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Research Article

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Significance of RAP Content and Foamed Binder Content on Mechanistic Characteristics of Recycled Foamed Bituminous Mixes

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Abstract

To reduce the energy consumption and CO_2 emissions during asphalt production, several environmentally friendly technologies have been developed during the last years. One of these technologies is the cold recycling by using foamed bitumen. Foaming the bitumen reduces the binder viscosity temporarily and increases the volume as well. Homogenous foams are produced by injection of cold water into hot bitumen. The paper presents the results of laboratory testing of the physical and mechanical parameters of the recycled mixes using the foamed bitumen and resistance to the action of water. The aim of the tests was to evaluate the properties of the mixes in terms of the RAP Content and Foam Binder Content. To evaluate the significance of impact of both factors i.e., Foam Binder Content and RAP Content on the distribution of the analyzed parameters, two-way Analysis of Variance (ANOVA) was performed. ANOVA Analysis results suggest that the RAP in cold mixes is not completely acting as black rock implying that some portion of the residual aged binder is possibly rejuvenated or softened by adding new binders.

Keywords: ANOVA; Bituminous; Conservation; Energy consumption; Foamed binder content; RAP

Introduction

Assessment on conservation of energy and properties of road materials are important for achieving sustainability in road construction. For the last one decade and till date, major road infrastructure activities have been undertaken in India by different road construction agencies. Major road infrastructure activities currently under taken by different agencies in India for the last one decade have shown greater impact on energy consumption and depletion of aggregates. It is also to be noted that thicknesses of existing pavements are increasing due to addition of periodic overlays. The rise of road levels causes serious drainage problems in the urban areas. The production of huge quantities of Hot Mix Bitumen (HMA) releases a significant amount of greenhouse gases [1]. There is a problem with non-availability of good quality aggregates in some states of the country and aggregate being very expensive because of large lead distances. The use of diesel for running these trucks further contributes to large emission of pollutants. For a lead of 200 km, it will require 180 lakh liters of diesel in transportation alone. Therefore, a serious attempt has to be made to develop and adopt alternative technologies for road construction and maintenance with a quest to reduce consumption of fuel and aggregates. Recycling of existing bituminous pavement is the sustainable solution. The study attempts to identify and develop one such cold bituminous mix technology. In such cases, already existing bituminous pavement layers such as Dense Bituminous Macadam (DBM) and Bituminous Concrete (BC) has to be milled and the Reclaimed Bitumen Pavement (RAP) thus produced can be used in recycling. Of the number of recycling techniques available, rehabilitation of pavement using foam bitumen is a common practice in South Africa, Europe and US. This is a recent technique adopted in India. The aim of the study was to evaluate the properties of the mixes in terms of the recycled aggregates and Foamed Binder Content. Study shows the effect of recycled aggregate and foamed binder percentage on mix properties and the effect is verified statistically using Analysis of Variance.

Characterization of Materials

Evaluation of RAP material and virgin aggregate

By proper crushing and screening, well-graded high quality aggregates coated by bitumen binders can be produced from RAP material. In this study, RAP material was collected from Narela region near Delhi for laboratory testing. Firstly average binder content in RAP material was found according to ASTM D6307 [2] which were 3.6% (by weight of total mix). Later the next two processes were done according to ASTM D2172 and D 1856 [3,4] for the recovery of binder through abson method. From the following test results in Table 1 it is shown that harder bitumen grade properties are observed from recovered binder. Finally the washed aggregate obtained in the binder extraction process were dried in oven for 24 hours followed by sieve analysis for gradation. In this present study [5] standard has been used for gradation of RAP in bituminous mixes. The gradation of RAP obtained is given in Table 2. In order to satisfy the standard gradation, RAP aggregate is blended with virgin aggregate which were obtained from local quarry near Delhi. These virgin aggregate properties satisfied [6] specifications under various physical tests. A blend of upto 80 percent RAP material and 1 percent active filler (Cement OPC 43 Grade) met the grading requirements for recycled foam mixtures. Figure 1 shows the gradation of the RAP material and the blended material with IRC 37: 2012 grading limits.

Characterization of foamed bitumen

In the present study, VG-10 grade bitumen, procured from

Property	Specification Adopted	Test Results
Penetration, 25°C	IS 1203	37
Softening point, °C	IS 1205	61.2
Viscosity at 60°C,Poises	ASTM D4402	2802
Viscosity at 135°C,Poises	ASTM D4402	875

Table 1: Physical properties of recovered binder.

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Size of Sieve (mm)	Gradation of RAP	Percentage Passing
45	100	100
37.5	100	87-100
26.6	100	77-100
19	100	66-99
13.2	83	67-87
4.74	31	33-50
2.36	18	25-47
0.60	11	12-27
0.3	8	8-21
0.075	2	2-9

Table 2: Gradation of the washed aggregates from RAP.

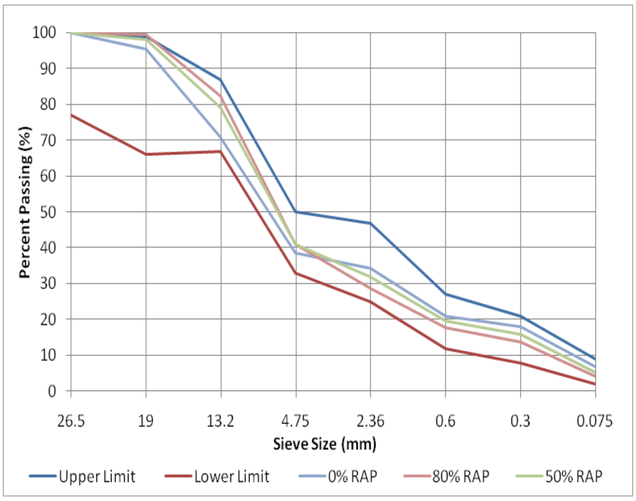

Figure 1: Aggregate gradation adopted for all different RAP percentages in mix.

Figure 2: Wirtgen foaming equipment WLB 10S.

Mathura refinery, has been used and its physical properties followed Indian Standard. Injection of cold water and air with varying pressure into hot bitumen produces foamed asphalt. This asphalt foaming process is tested to find out optimum percentage of foamant water and temperature, for producing best foam by gaining maximum ER and HL. Wirtgen WLB 10S foaming equipment as shown in Photo 1 has been used for foaming of asphalt at the following prefixed set conditions of air pressure at 500 kpa and water pressure at 550 kpa. The optimum water addition is chosen as an average of two water contents required to meet minimum criteria of ER ≥ 8 and HL ≥ 6 seconds [7,8]. Foaming experiment is conducted at each of the four different asphalt temperatures and water contents. Figure 2 illustrates the ER and HL measured at varying water contents ranging from 2.0 to 11.0%, at an increment of 2.0% interval each at 120, 130, 140, 160, and 180°C. As shown in Figure 2, expansion ratio increases and half-life decreases with increase in water content. However, there is significant reduction in the increase of ER and increased HL is observed with increase in temperature from 120 to 180°C. This variation may be due to bitumen composition as it could also seem to influence the foaming characteristics. Among this best foam was observed at temperature of 130, 140, 160 and 180°C and foaming water content of 8.5, 8.0, 6.5 and 4.5% as shown in Table 3. 130°C of foaming temperature and 8.5% of optimum foaming water content was selected for the VG-10 asphalt binder in mix design.

Preparation of foam mix

Several agencies developed guidelines for mix design of cold recycled foam mixtures, based on laboratory tests, empirical formulae or past experience with identical projects [7-12]. Materials like blended aggregate of RAP gradation, foamed bitumen with VG-10, and filler as cement of about one percent is used. Different percentages of RAP that is, 0%, 50%, and 80% is blended with virgin aggregate to meet the gradation requirement of IRC 37: 2012. As per ASTM D2216-10 [13], RAP has initial moisture content of about 0.1 - 0.12% and has been subtracted from OMC during mixing. First, Laboratory testing has been carried out to find the physical properties of materials. In this study, VG10 binder was considered for foaming in laboratory by using Wirtgen WLB 10 S foaming equipment. Optimization of foamed bitumen considered an ER 15 times and HL time of 15seconds was obtained at foaming temperature of 130°C and foaming water content of 8.5%, which satisfied the minimum requirement as specified by TG-2. Later Optimum Moisture Content (OMC) of the untreated blended materialswas determined using the moisture-density relationships according to AASHTO T180 [14] which are discussed in below sections. Add this pre-wetting water content to get better dispersion of foam in the mix. The sample of minimum 10 kg of material was prepared and mixed at particular Foamed Binder Content in Wirtgen WLM 10 pug mill mixer. Thus different batches by varying the foam bitumen content from 1.8% to 2.0% by weight of aggregate was prepared increment of 0.2% binder content. The main advantage of foamed mixes is that it contains lesser binder content. This is almost 50% less when compared with HMA. Upon mixing, samples were prepared using marshal compactor. Compacted mix was then cured for 72 hrs at 40°C in an oven. Six numbers of specimens were manufactured from each batch in which three were tested for ITS dry and other three for ITS wet after cooling them to 25°C according to ASTM: D6931-12 [15]. Six more number of samples were prepared and tested for resilient Modulous at 25°C and 35°C.

Determination of optimum moisture content

Compaction characteristics of untreated bitumen mixes according to Modified Proctor Test is shown in Figure 3. This resulted in reduction of maximum dry density (MDD) and the corresponding increase in optimum moisture content (OMC), when the RAP content increased. The decreased dry density is obtained due to the weak bond between RAP and the virgin material and also due to less fine material that plugged the voids to produce denser mix. The corresponding increase

Temperature (°C)	Optimum Water content	ER, (%)	HL, (sec)
120	9	11	11
130	8.5	15	15
140	8	15	15
160	6.5	14	14
180	4.5	14	14

Table 3: Optimum expansion ratio and half-life at different binder temperature.

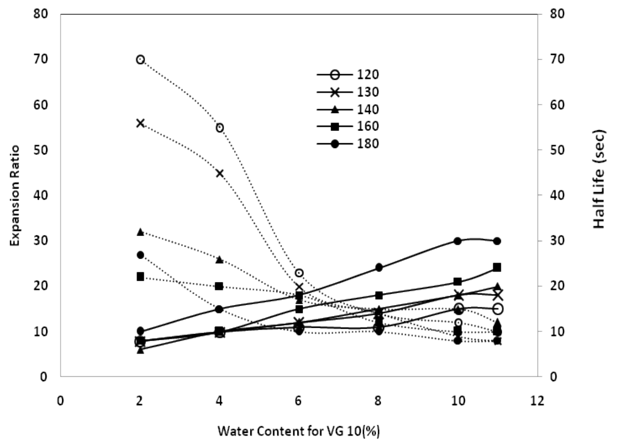

Figure 3: Expansion ratio and half-life measured at different moisture contents and temperatures.

in OMC is observed with increase in RAP content. Thus as the surface area of the particles increases with increase in RAP content more water is required to lubricate the whole mixture. Water is also consumed in cement hydration reaction to enhance compaction.

Analysis of variance (ANOVA)

It is a collection of statistical models used to analyse the differences among group means and their associated procedures (such as "variation" among and between groups), developed by statistician and evolutionary biologist Ronald Fisher. To determine the impact of control variables [16] ANOVA was used to analyze and study the contribution of the different variables. It was applied to analyze the significant factors to determine the influence of each factor. For the convenience of ANOVA, there was a need to classify the data measured in accordance with the required parameters, but there should not be too many levels. To obtain a better understanding of the mix properties such as Indirect Tensile Strengths, Tensile Strength Ratio and Resilient Modulus at different temperature, Analysis of Variance (ANOVA) was performed on Foamed Binder Content and RAP Content. If the F value was determined to be smaller than the F_{crit}, then the factors are statistically significance and vice versa. In the present study, ANOVA is calculated using Excel at significance level of 5%.

Performance Testing Methods

To assess the durability and performance of bituminous mixes, several laboratory tests are conducted and the details are given below.

Indirect tensile strength

Indirect tensile strength test is useful to evaluate resistance of compacted bituminous mixture to cracking. These specimens were tested for their tensile strength at 25°C. The failure load was recorded and the indirect tensile strength (St) was calculated using following Equation (1)

$$s_t = \frac{2P}{\pi Dt} \qquad (1)$$

Where, P is the load (kg), d is the diameter in cm of the specimen; t is the thickness of the specimen in cm.

Tensile strength ratio test

To identify whether the coating of bitumen binder and aggregate is susceptible to moisture damage, Tensile Strength Ratio (TSR) is determined according to ASTM D 4867 [17]. The specimens are usually compacted to a void content range of 6 to 8%, which corresponds to void levels expected in the field. TSR is the ratio of average indirect tensile strength of conditioned specimens to the unconditioned specimens. Unconditioned specimens are maintained at room temperature and then adjusted to 25°C. The conditioned specimens were placed in a water bath maintained at 60°C for 24 hours and then placed in an environmental chamber maintained at 25°C for two hours. Then tensile strength of each specimen is determined by the tensile splitting test. The Tensile Strength Ratio (TSR) of specimen is computed by Eq. (2).

$$TSR = \left(\frac{T_{wet}}{T_{dry}}\right) * 100 \qquad (2)$$

Where, T_{wet} average indirect tensile strength of conditioned specimens and T_{dry} is indirect tensile strength of unconditioned specimen.

Resilient modulus test

This test is used to analyse the pavement response for the repeated traffic loading by measuring the indirect tensile strength according to ASTM D7369 [18]. The test is performed on Universal Testing Machine (UTM-16). After preparing the specimens, they were placed in a controlled temperature chamber for a minimum of 6 hrs. and brought to the specified test temperature. As per this method, a compressive load is applied with haversine waveform at different temperatures. Specimens prepared at their optimum binder content were loaded by diametrical force in pulse loading. Test parameters were; Haversine Load Pulse, condition pulse count of 5, pulse width of 250 ms, peak loading force of 1000 N and poisons ratio of 0:35.

Results and Discussion

Indirect tensile strength (ITS)

Figure 4 shows the dry ITS values of foamed mix at different foamed binder content and RAP Content. Table 4 presents evaluate the significance impact of the tested factors i.e., foamed binder content and RAP Content on the distribution of the analyzed feature, which was performed using the analysis of variance. The analysis of the tests results presented in Figure 4 indicates that the amount of the applied foamed bitumen in the road base mixes exerted an important impact

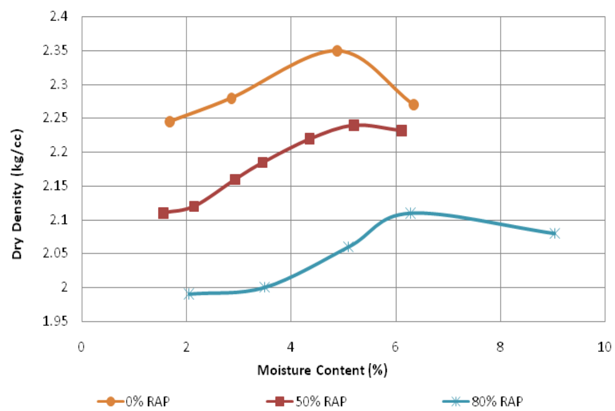

Figure 4: Optimum moisture content.

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showing lower p-value compared to alpha value. Variation of RAP content has not significant effect on the dry ITS value.

Tensile strength ratio test

ANOVA Analysis results suggest that the RAP in cold mixes is not completely acting as black rock implying that some portion of the residual aged binder is possibly rejuvenated or softened by adding new binders. TSR increases with increasing RAP content in mixtures significantly except for 80% RAP at higher binder content (Table 5 and Figure 5).

Resilient modulus test

Stiffness of the bituminous materials can be measured using the Resilient Modulus test, which is a nondestructive method. The resilient modulus expresses the relationship of stress and strain at a certain temperature and load. In addition, the visco-elastic characteristics are contained in the expression of stiffness modulus. According to Wirtgen Cold Recycling Manual [8], the resilient modulus of the recycled mixes at 25°C with foamed bitumen should range from 2500 MPa to 4000 MPa. The recycled foam mixtures with Foamed Binder Content in the range of 1.8% to 2.2% reach required value (Figures 6 and 7). The two-way analysis of variance (Table 6) showed that p-value for statistic F for factors (Foamed Binder Content and RAP Content) was more than the assumed significance level (α = 0.05) for resilient modulus at 25°C. It can then be stated that both RAP and Foamed Binder Content in the recycled mixtures had no significant impact on resilient modulus at 25°C. From statistical analysis, it can be concluded that only Foamed Binder Content had a significant effect on resilient modulus at 35°C.

Source of Variation	RAP Content	Foamed Binder Content
Sum of Squares	6486.6	33291.3
Degree of freedom	2	2
Mean of Squares	3243.3	16645.6
F	4.0	20.6
P-value	0.10	0.008
F_{crit}	6.9	6.9

Table 4: Evaluation of significant influence (two-way ANOVA) of the factors (RAP content and foamed binder Content) on the dry ITS value.

Source of Variation	Foamed Binder Content	RAP Content
Sum of Squares	83.74	85.8
Degree of freedom	2	2
Mean of Squares	41.87	42.9
F	8.7	9.0
P-value	0.03	0.03
F_{crit}	6.9	6.9

Table 5: Two-way (ANOVA) analysis of variance.

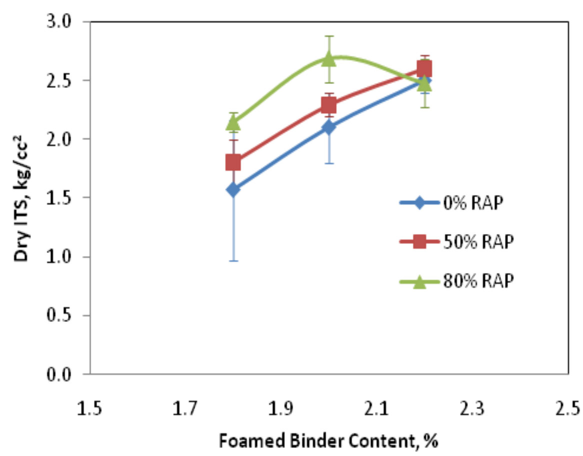

Figure 5: Foamed binder content versus dry ITS.

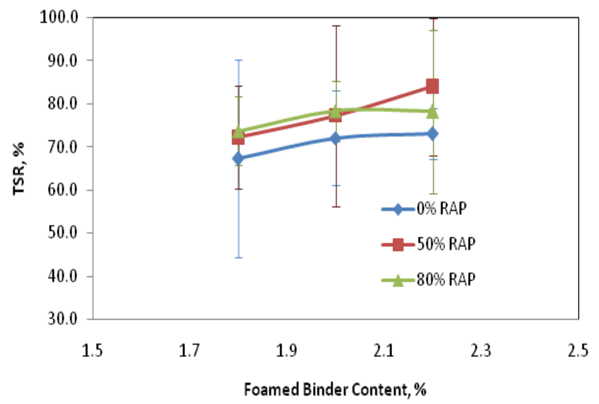

Figure 6: Relationship between TSR, amount of foamed binder content and RAP content.

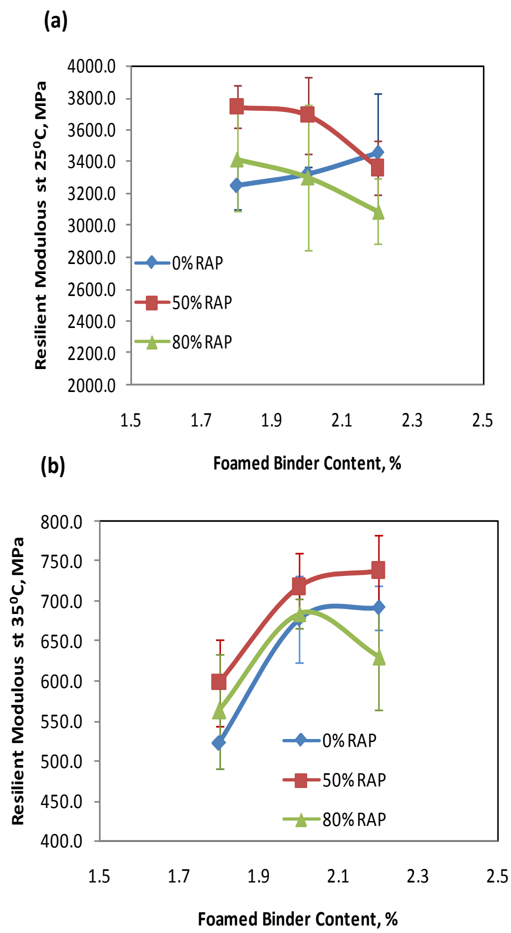

Figure 7: The impact of the foamed binder content on resilient modulus at (a) 25°C (b) 35°C.

Source of Variation	MR at 25°C		MR at 35°C	
	Foamed Binder Content	RAP Content	Foamed Binder Content	RAP Content
Sum of Squares	48144.02	177290.10	33291.36	6486.62
Degree of freedom	2.00	2.00	2.00	2.00
Mean of Squares	24072.01	88645.05	16645.68	3243.31
F	0.85	3.13	20.69	4.03
P-value	0.49	0.15	0.01	0.11
F_{crit}	6.94	6.94	6.94	6.94

Table 6: Two-way (ANOVA) analysis of variance of resilient modulus.

Conclusion

Based on the analysis of the test results of the recycled foamed bitumen mix, the following conclusions can be drawn

- Moisture susceptibility in terms of a tensile strength ratio (TSR) was higher than the minimum value required for recycled foam mixtures as per IRC: 37, which means that they satisfied the basic criterion set for the resistance to the action of water.
- Mechanical parameters and moisture resistance of foamed bitumen mixes with recycled aggregate were considerably higher than of the mixes without recycled aggregate.
- The foamed binder content in the mixtures have a significant influence on the changes of the resilient modulus at 35°C; moisture stability and dry ITS value.
- The RAP content in the mixtures has a significant influence on moisture susceptibility of mixture.
- The RAP content of 50% has a positive influence on the resistance to moisture ensuring proper stiffness and durability to deformation at the same time.

Higher resilient modulus values were found in RAP mixes when compared to the conventional mix at all the selected test temperatures indicating that mix becomes stiffer with increase in RAP content. The highest modulus value is obtained for 50% RAP incorporated bituminous mix.

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