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INVESTIGATING THE USE OF RECLAIMED ASPHALT PAVEMENT AND POLYETHYLENE TEREPHTHALATE IN BITUMIONUS CONCRETE

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Abstract.
Rapid development in growing countries has led various issues like environmental degradation, urbanization, resource depletion and health issues. Among these urbanization poses a significant challenge of disposal of non-bio degradable plastic and its challenging recycling. Also, road construction faces a major issue of RAP disposal and natural material scarcity. To address this issue, a method has been developed that effectively replaces natural construction materials with greater efficiency. The primary objective of this research is to develop a methodology for incorporating Reclaimed Asphalt Pavement (RAP) as a partial replacement of coarse aggregates at varying proportions of 10%, 20%, and 30%. Furthermore, to enhance the properties of bitumen, Polyethylene Terephthalate (PET) is used as a modifier at different percentages. Various bitumen tests were conducted to determine the optimum dosage of PET, which is found to be 8%. A total of 90 samples were prepared and evaluated as per Marshall Mix Design Method. The laboratory results revealed that the mix with combination of 8% PET and 20% RAP demonstrated improved Marshall stability and volumetric characteristics compared to conventional mix. This study provides a feasible and sustainable solution to the problem of material scarcity in the construction of pavement and solving the problem of disposal of waste PET and RAP. By utilizing RAP and PET, construction projects can be completed more efficiently and effectively, while contributing to a cleaner and greener environment. The findings suggest that the use of combination of RAP and PET can lead to more efficient and eco-friendly construction practices, representing a significant step towards sustainability in pavement construction.

Keywords:
Bituminous Concrete, Reclaimed Asphalt Pavement (RAP), Polyethylene Terephthalate (PET), Marshall Stability, Volumetric Properties, Flow Value.

I. Introduction

Asphalt recycling is a method that involves adding additives to the already damaged pavement to regenerate its engineering properties. The process involves using the recycled asphalt pavement (RAP), which is obtained after removing the top layer of flexible pavement [1,2,3]. Recycling asphalt allows for the recovery of good quality materials that can be used to enhance the properties of the mix [4]. The use of RAP materials improves the inter-molecular bonding between the binder-coated aggregates and bitumen, leading to better parameters such as Marshall stability, flow, and bulk density [5]. Using RAP in asphalt mixes through partial replacement results in enhanced Marshall test results, leading to a more impermeable mix [6]. India needs to develop more efficient technique and determine the optimal amount of RAP materials to use in pavement construction in order to reduce demand for virgin materials, mitigate waste disposal issues, and minimize land use. India lags behind other nations in this area [7].

Incorporating RAP in pavement construction adds stiffness to the mix, improving resistance against rutting and fatigue cracking up to certain limit [North Carolina Department of Transportation (2007), FHWA RAP ETG Survey]. To address the extra stiffness introduced by RAP in pavement construction, research suggests using additives like Polyethylene (PE), Styrene Butadiene Styrene

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(SBS), and Polyethylene Terephthalate (PET) to prepare a more efficient mix [8]. Several studies suggest that polymer modification significantly improves the long-term performance of pavement [9]. Plastic waste disposal is a significant problem, with India generating about 36million tones of plastic annually, of which only 50% is recycled and is increasing at 15% per year [Central Pollution Control Board, Annual Report 2018-2019], if not addressed, this issue could have disastrous consequences. Recycling plastic waste is importance in countries like India, where plastic waste generation is high. Using plastic in pavement construction can help in waste disposal and prevent pavement failure due to high temperatures.

This study aims to determine optimum percentage of RAP and PET for pavement construction to increase lifespan of flexible pavement by addressing conventional deficiencies leading to pavement failures. The use of non-biodegradable waste materials such as RAP and PET in pavement construction helps in waste disposal issues and provides a recycling solution.

1.1 Reclaimed Asphalt Pavement (RAP)

Reclaimed Asphalt Pavement (RAP) is the top surface of pavement layers that consists of aggregates and bitumen. RAP material can be processed to generate high quality, binder coated aggregates that can be used in pavement construction. This approach to utilize RAP not only satisfied the need for new aggregates but also reduces costs and saves energy [U. S. Department of Transportation, Federal Highway Administration Research and Technology]. Fig.1 shows the image of Reclaimed Asphalt Pavement.

Fig.1: Reclaimed Asphalt Pavement

1.2 PET (Polyethylene Terephthalate)

PET, a thermoplastic material, can be utilized as a bitumen modifier and this modification results in significant benefits such as improved resistance to deformation, moisture damage, stability, strength, durability, and fatigue life of pavements [IRC SP 98:2013]. PET is can be used in pavement construction in two forms: PET-modified binder and plastic-coated aggregates made by mixing PET with aggregates, which are then mixed with binder [IRC SP 98:2013]. PET is commonly used plastic material found in beverage bottles and other packaging [10]. It is a non-biodegradable plastic composed of $C_{10}H_8O_4$ units formed through the polymerization of ethylene glycol and terephthalic acid with catalyst [11]. Various engineering properties of PET is shown in Table 1 below. Using PET as a modifier in asphalt binders can enhances or satisfy stripping characteristics and Marshall properties [12]. The various properties of PET are shown in Table 1 [13].

Table 1 : Various properties of Polyethylene Terephthalate

S. No.	Material Properties	Test Value
1.	IUPAC name	Polyethylene Terephthalate
2.	Chemical formula	$C_{10}H_8O_4$
3.	Density	1.41 gm/cc at 20℃
4.	Melting point	265℃
5.	Molecular Weight	192 gm/mol
6.	Tensile strength	1700 MPa

7.	Yield Strain	4%
8.	Water Absorption	0.5%

Source: Firas Awaja, Dumitru Pavel (2005)

1.3 Objectives of the Study

1. To investigate the Marshall properties of virgin aggregates, RAP aggregates, virgin binder (VG-30) and PET.
2. To determine the optimal percentage of RAP that can be utilized as a substitute for coarse aggregate as well as to determine the effect of RAP in bituminous concrete.
3. To identify the optimum dose of PET in bitumen by performing various tests on PET modified binder with varying percentages.
4. To study the volumetric properties of different bituminous concrete mixes (i.e., conventional mix with optimum RAP, with optimum PET and conventional mix with optimum RAP and optimum PET).

II. Literature Reviews

The disposal of waste generated from road construction has been a major issue, with past methods of dumping and burning causing environmental harm. The concept of sustainable development is now gaining importance to reduce waste production and conserve resources [14]. Prior research has explored using RAP as a coarse aggregate replacement and PET as a binder modifier, resulting in improved mix properties and performance [15,16]. Studies have shown that replacing virgin materials with RAP in bituminous roads can decrease optimum bitumen content, potentially due to the RAP binder filling voids in the mix or the rounded shape of RAP aggregates. Increasing RAP percentage from 0% to 40% can decrease the optimum binder content from 5.57% to 5.10% [17]. Using 30% RAP increased Marshall stability by 30% and decrease bulk density by 40% compared to conventional mix. DBM grafe-2-layer construction by replacing 15-25% virgin aggregates with RAP aggregates yielded satisfactory results [18]. Previous studies have shown that using PET as a binder modifier in pavement construction can significantly improve mix properties. It can be added in either wet or dry form, with wet process improving rutting and dry process improving resistance to moisture damage [19]. Studies on PET-modified binder have shown that PET content up to 12% can be used as a binder modifier. PET makes the binder harder and stiffer, increases ductility by 12%, and enhances weather resistance. Softening point increases from 45 to 56°C for PET content 10 to 12%, while viscosity of bitumen increases for PET content up to 12%, then starts decreasing [20]. The addition of up to 6% PET as a bitumen modifier in DBM mix showed improved properties such as increased Marshall stability by 57.16%, decreased flow value and air voids, increased indirect tensile strength [21]. Combining RAP and PET-modified binder in pavement construction can lead to improved properties of the mix. Research has shown that using 2% PET-modified binder and 30% RAP results in increased Marshall stability, Marshall quotient, and resistance against permanent deformation [22]. Using PET waste in pavement construction not only provides a solution for waste disposal but also improves the properties of pavement [23].
Therefore, an effort can be made to develop a methodology for utilizing waste PET and RAP materials in pavement construction with the right proportions for optimum results.

III. Methodology

The aim of the present study is to utilize waste materials in optimum percentage to produce Bituminous Concrete (BC) Grade-I by replacing RAP aggregates with 19mm virgin aggregates and using PET as a bitumen modifier. The initial stage involves collecting materials and conduction basic tests to identify the suitable materials for experimental process. Subsequently, various trials were conducted to determine the optimal dose of PET, tests such as penetration, softening point, and viscosity test were performed, and the results were analyzed. The Marshall test was then conducted in accordance with the MS-2 Asphalt Institute Manual to evaluate the mix's volumetric properties. A conventional mix was initially prepared with virgin aggregates and binder, followed by the preparation of mixes incorporating RAP materials. Three identical samples were prepared for each percentage of RAP, with five different bitumen percentages ranging from 4% to 6% at an interval of 0.5% to obtain more precise results. Thus, a total of 90 samples were prepared. Mixes were prepared with varying RAP percentage, replacing the coarse aggregates. After analyzing the obtained results and comparing them with those of conventional mix, the optimal RAP dose was determined. Finally, a mix was prepared with the optimal PET and RAP percentage to evaluate the combined effect of waste materials. The results were then compared to those of conventional mix. Overall, the study aimed to identify the most efficient and sustainable combination of materials for road construction. Fig. 2 showing the number of samples with varying bitumen content and the flow chart of adopted methodology is shown below in Fig.3.

Fig. 2 : Samples with varying bitumen content

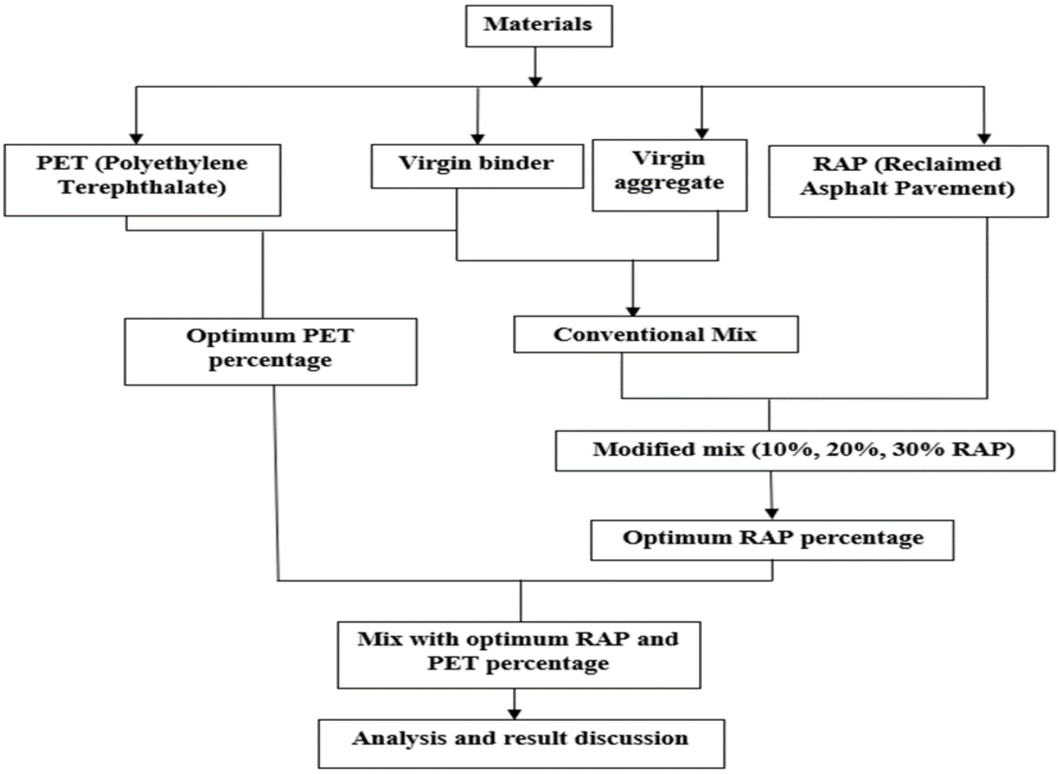


Fig. 3 : Flow Chart of Methodology

IV. Material

4.1 Conventional Materials

In the construction of flexible pavement, the basic materials used are aggregates and binder. To ensure the suitability of these materials for further use in the experimental process, basic testing was conducted in accordance with codal provisions.

4.2 Virgin aggregates

The suitability of aggregates collected from a local crusher plant was assessed by conducting basic tests such as impact value, crushing strength, specific gravity, and water absorption. The results are presented in a Table 2.

Table 2 : Physical Properties of Virgin Aggregates

S. No.	Properties	Test results			IS code	Permissible limits
		19mm	10mm	6mm		
1.	Impact value	15.55%	16.12%	16.5%	IS 2386 Part I	24%
2.	Crushing	20.85%	21.73%	19.12%	IS 2386 Part IV	30%
3.	Specific gravity	2.875	2.855	2.905	IS 2386 Part III	-
4.	Water absorption	0.60%	1.88%	1.62%	IS 2386 Part III (b)	Max 2%

4.3 Virgin binder

VG-30 grade bitumen was used as a binder and basic tests were done to evaluate its engineering properties, presented in Table 3.

Table 3 : Physical Properties of Virgin Binder

S. No.	Properties	Test value	IS code	Permissible Limits
1.	Penetration Value	63.33 mm	IS 73:2013 (VG-30)	50-70mm
2.	Softening point	57.65°C	IS 73:2013 (VG-30)	Min 47°C
3.	Density	1.06 gm/cc	IS 1202	-
4.	Viscosity	2520 poise	IS 73:2013 (VG-30)	2400-3600 poise

4.4 Reclaimed Asphalt Pavement

RAP (Recycled Asphalt Pavement) was collected from PMGSY road, Khategaon, Dewas District (M.P) and processed into smaller size. The binder was extracted using a benzene solution and centrifugation technique, and its engineering properties were evaluated. The physical properties of RAP aggregates were also evaluated by conducting various tests, such as impact value, crushing strength, specific gravity, and aggregate gradation, and the results are presented in Table 4.

Table 4 : Physical Properties of RAP

S. No.	Properties	Test results	IS code	Permissible limits
1.	Impact value	10.38%	IS 2386 Part I	24%
2.	Crushing	13.67%	IS 2386 Part IV	30%
3.	Specific gravity	2.895	IS 2386 Part III	-

4.	Water absorption	1.57%	IS 2386 Part III (b)	Max 2%

4.5 Polyethylene Terephthalate
PET in the form of shredded particles of size 5mm to 6mm was used in the study. It was obtained from locally collected plastic bottles such as drinking water and soft drink bottles. The engineering properties of PET are presented in Table 5.

Table 5 : Engineering Properties of PET

S. No.	Materials Properties	Test Value
1.	Density	1.38gm/cc
2.	Melting point	240°C
3.	Water absorption	0.5%

V. Determination of Optimum PET

In this study, different samples were prepared with varying percentages of PET by weight of binder to determine the optimum PET percentage for PET-modified binder. Penetration value, softening point, and viscosity tests were performed and the results were compared to virgin VG-30 binder results. The percentage of PET satisfying all permissible limits was taken as the optimum PET percentage, and the results are presented in Table 6. Viscosity test results are acceptable for PET content up to 8%, but exceed specified limits beyond that, while softening point and penetration value are within limits for all percentages of PET.

Table 6 : Physical Properties of Virgin binder with varying percentages of PET

S. No.	% PET by weight of bitumen	Penetration value (mm)	Softening point (°C)	Viscosity (poise)
1.	2%	62.37	58.25	2718
2.	4%	58.01	59.19	2930
3.	6%	56.32	60.20	3156
4.	8%	53.56	60.89	3360
5.	10%	52.22	61.36	3721
6.	12%	51.97	62.51	3987
7.	Permissible limits	50-70 mm	Min. 47°C	2400-3600 poise

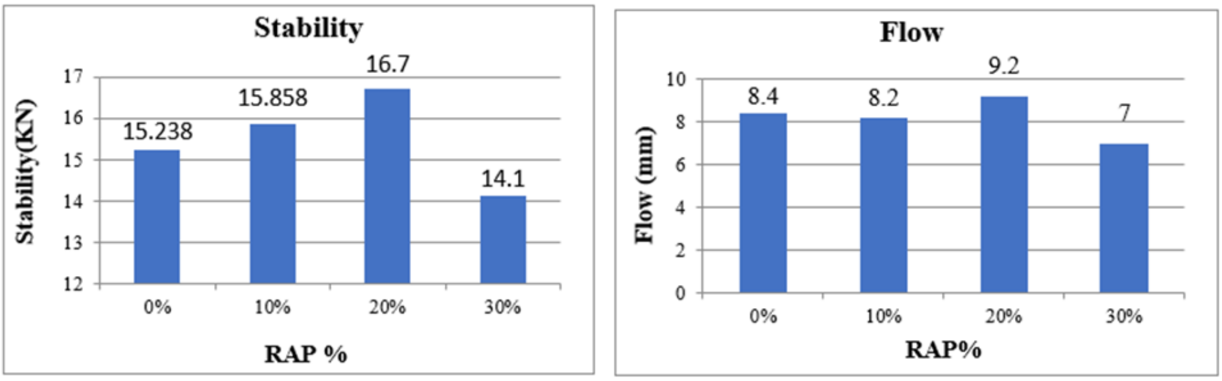
VI. Test and Results

Evaluating the Marshall properties of bituminous mix and achieving an optimal blend is a key component of this research. The process of designing a bituminous mix involves finding up the most optimum proportions of materials that will affect its cost, workability, durability, and strength. The Marshall mix design approach, which is carried out in accordance with the Asphalt Institute Manual MS-2, 7th revision, 2014, is used to assess the volumetric properties of the mix. The approach states that the optimum binder content is the binder content corresponding to 4% air voids in the mix. First, a conventional mix is prepared using virgin binder (VG-30) and a virgin aggregate graded according to MoRTH section 500 BC Grade-I. Then, modified mixes were prepared replacing 10%, 20%, and 30% of RAP aggregates with 19mm coarse aggregates and further, the mixes were prepared with optimum dose of PET modified binder. Last mix prepared with the combination of optimum percentage of RAP and optimum dose of PET modified binder and then the results obtained were compared with conventional mix to find out the best possible mix to be used for the construction of road.

6.1 Effect of RAP in conventional mix

6.1.1 Stability and flow

Marshall stability test is performed according to Asphalt Institute Manual MS-2. Marshall stability is the maximum load that a cylindrical Marshall specimen with dimensions of 60.5 mm and 101.5 mm in diameter can withstand before failure at the defined temperature when loaded at a rate of 50.8 mm per minute. Marshall stability describes the maximum load that a pavement can withstand while resisting deformation**.** The outcomes of the Marshall stability test for various combinations are presented in Fig. 4 (a). Similarly, Flow value is defined as the total deformation on Marshall specimen occurs before failure expressed in terms of 0.25 mm units. According to Table 7.2 Asphalt Institute Manual MS-2, Flow value should be between 8-18 mm. Fig. 4 (b) Illustrates the variation of the flow value for different mixes.



(a) (b)

Fig. 4 (a) & (b): Stability and Flow of RAP mixes and Conventional mix

The stability value of the asphalt mixture is in allowable range and meet the minimum stated limit of 3.326KN for all mixes. It was observed that incorporating reclaimed asphalt pavement (RAP) aggregates into the mixture enhances its stability when compared to a conventional mixture. However, the stability value starts to decrease after 20% RAP content, i.e., at 30% RAP content, the stability value is lower than that of the conventional mixture. As a result, it can be concluded that the optimal RAP content is 20%. Additionally, it was found that the flow value increases when RAP aggregates are used up to 20% and then decreases at 30% RAP.

6.2 Unit weight and Air Voids

The percentage of total voids in the asphalt mixture, also known as air voids, is a crucial factor in determining the optimum binder content. It is expressed as a percentage of the mixture’s volume. According to the Asphalt Institute Manual MS-2, air voids should fall between 3% and 5%. Excessive air voids can cause the mixture to become more porous, leading to lower bitumen content, while insufficient air voids can cause bitumen to flow and bleed. Therefore, air voids should remain within allowable range. Fig. (c) and Fig. 4 (d) shows the variation units weight and air voids against percentages of RAP.

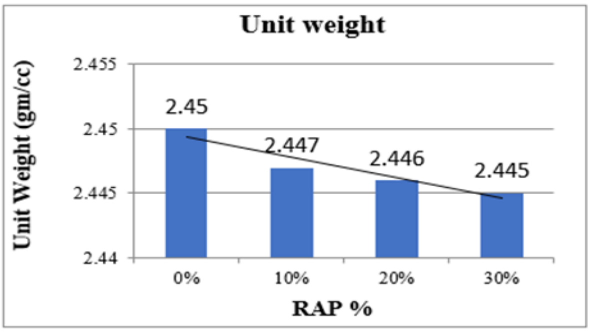


Fig. 4 (c)

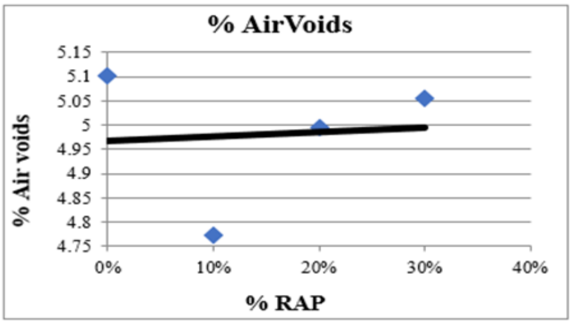


Fig. 4 (d)

Fig. 4 (c) & (d): Unit Weight and % Air Voids of RAP mixes and Conventional mix

Compared to the conventional mix with a unit weight of 2.430 gm/cc, the addition of RAP aggregate led to a decrease in the unit weight of the mix, with a value of 2.448 gm/cc. Moreover, the air voids in aggregates increased with the use of RAP, with the highest value observed at 30% RAP content, reaching 4.063% at the optimum bitumen content.

6.3 Voids Filled with Bitumen (VFB) and VMA (Voids in Mineral Aggregates)

In Fig. 4 (f), the VFB values for different mixes were plotted against percentages of RAP. The results were compared with the Asphalt Institute Manual MS-2 specifications, which recommend VFB values between 70% to 80% for low volume roads. It was observed that VFB values for all mixes satisfied the specified criteria. Voids in mineral aggregates are the sum of air voids and voids filled with bitumen. To ensure proper pavement construction, the VMA values should be greater than 13% for a nominal aggregate size of 19 mm and air voids of 4%. The fig. 4 (e) shows VMA values for different mixes.

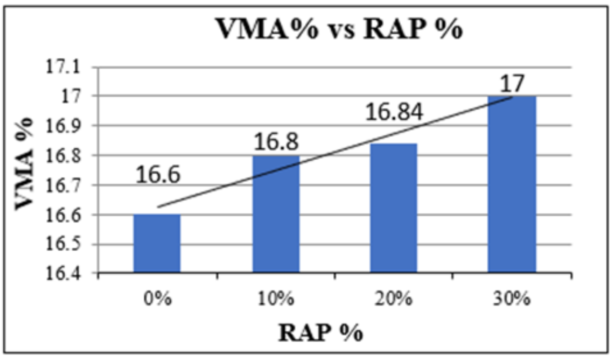


Fig. 4 (e)

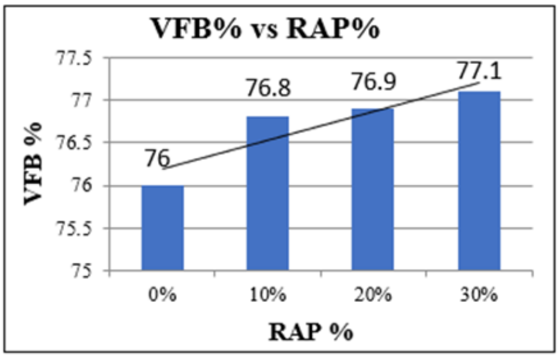


Fig. 4 (f)

Fig. 4 (e & f): VMA and VFB of RAP mixes and Conventional mix

The mix containing 30% RAP showed the highest VFB among all the mixes and it can be observed that VFB is increasing as we increase the percentage of RAP. On the other hand, the values of VMA for all bitumen contents and different mixes were found to meet the minimum specified limit. The replacement of RAP aggregates led to an increase in the voids in mineral aggregates compared to the conventional mix.

6.4 Effect of PET in conventional mix

Fig. 4 (g to l) presents a comparison of various Marshall properties of the conventional mix and the mix containing optimum PET content. The results show that the addition of PET-modified binder has a positive impact on the mix. The stability value of the PET-modified mix increased from 14.9 KN to 18.5 KN, indicating improved resistance to deformation, while the flow value decreased, indicating

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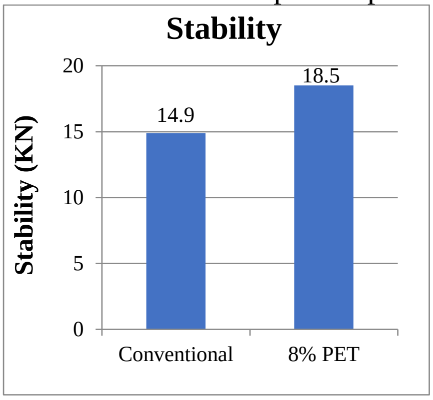
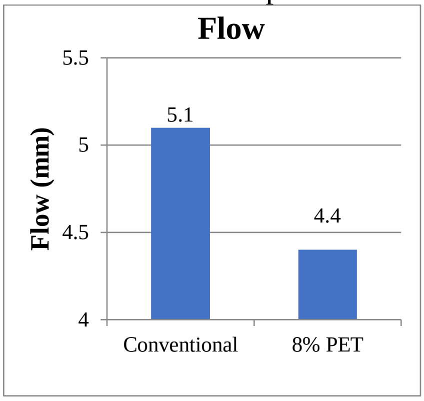
increased resistance to flow. The unit weight of the PET-modified mix increased from 2.45 gm/cc to 2.464 gm/cc, which can be attributed to the replacement of less dense bitumen with the denser PET. The air voids in the PET-modified mix decreased by 13.72%, indicating a more compact and dense mix. The VMA and VFB values also decreased compared to the conventional mix, indicating a reduction in the percentage of voids in the mix. These findings suggest that the use of PET-modified binder can lead to improves performance of the mix in pavement construction applications.



(g)



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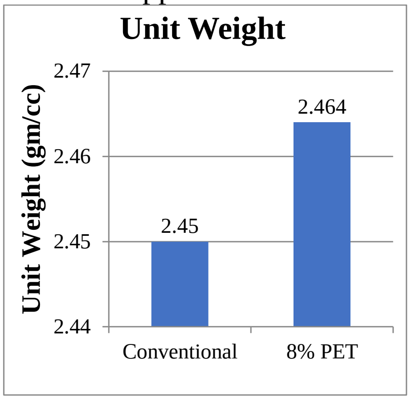

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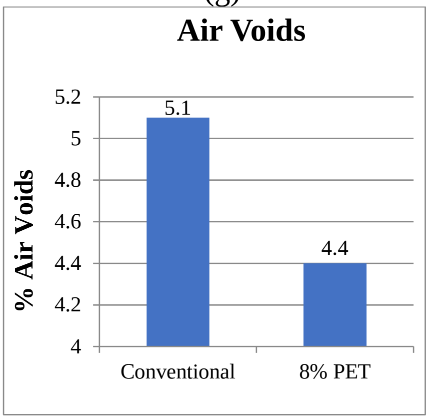
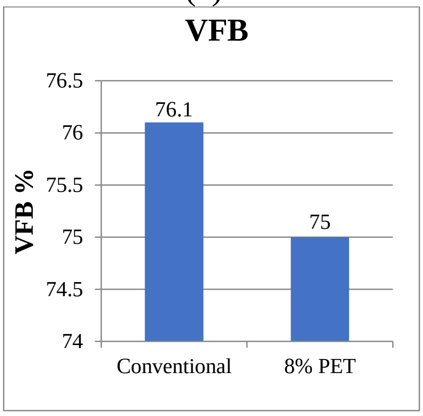


(j)



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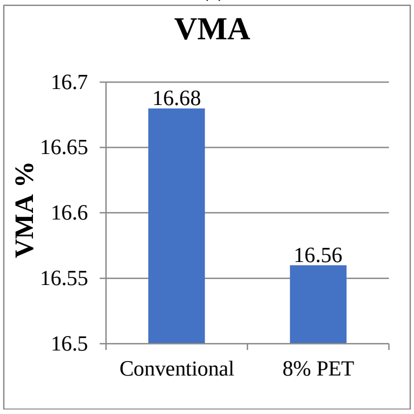

(l)

Fig. 4 (g to l) : Marshall parameters of PET-modified mixes and Conventional mix

6.5 Effect of combination of PET and RAP in conventional mix

The Marshall test results for a PET-modified mix and a mix containing RAP have been depicted in Fig. (m to r). The stability value of the combination of PET and RAP was found to be higher than that of the conventional mix. The flow value of the combination of PET and RAP was found to be lower than that of the conventional mix. Additionally, the unit weight of the mix increased slightly from 2.450 gm/cc to 2.455 gm/cc, which is lower than the unit weight of the PET-modified mix (2.464 gm/cc). These results suggest that the incorporation of PET increases the unit weight of the mix, while the addition of RAP decreases the unit weight. The unit weight of the modified mix falls somewhere between the unit weight of the conventional mix and the PET-modified mix. Furthermore, the air voids in the modified mix were found to be 21.56% lower than those in the conventional mix, indicating that the voids in the mix were reduced, which can improve the mix's performance. However, the values of VMA and VFB of the modified mix were lower than those of the conventional mix. Overall, the results suggest that the combination of PET and RAP mix shows promising properties for use in pavement construction due to its improved stability and reduced air voids.

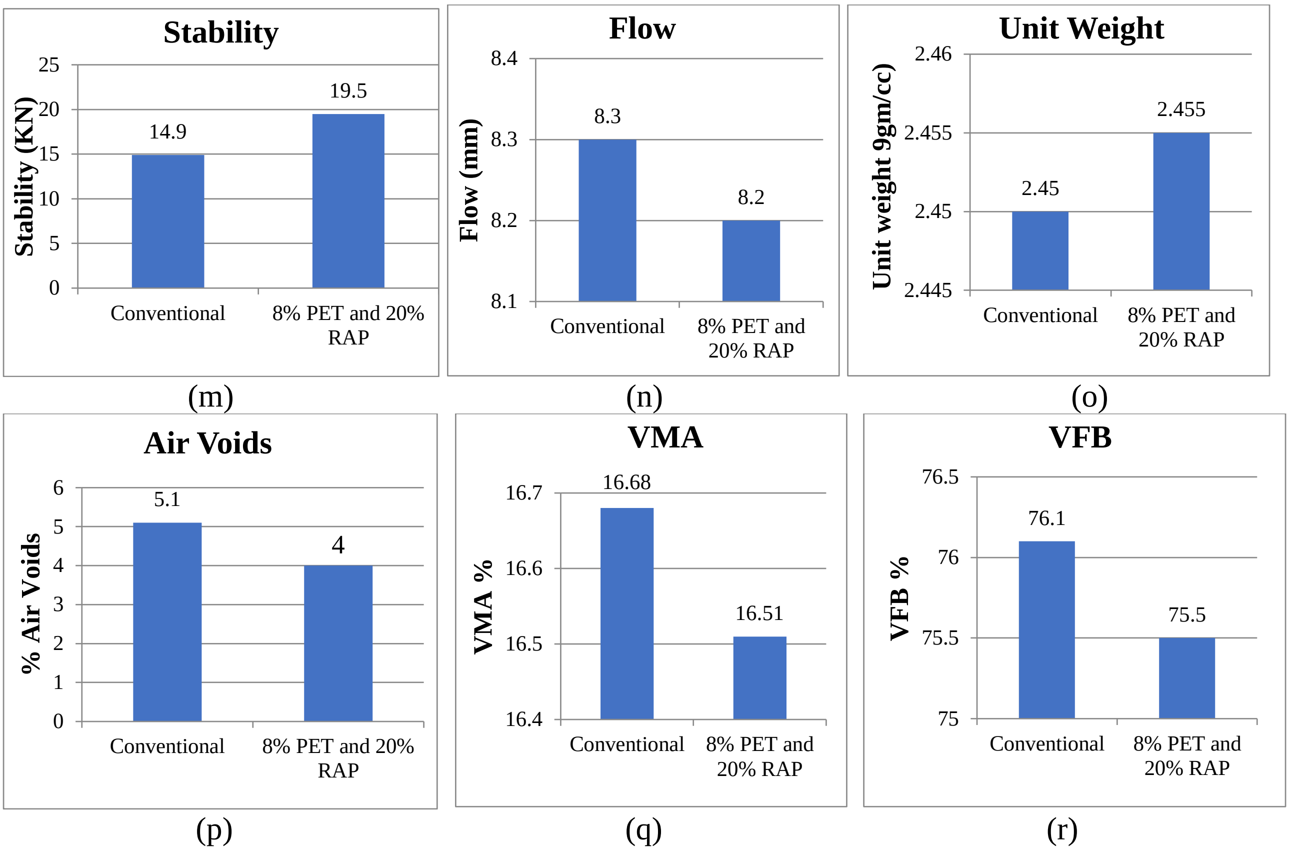

Fig. 4 (m to r) : Marshall parameters of (PET and RAP mixes) and Conventional mix

6.6 Results comparison of different mix

Table 7, shows the results of tests conducted on various mixes, including those containing RAP aggregates and PET-modified binder, at the optimum bitumen content. These results were compared with the results of tests on the conventional mix, and the desired specification limits were used to assess the impact of using RAP aggregates and PET-modified binder on the mix. The purpose was to evaluate the suitability of these modified mixes for use in pavement construction by assessing their compliance with the relevant standards and specifications.

Table 7: Comparison Table of all Mixes

S. No.	Property	Conventional Mix	20% RAP	8% PET	8% PET and 20% RAP	MS-2 Specifications
1.	OBC %	5.62	5.592	5.57	5.547	
2.	Stability (KN)	14.9	16.5	18.5	19.5	Min. 3.336KN
3.	Flow (mm)	8.3	9.2	8	8.2	8-18 mm
4.	%Air voids	4	4	4	4	-
5.	Unit weight (gm/cc)	2.45	2.446	2.464	2.455	3-5%
6.	VFB %	76.1	7	75	75.5	70-80%
7.	VMA %	16.68	16.81	16.56	16.51	Min. 13%

VII. Conclusion

Based on the results of the experimental study, several conclusions can be drawn. The study found that the bitumen properties of the 8% PET-modified binder were within the specified limits, but further addition of PET did not meet the criteria. The optimum dose of PET was determined to be 8% through various bituminous tests. Also, the study found that the optimum bitumen content for the conventional mix was 5.62%, with other Marshall parameters such as stability and flow meeting the specified limit. Moreover, the study found that the Marshall parameters and volumetric properties at RAP 20% were within specified limits, while, with further increments in the percentage of RAP, the Marshall parameters did not meet the desired specifications when compared to conventional mix. For the 20% RAP modified mix, the optimum binder content was 5.592%, and the Marshall stability, flow, VFB, and VMA increased, while unit weight decreased compared to the conventional mix. For the 8% PET-modified mix, the optimum binder content was found to be 5.57%, and the Marshall stability, unit weight, and other parameters increased, while VMA, VFB, and flow decreased compared to the conventional mix.

Furthermore, the study found that for the combination of 8% PET and 20% RAP (optimum dose of RAP) modified mix, the optimum binder content was 5.547%, and the Marshall stability, unit weight, and VMA increased, while VFB and flow decreased compared to the conventional mix.

Based on these results, it can be concluded that the mix with the combination of 8% PET and 20% RAP demonstrated improved Marshall stability and other volumetric properties when compared to all other mixes. These findings suggest that this combination of PET and RAP can be effective way to improve the performance of bituminous mixes while reducing construction costs.

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