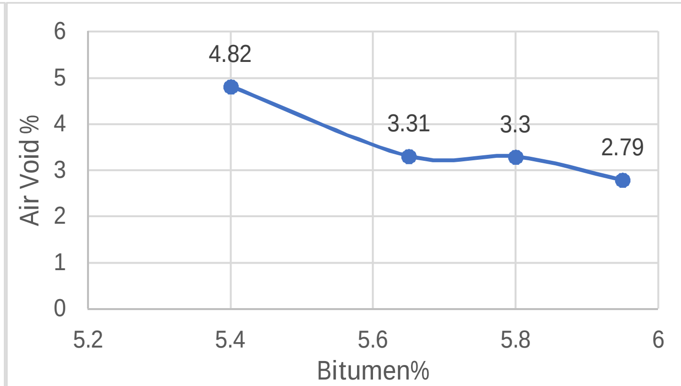

Fig 4: Air Void v/s Bitumen%

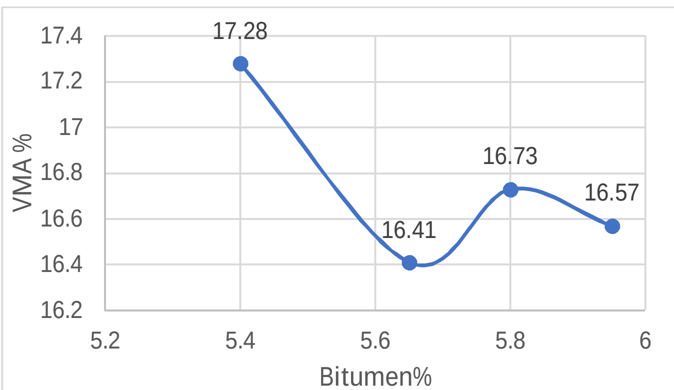

Fig 5: VMA v/s Bitumen%

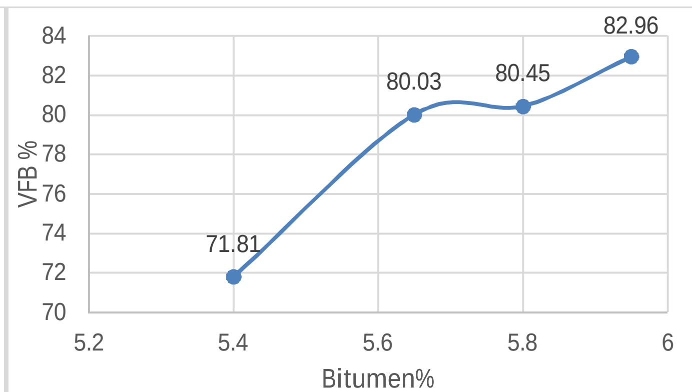

Fig 6: VFB v/s Bitumen%

The optimum binder content (OBC) of the bituminous mix was found to be 5.65% by weight of the total mix, providing the best balance of Marshall Stability, flow value, and air void as per standard. At this binder content, the mix exhibits optimum durability, adequate aggregate coating, sufficient flexibility, and improved resistance to cracking and temperature variations.

B. Mix Design by Using a Varying Percentage of RAP

We will prepare the mix using RAP at different percentages, such as 27.5%,30%,32.5%. There is the reduction is attributed to the contribution of aged binder from RAP, which decreases the demand for fresh bitumen in the mix.

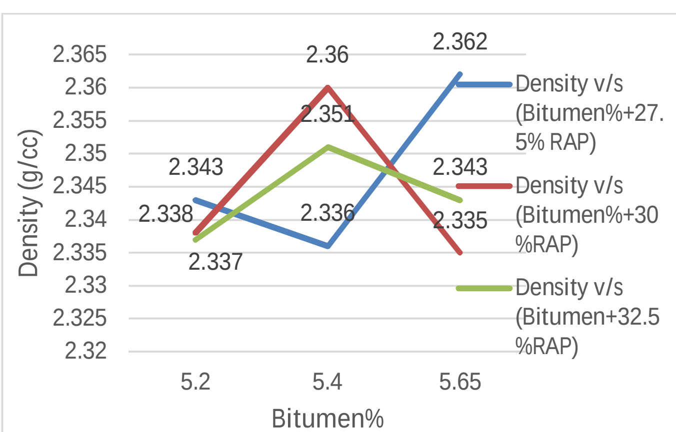

Fig 7: Density v/s Bitumen%

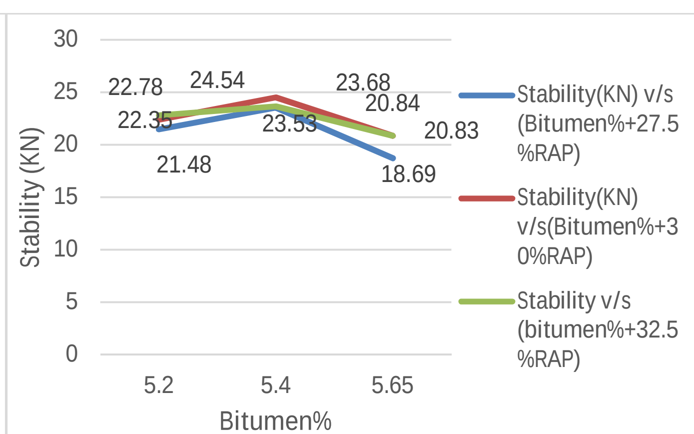

Fig 8: Stability v/s Bitumen%

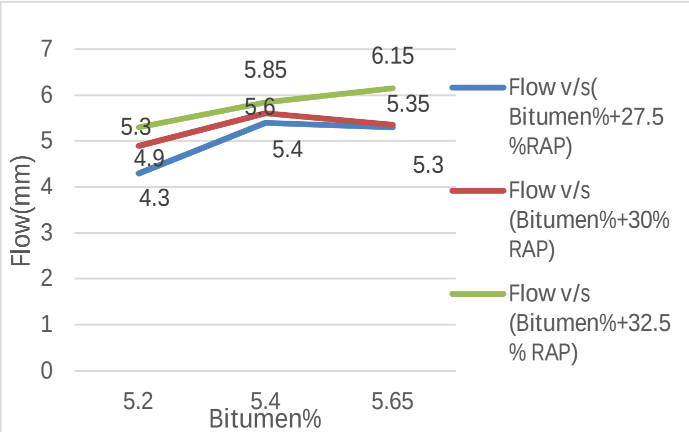

Fig 9: Flow v/s Bitumen%

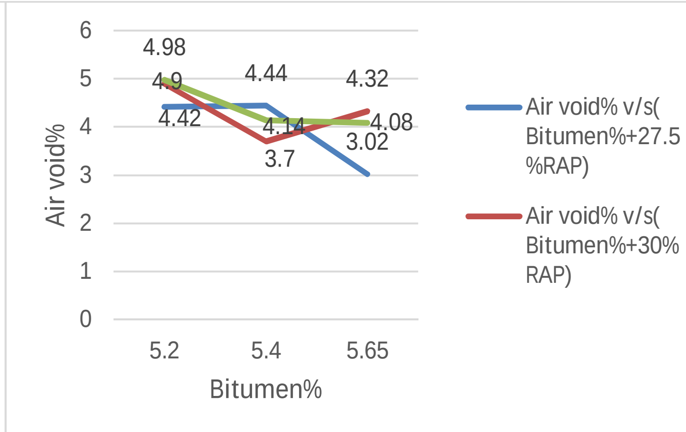

Fig 10: Air Void v/s Bitumen%

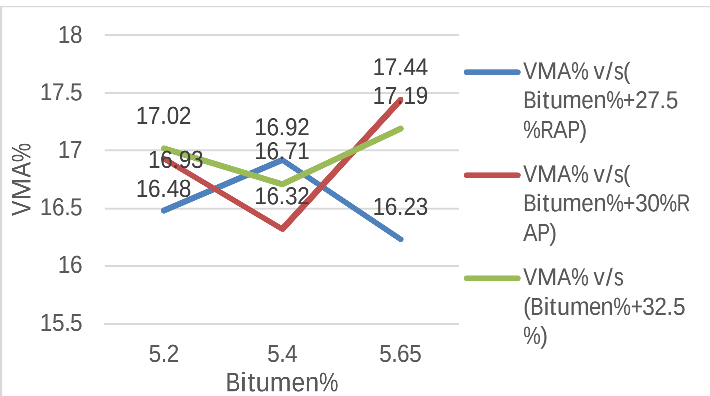

Fig 11: VMA v/s RAP %

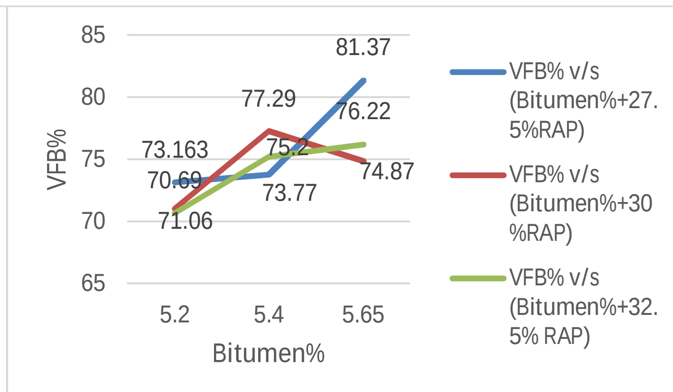

Fig 12: VFB V/S RAP%

Marshall mix design results indicate that the optimum mix design was achieved at 27.5% RAP and 5.20% bitumen content. As a result, less fresh bitumen is needed to achieve the desired coating of aggregates and to meet the target stability, flow, density, air voids, and VMA criteria. Thus, using RAP lowers binder demand while maintaining performance requirements.

C. Mix Design Using Optimum RAP and Varying EPS Percentage

With the optimum mix comprising 5.2% bitumen and 27.5% RAP, Bituminous concrete mixes were prepared by incorporating EPS at contents ranging from 3% to 7% by the weight of bitumen. Marshall specimens were tested for stability, flow, and volumetric properties following the standard procedure. The averaged results were analyzed and plotted to identify the EPS percentage that provides the optimum balance of stability, flow, and mix volumetrics for recommendation.

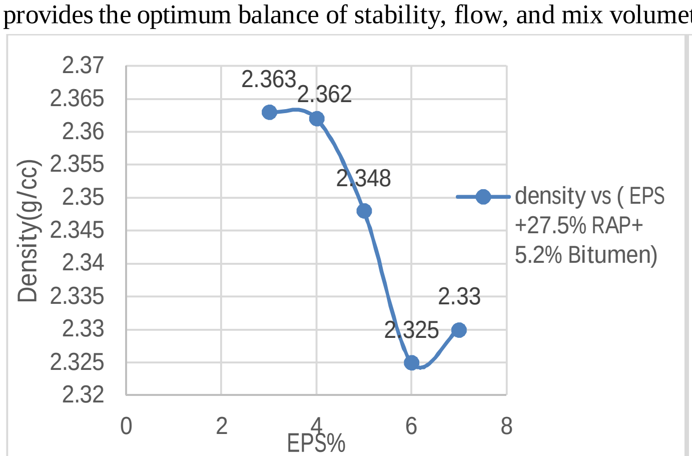

Fig 13: Density v/s EPS%

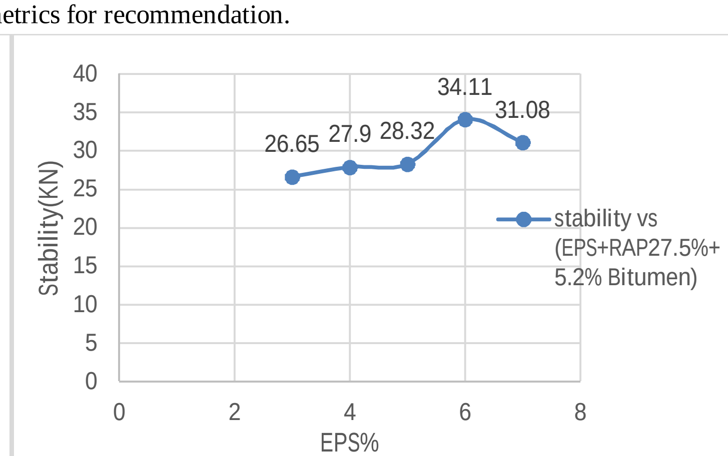

Fig 14: Stability v/s EPS%

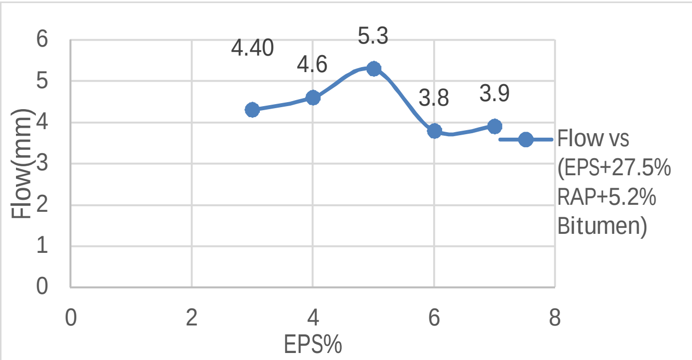

Fig 15: Flow v/s EPS%

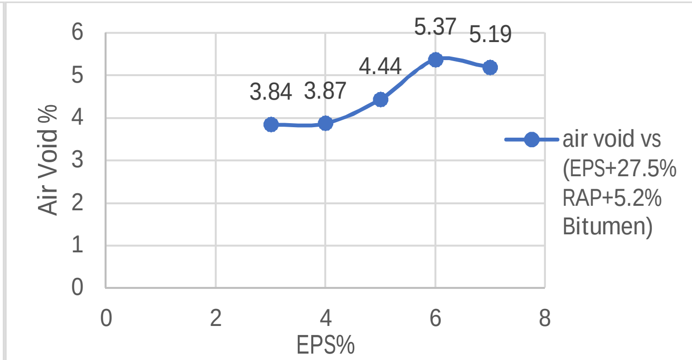

Fig 16: Air void v/s EPS%

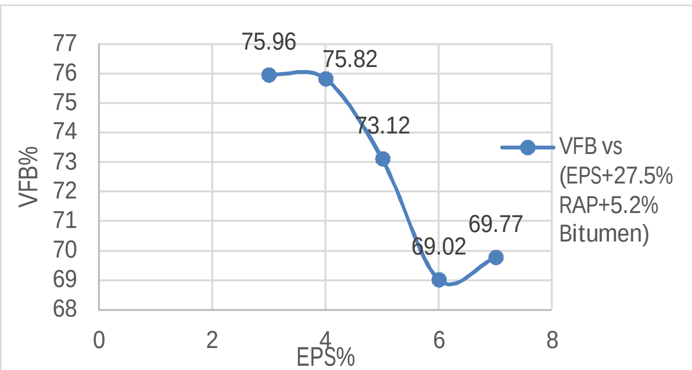

Fig 17: VFB v/s EPS%

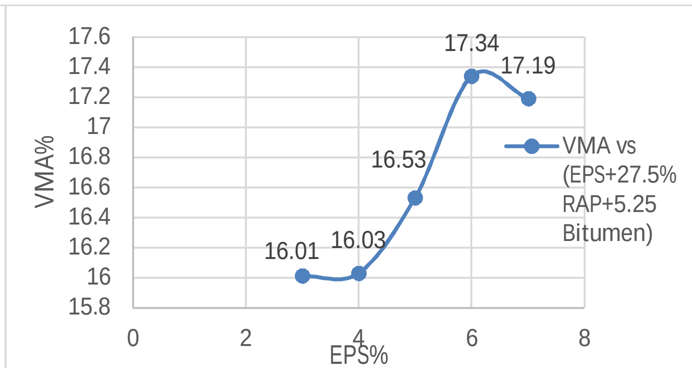

Fig 18: VMA v/s EPS%

Marshall test results indicated that the mix containing 5% EPS, 5.2% binder content, and 27.5% RAP achieved the highest stability with acceptable flow and satisfactory volumetric properties within specified limits. Thus, this composition was identified as the optimum mix, offering improved strength, durability, stability, and good workability of bituminous concrete

D . Indirect Tensile Strength Testing

After fixing the OBC at 5.2%, Indirect Tensile Strength (ITS) tests were conducted on mixes with RAP contents of 27.5%, 30%, and 32.5% to evaluate tensile strength and cracking resistance using standard preparation and testing procedures. After adjusting the OBC to 5.2% and the RAP content to 27.5%, ITS tests were conducted on mixes containing 3%, 4%, and 5% EPS. The specimens were tested under standard conditions to evaluate tensile strength and resistance to cracking under traffic loads.

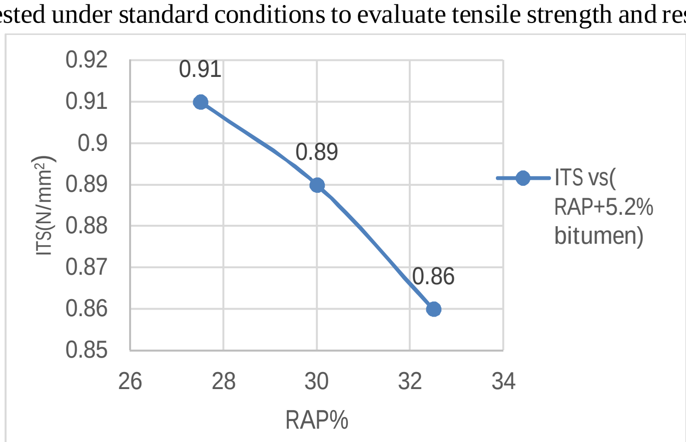

Fig 19: ITS v/s RAP%

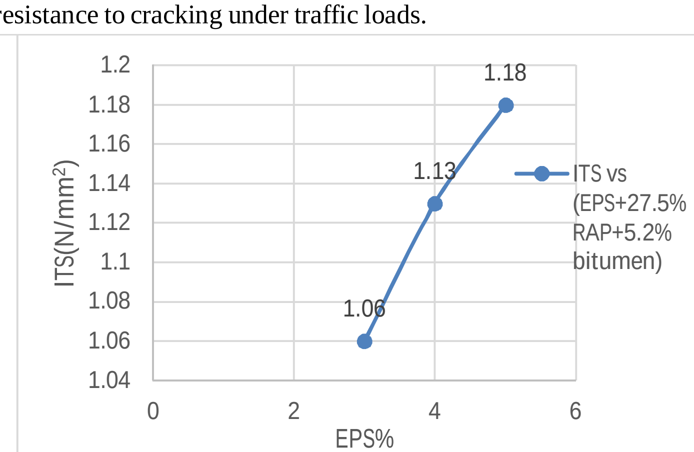

Fig 20: ITS v/s EPS%

VIII. CONCLUSION

The following conclusions have been derived after analyzing the test results:

1) Among the tested binder contents of 5.40%,5.65%, 5.80% and 5.95% for the control mix, the optimum binder content was determined to be 5.65%, indicating the most suitable proportion for achieving the desired mix properties.
2) EPS did not mix homogenously with VG-30 bitumen; it formed flocculates on top when mixed with VG-30
3) It was found that the physical properties of bitumen, such as penetration and softening point, were improved with the addition of EPS. EPS modified VG-30 gives a lower penetration value and a higher softening point value as compared to Virgin VG-30 Bitumen
4) For the mix containing 27.5% RAP, the stability value was 21.48 kN. When EPS was incorporated into the 27.5% RAP mix, the stability value increased to 28.32 kN at 5 % EPS content.
5) Performance Enhancement: Adding EPS up to 5% significantly improved stability, tensile strength, and temperature resistance of the mix without compromising workability or compaction
6) Indirect tensile strength decreased from 0.91N/mm2 at 27.5% RAP to 0.86N/mm2 at 32.5% RAP. Tensile strength has reduced, making it less resistant to cracking under load.
7) Indirect tensile strength increased from 1.06N/mm^2 at 3% EPS to 1.18N/mm^2 at 5% EPS, indicating improved resistance to cracking and tensile under load.

IX. FUTURE SCOPE

From the Experimental study, it has been derived the following investigations should also be conducted in the future:

1) To complete the investigation, the VG-30 Grade binder is used. Similar patterns may be utilized to study the behavior of other grades, such as VG-10 &VG-20
2) The study focuses only on five binder contents percentages that are within a commonly used range: 5.2%, 5.4%, 5.65%, 5.80%, 5.95%
3) Research has been done to be used in bituminous concrete mix. It is possible to do research on several bituminous mixtures, including SDBC and DBM mixtures
4) The Research has been done with the use of RAP, but it is possible to do without RAP

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