Performance Evaluation of Full Depth Reclamation (FDR) Mixes Containing Emulsified Asphalt

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ABSTRACT: Full Depth Reclamation (FDR) is a sustainable and cost-effective pavement rehabilitation technique that involves the in-place recycling of existing pavement materials. The current study evaluates the performance of FDR mixes treated with stabilizing agents such as cement and emulsion. The research compares three distinct gradations considering various in-service pavement compositions carrying different traffic volumes: (i) 100% RAP mix (ii) 50% RAP mix and (iii) 42% soil mixture. Mix design was performed and the performance characterization has been carried out for all three mixes. The performance was assessed through the indirect tensile cracking tolerance test. The results show that the increasing the cement content or the emulsion content can improve the indirect tensile strength of the FDR mixes. However, the increase in cement content can reduce the flexibility and cracking tolerance of the mix whereas increase in emulsion content can improve the flexibility of the FDR mix.

1 INTRODUCTION

The increasing demand on roadways over the past few decades, combined with shrinking budgetary allocations and the necessity to maintain a safe, efficient, and cost-effective transportation system, has created a pressing need to rehabilitate aging pavement infrastructure. In this context, asphalt recycling and reclaiming have gained significant attention as both technically and environmentally sustainable methods for pavement rehabilitation (ARRA, 2015). These techniques align with societal goals by providing safer and more durable roadways while reducing environmental impacts and energy consumption compared to traditional reconstruction methods.

Among the various recycling methods, Full Depth Reclamation (FDR) has emerged as a preferred rehabilitation technique (Smith & Braham, 2018). FDR involves pulverizing the entire thickness of the asphalt pavement, along with a portion of the underlying layers (such as base, subbase, and subgrade), to create a homogenous material (Ghanizadeh, et al., 2018). This reclaimed material can often serve as a stable base for a new surface layer. However, when necessary, mechanical, chemical, or bituminous stabilization methods are employed to enhance the structural and functional properties of the reclaimed material.

The depth of FDR typically ranges between 100 mm and 300 mm, depending on factors such as existing pavement thickness, soil characteristics, and traffic load repetitions (Mallick et al.). The use of FDR improves the pavement's bearing capacity, structural integrity, and longevity, thereby enhancing overall performance. By recycling existing materials, FDR minimizes environmental impact while offering a cost-effective solution for modern infrastructure development (Smith & Braham, 2018).

Full Depth Reclamation (FDR) materials treated with a combination of emulsion and cement demonstrate superior performance in submerged conditions compared to those treated with emulsion alone. The addition of cement enhances the mixture's durability and significantly increases its indirect tensile strength, ensuring improved structural integrity and long-term performance (González et al., 2016). The Indirect Tensile Strength (ITS) of bitumen-stabilized materials improves with increasing emulsion content at a constant cement dosage (Grilli et al., 2018). It has been reported that the stiffness modulus of bitumen-stabilized materials decreases with an increase in reclaimed asphalt content from 0% to 80%. However, this improved when cement dosage was increased from 1% to 2% at a constant emulsion content (Grilli et al., 2018). Studies showed that increase in the cement content in bitumen-stabilized materials (BSM) reduces the slope of fatigue lines, indicating a transition in material behavior from asphalt mix to cement-treated materials (Modarres et al.) Despite its advantages, FDR design in India faces challenges due to the lack of comprehensive guidelines.

2 OBJECTIVES

The current study aims to carry out a performance evaluation of FDR mixes with three distinct gradations corresponding to in-service pavement compositions carrying different traffic volumes, viz, (i) 100% RAP mix (ii) 50% RAP mix and (iii) 42% soil mixture. The 50% RAP mix and 42% soil mixes are indicative of roads carrying high and low traffic volume respectively. The FDR are mixes are subjected to indirect tensile test and their performance is evaluated by determining the Cracking Tolerance Index (CTI).

3 MATERIALS

3.1 *Cement*

Ordinary Portland Cement (OPC) 43-grade was utilized in this study. The Properties of Cement comply to IS Standards (IS: 8112-1989).

3.2 *Bituminous Emulsion*

A slow-setting bituminous emulsion (SS-2) containing 61.80% bitumen by weight was used (table 1).

3.3 *Virgin Aggregates*

Virgin aggregates of varying sizes, including 40 mm, 20 mm, 10 mm, 6 mm, and stone dust, were incorporated into the mix. The aggregates were graded in accordance with standard specifications to ensure proper particle size distribution for optimal performance.

Table 1. Properties of SS-2 emulsion

Properties	Result	Specifications	Test method
Penetration (residue) at 25◦C, 100 g, 5 s, 0.1 mm	65	60-350	IS8887
Residue 600 micron IS Sieve (% mass)	0.038%	Max 0.05	IS8887
Viscosity by Say bolt Furol Viscometer, Seconds	41	30-150	IS3117
Storage stability after 24 h, %	0.7	Max 2	IS8887
Miscibility with water (coagulation)	No Coagulation	No Coagulation	IS8887
Residue by evaporation, %	61.80%	Min 60	IS8887

3.4 *Reclaimed Asphalt Pavement (RAP)*

Reclaimed Asphalt Pavement (RAP) material containing 4.4% residual binder was used in the preparation of the samples.

4 GRADATION

The gradations were selected in such a way that they represent the actual reclaimed material during FDR of in-service pavements. The 100% RAP mix represents the scenario of reclaiming a thick asphalt layer (figure 1). The 50% RAP mix and 42% soil mixes are indicative of roads carrying high and low traffic volumes as shown in Figure 1. It has been ensured that the selected three gradations comply with the Technical Guideline 2 (TG2) for bituminous stabilized materials and Cement-Treated Base (CTB) gradation limits for FDR materials (MoRTH, 2013).

Figure 1. Criteria used for selecting FDR gradations

4.1 *High volume Road*

Trial and error exercises with different crust compositions corresponding to the available templates (1 to 8) in IRC 37: 2018 (based on standard axle road repetitions and California Bearing Ratio) were performed to arrive at the required graduation for high-volume roads. The thickness of the Full Depth Reclamation (FDR) material was limited to 300 mm. The overall reclamation thickness of 300 mm serves as the basis for calculating the contribution of each pavement layer to the overall gradation.

Blending was performed considering the gradation for the base course (WMM) as per MoRTH (2013), and the actual gradation of RAP milled from the wearing and binder courses. To represent those pavements that have been rehabilitated in the past with multiple overlays, 100% RAP mixes were considered in the study. In order to represent high-volume traffic roads, 50% RAP mixes were included, considering both RAP and granular layer (WMM).

4.2 *Low Volume Road*

For low-volume roads, the choice of gradation was based on the pavement design catalogues for gravel and granular bases/subbases outlined in IRC-SP-72:2015. Similar to high-volume roads, the thickness of the FDR layer is limited to 300 mm to analyse the contribution of the top layer of pavement. The gradation for layers such as Granular Subbase (GSB) and Gravel Base are obtained from the MORD (2014). A blending exercise is conducted for varying CBR values and traffic categories using the design templates from IRC-SP-72:2015.

Traffic category T2 with a CBR range of 7-9% was considered to arrive at the final FDR gradation. The final gradation for FDR was developed by blending the fractions from different layers, ensuring alignment with low-volume road performance requirements. Figure 2 shows the final gradation for a) 100% RAP, b) 50% RAP (high volume) and c) low volume roads. The upper and lower limits for cement-treated base material (IRC 37, 2018) are also included for reference.

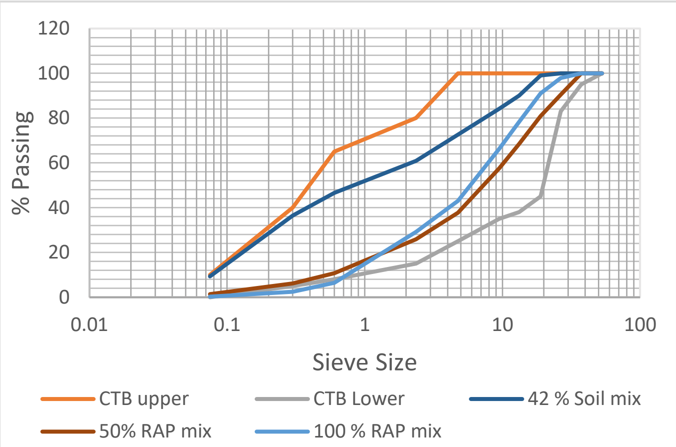

Figure 2. Final Gradation for the FDR mixes

5 MIX DESIGN FOR FDR MIXTURES

The mix design for Full Depth Reclamation (FDR) was performed considering three distinct mixtures: a) 100% RAP, b) 50% RAP + 50% fresh aggregates and, c) 41.7% soil and 58.3% fresh aggregates.

To stabilize these mixtures, bituminous emulsion at 3% and 4%, and cement at 1% and 2% were incorporated, resulting in a total of 12 combinations. The determination of the Optimum Moisture Content (OMC) for each mixture was performed, and the results are summarized in Table 2. The OMC included the pre-wetting water content and the water content of the emulsion.

Table 2. Optimum Moisture Content for Different Mixtures

Mixture Composition	Cement Content (%)	OMC (%)
100% RAP	1	3.70
	2	3.80
50% RAP + 50% Fresh Aggregate	1	3.90
	2	4.10
41.7% Soil + 58.3% Fresh Aggregate	1	4.00
	2	4.25

5.1 *Sample Preparation and Compaction*

Initially, the sample was prepared as per the required gradation to which the specific cement content (1, 2%) was added. Further, 1% pre-wetting water content was added to the mix, followed by the addition of emulsion. Further, the mix was cured at 40°C for 30 minutes in accordance with the guidelines provided by ARRA. The samples were further compacted using the Marshall Compaction method, where 75 blows were applied on both sides of the specimen to achieve the required density. After compaction, the specimens underwent post-compaction curing at 40°C for 72 hours. Following the curing process, the samples were subjected to a series of performance tests to evaluate their mechanical characteristics. Four samples were tested in each combination to ensure repeatability. The air void content in the sample ranges between 7- 13%.

5.2 *Indirect Tensile Cracking Tolerance Test*

The Indirect Tensile Cracking Tolerance test (IDEAL-CT) test was conducted at a temperature of 25°C to determine the cracking resistance of asphalt mixes (ASTM D8225-19). The load vs deformation curve gives an indication of the flexibility of the mixes. CT index is calculated as Eq (1)

$$CT_{index} = \frac{t}{62} \times \frac{l_{75}}{D} \times \frac{G_f}{|m_{75}|} \times 10^6 \quad (1)$$

Where, $|m_{75}|$ = absolute value of the post-peak slope (N/m), D = Average diameter of the sample (mm), t = Average height of the sample (mm), G_f = Failure Energy (Joules/mm^2), and l_{75} = Displacement at 75 % of the peak load after the peak (mm).

6 RESULTS AND DISCUSSIONS

Figure 3 shows the ITS (indirect tensile strength) values of the FDR fixes at varying cement and emulsion dosages. Table 2 shows the Cracking Tolerance Index (CTI) of the different mixes.

It can be observed that increasing either cement or emulsion content leads to an increase in the ITS for all the mixes. However, at a constant emulsion content, an increase in cement dosage results in a decrease in the crack tolerance index (CTI). In contrast, increasing the emulsion content at a constant cement content results in an increase in both the ITS and the CTI of the mixes.

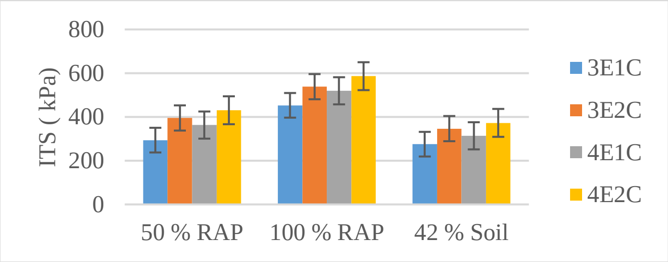

Figure 3. Indirect Tensile Strength (ITS)

Table 2: ITS strength And CT Index of FDR mixture

Mix	Notation	Emulsion (%)	Cement (%)	CTI
50 % RAP	50 R E3C1	3	1	25
	50 R E3C2	3	2	10
	50 R E4C1	4	1	33
	50 R E4C2	4	2	20
100 % RAP	100 R E3C1	3	1	43
	100 R E3C2	3	2	34
	100 R E4C1	4	1	66
	100 R E4C2	4	2	42
42 % Soil	42 S E3C1	3	1	7
	42 S E3C2	3	2	5
	42 S E4C1	4	1	8
	42 S E4C2	4	2	5

Figure 4 shows the load vs deformation curve for 100% and 50% rap mixes at specific cement and emulsion contents.

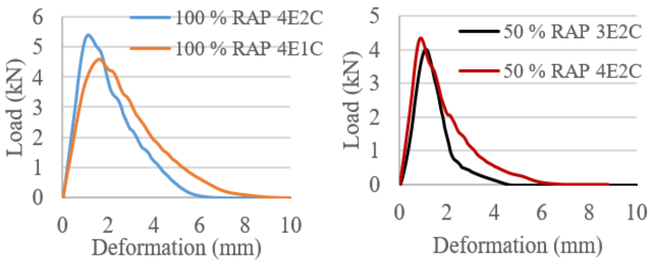

Figure 4. Load Vs Deflection Curve

Though the increase in cement content (1 to 2%) results in a higher peak load, the area under the curve significantly reduces. In contrast, an increase in emulsion content (3 to 4 %) improves the area under the curve and the overall flexibility of the mixes. It was observed that the soil mixes exhibited brittle behavior, failing suddenly without significant deformation.

7 CONCLUSIONS

The influence of emulsion on FDR mixes containing RAP is significant due to the improved flexibility and cracking resistance imparted by the bituminous emulsion. Though the increase in cement dosage can increase the indirect tensile strength, the flexibility of the mix is adversely affected. However, the addition of emulsion along with cement can improve the indirect tensile strength as well as the flexibility of the FDR mixes. The influence of emulsion on soil mixes is not significant and it was observed that the soil mixes exhibited brittle behaviour.

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