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Research Article

Evaluation of cold emulsified bitumen mixes using recycled concrete aggregates as a base course

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Abstract: The utilization of cold bituminous mixes in road construction is an environmentally and economically viable alternative to other stabilization processes. Besides, the incorporation of recycled materials into the cold mixes increases sustainability and decreases waste generation. The stabilization of Recycled Concrete Aggregates (RCA) with cement for pavement bases is a known one. However, the stabilization of RCA using bitumen emulsion is limited in nature. The present study evaluated the mechanical properties of the cold mixes prepared using RCA in different proportions (25%, 50%) with varying bitumen emulsion contents (5, 6, 7%). The compacted and cured samples are investigated for mechanical characteristics like density, Marshall Stability, Indirect Tensile Strength (ITS), Resilient Modulus, and permanent deformation. The dynamics of moisture evaporation and durability in terms of tensile strength ratios are studied. In the end, the vertical compressive and horizontal tensile strains of the pavement sections with bitumen emulsion stabilized bases are analyzed using IITPAVE software. The obtained results are compared using the critical strains calculated from the performance equations given by IRC (2018). It is noted that there is a decrease in the overall thickness of the pavement for the design traffic that varies from 5msa to 50msa. From this study, the base courses are recommended with bitumen emulsion treated RCA mixes, for traffic levels, up to 20 msa which would result in both -reductions in cost as well as the reduction in pavement overall-thickness. The present study also concluded that the optimum emulsion content of 6% does not show better resistance to permanent deformation. From the results, it is also suggested multi-variant mix-design criteria rather than a single indicative parameter.

Keywords: Cold emulsified-bitumen mixtures (CEBM), recycled concrete aggregates (RCA), dynamic creep, bitumen emulsion content (EAC), moisture loss, pavement design.

1. Introduction

The road-infrastructure has been rapidly expanded in recent years due to urbanization, industrialization and to facilitate the connection among the unconnected habitants due to increase in population. To expand the road-infrastructure, large quantities of materials such as aggregates and binders are required, but there is a scarcity of natural aggregates. In addition, a large amount of heat is being generated from the conventional hot-mix asphalt techniques. All these circumstances lead to the development of innovative and sustainable technologies. One of these technologies i.e., cold emulsified-bitumen mixtures (CEBM) can be used either in the construction of the base course or surface and binder-course (Mohammad and Nazzal, 2017). The base/surface courses with CEBM can facilitate to minimize the utilization of natural aggregates by replacing with recycled aggregates (Lyubarskaya et al., 2017; Flores et al., 2020). Further, the production of cold mix asphalt doesn't involve in heating of the aggregates which leads to reduction in energy consumption, temperature, and emissions of greenhouse gases (Zapata and Gambatese, 2005; Swaroopa et al., 2015; Ma et al., 2016; Chehovits and Galehouse 2010; Peng et al., 2015; Thives and Ghisi, 2017). Further, the workability of mixes can be achieved by using low-viscous binders such as emulsified bitumen or foamed bitumen.

The production of CEBMs involves in mixing of dry aggregates and active fillers such as lime and cement, pre-wetting of dry-mix, mixing of bitumen-emulsion. The pre-wetting water content which contributes towards the better coating of the bitumen-emulsion over the aggregates and it depends on the gradation of aggregates (the proportion of fine and coarse aggregates) and dosage of active filler. While the bitumen-emulsion and active-filler are helpful to achieve a better strength (in terms of indirect tensile strength) of CEBMs. South African guidelines (Asphalt Academy, 2009) and Indian guidelines (IRC:37-2012) are limited to bitumen emulsion treated mixes with RAP material and 1 % cement only. However, the previous research reported a maximum dosage of cement up to 2% (Kumar et al., 2008). The type and gradation of aggregates, proportion of recycled aggregates influences the optimum dosage of bitumen-emulsion, dosage of pre-wetting water content and henceforth the mechanical performance of CEBMs (Kumar et al., 2008; Graziani et al., 2018). Hence, it is essential to carry out the influence of mix-constituents on mechanical behavior of CEBMs with different types of recycled aggregates. Towards this, few past studies were conducted on mechanical characterization of the cold mixes with Reclaimed Asphalt Pavement (RAP) material (Arimilli et al., 2016; Yan et al., 2017; Flores et al., 2019; Dong and Charmot, 2019). However, the studies related to cold mixes using RCA are limited (Behnood et al., 2015; Ge et al., 2015; Gómez-Meijide et al., 2016). Coming to India, the usage of Emulsified Bitumen Treated (EAT) mixes was initiated in the third revision of the Indian Roads Congress (IRC 2012) with a facility to utilize RAP material, but it did not present the incorporation of RCA material in EAT-bases. So, in the current study, RCA is replaced (25% and 50%) with conventional aggregates and further the influence of incorporating the RCA on mechanical properties of CEBMs is investigated.

2. Literature review

Traditionally, cold bituminous mixes are evaluated in terms of Indirect Tensile Strength (ITS), moisture sensitivity, Resilient Modulus (M_R), fatigue, and rutting resistance. Among the aforementioned characteristics, ITS is considered an indicative parameter for mix-design (Asphalt Academy 2009; IRC 2012; Arimilli et al., 2016; Ouyang et al., 2019; Zhu et al., 2019). In general, the mix design comprises of optimization of water content and emulsified bitumen content (Asphalt Academy 2009; Asphalt Institute 1997; IRC 2014). The optimization of pre-mix water content involves the determination of dry-density (IRC 2012) or ITS (Arimilli et al., 2016) or a degree of coating (Asphalt institute 1997; Joni, 2018). The coating bitumen over aggregates is achieved in two phases. The breaking of bitumen emulsion, the first phase, takes place due to chemical reaction between aggregate and bitumen-emulsion whereas the bitumen-emulsion is coated over aggregates in the second phase (kar et al., 2023). The breaking rate of emulsion is a key factor in achieving the early strength. Further, the evaporation of moisture from CEBMs influences the mechanical performance of CEBMs. Hence, the present study monitored the moisture loss over the time for better understanding of mechanical performance (in terms of indirect tensile strength, ITS). In addition, the past studies revealed that the major failure of cold-bituminous mixes (with lower dosage of active filler < 2.0%) is permanent deformation rather than cracking as the cold-bituminous mixes do not come under fully bounded mixes (bonding presents only among the fine-aggregates) (Flores et al., 2019; Dong and Charmot, 2019). Hence, it is necessary to investigate the rutting behavior instead the cracking resistance of CEBMs.

In prior to perform rutting tests, the mix-design is considered as the primary step for ensuring the better strength of CEBMs. Even though majority of studies were considered ITS as the indicative parameter of the mix design, the Marshall Stability also introduced as indicative measure in different specifications (Asphalt Institute 1997; IRC 2014). Two mix-design parameters such as degree of coating and ITS are considered. But, ITS cannot be sufficient for better understanding of both rutting and cracking behavior of bituminous mixes (ASTM, 2012). Hence, in this study, two additional bitumen emulsion dosages (optimum dosage ± 0.5%)) other than optimum bitumen emulsion (obtained based on maximum ITS criteria) are taken for evaluating the rutting resistance of CEBMs. The dynamic creep test is a simple performance test conducted to determine the resistance against permanent deformation (NCHRP 465 2002). This test is preferred over wheel tracking tests due to its simplicity in conducting. The dynamic creep test for cold mixes was conducted by different studies (Arimilli et al., 2016; Mohammad and Nazzal, 2017) to characterize the rutting behaviour.

In addition, M_R is also an essential criterion for characterizing cold bituminous mixes and which can be further taken as an input parameter to design a flexible pavement. The resilient modulus predominantly depends on the curing time and cement content (Graziani et al., 2018, Xiao et al., 2019). The M_R-test can be conducted either assuming or determining the Poisson's ratio. The value of M_R is considered as 800 MPa (IRC 2018). As this value is limited for CEBM with RAP and 1% cement, it is felt necessary to evaluate the value of M_R for cold bituminous mixes, other than the above composition. The ultimate aim of laboratory mix-material investigation is to implement or incorporate the corresponding material in to the pavement construction. Hence, the pavement analysis has been performed using IITPAVE software (works based on multi-layered linear elastic theory). This software is helpful to estimate the vertical compressive strain at the top of the subgrade and to determine the rutting life as per IRC:37-2018.

With this background, the objective of the study aims to evaluate and optimize the mechanical characteristics of CEBM with RCA and 2% cement. In addition to this, the analysis and design of the pavement are performed for traffic levels 5, 10, 20, 30, 40, and 50msa for 6% CBR. Finally, the overall cost is estimated for the obtained pavement-sections.

3. Materials and methods

3.1. Materials used

In the current study, the cold mix composite is prepared with Cationic Slow Setting (CSS-2) bitumen-emulsion with varying contents of 5%, 6%, and 7%. Bitumen Emulsion is tested for various properties and corresponding results, standard values are listed as per the specifications (Bureau of Indian Standards 1978a, 1978b, 2004, 2018) and presented in Table1. The initial emulsified bitumen content (IEBC) is determined by equation (1) given in the Asphalt Institute Manual Series MS -19. The obtained values are 5.3% and 4.9% for 25%, and 50% RCA mixes respectively.

$$IEBC\,(\%) = \frac{(0.06B + 0.1C)}{A} \times 100 \qquad (1)$$

where, A= % bitumen in the Emulsified Bitumen,
B= % weight of material passing through 4.75mm
C= 100-B = % weight of material retained on 4.75mm

Two types of aggregates namely RCA and natural aggregates (granite) are used in this study. The RCA is extracted from a locally demolished concrete building whereas the natural aggregates are collected from the local quarry-site. The physical properties of the aggregates and permissible values as per the specifications (Bureau of Indian Standards 1963) are included in Table 2.

Table 1. Properties of emulsified bitumen.

Test on Emulsion	Results	Permissible values	Test Method (year)
Residue on 0.6 mm Sieve, % by mass, Max	0.02	0.05	IS 8887 (2018) (Bureau of Indian Standards, 2018)
Viscosity (Say bolt furol viscometer), seconds, (at 25°C)	31	30-100	IS 3117 (2004) (Bureau of Indian Standards, 2004)
Storage stability (24 h), percent, Max	0.62	2	IS 8887 (2018) (Bureau of Indian Standards, 2018)
Particle charge	Positive	Positive	IS 8887 (2018) (Bureau of Indian Standards, 2018)
Stability to mix with cement (percent coagulation), Max	1.84	2	IS 1203 (1978) (Bureau of Indian Standards, 1978a)
Residue by evaporation (%), Min	62.66	60	IS 8887 (2018) (Bureau of Indian Standards, 2018)
Penetration 25°C/ 100g/5, sec	67	60-120	IS 1208 (1978) (Bureau of Indian Standards, 1978b)
Ductility,27 °C/cm, Min	60	50	IS 8887 (2018) (Bureau of Indian Standards, 2018)

Table 2. Physical properties of aggregates.

Test	NA	RCA	Permissible values	Test Method (year)
Combined FI and EI (%)	27	22	35	IS 2386- Part I (1963) (Bureau of Indian Standards, 1963)
Aggregate Impact Value (%)	21	35	30	IS 2386-Part IV (1963) (Bureau of Indian Standards, 1963)
Water Absorption (%)	0.1	2.3	2	IS 2386-Part III (1963) (Bureau of Indian Standards, 1963)
Abrasion value	30	27	40	IS 2386-Part IV (1963) (Bureau of Indian Standards, 1963)

The present study adopts Ordinary Portland Cement owing to its better strength characteristics and ease of availability (Visser 2004). The addition of cement as a secondary binder accelerates the breaking of bitumen emulsion and improves the early strength properties (Fang et al., 2016). Cement content of 2% is selected as it makes the cold mix homogeneous and stiff (Kumar et al., 2008; Asphalt Institute 1997; Bessa et al., 2016; Fang et al., 2016).

3.2. Experimental methodology

The mix design comprises of blending of aggregates, determination of Pre-Mixing Water Content (PMWC), and determination of Optimum Emulsified Bitumen Content (OEBC). The aggregates are blended as per the gradations given in Asphalt Academy (2009) guidelines. The gradation curves for 25% and 50% of RCA mixes are depicted in Figure 1. For the determination of PMWC, cement added dry aggregates are mixed with water followed by the addition of IEBC. Finally, 3% of PMWC is fixed based on the degree of the coating by visual observations. Before determining OEBC, cement is added to the dry aggregates and mixed thoroughly. To the dry mix, the obtained PMWC is added and mixed until the water is uniformly dispersed. After 1 to 2 minutes, bitumen emulsion is added to fabricate the specimens.

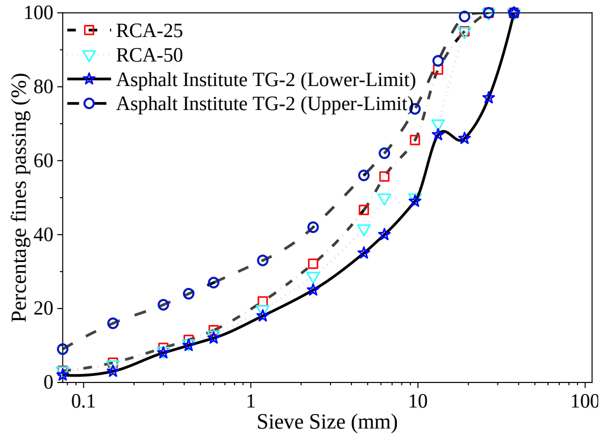


Figure 1. Gradation curves for RCA blends.

Specimens of diameter 100.6±1 mm and thickness 63.5±2.0 mm are compacted using Marshall Compaction method. The specimen-compaction is carried out with 75 blows on either side of the specimen. The compacted specimens are oven-cured for 72 hours at 40ºC and are allowed to reach room temperature for conducting the ITS test. Based on the maximum value of ITS, the OEBC is fixed for both 25 and 50% RCA mixes.

The methodology followed in this study includes a set of standard tests. The mixes are studied for dry density, Marshall Stability, ITS, M_R, and resistance to permanent deformation. A set of 84 samples is prepared for the above-listed mechanical characteristics. Out of 84 samples i.e., 72 (4 sets of 18) samples are studied for dry-ITS, wet-ITS, Marshall Stability, and M_R, while the remaining 12 samples are subjected to dynamic creep testing. These samples include 2 replicas for dynamic creep test and 3 replicas for the remaining tests.

ITS is an important parameter used to determine the tensile strength characteristics of the bituminous pavements. It helps in evaluating the fatigue and rutting potential of the bituminous mixes (ASTM 2012). A series of 36 specimens are fabricated, cured, and half of them are conditioned in water for 24hours to determine the wet-ITS. While remaining samples are kept idle for a day at room temperature. Conditioned and unconditioned samples are tested for ITS as per ASTM D6931 (ASTM 2012), at a loading rate of 50.8 mm per minute. The values of ITS are determined using the following equation.

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

where, S_T is the Indirect Tensile Strength in N/mm2,
D is the Diameter of the Specimen in mm,
t is the thickness of the specimen in mm, and
P is the Ultimate Failure Load in Newton

TSR is an indicative parameter for moisture sensitivity of the bituminous mixtures. It is calculated from the ratio of dry and wet ITS values. The minimum acceptable value for bitumen stabilized mixes and bitumen macadam mixes is 50% as reported in the specifications (Asphalt Academy, 2009; IRC 2014).

The dynamics of moisture loss is essential to understand the early strength properties of the cold mixes. The percentage of moisture-loss is calculated by measuring the weights of the specimens at 24, 48, and 72 hours after the compaction. The difference in weight of the sample at respective time intervals gives the moisture-loss in percentage, which is determined by using the following equation (3). The percentage of moisture-loss is used to observe the rate of curing of the cold mixes.

$$\%Moisture\,loss = \frac{W_{initial} - W_{final}}{W_{initial}} \times 100 \qquad (3)$$

where, $W_{initial}$ is the initial weight of the sample and
W_{final} is the final weight of the sample.

Marshall Stability is a well-known measure used in optimizing the bitumen content for the bituminous mixtures and is also used for cold mixes besides ITS. It is the maximum load that the bituminous specimen can resist at a loading rate of 50.8mm per minute. Unlike, the hot asphalt mixes, the CEBM specimens are tested at ambient temperature conditions without conditioning at 60ºC in a water bath.

Resilient modulus is a stiffness parameter used to characterize different pavement layers. The stiffness and thickness of the pavement layers are related to each other where the materials with lower stiffness require more thickness. Resilient modulus test represents actual traffic loading in the field by applying repeated load applications. The recoverable strains that are induced during the repeated loading are used to compute the MR. The test is performed as per the ASTM-D4123 (ASTM, 1995) for an assumed Poisson's ratio of 0.35.

Dynamic creep test is a simple performance test used to measure the rutting resistance of the bituminous emulsion stabilized mixes. The test is reliable in predicting the permanent deformation and simulates to the field conditions (Khodaii and Mehrara 2009; Kaloush 2003). Dynamic creep test was first developed by Monismith et al. 1975 to determine the resistance towards rutting for asphalt mixes (Kalyoncuoglu and Tigdemir 2011). In the current research, the test is conducted at a temperature of $25 \pm 2°C$, assuming that the temperature might not affect the base layer in the field as the base layer is covered by a surface course or binder course as a protection layer. The type of loading is haversine at the rate of 0.1 seconds loading period and 0.9 seconds rest period, which represents 1 Hz frequency. The applied loading creates stress of 150 plus or minus 5kPa, and deformation is measured using a Linear Variable Deformation Transducers (LVDT) of accuracy 0.0001 mm (NCHRP 465 2002). After the mechanical characterization of the CEBMs, the pavement analysis and cost estimation are carried out for the pavement section with an effective CBR value of 6%. The analysis is carried out using IITPAVE software. The reference sections are selected for effective CBR of 6% and pavement composition with EATB and CTSB (Design plate 26) are adopted according to IRC 37: 2018 (IRC 2018).

4. Experimental results and analysis

The obtained results from the investigation are explained throughout the undermentioned paragraphs. The exposition is subdivided into two parts. The first part is entirely related to the mechanical characterization of CEBM with EBC of 5, 6, and 7%. The secondary part deals with the pavement analysis and design of CEBM.

4.1. Mechanical characterization of CEBM

The performance of the CEBM is evaluated according to the relationship between the mechanical properties and the bitumen emulsion content. ITS test is considered to be an indicative test to categorize the cold mixes. In this study, the emulsified bitumen content is optimized, based on the ITS test conducted as per ASTM-D6931 (ASTM 2012). The failure pattern along with the aggregate interface due to breaking of RCA is commonly observed in CEBM (Figure 2). It is important to note that even if the CEBMs are prepared by the same amount of the PMWC and EBC, the 25% RCA mixes possess greater ITS (203.1kPa) as compared to that (168.4 kPa) of CEBM with 50% RCA corresponding to the OEBC (Figure 3). This indicates that the CEBM's with lower RCA content develop high tensile strength properties. The results showed the values of dry-ITS in the range of [111.9 kPa, 203.2 kPa] for CEBMs with RCA while the range is [72.4 kPa, 165.5 kPa] for wet-ITS (Figure 3).

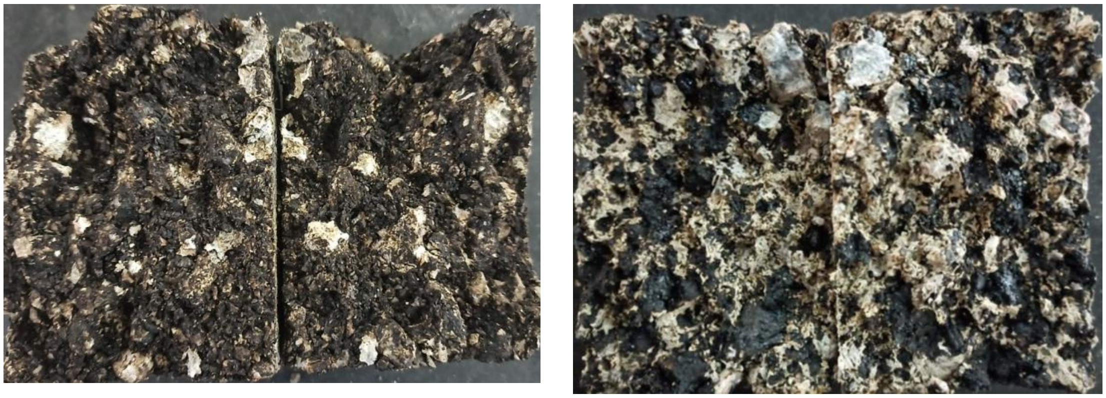
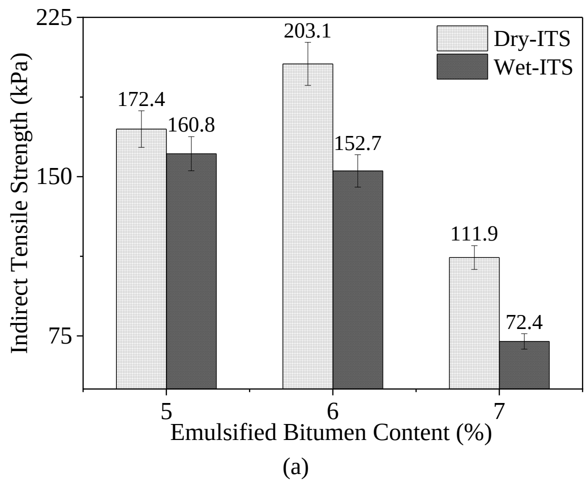


Figure 2. Failure pattern of a) RCA_25 b) RCA_50 (Scale factor=0.7).



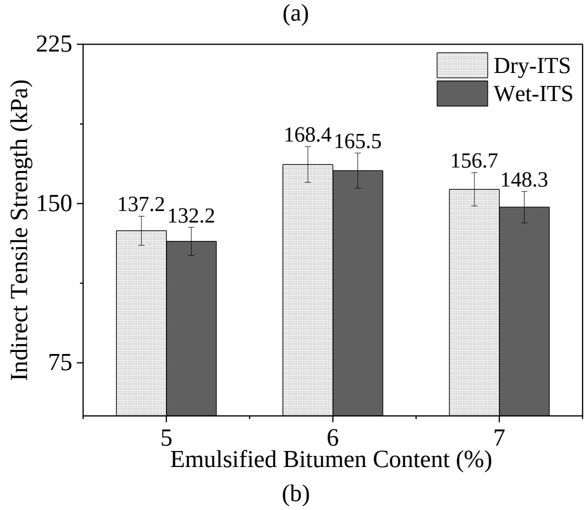


Figure 3. Dry and wet ITS values of CEBM with a) 25% RCA and b) 50% RCA.

It is necessary to determine the continuous evaporation of moisture in CEBMs for understanding the early strength properties. To construct a layer over the base course with CEBM, it is necessary to achieve the moisture content around 1-2%. To achieve the required in-field moisture content, it is also necessary to monitor the dynamics of moisture loss. The results of dry-densities and dynamics of water evaporation are represented graphically (Figures 4 and 5).

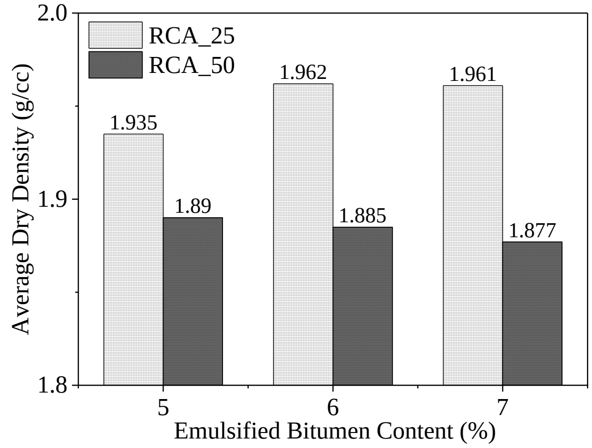


Figure 4. The dry densities of CEBMs.

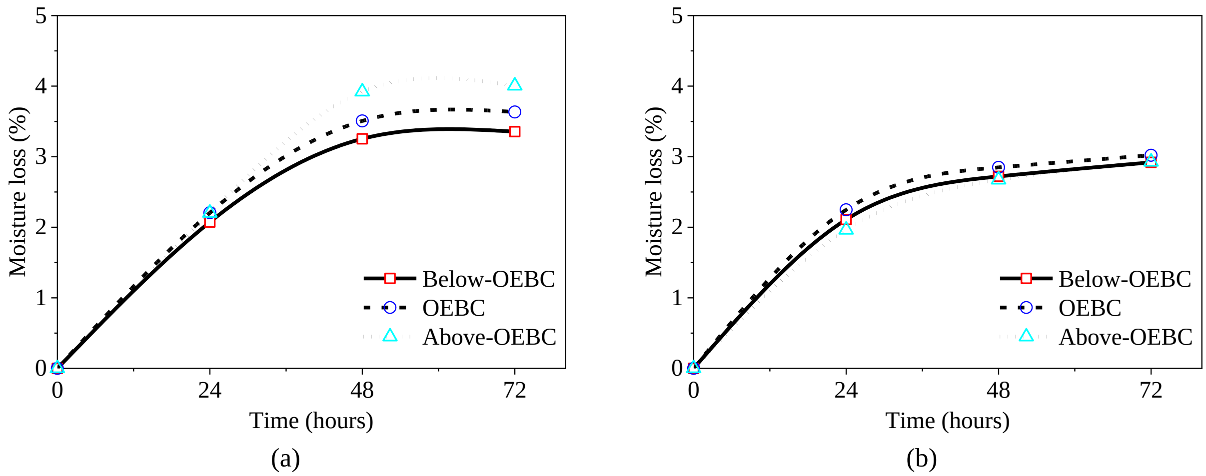


Figure 5. Dynamics of moisture loss for (a) 25% RCA (b) 50% RCA mixes.

The observed results prove that the dry densities of CEBMs with 25% RCA are more as compared to CEBMs blended by 50% RCA. For the CEBMs with 50% RCA, the dry density is reduced by an amount of 2.3, 3.9, and 4.3% for EBC of 5, 6, and 7% EBC respectively (Figure 4). It is found that the variation in dry density observed is due to the lower compactness of the mixes for corresponding gradations and RCA content. It is worth noting that the moisture loss is in the mixes with 50% RCA is more (Figure 5) and it can be concluded that the higher the RCA content, the higher will be the water absorption and lower will be the moisture loss.

A series of 18 specimens are fabricated and cured to investigate for Marshall Stability. The test results revealed that stability varies from 6.9 kN to 8.4 kN (Figure 6) and the maximum stability or the M_R observed at OEBC for all the mixes. Even though the ITS is a selective measure for ranking the cold mixes, the Marshall Stability can also be recommended for optimizing the EBC besides ITS based on the obtained results. Besides, the TSR values are within the specified limits of above 50% (Asphalt Academy, 2009).

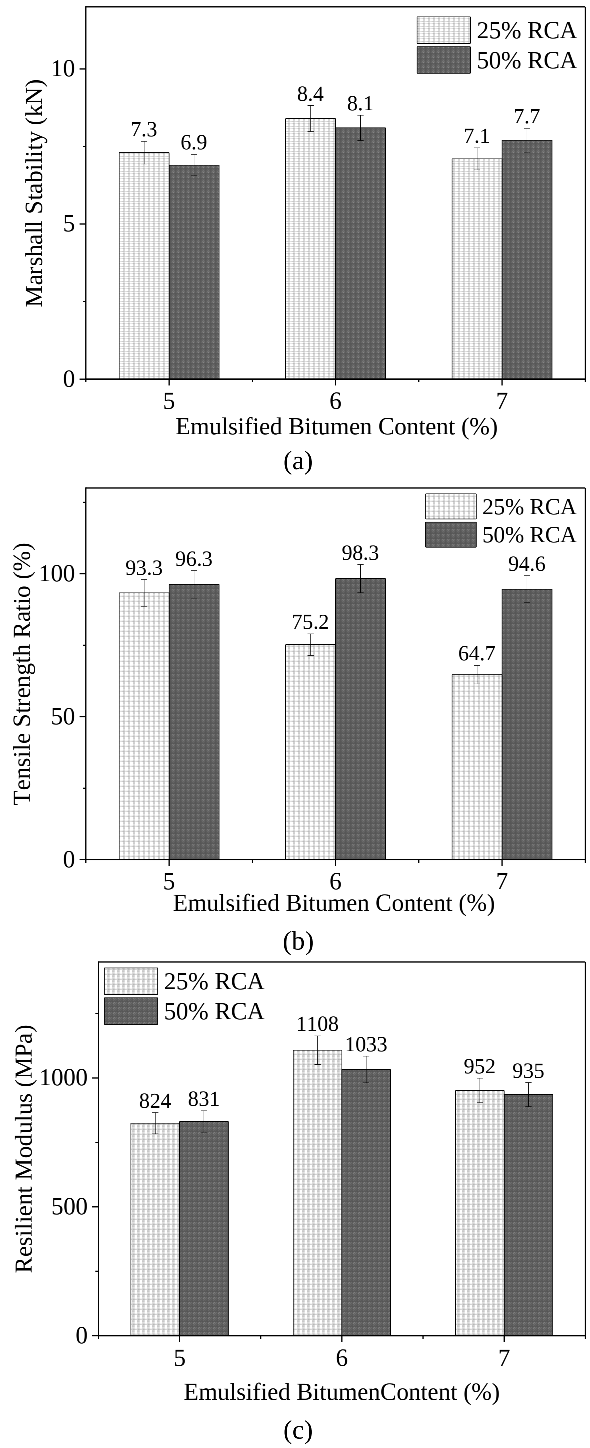
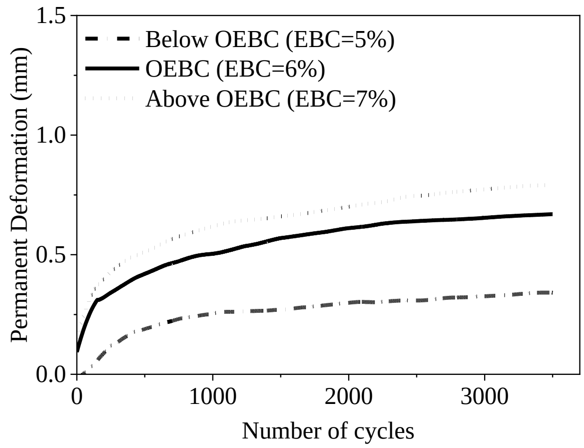
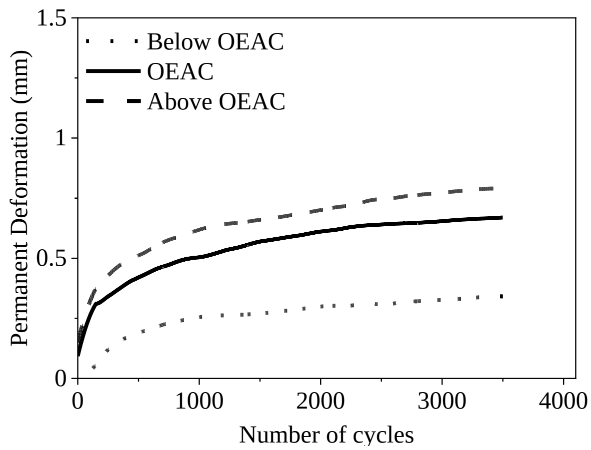


Figure 6. (a) Marshall stability (b) tensile strength ratios and (c) resilient moduli of cold mixes with RCA.

The rutting behavior of CEBM's is evaluated at various EBC's (below, above OEBC and OEBC). From the observations, the permanent deformation increases with the increase in EBC for both the mixes (Figure 7). Further, greater resistance to permanent deformation is observed at 5% EBC (i.e., below OEBC). Hence, OEBC is determined based on ITS does not necessarily produce better resistance against the rutting.



(a)



(b)

Figure 7. Permanent deformation of a) RCA_25 and b) RCA_50.

The durability or water sensitivity of the bituminous mixtures are analyzed using TSR. From the laboratory results, all the specimens exhibited higher retained strength or TSR values (Figure 6(b)) that exceeds an acceptable value of 50%. However, lower TSR values are observed for CEBM's with 25% RCA rather than 50% RCA. From this investigation, it indicates that the retained tensile strength is sensitive to the RCA content and variation in the gradation. Hence, the CEBM's with both the RCA contents can be preferred as pavement bases (Asphalt Academy, 2009).

The results of the M_R test shows that the cold mixes attain maximum stiffness at OEBC. The obtained values are 1108MPa and 1033MPa for CEBM with 25 and 50% RCA (Figure 6(c)). As there is no significant difference in the field and laboratory values of MR, the obtained laboratory values are used in the design and analysis of Pavements with CEBM's. (Guatimosim et al., 2016; Francois et al., 2019; Munoz et al., 2015).To maximize the utilization of RCA in place of NA, 50% of RCA is selected, rather than 25% RCA for the pavement design and analysis.

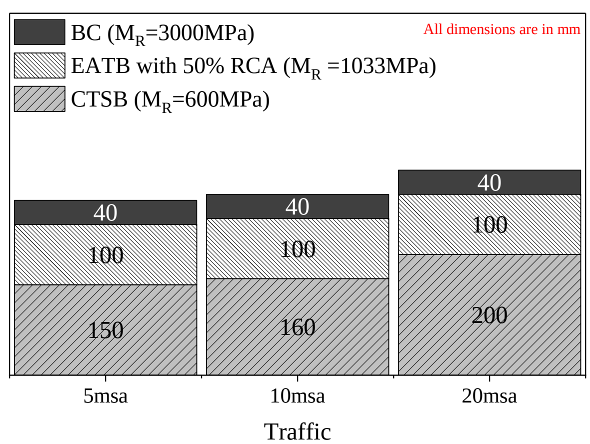
5. Pavement analysis and cost estimation

A detailed analysis is carried using IITPAVE software to understand the strains at the critical points in the pavement system. The critical positions for vertical compressive strain (εv) and the horizontal tensile strain (εt) are considered at the top of the subgrade and the bottom of the bituminous layer respectively. By considering effective CBR of 6% and MR of 1033MPa (corresponding to 6% EBC), the pavement analysis is performed. The critical strain values are calculated for 4.5% air voids and 11.5% (by volume) bitumen content. As per IRC (2018), a reliability of 80% and 90% is considered for corresponding traffic levels below and above 20msa respectively. The summary of pavement analysis is shown in Table 3. The obtained εt values are almost half of the critical εt. However, the obtained εv values are approximately the same as the critical εv. It is observed that the obtained values of εv are decreased below the critical value of εv with increase in thickness of the pavements (Traffic level). With this observation, it can be concluded that the vertical compressive strain is critical in fixing the thickness of the base layer with CEBM rather than the horizontal tensile strain.

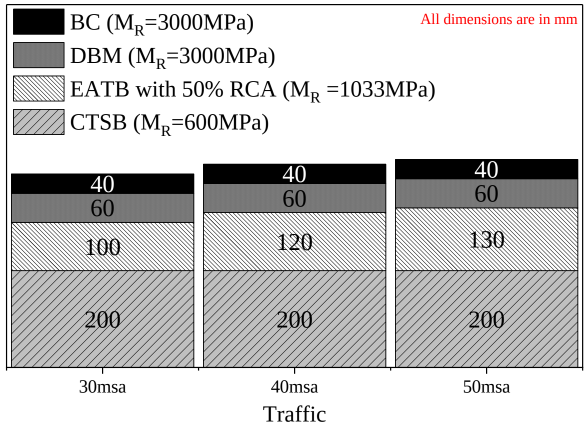
Table 3. The summary of pavement analysis.

Traffic (msa)	(εt) critical	(εv)critical	(εt) obtained	(εv) obtained
5	0.000376	0.000784	0.000169	0.000698
10	0.000314	0.000673	0.000169	0.000669
20	0.000263	0.000577	0.000163	0.000568
30	0.000181	0.000416	0.000091	0.000415
40	0.000168	0.000390	0.000088	0.000383
50	0.000159	0.000372	0.000087	0.000369

Corresponding to the above-mentioned strains, the pavement compositions are depicted separately for 80% and 90% reliability in Figures 8(a) and 8(b) respectively. For design traffic up to 20msa, a constant thickness of 100mm is considered for the Emulsified Bitumen Treated Bases (EBTB). But, the thickness of EBTB is considered as 100, 120, and 130mm for design traffic of 30, 40, and 50msa respectively. For the design traffic≥30msa, there is a reduction of 10 mm thickness which is significantly lower (Figure 9(a)) when compared with the lower traffic levels. That is the reduction in thickness is 50, 40, and 20mm for design traffic of 5, 10, and 20msa respectively.



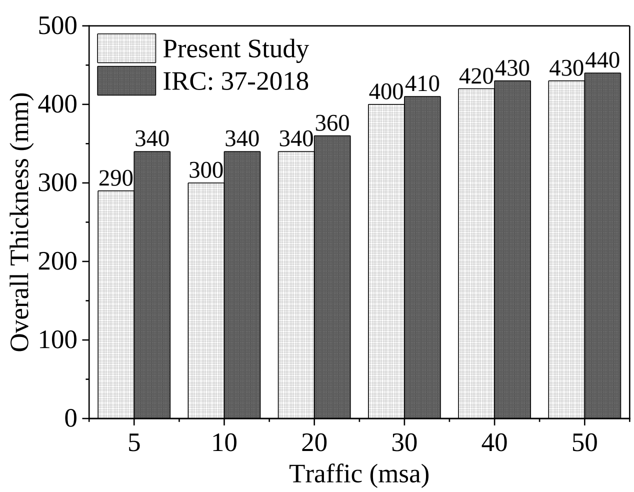
(a)



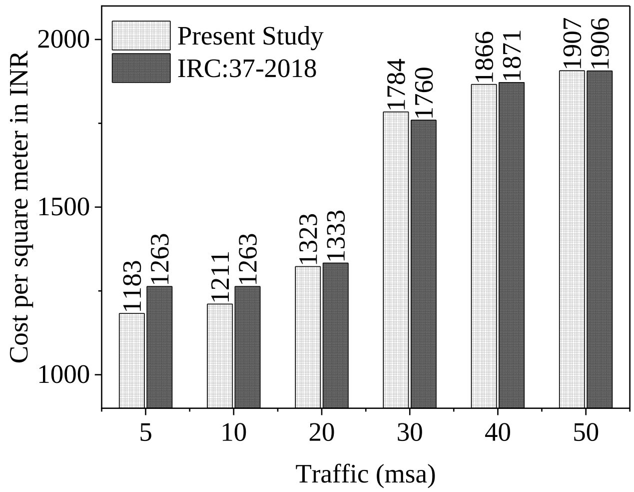
(b)

Figure 8. (a) Pavement composition for traffic levels up to 20 msa (b) Pavement composition for traffic levels from 30 to 50 msa.

The cost is estimated for the aforementioned pavement compositions. The price of the material/ manpower are taken from the common schedule of rates announced by the state government, local consultants, and previous cost estimations in India and previous research works (Aher et al., 2018). The estimated cost includes the cost of transportation in which a fixed cost is taken for all the materials transported from the plant to the site. RCA cold recycling is considered in plants as it involves the crushing of the aggregates and mixing with the virgin aggregates as well. The recycling cost of C & D waste is taken from local consultants. By replacing the RAP with RCA in EBTB, the overall cost is reduced by 6.3, 4.1, and 0.07% for traffic levels of 5, 10, and 20msa respectively (Figure 9(b)). With the improved laboratory performance, reduced cost, and thickness of the pavement, the CEBM's with RCA can be used as a base layer for design traffic up to 20msa.



(a)



(b)

Figure 9. (a) Comparison chart for the overall thickness (effective CBR = 6%) (b) Composition chart for the estimated cost.

6. Conclusions and comments

Based on the evaluation of CEBM's with RCA, the following conclusions can be drawn:

1. As the dry-ITS, wet-ITS and TSR values exceed the permissible values described in Asphalt Academy (2009) guidelines, the CEBM's are recommended for bituminous stabilized layers
2. The performance of CEBM's (in terms of Marshall Stability, Density, TSR, and MR) is better at OEBC calculated based on ITS, except in terms of resistance to permanent deformation. Hence, a multi –variant criterion rather than a single indicative parameter is suggested.
3. Although the TSR values are within acceptable limits, the retained tensile strength is lower for CEBMs with 25% RCA rather than 50% RCA. Hence, the gradation and the percentage of fines influence the moisture sensitivity apart from the RCA content.
4. From the results of the pavement analysis and design, it is recommended that CEBMs be utilized as base layer material, for design traffic upto 50msa. However, the thickness and the cost are reduced for the traffic upto 20 msa.
5. Further, study is recommended for temperature susceptibility and fatigue property of CEBM's comprised of RCA.

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