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Comprehensive studies on Influence of Fillers on RAP Incorporated Dense Bituminous Mix-II

Sumanth S[1], Dr. Manjesh L[2]

[1] Research Scholar, Department of Civil Engineering, UVCE, Bangalore University
[2]Professor, Department of Civil Engineering, UVCE, Bangalore University

Abstract

Sustainable pavement construction has become increasingly important in India due to rapid infrastructure growth and the depletion of natural aggregates. This study investigates the performance of Dense Bituminous Macadam (DBM-II) mixes incorporating Reclaimed Asphalt Pavement (RAP) at 10%, 20%, and 30% replacement levels, with different fillers (stone dust, fly ash, and Ground Granulated Blast Furnace Slag) and bitumen VG-30 as binders. Laboratory investigations were carried out to evaluate the mechanical and durability characteristics of the mixes through Marshall Stability, Retained Marshall Stability (RMS), Indirect Tensile Strength (ITS), Tensile Strength Ratio (TSR) and Cantabro Abrasion Loss (CAL) and Resilient Modulus (M_R). Results indicated that virgin binder demand reduced with RAP incorporation, although Marshall Stability decreased slightly due to the stiff aged binder in RAP. GGBS mixes consistently demonstrated superior stability, tensile strength, moisture resistance, and abrasion resistance compared to stone dust and fly ash mixes. All mixes satisfied MoRTH requirements for stability (>900 kg), RMS (>80%), TSR (>80%) and abrasion loss confirming their suitability for field applications. Overall, the findings establish that DBM-II mixes with up to 30% RAP, particularly when combined with GGBS filler, can deliver durable and environmentally sustainable pavement solutions.

Keywords: Sustainable Pavement, Reclaimed Asphalt Pavement, Dense Bituminous Macadam

1. Introduction

Roads are a vital component of transportation infrastructure, facilitating the mobility of people, goods, and services while contributing to regional and national development. They not only enhance trade, commerce, and tourism but also support education, healthcare, and emergency services by improving accessibility. In India, which possesses the second-largest road network in the world at over 6.67 million kilometers (MoRTH, 2023), road infrastructure plays a pivotal role in socio-economic growth. Approximately 90% of Indian roads are flexible pavements, primarily constructed with bituminous mixes comprising aggregates and binder (Surender Singh et al., 2018). Aggregates, which constitute nearly 95% of these mixes by weight, are sourced from natural deposits, but their extensive extraction has led to significant environmental concerns, including depletion of resources, ecological imbalance, and pollution (Kumar & Natarajan, 2019).

To address these challenges, the incorporation of Recycled Asphalt Pavement (RAP) has gained increasing attention as a sustainable alternative. RAP, obtained from milling deteriorated pavements, contains aged binder and aggregates that can partially replace virgin materials in new mixes. This practice not only conserves natural resources but also reduces construction waste, energy consumption, and overall project costs (Liu et al., 2020, Pradyumna et al., 2013;). Despite these benefits, challenges such as binder stiffness, compatibility with virgin materials, and potential reductions in flexibility necessitate careful optimization in mix design.

Further improvements can be achieved by introducing alternative fillers such as fly ash and Ground Granulated Blast Furnace Slag (GGBS) over conventional filler stone dust. These materials enhance performance by improving durability, moisture resistance, and mechanical properties, while simultaneously promoting sustainable waste utilization (Veropalumbo et al., 2020; Shiva Kumar Mahto et al., 2022). Against this backdrop, the present study evaluates DBM-II mixes incorporating RAP (10%, 20% and 30%), binders (VG-30), and fillers (Stone Dust, Fly ash and GGBS) to develop durable, and environmentally sustainable pavement solutions.

2. Materials and Methodology

2.1 Materials:

Crushed virgin granite aggregates were used as coarse aggregates, while stone dust served as the fine aggregate. Both were procured from a quarry located near Bidadi, Bengaluru. Reclaimed Asphalt Pavement (RAP) aggregates were obtained from a 13 to 14 year old national highway through the milling process and stockpiled for about 9–10 months at a RAP storage facility near Chikkajala, Bengaluru. The particle size distribution of virgin and RAP aggregates is presented in Figure 1, and their physical properties are summarized in Table 1. The specifications of paving-grade bitumen VG-30 are provided in Table 2. For filler materials, three types were selected: stone dust sourced from a private crusher plant at Bidadi, Class F Fly Ash from Raichur Thermal Power Plant (Raichur District, Karnataka), and Ground Granulated Blast Furnace Slag (GGBS) from JSW Steel Plant (Ballari District, Karnataka). Table 3 gives the composition details of fillers.

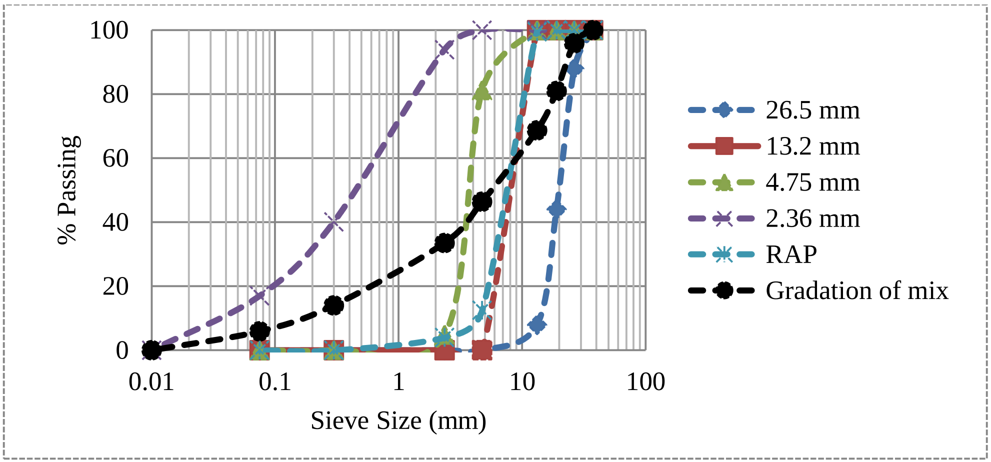

Figure 1: Particle size distribution of Virgin aggregates and RAP aggregates

Table 1: Physical Properties of aggregates

Properties	Virgin aggregates	RAP aggregates	MoRT&H-V (2013) Specification limit
Specific Gravity			
26.5mm	2.673	2.593	-
13.2mm	2.666		
4.75mm	2.655		
2.36mm	2.716		
Crushing value, %	18.20	26.02	-
Impact value, %	16.19	22.24	Max 27%
Los angles abrasion value,%	23.00	26.15	Max 35%
Combined indices,%	22.98	25.04	Max 35%
Water absorption,%			
26.5mm	0.23	0.31	Max 2%
13.2mm	0.27		
4.75mm	0.28		

Table 2: Properties of Binder

Characteristics	VG-30	RAP Binder	Requirements as per Table-1, IS 73:201 (VG 30)
Penetration, 0.1 mm	51	18	45
Absolute viscosity, Poises	3184	22676	2400- 3600
Flash point,°C	282	---	220
Softening point (R&B), °C	51	81	47
Ductility at 25°C, cm, Min	96	---	40
Specific Gravity	1.02	---	1.10

Table 3: Composition Details of Fillers

Elements	Stone Dust,%	Fly Ash,%	GGBS,%
SiO_2	57.27	55.94	34.26
Al_2O_3	17.38	31.17	16.80
Fe_2O_3	6.71	5.61	---
MgO	6.44	---	6.74
TiO_2	---	3.51	---
K_2O	---	2.01	---
CaO	---	1.77	42.19

2.2 Methodology:

The collected materials were subjected to a series of fundamental laboratory tests to evaluate their suitability for use in the study. The physical and mechanical properties of virgin aggregates and RAP aggregates are presented in Table 1, while the characteristics of virgin binder and binder recovered from RAP are summarized in Table 2. For binder recovery, the centrifuge extraction method (ASTM D2172) was employed to separate the aggregates and binder in RAP, followed by the Abson Recovery Method (ASTM D1856-95A) to obtain the extracted binder. The binder content in RAP is found out to be 3.86% by weight of aggregates. Sieve analysis was carried out on individual fractions of aggregates, and the results were combined to achieve the desired aggregate gradation for all mixes, illustrated in Figure 1. The aggregates are categorized into the following size fractions: 26.5mm–19mm, 19mm–13.2mm, 4.75mm–2.36mm and 2.36mm and below, with which the proportions of this fractions used for sample preparation is 34%, 17%, 14% and 33%, respectively. RAP is introduced to this mix in various proportions (10%, 20% and 30%) replacing from virgin aggregates. 2% filler is added to this mix and different types of mix is prepared (refer Table 4).

The Marshall Stability test, conducted in accordance with the Asphalt Institute Manual MS-2, to determine the Optimum Binder Content (OBC) and to assess the volumetric properties of each mix. To evaluate moisture-induced damage, Retained Marshall Stability (RMS) tests (ASTM D1075), Indirect Tensile Strength (ITS) tests, and Tensile Strength Ratio (TSR) tests (AASHTO T283) were performed. The Cantabro Abrasion Loss (CAL) test was conducted to examine the toughness of RAP-incorporated mixes.

Table 4: Nomenclature of Mix

Sl. No.	Filler Type	RAP Content (%)	Type of Mix	Nomenclature
1	Stone Dust	0	PSTM	PSTM - 1
2		10		PSTM – 2
3		20		PSTM – 3
4		30		PSTM - 4
5	Fly Ash	0	PFTM	PFTM -1
6		10		PFTM – 2
7		20		PFTM – 3
8		30		PFTM – 4
9	GGBS	0	PGTM	PGTM - 1
10		10		PGTM – 2
11		20		PGTM – 3
12		30		PGTM – 4

3. Experimental Programme

3.1 Marshall Stability Test

Aggregates, including 2% filler, were weighed to 1200 g and mixed with bitumen using the Marshall method, starting at 4% binder (by aggregate weight) with 0.5% increments up to 5.5%. Aggregates were preheated to 150°C, blended with preheated bitumen, and compacted in preheated molds using a 4.53 kg rammer (457 mm drop, 75 blows per side). Three samples were prepared per binder content. Each was weighed in air, water, and SSD condition. After conditioning at 60°C for 35 minutes, Marshall Stability and flow tests were conducted. Volumetric properties (Va, VMA, VFB) were calculated using standard equations.

3.2 Retained Marshall Stability

The Retained Marshall Stability (RMS) test evaluates the resistance of bituminous mixes to moisture-induced damage. Two sets of Marshall specimens are prepared at the Optimum Binder Content (OBC) with similar air void content. The unconditioned set is immersed in a water bath at 60°C for 30–40 minutes, while the conditioned set is soaked at 60°C for 24 hours. Marshall Stability values are then determined for both sets using the standard procedure. RMS is expressed as the percentage ratio of conditioned to unconditioned stability. According to MoRTH (2013), DBM mixes must achieve a minimum RMS of 80% to be acceptable.

3.3 Tensile Strength Ratio

The Tensile Strength Ratio (TSR) test, conducted as per AASHTO T-283, evaluates the moisture susceptibility of asphalt mixtures. Two sets of specimens with 6–8% air voids are prepared: conditioned and unconditioned. Conditioned specimens are wrapped with 10 ml water, frozen at −18°C to +3°C for 16–24 hours, then subjected to a thaw cycle in a 60°C water bath for 24 hours. They are equilibrated at 24°C for 2 hours before testing, while unconditioned specimens are only conditioned at 24°C for 2 hours. Indirect tensile strength (ITS) is measured for both sets, and TSR is calculated, with higher values indicating superior moisture resistance.

$$\text{ITS} = \frac{2P}{\pi DH} \qquad (1)$$

Where, ITS is the indirect tensile strength in Kg/cm^2 , P is the peak load in Kg, D is the diameter of the sample in cm and H is the height of the sample in cm.

$$\text{TSR} = \frac{\text{ITS of conditioned samples}}{\text{ITS of Unconditioned samples}} \text{X } 100 \qquad (2)$$

3.4 Cantabro Abrasion Loss

The abrasion resistance of DBM mixes is evaluated as per [IRC:129-2019, Kumari monu et. al. (2018) , Abhijith Mondal (2023)] using cylindrical specimens (100 × 63.5 mm) cast at Optimum Binder Content. Six specimens were prepared for each mix—three conditioned in water at 20 °C for 20 hours (unaged) and three oven-aged at 60 °C for 24 hours. All were brought to 25 °C before testing in a Los Angeles Abrasion Machine (without charges) for 300 revolutions at 30–35 rpm. The percentage mass loss after testing was recorded as the abrasion loss.

$$\%\text{ Mass Loss} = \frac{W1-W2}{W1} \times 100 \qquad (3)$$

Where, W_1= Initial mass of the specimen, gm &W_2= Final mass of the specimen, gm

3.5 Resilient Modulus of Bituminous mixes

The resilient modulus test (ASTM D 4123) is conducted at a temperature of 35 °C, where Marshall specimens were conditioned for 24 hours before testing. A haversine load pulse at 1 Hz (0.1 s load and 0.9 s rest) was applied along the vertical diameter of the specimen. The test was performed for 200 load cycles, and the resilient modulus was calculated as the ratio of applied tensile stress to recoverable strain, assuming a Poisson's ratio of 0.35.

$$\text{Resilient Modulus, } M_R = \frac{P \text{ x } (0.27+\mu)}{HR \text{ x } t} \qquad (4)$$

Where, M_R = Resilient Modulus, MPa, H_R = Resilient Horizontal Deformation, P = applied repeated load, N, μ is Poisson's ratio (0.35), t=thickness of specimen, mm

4. Results and Discussion

4.1 Marshall Stability

Marshall Stability test results are presented in Table 5. With the incorporation of RAP, the required virgin binder content decreased due to the presence of residual binder in RAP. However, this binder is stiffened by long-term oxidation, leading to a reduction in stability with increasing RAP content. The superior quality of virgin aggregates and fresh binder compared to RAP also contributes to this trend. The results further indicate that filler type significantly influences stability, mixes with GGBS exhibited the highest stability, followed by stone dust mixes and fly ash mixes showed lower values. Despite these variations, all mixes satisfied the MoRTH-V specified minimum stability requirement of 900 kg. An increase in flow values was observed with higher RAP content, attributed to the presence of stiff aged binder. Concurrently, the bulk density (G_{mb}) decreased, as RAP aggregates generally possess lower specific gravity than virgin granite. VFB and VMA increase slightly with RAP because reduced density, aged binder, and irregular RAP aggregates create more voids in the mix. Throughout the study, air voids (V_a) were maintained at approximately 4% to ensure uniform comparison.

Table5: Marshall Stability Test Results

Mix type	Actual Binder Content (%)	Virgin Binder Added (%)	Marshall Stability, (kg)	Flow, (mm)	G_{mb}, (g/cc)	V_a, (%)	VFB (%)	VMA (%)	Marshall Quotient
PSTM-1	4.53	4.53	1318	3.2	2.402	4.2	71.53	14.82	4.12
PSTM-2	4.67	4.51	1269	3.4	2.391	4.2	72.56	15.16	3.73
PSTM-3	4.76	4.23	1212	3.7	2.380	4.1	73.88	15.52	3.28
PSTM-4	4.99	4.09	1158	3.8	2.370	4.2	73.95	15.97	3.05
PFTM-1	4.67	4.67	1286	3.4	2.384	3.93	73.81	15.00	3.80
PFTM-2	4.72	4.57	1242	3.6	2.377	3.87	74.50	15.16	3.50
PFTM-3	4.85	4.33	1204	3.7	2.366	3.94	74.70	15.56	3.30
PFTM-4	4.94	4.04	1169	3.9	2.355	4.02	74.74	15.91	3.10
PGTM-1	4.53	4.53	1401	3.2	2.416	3.96	72.39	14.33	4.38
PGTM-2	4.58	4.41	1365	3.5	2.393	3.92	73.95	15.06	3.90
PGTM-3	4.76	4.23	1303	3.8	2.383	3.98	74.28	15.50	3.46
PGTM-4	4.85	3.94	1222	3.8	2.376	3.99	74.53	15.67	3.19

4.2 Retained Marshall Stability

All mixes (PSTM, PFTM, and PGTM) recorded RMS values above 92%, which is well above the MoRTH-specified minimum requirement of 80%, confirming satisfactory moisture resistance (Figure 2). The presence of stiff aged binder in RAP, although less ductile, contributed to overall cohesion and helped reduce binder loss during moisture exposure. Filler type was also observed to play an important role in the moisture susceptibility of the mixes. While no clear trend was identified with respect to RAP content and filler type, all combinations demonstrated consistently high RMS values, ensuring reliable moisture resistance across the studied mixes.

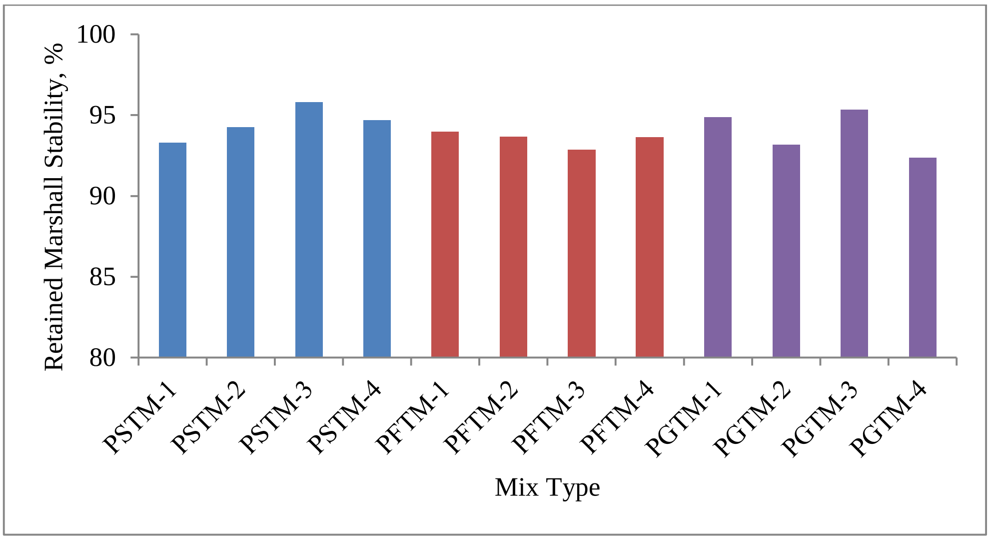

Figure 2: Retained Marshall Stability (RMS) test results

4.3 Indirect Tensile strength

The Indirect Tensile Strength (ITS) test results for both unconditioned and conditioned specimens are shown in figure 3. The unconditioned ITS values of the mixes varied between 0.93 and 1.22 N/mm², while the conditioned ITS values ranged from 0.78 to 1.11 N/mm², showing a noticeable reduction after moisture conditioning. This reduction highlights the effect of water in weakening the mix structure, though the extent of reduction varied with filler type. Among the mixes, PGTM (with GGBS filler) consistently exhibited the highest ITS values in both dry and wet conditions, with maximum values of 1.22 and 1.11 N/mm², respectively. PSTM mixes (stone dust filler) showed intermediate performance; whereas PFTM mixes (fly ash filler) recorded comparatively lower ITS values. Despite these reductions, all mixes retained a significant portion of their strength after conditioning, demonstrating satisfactory tensile strength and adequate resistance to moisture-induced damage.

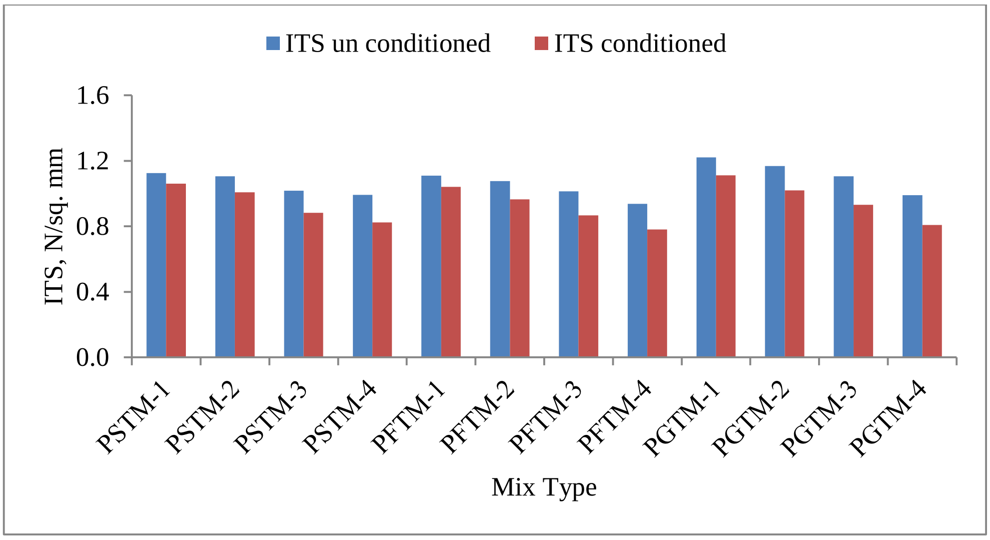

Figure 3: Comparison of Indirect Tensile strength (ITS) test results for conditioned and Un conditioned samples

4.4 Tensile Strength Ratio

The Tensile Strength Ratio (TSR) values of all mixes are above 80%, thereby meeting the MoRTH minimum requirement of 80%, indicating acceptable resistance to moisture-induced damage (Figure 4). Among the fillers, stone dust mixes (PSTM) and fly ash mixes (PFTM) showed comparatively higher TSR values, with maximum values of 94.25% and 93.98% at lower RAP contents, respectively. In contrast, GGBS mixes (PGTM) showed slightly lower TSR values, though still well above the specified limit. A general decreasing trend in TSR was observed with increasing RAP content across all filler types. This reduction is mainly attributed to the presence of stiff aged binder in RAP, which reduces bonding efficiency under wet conditions. Despite this, all mixes maintained TSR values above 81%, confirming that the studied RAP–filler combinations provide adequate moisture resistance and are suitable for field applications.

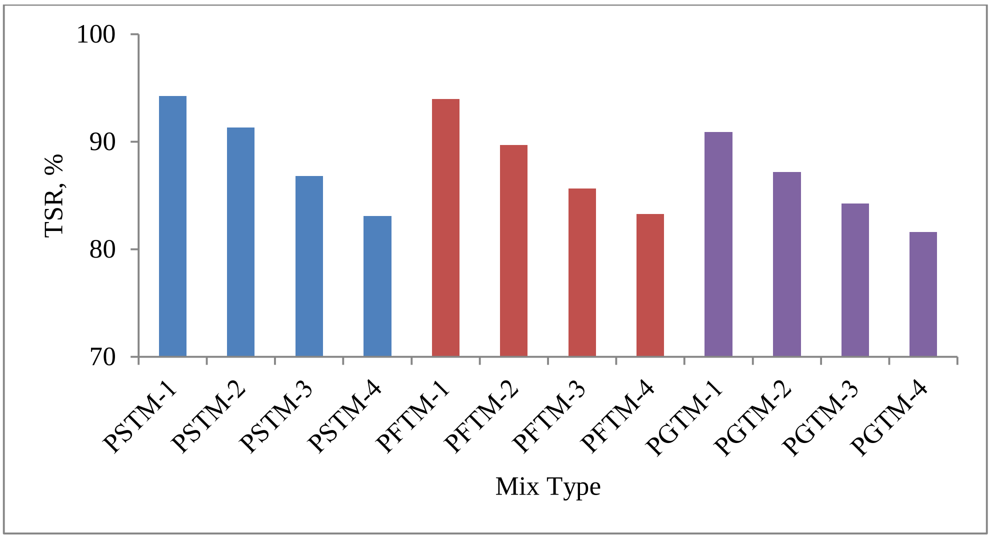

Figure 4: Tensile Strength Ratio (TSR) test results

4.5 Cantabro abrasion Loss

The Cantabro abrasion test results show a reduction in mass loss with increasing RAP content across all mixes (PSTM, PFTM, and PGTM). For un-aged samples, the mass loss ranged between 7.23% and 2.38%, while aged samples showed slightly lower values, ranging from 6.44% to 1.31%, indicating that aging improved the durability of the mixes by reducing raveling susceptibility. Among the fillers, GGBS mixes (PGTM) consistently exhibited the lowest mass loss values (minimum 2.38% un-aged and 1.31% aged at higher RAP content), followed by stone dust mixes (PSTM), while fly ash mixes (PFTM) showed comparatively higher losses. The decreasing trend with RAP addition can be attributed to the stiffer aged binder present in RAP, which enhances aggregate coating and improves resistance to abrasion. Overall, the results demonstrate that RAP incorporation, particularly with GGBS as filler, improves durability against abrasion and ensures better long-term performance of DBM mixes.

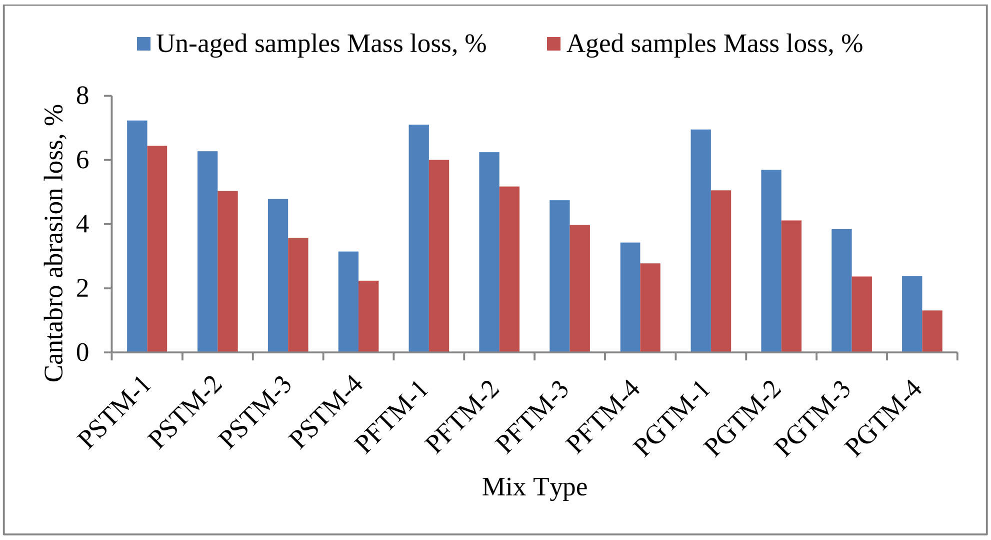

Figure 5: Comparison of Cantabro Abrasion Loss (CAL) test results for conditioned and Un conditioned samples

4.6 Resilient Modulus of Bituminous mixes

The resilient modulus values of all mixes increased with RAP content, reflecting enhanced stiffness due to the presence of aged binder. Among the mixes, PGTM (with GGBS filler) exhibited the highest modulus, ranging from 2944 MPa at 0% RAP to 3916 MPa at 30% RAP, followed by PSTM (stone dust filler) with 2192–3075 MPa, while PFTM (fly ash filler) recorded the lowest range (2084–2854 MPa). This highlights the significant role of filler type, with GGBS contributing more effectively to stiffness than stone dust or fly ash. However, as per IRC:37-2018, the maximum resilient modulus for DBM layers at 35 °C is limited to 2000 MPa for design purposes. Hence, despite experimental values being higher, 2000 MPa must be adopted for pavement design. The results confirm that RAP incorporation up to 30% ensures sufficient stiffness and can be reliably utilized in DBM-II mixes.

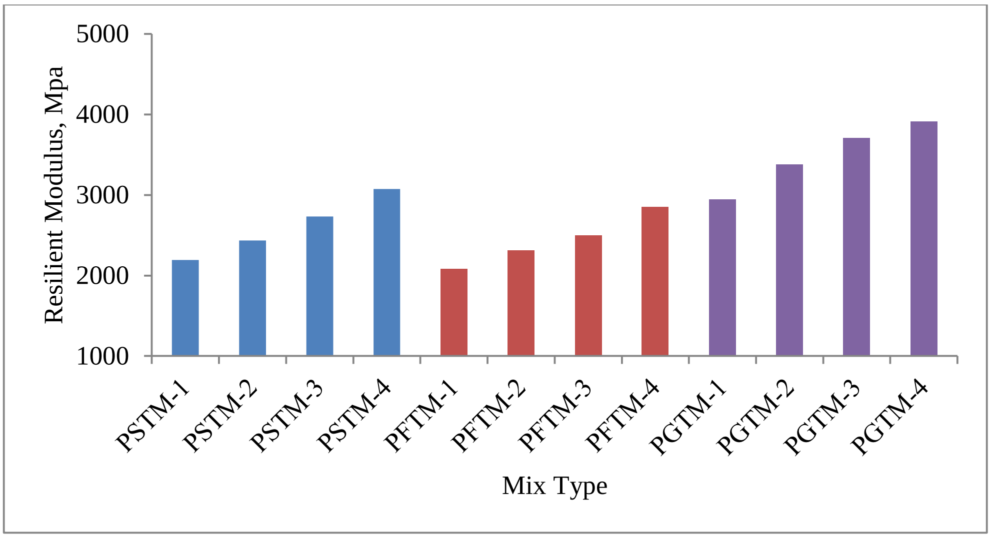

Figure 6: Resilient Modulus Test results

5. Conclusion

- Incorporation of RAP in DBM-II mixes reduced the demand for virgin binder and binder cost, though Marshall Stability showed a decreasing trend with higher RAP due to the stiffened aged binder and inferior aggregate quality.
- With increasing RAP, flow values increased, bulk density decreased, and VFB/VMA rose slightly due to lower RAP aggregate density and increased voids.
- All mixes satisfied the MoRTH-specified minimum requirements for stability (>900 kg) and Retained Marshall Stability (>80%), confirming adequate strength and moisture resistance for field applications.
- Filler type played a crucial role in performance: GGBS mixes consistently showed superior stability, ITS, TSR, and abrasion resistance, followed by stone dust, while fly ash mixes performed comparatively lowers.
- Cantabro abrasion loss decreased with RAP incorporation, particularly in GGBS mixes, indicating improved durability and raveling resistance, thereby validating RAP with suitable fillers as a sustainable solution for DBM-II mixes.
- Resilient modulus increased with RAP content, with GGBS mixes showing highest stiffness. Although experimental values exceeded 2000 MPa, IRC:37 specifies adopting 2000 MPa as the design value for DBM layers.

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