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Research Article

Effectiveness of Liquid Antistripping Additive for Emulsion-Treated Base Layer Using Reclaimed Asphalt Pavement Material

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In the new global economy, getting natural aggregates (NA) has become a central issue for constructing flexible pavements due to the scarcity of aggregates and the ban on mining in various states in India. This research is an attempt to achieve sustainability by using a liquid antistripping additive for emulsion-treated base layer to improve the performance of Reclaimed Asphalt Pavement Material (RAPM) inclusive aggregates. RAPM was evaluated, with inclusion percentages of 50 and 70 percent, whereas, the control mix was prepared using 100 percent natural aggregate (NA). The effect of inclusion of liquid antistripping additive (ASA) with different RAPM percentages on various properties of ETB mixes, such as maximum dry density, indirect tensile strength, moisture resistance and resilient modulus, was studied. Furthermore, when compared to RAP-ETB mixes without ASA, RAP-ETB mixes with ASA were found to preserve many of their qualities. The present study aimed to propose the laboratory design of optimum bitumen emulsion content (OBEC) for ETB in a simpler manner. For 50 RAP, obtained OBEC was at 4.4%, whereas for 70 RAP, OBEC was obtained at 3.8%. However, for 100 % NA, calculated OBEC was 7.0% as there was 0% RAP in it, hence binder absorption was more. The strength parameter was assessed using the Indirect Tensile Strength (ITS) test. At the same time, the pavement response was measured in terms of Resilient Modulus (MR). MR of 70 RAP mixes was higher than that of 50 RAP mixes, and 100 NA mixes with antistripping additive. Test results were encouraging, and significant improvement in strength was caused by cement filler and antistripping additive.

1. Introduction

The increasing cost of binder and environmental concerns attract Government agencies and the construction industry to use other alternatives for pavement construction [1–6]. Moreover, getting a natural aggregate is becoming more challenging due to the ban and restriction in mining. This is equally responsible for shifting to other alternatives of construction [4, 7–9]. To overcome this issue, the use of reclaimed asphalt pavement (RAP) seems a promising alternative. When the mixture of bitumen and aggregate is removed from the flexible pavement by controlled milling up to the desired depth, the collected material is termed RAP material. Moreover, utilization of RAP for the construction of emulsion-treated base (ETB) by cold in-place recycling (CIPR) not only reduces the cost of virgin aggregates but also provides a stiffer base course and reduces the problem of stockpiling of RAP material due to which its properties get degraded [1, 10–12]. According to Federal Highway Administration (FHWA) reports, up to 33 million metric tons (36 million tons) of excess asphalt concrete is currently being used as a portion of recycled hot mix asphalt, in cold mixes, or as aggregate in granular or stabilized base materials, accounting for 80 to 85 percent of all asphalt concrete currently produced. The quantity of surplus asphalt concrete that needs to be disposed of is expected to be less than 20% of the total amount of RAP produced each year.

Extensive research has shown that [13–19] fumes from hot bituminous mixes are a health concern for construction workers, which needs to be eliminated to provide a safe and healthy environment for construction. In the current study, the mix design of ETB was done using cold mix technology (CMT) over conventional hot mix technology (HMT) as it has various environmental merits and lower production plant emissions [5, 13–20]. In HMT, all the mix ingredients such as bitumen, coarse aggregate, fine aggregate, and filler (if any) are heated. However, in the case of CMT, no heating is required to make the mix. Moreover, there is no need to stockpile the material in advance as the whole recycling process can be carried out using the cold in-place recycling (CIPR) technique. There are inherent benefits to this technology; from reducing greenhouse gas emissions to lesser number of truck trips to the construction site as the requirement of virgin aggregates is significantly less as compared to the conventional construction technologies, and one can achieve an overall economy in the project due to lesser fuel consumption during construction [4, 5, 16–19, 21, 22].

Fluid plays a vital role during the mix design of ETB. If the material is dry, then emulsion might break prematurely during mixing. Also, if there is too much fluid content, the mix will prematurely break due to the detachment of bitumen film from the aggregate; the phenomenon is known as stripping of aggregate. It is hypothesized that the presence of moisture may be one of the reasons for lower early strength in ETB. Therefore, in the present research work, to improve the resistance against moisture damage or to avoid stripping of aggregates in ETB, the thought of using liquid antistripping additive might reap advantages. Even in the presence of moisture, using a little amount of antistripping additive allows the binder to coat the aggregate properly, resulting in improved moisture resistance properties [13, 14, 23]. It has been previously observed that on adding antistripping additives in the mix, moisture resistance was increased [15].

This study set out to investigate the usefulness of using liquid antistripping additives for ETB using RAP for constructing a sustainable strong sub-base layer. Efforts had also been made to utilize the maximum percentage of RAP without compromising the performance of the mix to achieve economic and environmental benefits. Researchers have investigated various approaches to utilizing RAP in surface layers and binder layers [24–31]. However, the Indian Roads Congress (IRC) recommends only up to 30 percent RAP to achieve the desired strength characteristics without compromising its performance [16]. Moreover, the effect of using more percentage of RAP material with antistripping additive and cement had not been studied and reported in detail for a base layer. Therefore, the current paper explores how the maximum amount of the RAP material could be utilized by identifying the optimum dosage of bitumen emulsion and antistripping additive. 100% Natural Aggregate (NA), 50% RAP, and 70% RAP were used for the design of the ETB mix in the current study. The amount of RAP percentage was decided to target the mid-value gradation requirements and to satisfy the gradation limits. The optimum bitumen emulsion content (OBEC) was based on the indirect tensile strength (ITS) test, where the peak load was calculated for both dry and wet Marshall specimens. The mix were evaluated for estimating the cracking resistance and extent of moisture damage in the mix. Moreover, the present study also investigates the effectiveness of the use of liquid antistripping additive with mix for ETB layer. The paper also ascertains the performance of liquid anti-stripping additive Levasil by studying and comparing its rheological properties with residual emulsion. For the design purpose of the current pavement section, guidelines for the design of flexible pavement were used [17].

2. Materials and Methods

2.1. Materials

2.1.1. Aggregate and Gradation. Natural aggregates (NAs) and RAP were used to cast and test emulsion-treated base layer mix in the laboratory. NAs were collected from the local stone quarry, whereas RAP was collected from NH-344 using a controlled milling technique. Residual asphalt content (RAC) in the milled material was extracted in accordance with ASTM D2172-11, Standard Test Methods for Quantitative Extraction of Asphalt Binder from Asphalt Mixtures [18]. It can be seen from the data of Table 1 that the RAP material reported significantly more water absorption value as the RAP was collected through milling, and material from layers beneath might have collected. Another reason for such high-water absorption may be the presence of dust particles as the RAP material was collected and stored in the open bins behind the Indian Institute of Technology (IIT) Roorkee laboratory for testing and research purposes. Other physical properties of NAs and RAP aggregates are shown in Table 1. Both fine and coarse RAP were used in the study after gradation analysis and blending. The blending proportions were determined to satisfy the specification in Table IX-1 of IRC: 37-2012 [19] to produce a mix for emulsion-treated base layer using RAP [19]. Since the RAP was recovered by milling technique, 100% RAP cannot be used as it did not satisfy the aggregate gradation requirement. Based on the blending exercise, the selected RAP percentages for the current study were selected as 50% RAP and 70% RAP (50 RAP, 70 RAP, and 100 NA, respectively) for the mix preparation, and the rest were NAs satisfying the mid-value aggregate gradation requirements as per the Indian Roads Congress (IRC) specifications. The adopted gradation curve is shown in Figure 1.

2.1.2. Bitumen Emulsion and Antistripping Additive. In this study, a cationic slow setting bitumen emulsion (SS_2) was collected from Total Bitumen, Jodhpur, India, which was used as a base binder. The specific reason for using slow setting bitumen emulsion as a base binder and not using rapid setting (RS) grade bitumen emulsion was the setting time of bitumen emulsion because RS sets faster compared to SS_2. As a result, the bitumen emulsion may be unable to

Table 1: Physical properties of NA and RAP.

Description	Standard specification	Specified limits	Test results	
			Natural aggregate	RAP aggregate
Combined FI & EI	IS:2386 part I	Max 35%	12%	7%
Aggregate impact value	IS:2386 part IV	Max 27%	15.82%	21%
Aggregate crushing value	IS:2386 part IV	Max 30%	13%	15.57%
Los Angles abrasion value	IS:2386 part IV	30	18%	24.59%
Specific gravity of coarse aggregate	ASTM C127	—	2.619	2.559
Water absorption of coarse aggregates	ASTM C127	—	0.629	1.54
Stripping test value	IS:6241	Min Retained coating 95%	98%	—
Plasticity index (%)	IS:2720 part V	Min 6	—	Non-plastic (N.P.)
Residual asphalt content (RAC) (%)	ASTM D2172	—	—	3.50%

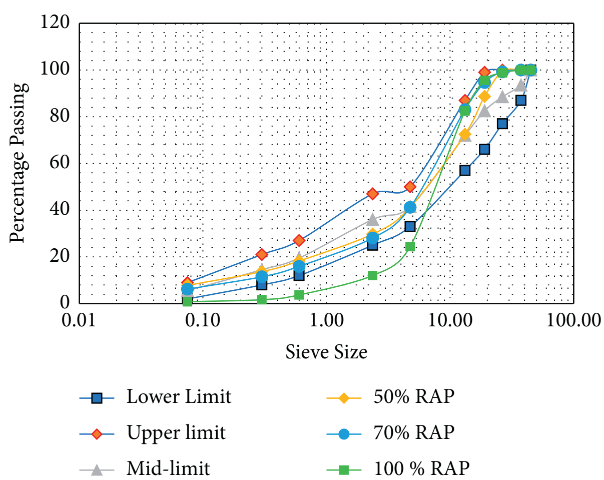


Figure 1: Adopted aggregate gradation after blending.

coat the larger particle in the case of RS due to its fast-setting tendency. However, SS_2 aims to coat the coarser aggregates and delay setting time, which helps in proper mixing and compaction of material by using the cold in-place recycling (CIPR) method for laying ETB. To study the rheological properties of bitumen emulsion, the residue was obtained using oven method as per IS 8887, *Indian Standard for Bitumen Emulsion for Roads (Cationic Type)–Specifications, Third Revision* [21]. The residual binder and liquid antistripping additive-modified binder was tested for rheological tests on residual binder which includes, penetration, ductility, residue by evaporation tests in accordance with ASTM D2397–20, *Standard Specification for Cationic Emulsified Asphalt* [32] and IS 8887, *Indian Standard for Bitumen Emulsion for Roads (Cationic Type)–Specifications, Third Revision* [21]. Apart from basic rheological tests, the residual binder was also tested for determining the softening point of the base binder and modified binder, which the authors believe is one of the important tests for predicting the quality control of the binder. The addition of a liquid antistripping additive improves the softening point of the base binder. The liquid antistripping additive Levasil was used and it was in the liquid form. It is believed that the small addition of this antistripping additive helped in enhanced aggregate coating and improved moisture resistance [24, 25, 33]. The properties of the base binder and antistripping additive are presented in Table 2.

2.1.3. Cement. Commercially available ordinary Portland cement, Grade 43 (OPC 43) conforming to IS: 8112, *Ordinary Portland Cement 43 Grade–Specification, Second Revision* [26], was used in this study as a filler substituting the stone dust filler. Cement was collected from a local vendor in Roorkee, India. Considering the literature [27], cement was used at a fixed dosage of 1 percent by weight of aggregate to improve the adhesion between binder and aggregate. An amount greater than 1 percent might make the ETB brittle, and it will act more as a cement-treated base (CTB) layer [27].

2.2. Testing Methods. As mentioned in the preceding paragraph, different fractions of RAP were used to determine the maximum amount of RAP for ETB mixtures, and the methodology used is shown in Figure 2. Based on many performance and durability criteria, the maximum amount of RAPM for cold ETB mixture was determined.

2.2.1. Maximum Dry Density and Optimum Fluid Content. To compact the RAP bitumen emulsion-treated mix to its maximum density, optimum fluid content (OFC) is required [19, 28]. OFC is the sum of water present in the emulsion, aggregate moisture content, and additional water added to the mix. Here, the moisture content of the aggregate is zero, as the aggregates were taken after being oven-dried in a hot air oven at least for 24 hours before making the mix to remove the excess moisture content from the RAP material. However, this OFC can be increased or decreased at the site depending on the weather conditions. In the case of ETB, two fluids are present; one is the fluid that is added while preparing the bitumen emulsion, the other is the fluid that is used as water content for compaction of the mix. Higher water content may result in deformation of the surface during compaction [27]. Hence, optimum fluid content has to be determined in the laboratory for a proper mix design procedure. In the current study, the maximum dry density (MDD) and optimum fluid content for the mix were determined as per IS 2720 (Part VIII), *Determination of Water content–Dry Density Relation Using Heavy Compaction* [29]. The mix was prepared using a standard proctor test employing 150 mm diameter mold, of volume 2250 cm^3; the material was compacted into five layers, giving 55 blows to each layer using a rammer of weight 4.89 kg having a free-

Table 2: Properties of residual emulsion and modified residual emulsion.

Test parameters	Standard specification	Emulsion (E)	$E + 0.3\%$ additive	$E + 0.4\%$ additive	$E + 0.5\%$ additive
Residue by evaporation (%)	ASTM D7497	62.08	—	—	—
Stability to mixing with cement (coagulation), %	ASTM D244	1.62	—	—	—
Specific gravity	ASTM D70	1.03	—	—	—
Penetration of residue at 25°C, 100 g, 5 s, 0.1 mm	ASTM D5	90	86	84	79
Softening point (ring and ball), °C	ASTM D36	44.1	45.1	45.7	46.4
Ductility of residue (cm)	ASTM D113	67	65	63	59

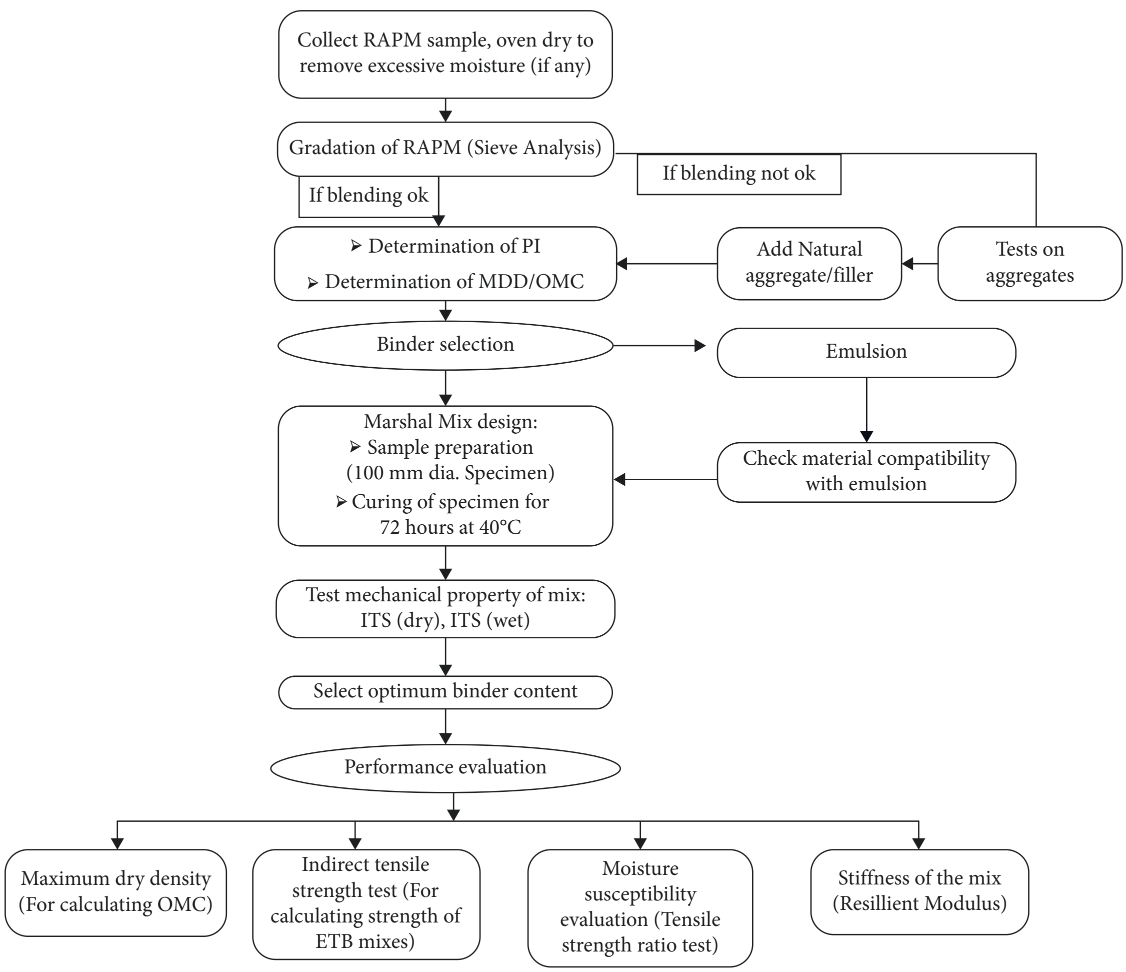


Figure 2: Work methodology for the experimental program.

falling drop of 450 mm height. In order to provide higher interlocking among the compacted layers and to minimize the cracks inside, each layer was scarified before adding the subsequent compacted layer [2, 30]. A blend of emulsion and water by volume was prepared in a 1 : 1 ratio; this blend is known as “total fluid.” The amount of emulsion was kept constant, while fluid content was increased by 1% increment, and three samples were cast at each fluid content of 4, 5, 6, 7, and 8 (by weight of total mix). The mix was then transferred to a standard 100 mm diameter Marshall Mold and compacted at 75 blows on each side. To ensure homogenous mixing and uniform coating of the RAP and virgin aggregates, the mixes were prepared using a pugmill mixer for three minutes. The fluid content of the specimens was determined by drying the specimens in a hot air oven for 24 hours at a specified 100°C temperature, and the dry density of the specimens was calculated by equation [19].

$$D_{dd} = \frac{(D_{bulk})}{(1 + FC)}, \tag{1}$$

where D_{dd} = dry density in gm/cm^3, D_{bulk} = Bulk density in g/cm^3, FC = Fluid content by dry weight of aggregates in decimal

2.2.2. Indirect Tensile Strength. The optimum bitumen emulsion content (OBEC) for ETB was determined by using Marshall specimens. The indirect tensile strength test of ETB mixtures was performed in accordance with ASTM D 6931, *Standard Test Method for Indirect Tensile (IDT) Strength of Asphalt Mixtures* [34, 35]. Mix specimens were prepared using Marshall molds, targeting 100 mm diameter and 63 mm height by taking approximately 1200 grams weight of each sample. A total of six samples (three conditioned and three unconditioned) were casted with the help of a pugmill mixture at each emulsion content, as shown in Figure 3(a), for three RAP contents (50 RAP, 70 RAP, and 100 NA) compacted with 75 blows on each side were casted starting from 3.2% to 4.7% bitumen emulsion with an increment of 0.3% percent by weight of the total mix. A total of 108 samples [(6 $ITS_{Dry + Wet}$) ∗ (6 Emulsion contents) ∗ (3 RAP contents) = 108)] were cast for finding OBEC and 54 samples [(6 $ITS_{Dry + Wet}$) ∗ (3 Anti-stripping additive content) ∗ (3 RAP contents) = 54)] for determining the effective liquid antistripping additive dosage. The specimens were cured at room temperature for 24 hours in molds and then extracted to cure it further cured for 72 hours at 40°C in a hot air oven (Figure 3(d)), as the sample contains compaction water and water in emulsion [16].

Marshall loading frame was used, which applied a load of 50.8 mm per minute to perform the Indirect Tensile Strength Test at 25°C, an illustration of the test assembly is shown in Figures 3(b) and 3(c) [34]. Three samples were tested for ITS_{dry} at 25°C, and the rest three samples were kept in a water bath for the next 24 hours and then tested for ITS_{wet} at 25°C (Figure 3(e)). ITS value of each briquette mold was calculated using the below-mentioned equation.

$$ITS = \frac{2 * P}{\pi * d * h} * 1000, \quad (2)$$

where ITS = Indirect tensile strength, kPa. P = maximum load, N, d = diameter, mm, h = height, mm.

2.2.3. Moisture Susceptibility Evaluation. The ratio of ITS_{wet} and ITS_{dry} is termed as Tensile Strength Ratio (TSR), expressed as a percentage, which is the measure of evaluation of moisture susceptibility [14, 36, 37]. Also, for Bitumen stabilized materials (BSM), if ITS_{dry}>400 kPa and TSR <50%, it indicates the requirement of active filler as the material confirms the presence of a clayey particle in it [1]. TSR is an important parameter to evaluate the stripping or the detachment of bond between the aggregate and bitumen emulsion during their service life; it should be greater than 80. Six samples were prepared at each bitumen emulsion content, and the samples were kept in a hot air oven at a controlled temperature of 40°C for 72 hours. During the process, the samples reached a constant mass, as the moisture inside the samples dried out. Out of these six samples, three samples were tested for ITS_{dry} and the rest three samples were tested for ITS_{wet} by further keeping the samples for next 24 hours in water bath at 25°C. The TSR of samples can be calculated using equation.

$$TSR = \frac{Avg\,.\,Wet\,Tensile\,Strength}{Avg\,.\,Dry\,Tensile\,Strength} * 100. \quad (3)$$

2.2.4. Resilient Modulus (MR). Generally, to evaluate the quality of materials, the resilient modulus value can be used. The elastic modulus based on the recoverable strain under repeated loads is called the Resilient Modulus (MR). Resilient modulus correlates stress-strain for rapidly applied load, with a loading duration of 0.1 sec and rest of 0.9 sec. A cylindrical specimen of diameter 100 mm of ETB mix is loaded vertically. MR is the measure of the stiffness of the mixture within its linear elastic region. MR is the nondestructive testing performed by using a Universal testing machine (UTM) as per ASTM D 4123 [38] as shown in Figure 4. The test was conducted at 35°C as per Indian conditions, as the average annual average temperature range is around 35°C. Before conducting the test, the test specimen was conditioned at least for 24 hours at the specified load temperature.

3. Results and Discussion

3.1. Maximum Dry Density and Optimum Fluid Content. Fluid plays a vital role during the mix design of ETB. If the material is dry, then emulsion might break prematurely during mixing. Therefore, attention must be given while mix the design process in the laboratory. Figure 5 shows the variation of maximum dry density (MDD) and fluid content (FC), from which the corresponding optimum fluid content (OFC) was calculated for different percentages of RAP mixes. OFC is required to compact the RAP bitumen emulsion-treated mix to its maximum density. Corresponding to MDD, OFC for 100 NA, 50 RAP, and 70 RAP was found to be 5.5%, 6.0%, and 7.0%, respectively. Moving on to MDD results, 100 NA mix had the highest MDD (2.280 g/cm^3) with lowest fluid content (5.5%). The addition of 50% RAP to the 100 NA mix increased the fluid content value and decreased the MDD value considerably. At the same time, 70 RAP mixes showed a further decrease of MDD by 3.07% and 1.81% compared to 100 NA mixes and 50 RAP mixes, respectively. Together, these results suggest that there is an association between MDD, OFC, and different percentages of RAP. It was found that the addition of RAP leads to the reduction of MDD and an increase in fluid content. The reduction in MDD and increase in fluid content can be due to the poor internal friction between the RAP material. Also, the decrease in MDD in RAP mixes was owing to the lower specific gravity of RAP aggregates as compared to natural aggregates. Although the presence of dust from the lower layer in the RAP mixes results in higher water absorption of RAP, aggregates may be held responsible for increased OFC in the RAP mixes [11, 39].

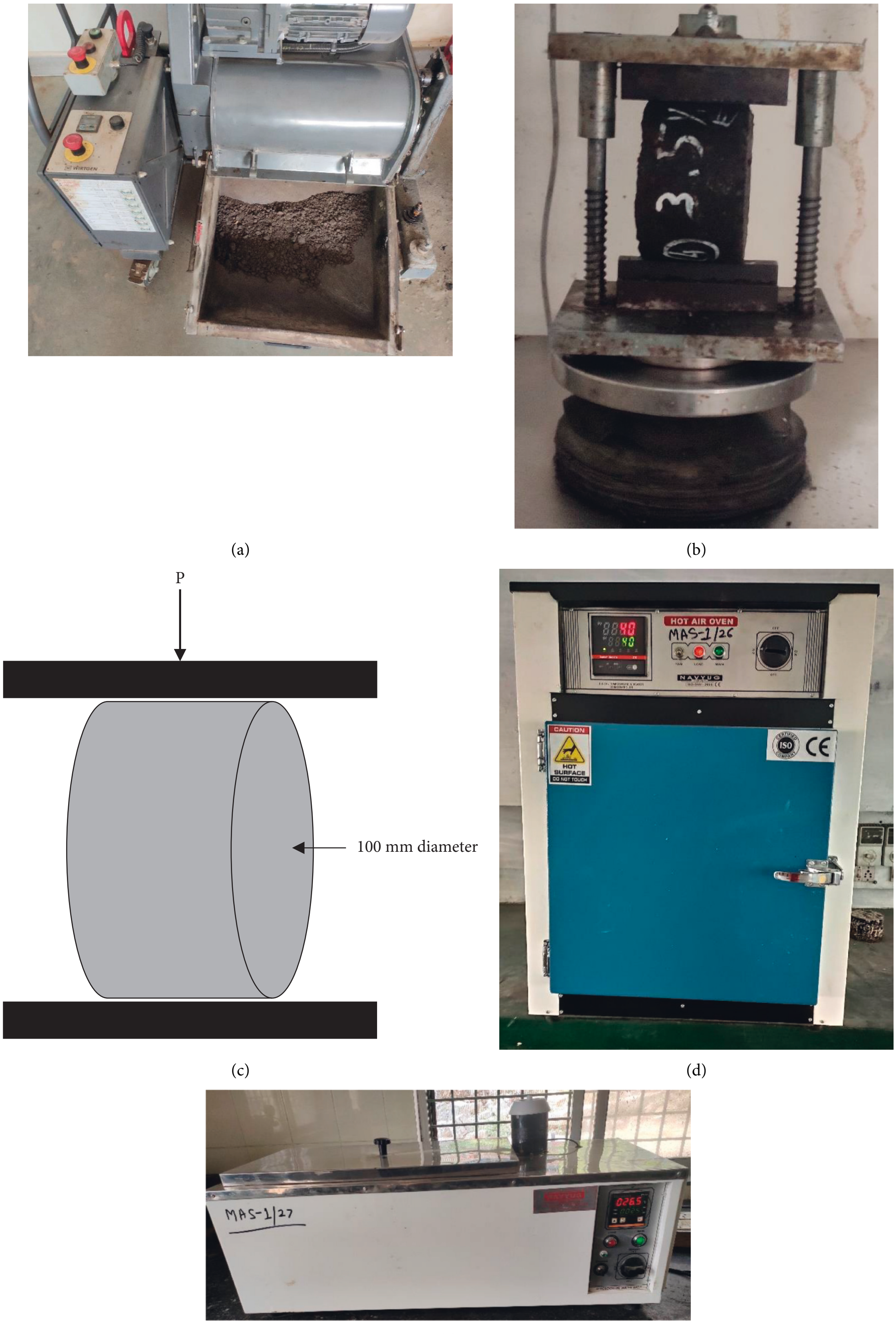


FIGURE 3: (a) Pugmill mixture (b) Indirect tensile strength test. (c) Loading assembly illustration. (d) Test specimens at 40°C for 72 hours in hot air oven. (e) Water bath for ITS_{wet}.

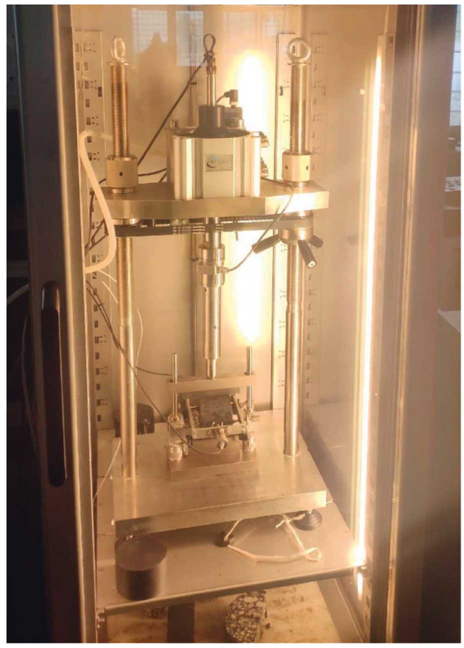


Figure 4: Resilient modulus test set-up.

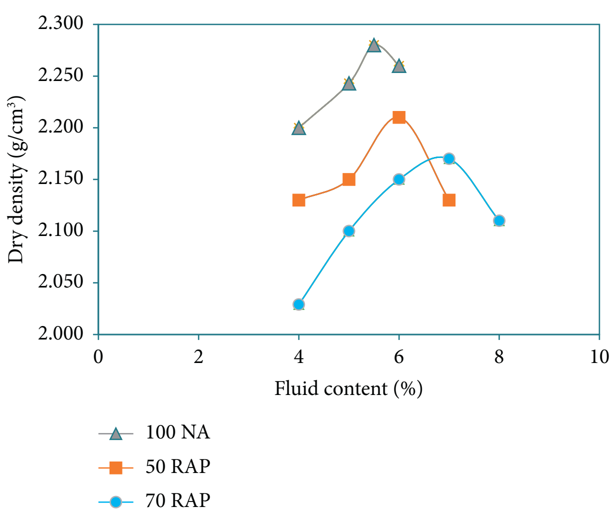


Figure 5: Relationship between fluid content and dry density.

3.2. Indirect Tensile Strength. Optimum bitumen emulsion content (OBEC) was calculated by Indirect Tensile Strength (ITS) of both conditioned and unconditioned samples before adding a liquid antistripping additive. A total of $6*6*3=108$ Marshall samples were cast and tested for finding OBEC. All these samples contain 1% cement as the use of cement provides better stiffness to the mix and helps in gaining early strength, whereas the purpose of the antistripping additive was to keep the bond of aggregate and bitumen emulsion safe from the OFC, which was added for the preparation of ETB mix. For 50 RAP, 4.40% was the OBEC, similarly for 70 RAP, OBEC was obtained at 3.80% whereas, for 100 NA, OBEC was at 7%. The reason for a higher amount of Bitumen emulsion required for 100 NA was due to the use of fresh aggregates as there was no RAP bitumen present on the surface of the aggregate, which increased the requirement of fresh bitumen emulsion due to increased surface area. However, for 50 RAP and 70 RAP, the presence of stiff aged binder and dust from the lower layer around the aggregate surface can be the possible reason for lower emulsion content, as it is difficult to bind them with RAP aggregate. This is in agreement with some previous studies [10, 15, 24, 40].

Based on OBEC, liquid antistripping additive Levasil was added, and $6*3*3=54$ mixes were prepared and further tested for ITS_{dry} and ITS_{wet} to determine the optimum dosage of liquid antistripping additive. It can be seen from the data in Figure 6 that 100 NA reported significantly more average ITS values, with and without using liquid antistripping additive, than the other two groups, namely 50 RAP and 70 RAP. Figure 7(a) depicts the ITS machine used for testing, Figure 7(b) for sample conditions after the testing and Figure 7(c) for RAP material shown after splitting the sample into two halves. This can be related to lower impact, crushing, and abrasion values of natural aggregates as compared to those with aged RAP aggregates. It was noted that 70 RAP with 0.4% RS generates average ITS_{dry} and ITS_{wet} values of 496 kPa and 464 kPa, whereas 50 RAP with 0.4% RS was able to get average ITS_{dry} and ITS_{wet} values of 410 kPa and 352 kPa, respectively, which were 17% and 24% more than 50 RAP. The results clearly demonstrate the higher ITS values of liquid antistripping additive Levasil samples as compared to the samples without Levasil irrespective of the RAP percentages that clarify better adhesion of bitumen emulsion with aggregates. However, on closely observing the values (average of three Marshall molds) from Figure 6, it can be observed that ITS_{dry} and ITS_{wet}values kept on increasing upto a certain limit by adding liquid antistripping additive , then it decreased. The main reason

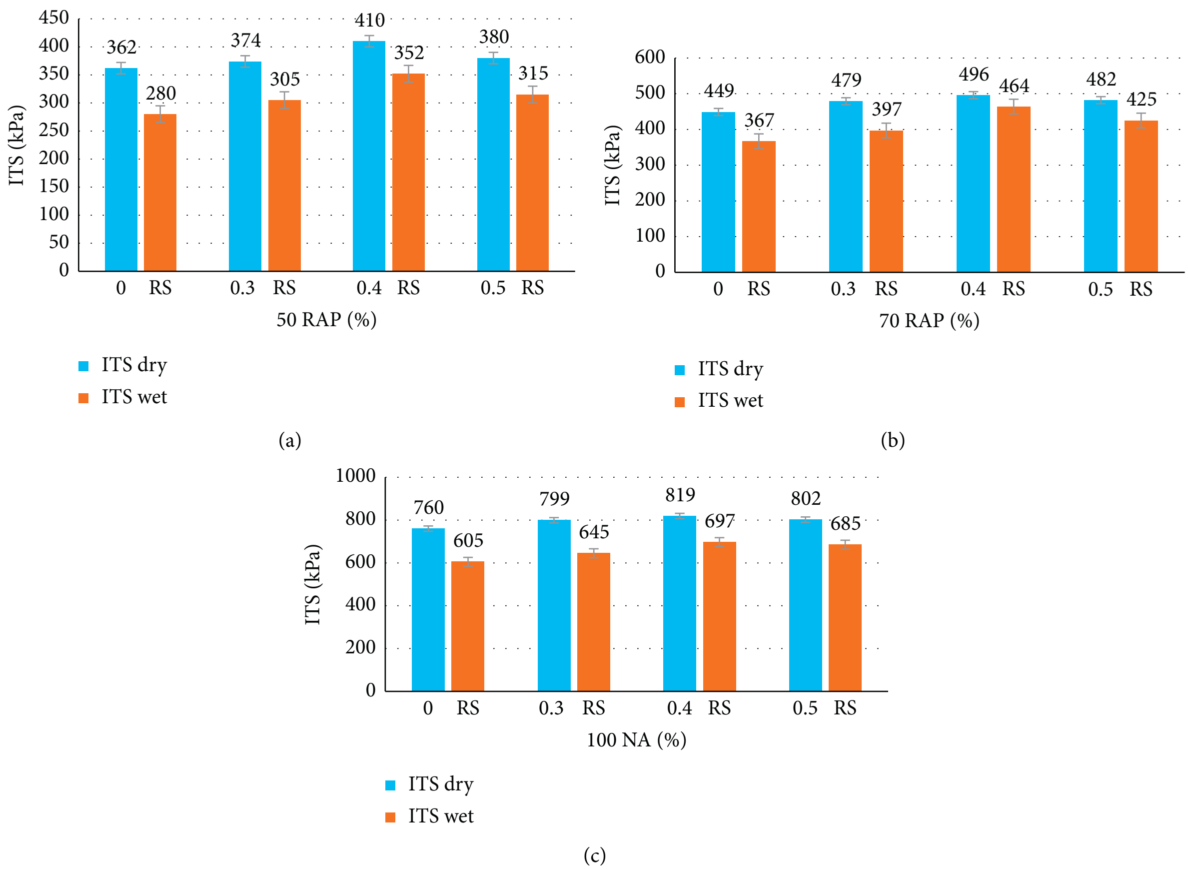


Figure 6: ITS values for (a) 50 RAP. (b) 70 RAP, and (c) 100 NA.

behind this is due to the stiff nature of bitumen emulsion by the addition of Levasil in it. The same behavior was observed during binder testing as described above in softening point and ductility test results. This trend of results is in agreement with few previous studies [41, 42].

3.3. Moisture Susceptibility Evaluation. The moisture susceptibility of compacted specimens was evaluated in terms of TSR value. The presence of moisture results in loss of adhesion between the bitumen emulsion and aggregates [37]. The samples of ITS_{wet} were further kept in a water bath for the next 24 hours curing at 25 °C for ITS_{wet}. The specimens were then put on the drainboard for 30–40 minutes to remove excess moisture from it before testing the indirect tensile strength. From Table 3, it was observed that samples with Levasil showed higher TSR values as compared to those without adding Levasil. In general, 70 RAP exhibited a higher TSR value as compared to 50 RAP and 100 NA mixes. Higher TSR values indicate better moisture resistance against moisture damage which is important in the case of ETB as it contains OFC also in its mixture. The TSR values of RAP mixtures showed better resistance against moisture susceptibility than the 100 NA mixtures since RAP mixtures were already stiff due to aging during its service life.

3.4. Stability Loss in Water. An effort has also been made to determine the loss of stability (%), which was calculated for specimens of optimum binder and additive content after curing at 25°C in water. Figure 8(a) demonstrated that even after keeping the samples submerged in water for 24 hours, samples showed improved stability of both RAP mixes. A similar trend can be seen for mixes prepared with 100 NA. Usage of cement and Levasil can be combined reasons for the lesser loss of stability in the RAP and NA mixes. Stability loss in water has not been reported in the past literature, but the authors believe that it can help the researchers in identifying the mixture behavior after keeping the samples immersed underwater, as shown in Figure 8(b). Also, stability loss in water indicates the durability of the sample, and it highlights the impact on the sustainability of RAP materials.

3.5. Resilient Modulus (MR). Pavement response to loading can be measured by resilient modulus (MR). The resilient modulus test values were found by taking an average of three values from each sample of optimum emulsion content at RAP content, i.e., 50 RAP, 70 RAP, and 100 NA, and, with a combination of 0% RS and 0.4% (optimum dosage of antistripping additive), respectively. Since the resilient modulus test was nondestructive, the same sample can be used to take three readings from each sample. The test was conducted at 35°C, and the results are depicted in Figure 9.

From Figure 9, it can be observed that for the mixes prepared with RAP content and antistripping agent, MR

(a) (b)

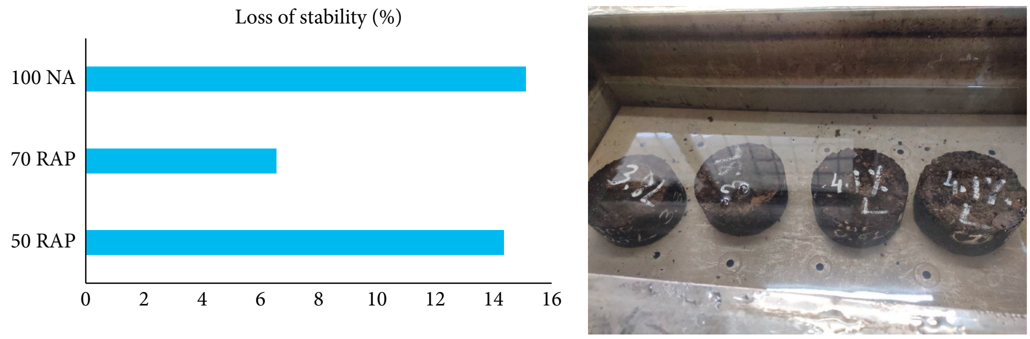
(c)

Figure 7: (a) ITS testing machine. (b) Sample after testing. (c) Sample after breaking.

Table 3: Tensile strength ratio values and coefficient of variation (COV) for 50 RAP, 70 RAP, and 100 NA.

Mix notation	50 RAP		70 RAP		100 NA	
	Average TSR (%)	COV (%)	Average TSR (%)	COV (%)	Average TSR (%)	COV (%)
0% RS	77	3	82	3	80	4
0.3% RS	82	4	83	2	81	3
0.4% RS	86	2	94	1	85	2
0.5% RS	83	3	88	2	85	2

values were higher than that of natural aggregate mixes. As the RAP percentage increased, resilient modulus values also increased, indicating that the presence of RAP makes the mix stiffer. This behavior can be attributed to the stiff nature of RAP-modified mixes, the same was confirmed by different rheological test results discussed in the above sections. From all types of mixes, 100 RAP showed lesser MR values as compared to 50 RAP and 70 RAP, reason being it having no



(a) (b)

Figure 8: (a) Los of Stability (%). (b) Samples submerged in a water bath.

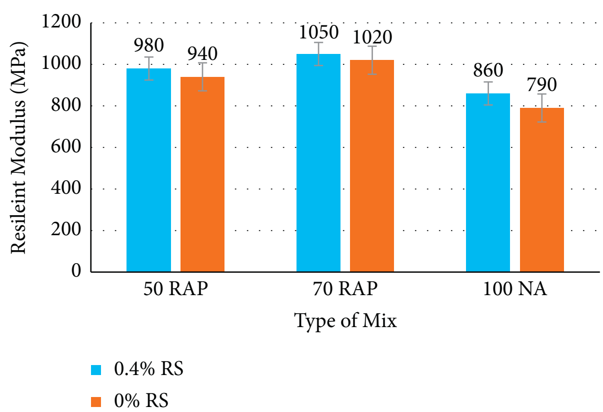


Figure 9: Resilient modulus of emulsion-treated base mixes at 35°C.

RAP percentage. However, the effect of different percentages of bitumen emulsion on MR value needs to be studied further.

4. Conclusions

The use of liquid antistripping additives with RAP inclusive mixtures was studied using different RAP percentages for ETB mix design aiming the sustainability aspect during research work. The final mix design includes an optimum percentage of additive, RAP, and bitumen emulsion with a constant percentage of cement as a filler material. Hence, based on aggregate gradation and blending exercise, 50 RAP and 70 RAP were considered along with 100 NA as a control mix for the mix design procedure. As gradation plays a vital role while designing ETB mix and can affect the mix performance adversely, that is why 100 RAP was discarded as it did not meet the aggregate gradation requirements. Binder properties were evaluated in detail, including conventional tests studying the effect of liquid antistripping additives on bitumen emulsion residual binder. Maximum dry density and optimum fluid content, indirect tensile strength test, tensile strength ratio, and resilient modulus tests were conducted to predict the performance and for the mix design of ETB in the laboratory. An attempt was also made to predict the stability loss (in percentage) due to the curing of conditioned samples, which can be a new parameter added to predict the strength and performance of the ETB samples prepared in the laboratory. Following are the conclusions drawn, based on the various test results:

(i) Properties of 50 RAP and 70 RAP aggregates were satisfying as per the specifications, but 100 RAP was rejected for the current study as it did not meet desired gradation specifications. However, water absorption of RAP aggregates was higher on comparing it with the NA, which is the main reason for the increased OFC in RAP mixes.

(ii) Observed OFC of RAP mixes was more as compared to 100 NA mixes due to increased water absorption behavior of RAP mixes due to poor internal friction of RAP mixes.

(iii) Although 100 NA mixtures performed better in terms of ITS and TSR than 50 RAP and 70 RAP, using RAP considerably helps reduce the project's cost and saves natural resources resulting in ETB as a sustainable construction technique for the years to come. Also, 100 NA showed more stiffness that can change the material behavior, and performance might be significantly compromised as the mixture may lose its flexibility.

(iv) The addition of liquid antistripping additive Levasil improved the performance of ETB mixes which shows better resistance to moisture susceptibility and increased compatibility of ETB mixes.

(v) Improved stability was observed when the mixes were kept in a water bath for 24 hours, indicating the mix's improved performance. It shows better adhesion property of the ETB mix.

(vi) Resilient modulus of the RAP mixes was more as compared to natural aggregate mix, which clearly indicated that due to the presence of RAP aggregate, the mix became stiffer. MR values for 70 RAP were highest among all the ETB mixes.

Overall, this study strengthens the idea that while using RAP and liquid antistripping additives together, the performance of ETB may improve significantly, and the use of natural aggregates can be restricted, resulting in considerable savings in the project and saving natural resources. Hence, the current laboratory mix design and construction method by CIPR is recommended for the construction of the ETB layer as a sustainable way of construction.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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