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The Effect of Compaction Effort on Fatigue Performance of Cold Emulsified Bitumen Mixes with Reclaimed Asphalt Pavement

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Abstract - **During the service period, flexible pavements tends to produce series of distresses, such as rutting, cracking, pothole, etc. When the distresses are severe, the best method is to recycle the distressed layer using stabilizers like emulsified asphalt or some additives and that layer can be used as a base\sub base or surface course based on the purpose. The milled material is known as Reclaimed Asphalt Pavement (RAP) and the application of emulsified asphalt comes under cold mix asphalt technologies. This can help to create a cleaner production including lesser usage of natural aggregates and lower carbon emissions. Compaction is one of the significant factors in order to prevent premature failures and for better performance of the mix. A properly compacted base develops adequate density and strength; the present study investigated the influence of compaction effort on the fatigue performance of Emulsified Asphalt Treated Bases (EATB). The performance indicators include Indirect Tensile Strength (ITS), Resilient Modulus (M_R), and fatigue characteristics. Finally, the study developed the models between ITS and M_R for different fluid contents.**
Keywords: **Compaction Effort, Reclaimed Asphalt Pavement, Indirect Tensile Strength**

I. INTRODUCTION

India is second-largest country in the world with 5.89million kilometers of road length. Out of which 95% of the roads are flexible pavements. The construction of roads is rapidly increasing all over the world. India aims to build 26.93 km/day roads in 2018-19 and 27.40 km/day in 2019-20 (NHAI, 2018). This increasing rate of road construction creates environmental pollution in terms of global warming. Further, there is depletion in the availability of natural resources and increases environmental pollution because of the conventional construction methods. The in-service flexible pavement is progressively deteriorated due to vehicle load repetitions and environmental factors. When pavement condition reaches a poor Pavement Serviceability Index (PSI), it must utilize practical remedy methods to improve its PSI. One of the techniques is pavement recycling which is cheaper, quicker, and has fewer traffic disruptions alternative to conventional reconstruction strategies. The best alternative is to recycle ancient pavements using foamed asphalt, asphalt emulsion, and cut back bitumen. Further, the recycled surface can be used as a base course by modifying its properties using different techniques; one of the best methods is cold mix asphalt technologies.

Cold recycled asphalt mix is formed by mixing bitumen emulsion with unheated aggregates in presence of additives and pre-wetting water. Currently, it is used primarily for minor construction and repair works. The manufacturing temperature of cold mix is at ambient temperatures. So, cold mixes does not require heating, resulting in a significant amount of energy-saving (Lu *et al.*, 2013). It can be used in inaccessible areas; for initial construction (100% virgin mixes) and for asphalt pavement recycling (using of RAP). Generally, foamed asphalt and emulsified asphalt are used in the cold mix preparation. The design of EATB involves determining the optimum emulsified asphalt content at which the adequate strength of the base is achieved. There is no universally accepted procedure for the design of cold mix. Several factors involved in the strength improvement of these EATB, including aggregate gradation, amount of RAP, percentage of cement, and optimum pre-wetting water content. The present study mainly focuses on determining the influence of compaction effort on EATB mixes.

II. LITERATURE REVIEW

Bissada (1984) investigated the resistance to compaction of bituminous mixes are affected by mix variables like filler, binder content etc. Higher the resistance of the mix to compaction, higher it's measured stiffness value and accordingly better resistance to permanent deformation performance is likely in the pavement. At higher fines, higher is the measured stiffness of mix at a lower value of resistance to compaction. Mohammad *et al.,* (2006) investigated the performance of Hot Mix Asphalt (HMA) prepared with different compaction efforts adopting the Malaysia Ministry of Public Works Department gradation and concluded that mixes designed with 75 blows using modified asphalt shown high performance.

Kumar *et al.,* (2008) examined recycled bituminous pavement materials with changing compaction energy and revealed that there is a significant increase in the modulus value for the recycled layer with higher compaction energy. Thanaya (2009) studied the effect of compaction delayed the rate of strength gain of cold emulsified asphalt mixtures cured outdoors with and without addition of cement. It is concluded that cold asphalt emulsified mixtures should be compacted immediately after mixing to get the best results and to avoid workability problems.

Jalili *et al.,* (2008) investigated the effect of additives on cold in-place recycled mixes properties adopting class C fly ash, Portland cement, and lime. They reported that the addition of cement significantly improved the resilient modulus, marshal stability, and indirect tensile strength of the mixes. Kim *et al.,* (2011) investigated the effect of moisture content and curing time on the mechanical properties of Cold In-Place Recycling (CIR) mixes with either emulsified asphalt or foamed asphalt and concluded that retained indirect tensile strength of CIR emulsified asphalt mixes were more than foamed asphalt mixes. Nageim *et al.,* (2012) studied the improvement in mechanical properties of cold mixes due to incorporating cement and discovered the chance of replacing the cement with waste fly ash materials. Albusaltan *et al.,* (2012) investigated the stiffness properties of the cold mixes with different types of fillers. The cationic slow-setting emulsion was used. They concluded that fly ash enhanced stiffness properties to CBEM's compared with cement and improved other characteristics such as cost and environmental impacts.

Meijide *et al.,* (2015) investigated the stiffness of cold asphalt mixtures with construction and demolition waste aggregates and control mixes with Natural Aggregates and their variation after different lengths of curing time at room temperature. They found the stiffness values of cold asphalt mixtures with 100% demolished aggregates and 100% natural aggregates at different curing periods. And concluded that mixes with 100% recycled aggregates perform well over the time. Sobhan *et al.,* (2011) studied the effect of compaction and gradation on properties of bituminous mixes with recycled concrete aggregates. Investigated the behavior of mix at two compaction levels (50, 75 marshal compaction blows) and also studied at medium and low traffic. From the study concluded that for better stiffness and to avoid rutting of the bituminous mix at higher temperatures, compaction efforts for medium traffic (50 blows) can be adopted when recycled aggregates are used as coarse aggregates in bituminous mixes. From the literature, limited studies were found on the influence of compaction effort on the cold mix performance. In the current study, the influence of compaction effort on various properties is investigated.

III. EXPERIMENTAL PROGRAM

A. Materials Used

The materials used in this study are RAP (75%), cement, natural aggregates, and Cationic Slow-Setting Emulsion (CSS-2). The RAP is collected from the highway section between Subedari and Kazipet near NIT Warangal main gate. The collected RAP processed using a jaw crusher to suitable gradation. The primary properties of aggregates were carried as per IS 2386 and compared with Ministry of Road Transport and Highways (MoRTH, 2013) specification limits and for Emulsified asphalt, tested as per IS 8887.

TABLE I PHYSICAL PROPERTIES OF AGGREGATES

Test property	NA	RAP	MoRTH, 2013 Specifications
Specific gravity	2.68	2.25	2.5-3.0
Combined EI and FI (%)	25.73	24.71	35
Los Angeles abrasion (%)	28.52	32.33	40
Aggregate impact value (%)	20.82	12.22	30
Water absorption (%)	0.24	1.11	Max 2

NA: Natural Aggregates, RAP: Reclaimed Asphalt pavement

It is observed from Table I that the Specific gravity of RAP is less compared to NA because the RAP is coated with bitumen. NA is more flaky and elongated compared to RAP aggregates. RAP aggregates have less abrasion resistance but having good impact resistance. All test results are within the permissible limits as per the MoRTH, 2013 specification limits.

TABLE II CHARACTERISTICS OF EMULSIFIED ASPHALT (CSS-2)

S. No.	Characteristics	Specification IS 8887-2004	Specification IS 8887-2018	Obtained Result	Test Method
1	Residue on 0.6mm sieve, % by mass, Max	0.05	0.05	0.03	IS 8887
2	Viscosity seconds, (at 25^0C)	30-150	30-150	36.53	IS 3117
3	Particle charge	Positive	Positive	Positive	IS 8887
4	Residue by evaporation, percent, Min	60	60	62.16	IS 8887
5	Storage stability after 24h, percent, Max	2	2	2	IS 8887
6	Miscibility with water	No	No	No	IS 8887
7	Penetration 25C/100g/5sec	60-100	60-100	110	IS 1203
8	Ductility 27C/cm, Min	50	50	96	IS 1208

All the test results are within the specified limits given by IS 8887-2018. But the penetration value is slightly higher than the specified limit because the emulsified asphalt is prepared using less viscosity bitumen (VG-10).

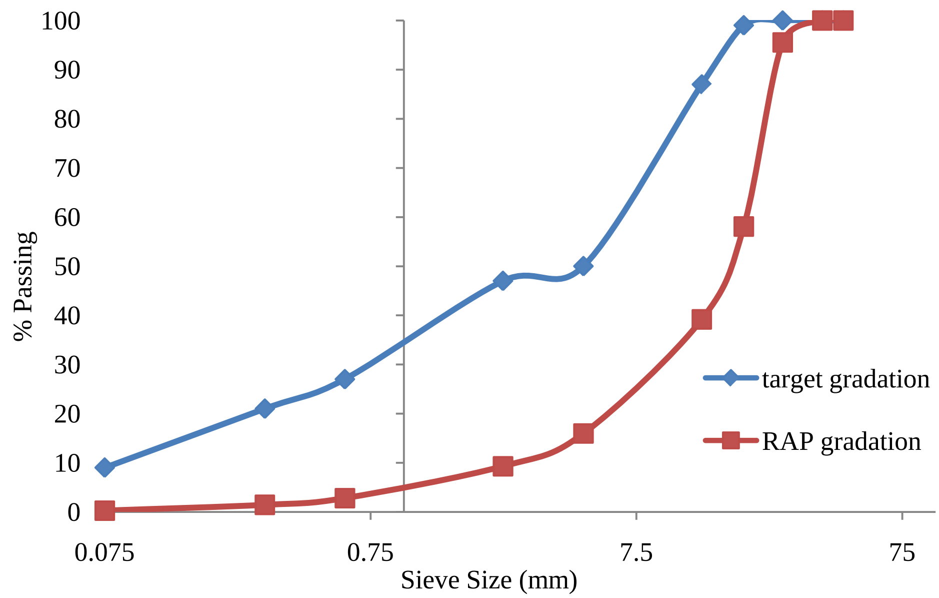

Fig. 1 Aggregate Gradation

Grain size analysis was carried for the aggregates extracted from RAP material. The gradation was adopted from the MoRTH, 2013. From the test results, as shown in Fig 1, it was observed that the percentage of fines is significantly less. In order to satisfy the gradation requirements NA of 25% by weight are added to meet the required gradation.

B. Cold Mix Design

The design of cold mixes involves selecting asphalt emulsion type, aggregate blending, additives, pre-wetting water, and determination of optimum emulsified asphalt content. Generally, the type of emulsified asphalt will be chosen based on the charge on the aggregate surface. The amount of cement is preferred in the range of 1-2% as per (TG-2 guidelines 2009), MS-19 guidelines, and IRC: SP100-2014. In the current study, 1% Ordinary Portland cement was used. Pre-wetting water enhances the coating of the emulsified asphalt on aggregates surface, improves workability, and reduces the loss of absorbed bitumen. The optimum pre-wetting water content was determined using a coating/adhesion test.

Fig. 2 Cold Mix Design (Sample preparation)

The minimum pre-wetting water content of 1-2.5% to be added for uniform coating as per Asphalt Institute, 2009, IRC: SP 100-2014, IRC: 37-2012. Preparation of samples involves four stages. In first step, weight of aggregates and cement were taken. In second step, they are mixed thoroughly for 1-2 minutes. After, optimum pre-wetting water is added and mixed for60 seconds. In fourth step, add emulsified asphalt and mix it until homogeneous mixture is obtained and allow it for some time to confirm the breaking of emulsified asphalt. Then the mixes are compacted and cured. The emulsified asphalt contents used in this study are 3%, 4%, 5%, and 6%, and curing of samples was done per the MS-19 guidelines.

C. Indirect Tensile Strength (ITS)

This test is helpful to study the resistance to cracking in the field by asphalt layers when subjected to tensile stress. There are two failure criteria in the design of flexible pavements: horizontal tensile strain at the bottom of the bituminous layer and vertical compressive strain on top of the sub grade. This test is helpful to evaluate the first criteria. ITS can also be used for rutting and moisture damage analysis. In the ITS test, the loading is applied across the vertical diametrical axis of the cylindrical specimen at 51 mm/min deformation rate at25℃ temperature. This test is conducted as per ASTM D6931.

D. Resilient Modulus (M_R)

Resilient Modulus (M_R) is one of the critical parameters in designing flexible pavements. There should be a minimum M_R value for different layers in the pavements prescribed in IRC 37-2018, and the test is conducted as per ASTM D4123. Before finding M_R, ITS should be found at the same test temperature. In M_R testing, a repeated load is applied vertically in the diametrical plane of a cylindrical specimen. Two horizontal LVDTS are connected to the sample for horizontal deformations. In this test, 10-20% of the ITS is applied at 1HZ frequency of 0.1sec loading period and 0.9sec rest period. The minimum (M_R) for EATB should be 800 MPaas mentioned in IRC 37-2018.

E. Repeated Load Indirect Tensile Fatigue Test

Fatigue resistance of asphalt mixes is the ability to withstand repeated loading without failure or crack. The life of pavements is directly related to this phenomenon, which must be correctly studied to ensure adequate structural design. Haversine loading is applied for the determination of fatigue life in bituminous mixes. Fatigue characteristics are generally expressed as a relationship between the initial tensile strain and the number of load repetitions to failure. In this study, the test termination condition adopted is a complete failure of the sample. In this test, the load is applied in compression to create tension in other direction. The test is conducted on the specimens prepared at various Marshall Method of compaction at 50, 75, 100, 125, and 150 on each side of the sample.

IV. RESULTS AND DISCUSSION

A. Indirect Tensile Strength

The pre-wetting water required more for upper gradation because upper gradation has more fines results more specific surface area. This optimum pre-wetting water content was determined using coating and adhesion tests. For the emulsified asphalt contents of 3.0%, 4.0% 5.0% and 6.0%, the corresponding pre-wetting water contents are 3.0%, 3.0%, 2.0% and 2.0% respectively.

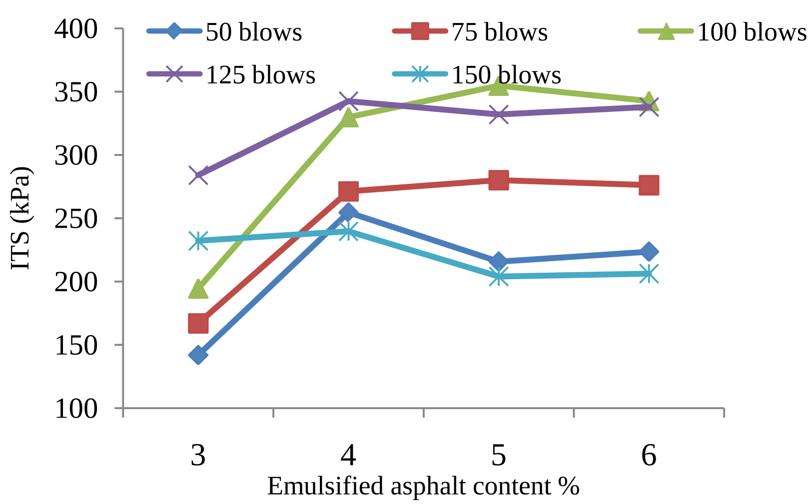

Fig. 3 Summary of ITS results

From Fig 3, the Optimum Emulsified Asphalt Content (OEAC) is significantly influenced by compaction energy up to 100 Blows. However, beyond this compaction effort, OEAC is unaffected. The maximum ITS value observed at 5% emulsion content with 100 compaction blows is 354.74 kPa. This is due to the good interlocking of the aggregates.

The optimum compaction energy was determined at each emulsified asphalt content based on the above results. Also, at 3.0%, 4.0%, 5.0% and 6.0% emulsified asphalt contents the optimum compaction effort is 125, 125, 100 and 100 compaction blows on each side respectively and corresponding ITS values are 283.9, 342.46, 354.74and 342.58 respectively.

B. Dry Density

From the Fig 4, it was observed that the maximum dry density is at 3% emulsified asphalt content with 125 compaction blows. As the compaction energy increases, the OEAC decreases. The maximum dry density is 2.121 g/cc.

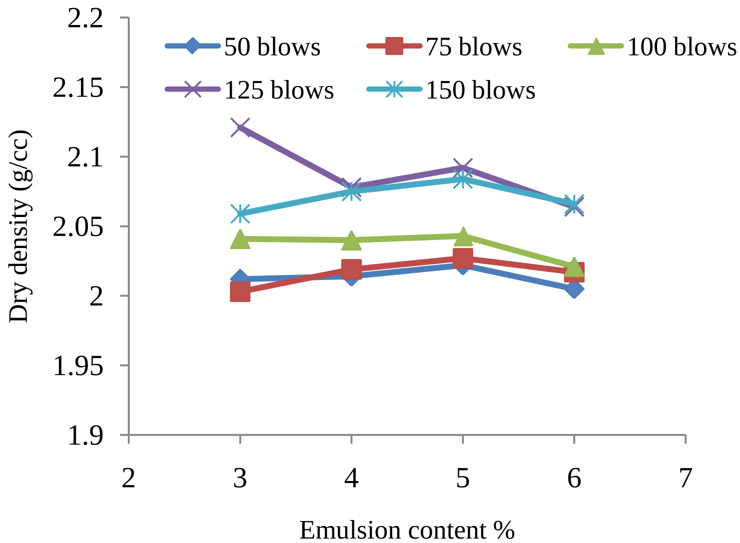

Fig. 4 Summary of Dry Density results

C. Resilient Modulus

From Fig 5, it was observed that the M_R value is high at 4% emulsion content corresponding to 125 compaction blows on each side. By increasing emulsified asphalt content above 4%, the M_R decreases because the mix loses its stiffness.

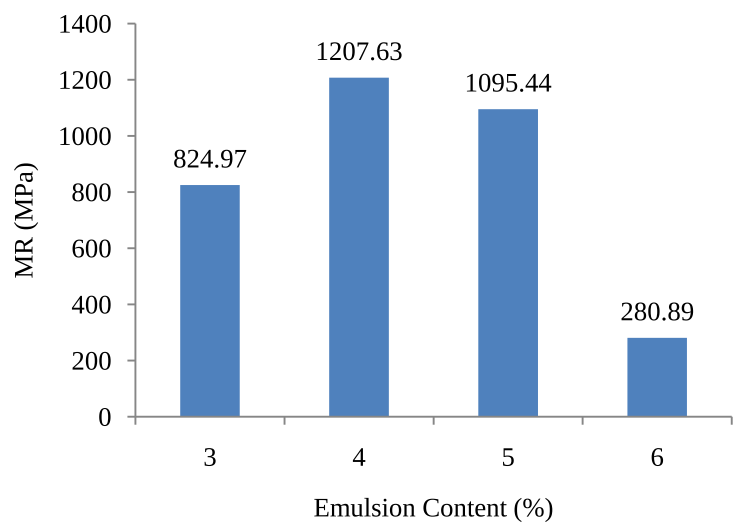

Fig. 5 Summary of Resilient Modulus Test Results

D. Development of Models between ITS and M_R

Present the flexible pavement is designed through the mechanistic empirical approach counting on the mechanistic behaviors of the Bituminous Concrete. In the pavement design the important parameter to be considered is Modulus of Resilience which is difficult to find; so we are developing the relationship between indirect tensile strength and Modulus of resilience. Indirect tensile strength can be calculated using simple instrument.

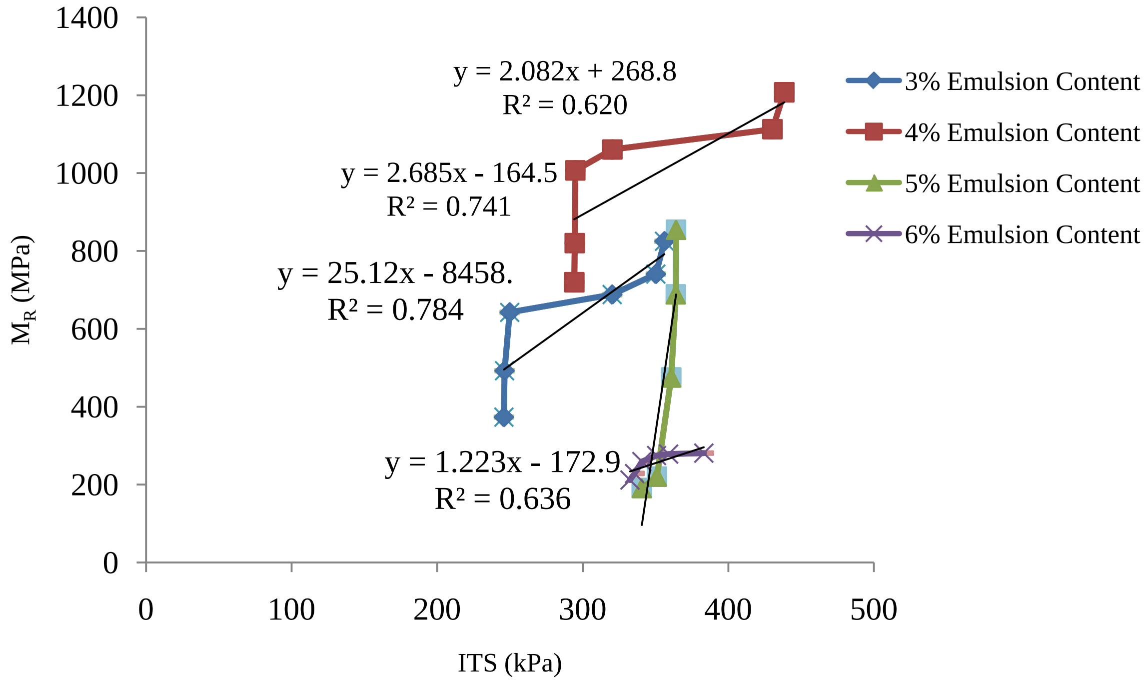

Fig. 6 Models between ITS and MR for 3%, 4%, 5%, and 6% emulsion content

TABLE III DEVELOPED MODELS BETWEEN ITS AND M_R

Emulsion Content (%)	Regression Equation	R2
3	M_R = 2.685ITS -164.25	0.741
4	M_R = 2.082ITS +268.8	0.62
5	M_R= 25.12ITS - 8458	0.784
6	M_R = 1.223ITS - 172.9	0.636

E. Repeated Load Indirect Tensile Fatigue Test

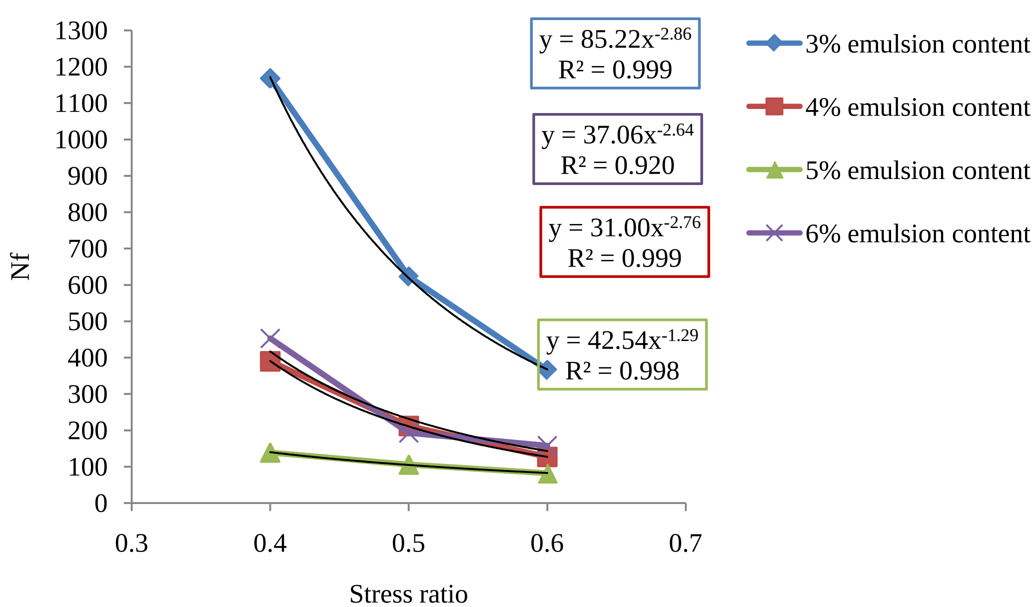

Fig. 7 Results of fatigue analysis (N_f vs Stress Ratio)

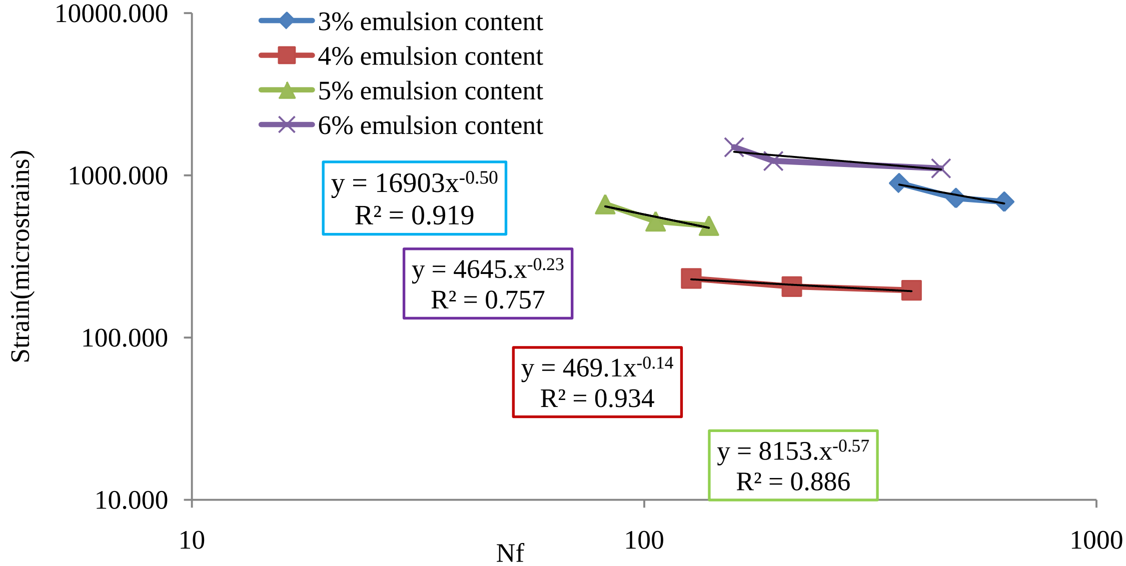

Fig. 8 Results of fatigue analysis (N_f vs Strain)

From the above results it was observed that the fatigue life is high at 3% emulsified asphalt content with 125 compaction blows on either side of the sample. The test is conducted at 0.4, 0.5, and 0.6 stress ratios. As compaction energy increases the stiffness increases thereby fatigue life is increases. It was also observed that as the stress increases the fatigue life is decreased.

TABLE IV FATIGUE LINE EQUATIONS FOR ALL EMULSION CONTENTS

Emulsion Content (%)	Developed Fatigue Equation	R^2
3.0	$\varepsilon = 16903 * N^{0.50}$	0.919
4.0	$\varepsilon = 469.1 * N^{-0.14}$	0.934
5.0	$\varepsilon = 8153 * N^{0.57}$	0.886
6.0	$\varepsilon = 4645. * N^{-0.23}$	0.757

F. Effect of Compaction on Gradation Parameters

TABLE V TEST RESULTS OF GRADATION PARAMETERS FOR UPPER GRADATION

Compaction Blows	D_{10}	D_{30}	D_{60}	C_U	C_C
50	0.087	0.864	6.620	76.308	1.299
75	0.077	0.832	6.575	85.715	1.371
100	0.077	0.809	6.593	86.017	1.295
125	0.075	0.798	6.687	89.166	1.270
150	0.067	0.665	6.294	93.836	1.047
Actual	0.094	0.864	7.026	74.949	1.133

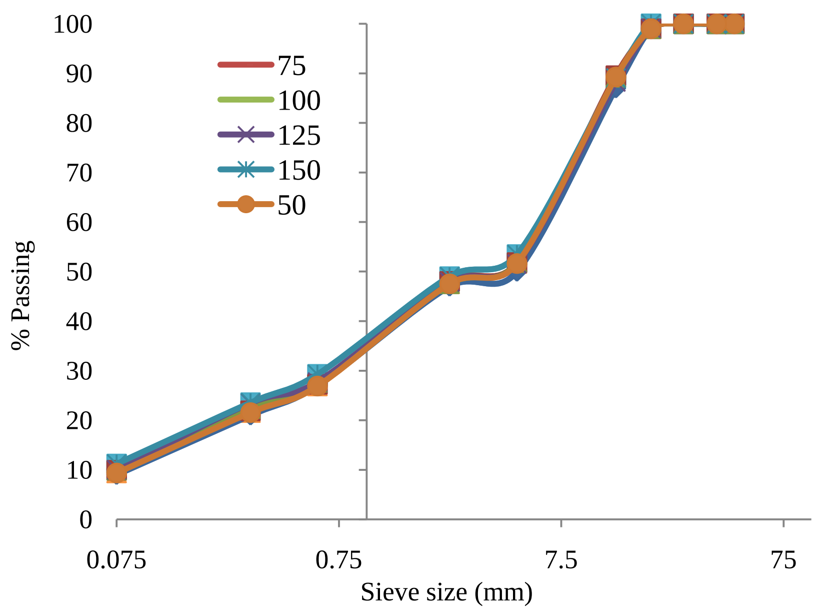

Fig. 9 grain size distribution chart for upper gradation at different compaction blows

The above results show that the aggregates are slightly crushed by increasing compaction energy, but that doesn't affect the gradation parameters like uniformity coefficient and coefficient of curvature. These aggregates have good impact resistance that is why the aggregates are not crushed even if we compact to 125 blows on either side. However, this doesn't correlate exactly with what happens when we use binders, but this study can explain the comparative study of different gradations with varying compaction levels. In upper gradation, if we compact the dry mix to 150 blows on each side, the coefficient of curvature value is nearly less than one; this means the aggregates are crushed to a greater extent as they are not well graded.

V. CONCLUSION

The engineering properties of RAP aggregates are within the specification limits and close to that of conventional aggregates. The dry density of the cold emulsified asphalt mixes is influenced by emulsified asphalt content and compaction energy. As the compaction energy increases, the dry density increases up to optimum density and follows a decreasing trend because of the crushing of aggregates as fines require more space. Maximum MR is observed at 125 Marshall Method of Compaction at 4% emulsified asphalt content which satisfied the specifications limitations as a base layer of 800 MPa. Increase in fatigue life is observed with emulsified asphalt content and at lower initial tensile strains. For lower optimum emulsified asphalt contents, the required compaction energy is higher. Further, the compaction energy is more the mixes with higher fines content.

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