Influence of Different Additives on Cold Recycled Mixes at Environmental Conditions of Pakistan

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Abstract: As with the passage of time, natural resources become extinct. Different recycling techniques are being developed for the use of recycled materials. Reclaimed asphalt pavement materials (RAP) have been used in cold in place recycled pavements worldwide from early nineties. The performance of CIPR technique varies in different zones of the world and up till now its mix design is under development stage. This research work is done to evaluate the behavior of CIPR mixes using different additives keeping in view the local conditions of Pakistan. For this purpose resilient modulus and static creep test has been performed on Marshall Samples of CIPR mixes using UTM-5P with foam and emulsified bitumen as additives. It was concluded that samples with foam bitumen showed more structural adequacy as compare to emulsified bitumen samples at various temperatures and loading frequencies according to Pakistani traffic conditions.
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Key words: CIPR, Foam bitumen, emulsified bitumen, RAP.

1. Introduction

Road Transportation system is one of the key components of the economic and social development process, often absorbing a high proportion of national budget. Pakistan, with more than 180 million people, has a reasonably developed transport infrastructure. Road transport is the backbone of Pakistan's transport system.

The current road density of Pakistan is 0.32 Km/Sq.Km with total road network of 260,000 Km (Both high and low type). It is much less even from regional standards; the road density of India is approximately 1.00. The maximum value of road density is considered of Japan, which are approximately 3.07. (Pakistan Economic Survey, 2009-10). Pakistan is endeavoring hard to double its road density, which is possible if maintenance and rehabilitation expenditure is controlled to an acceptable limit.

NHA has been experimenting new maintenance and rehabilitation techniques, including hot and cold recycling, to meet the demands of growing road network with scarce resources. Funds requirement for annual maintenance (2009-10) of highways is approximately Rs. 18.961 billion: Rs. 13.774 Billion are required for rehabilitation and periodic maintenance (structural and functional overlay), and about Rs. 5.187 billion for routine maintenance, highway safety, and other maintenance schemes. But NHA has resources of only Rs. 13 Billion for FY 2009-10. It is foreseen by the authority that a maintenance backlog would be created in 1 – 3 years' time if additional funding is not provided. It is an alarming situation for the developing country (NHA, AMP 2009-10).

Construction materials preservation, environment friendly construction, speedy and cost effective rehabilitation alternatives are the requirements of current age. Road roughness and condition surveys on NHA network have revealed that conventional methods of maintenance and rehabilitation could not perform up to the mark in the past due to several reasons; especially labour factor (Human) for patch works and quality control issues associated with bitman and even with pre-mix asphalt overlays in the small rehabilitation stretches far-off from the Asphalt Plant. In contrary, by adopting new techniques of asphalt pavement recycling, particularly cold in place recycling, a quality controlled final product is achieved using latest equipment i.e. Cold Recycler along with recycling train.

Cold in-place recycling (CIR) has become an attractive and popular method in the developed countries for rehabilitating asphalt roads that have good subgrade support and are suffering distress related to non-structural aging and cracking of the pavement layer. However, CIR pavement performance remains somewhat unpredictable. It has been observed in most parts of the world that roads recycled under similar weather and construction conditions perform very differently for no clear reason. Moreover, a rational mix design has not yet been developed, and there is no clear understanding of the cause-effect relationships between the choices made during the design/ construction process and the resulting performance. Past laboratory and field test results indicate that method of curing, temperature, and length of the curing significantly affect the properties of CIR mixtures. The research objectives are to explore different cost effective, having improved pavement performance and environment friendly additives to be used in CIPR.

2. Literature Review

To know about the effect of different asphalt binders, amount of reclaimed asphalt pavement used and aging of RAP, dynamic creep test was conducted by Gui-ping et al to evaluate the behavior if the foamed asphalt mixes. Creep strain slope, intercept and secant creep stiffness modulus has been taken into account during the test. Creep strain slope has been greatly affected by grade of bitumen. While percentage and aging of RAP did not have much effect on the creep strain slope (CSS). It has seen that FA Mixes are better than hot asphalt samples in susceptibility and creep strength. [1]

By following empirical mechanistic approach six different asphalt mixes containing reclaimed asphalt pavement material were evaluated. Determination of mechanical properties, strength of wearing and base course at different Percentages of RAP and evaluation of rheology of binder used and recovered were checked. It was concluded that recycled mixes gave same results and in some cases better than conventional mixes. [2]

Y. Niazi et al used different additives to check the behavior of cold in place mixes. For this purpose Portland cement, hydrated lime as powder and slurry were used. Against different properties such as resistance to permanent deformation, Marshall Stability, Tensile strength and resilient modulus, cement and lime added mixes showed better results than neat samples. Further among different additives the use of Portland cement is recommended. [3]

Hamad I. Al-Abdul Wahhab et al studies the effect of characteristics of asphalt foam and PAP (Pulverized Asphalt Pavement) material attributing the strength of mix. A fracture face image analysis procedure was used to quantify asphalt dispersion. It was found that foam ability of asphalt was one of the primary factors determining the quality of mix. Foams with higher expansion ratios and longer half-life have better dispersion through granular materials, resulting in greater strength improvement. High fine contents in the PAP materials have a negative effect on mix strength as they produce a continuous and weak unbounded mineral filler phase. The micro structural analysis found that the physical and chemical analysis of the PAP material should be done for every project because they significantly affect the dispersion of foam and mix strength. [4]

Pengcheng Fu et al investigated the behavior of foamed asphalt mixes against conventional crush aggregates for road bases. This work was conducted to find out the suitable recycled mix design using foam bitumen and RAP that behaves well in the climatic and loading conditions of Saudi Arabia. Design mixes were prepared using different gradations i.e. Granular Base Class A and B, Subbase material Class B and Reclaimed Asphalt pavement material (RAP). It was seen that foamed RAP has shown lowest rutting at soaked condition and also foamed rap behaves best in resilient modulus testing. [5]

This research was carried out to check the behavior of steel slag by substitution virgin aggregate on the properties of cold recycled pavement mixes. For satisfying gradation requirement of two different RAP material 20% and 10% of the steel slag has been added. It has been shown that by adding steel slag resistance to deformation, Marshall Stability, resilient Modulus and tensile strength has improved. [6]

Kang *et al* conducted a research work on the hydraulic and mechanical behavior of recycled materials by partially replacing the virgin aggregates. A total of 17 mixes were prepared using different recycled materials including RAP and various percentages of virgin aggregates. To investigate the mixes mechanically, resilient modulus test and shear test was performed on a triaxial cell. It was seen that with addition of RAP the resilient modulus and drainage characteristics of a base and subbase layer mixes improves to a great extent.[7]

Gonzalo Valdés et al presented an experimental work to assess the mechanical behavior of bituminous mixes containing high percentage of reclaimed asphalt pavement. Two different mixes containing semi dense mixtures of 12 mm and 20 mm maximum aggregate size and RAP percentages of 40 and 60 percent respectively were selected (fulfilling the Spanish specifications). Their mechanical properties were assessed by evaluating resilient modulus, indirect tensile strength and fatigue test. From results it was concluded that high percentage of recycled material can be efficiently incorporated by accurate characterization and usage of RAP stockpiles. [8]

Cold in place recycling is most efficient and economic rehabilitation technique that is practicing all over the world. But still there are short comings in the design of job mix formula and some were solved in the past. One of the problems was that densities obtained from the laboratory samples are higher than the samples that are taken from the field. María José et al was designed an in laboratory compaction procedure based on the dynamic modulus values that simulated best the onsite conditions of compaction.[9]

Jinhai Yan et al investigated the fatigue properties of cold recycled mixes with emulsion and foam bitumen using Cooper NU-14 tester. In this experimental study indirect tensile strength, stiffness modulus and fatigue life were evaluated. The results showed that with increase in temperature and stress levels stiffness modulus decreases. It was observed during indirect fatigue testing that foam mixes were more resistant at high fatigue levels as compared to emulsion mixes. According to law of vertical displacement three and two states of displacement development were seen from emulsion and foam bitumen mixes respectively.[10]

Amir Modarres et al conducted laboratory study to assess the fatigue behavior of cold recycling mixes with asphalt emulsion and different types of cement. Samples were prepared in the laboratory containing CSS-1h asphalt emulsion and two different types of cement. Resilient modulus and indirect tensile fatigue test were performed on specimens at various temperature and curing times. It was concluded after testing that curing time has no significant effect on the fatigue behavior but with increase in cement content and decrease in temperature, slope of fatigue line will be decreased. [11]

3. Methodology

To evaluate and check the structural performance of CIR mixes with foam and emulsified bitumen as an additive, resilient modulus and static creep test has been performed on UTM-5P machine at different temperature and loading conditions. The flow sheet for methodology and testing conditions are shown in the figure 1 and 2.

Material selection

After the collection of RAP material from the field it has been properly milled. Through sieving it has come to know that it falls in the ranges of type B gradation as mentioned in MS 21 Manual. The detail of the adopted gradation has been mentioned in table 1.

Table 1: Adopted gradation from MS 21 Type B [12]

Sieve No:	% Passing	% Retained	Commutative Percentage
25mm	100	0	0
19mm	95	5	5
9.5mm	50	45	50
4.75 mm	10	40	90
2.36 mm	5	5	95
No: 200	2	3	98
Pan	0	2	100
	Total	100%	

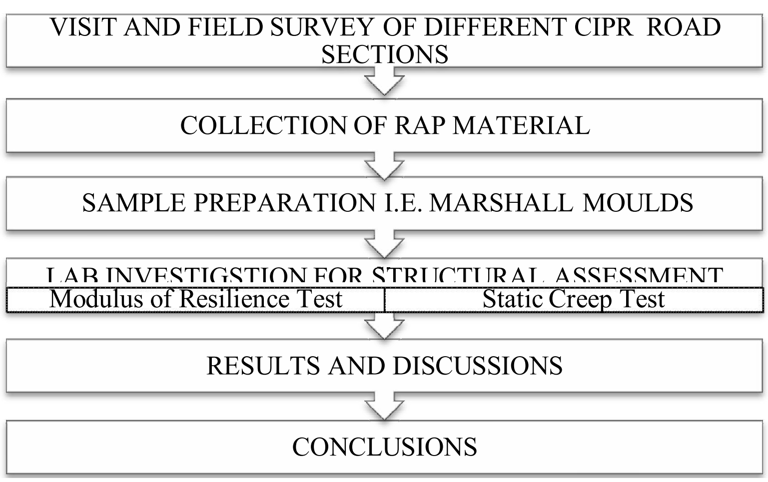

Figure 1. Flow sheet of methodology

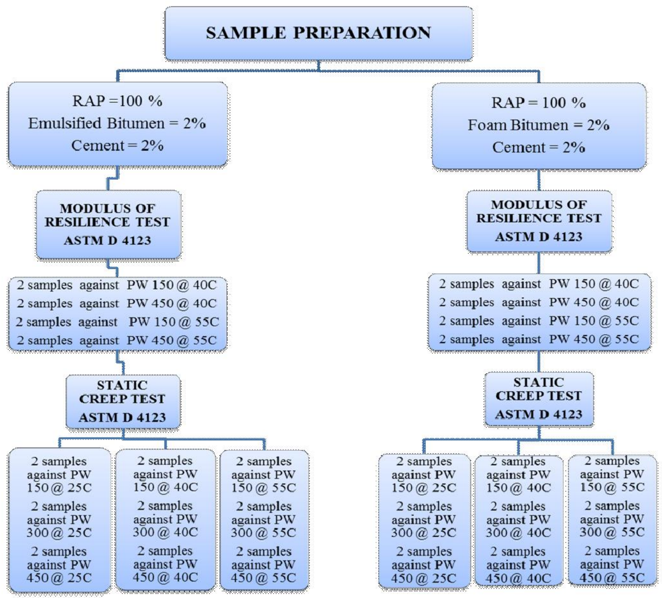

Figure 2. Flow sheet showing sample type and testing conditions

Selection of emulsified bitumen is important because of its diverse behavior with the different metallic and nonmetallic materials used as partial replacement against the aggregates. The reason behind this is that some emulsions are positively charged and some are negative. In our research anionic RS-1 bitumen emulsion is used. Table 2 shows the specifications of used emulsion.

Table 2: Physical properties of bitumen emulsion

PROPERTIES	RS-1
Residue	55-62%
Saybolt Furol Viscosity	20 sec – 30 sec @ 25 C
Partical size	5-6 micron
Nature	Anionic (Alkaline)
Initial set hours	2

Foamed bitumen is a hot asphaltic binder which has been temporarily transformed from a liquid to a foam state by the addition of a small % of water and pressurized air. It is described in terms of maximum expansion ratio (ERMax) and half-life (HL). According to Wirtgen Gmbh for achieving high quality foam asphalt mix ERMax should be greater than 15 and half-life should be within 5 and 10 s [13]. For optimizing the ERMax and half life , optimum foam moisture content can be determined by assessing the test data under different conditions. After analysis it was found that best foaming characteristics (ERMax = 12.9 and HL= 7.9 s) achieved at 2.5 % of moisture content.

Mix Design

Different design practices of cold in place recycling are being followed by different agencies all over the world and up till now no standard design has been produced. The amount of new binder required for cold recycling mixes ranges from 0.5 – 3 percent [12]. In our research bitumen extraction test was carried out on RAP in accordance with ASTM 2172 and 3.2 % bitumen content was found. The amount of new binder added is 2 % with 2 % of ordinary Portland cement. The optimum water content comes out to be 2 % for proper mixing.

Testing conditions selection

To know about the behavior of foam and emulsified bitumen testing has been conducted on different loading frequencies (pulse width PW) and temperatures as mentioned in testing flow sheet, fig 2. Some of the testing parameters that have been kept constant are mentioned below.

- Condition Pulse Count: 5
- Loading Cycles: 1200
- Condition Pulse Period (ms): 2000 millisec
- Test Pulse Period (ms): 1000 millisec
- Peak Loading Force (N): 300
- Estimated Poisson ratio: 0.40

4. Results and Discussions

Modulus of resilience test

Modulus of resilience also called indirect tensile modulus test has been performed in accordance with ASTM D 4123. Sample i.e. Marshall mould has been placed in a traverse direction in testing assembly of UTM-5P as shown in fig 3. Testing results has been shown below in table 3.

Figure 3. Sample orientation for MR test

Table 3: Results of Resilient Modulus test in MPa

SAMPLE TYPE	CONDITION	PULSE WIDTH	
	TEMP	150ms	450ms
Emulsified Bitumen+ Cement + RAP100%	40 C	2163.75	1435.5
	55 C	1444.25	788.75
Foam Bitumen+ Cement + RAP100%	40 C	3608.5	2607.25
	55 C	2259.25	1988.75

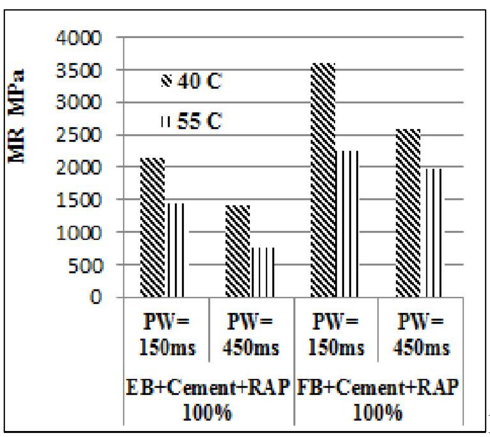

Figure 4 . Graph showing MR at different pulse widths and temperatures

Figure 4 shows that at 40 C value of MR of foam bitumen samples is 1.8 times more than that of emulsified bitumen samples at higher pulse widths whereas this values is more elevated i.e. 2.5 times at 55 C. This means that samples with foam bitumen behaves well in high temperature as compared to emulsified bitumen samples.

Static Creep Test

Static creep test also called repeated load uniaxial strain test was performed in accordance with ASTM D 4123. Sample i.e. Marshall mould has been placed in a longitudinal direction in testing assembly of UTM-5P as shown in fig 5. Testing results has been shown below in table 4.

Figure 5. Sample orientation for static creep test

The greater values shown by foam bitumen than emulsified bitumen samples at all temperatures and pulse widths are evident that foam bitumen samples are more resistant against permanent deformation. Fig 6 to fig 8 also shows that as the temperature increases difference between creep stiffness values between respective foam and emulsified bitumen samples decreases at all loading frequencies. In case of accumulative strain it can be seen that emulsified bitumen samples give more values as compared to foam bitumen at all temperatures and pulse widths so it is concluded that foam bitumen samples are more resistant against rutting. At lower temperature the value of accumulative strain of both types of samples are low but with increase in temperature the rate with which the strain value for emulsified bitumen samples increases is more as compared to foam bitumen samples.

Table 4: Values of creep stiffness at different temperatures and pulse widths

SAMPLE TYPE	Condition	PW= 150 ms		PW= 300 ms		PW= 450 ms	
	Temperature	Creep Stiffness (MPa)	Strain Value (%)	Creep Stiffness (MPa)	Strain Value (%)	Creep Stiffness (MPa)	Strain Value (%)
EB+Cement+RAP 100%	**25 C**	22.15	0.44	16.25	0.6	11.35	0.87
	40 C	14.46	0.71	11.51	0.925	10.25	1.05
	55 C	12.34	0.83	8.825	1.32	5.10	2.03
FB+Cement+RAP 100%	**25 C**	41.98	0.225	28.65	0.38	21.7	0.585
	40 C	19.365	0.405	16.35	0.675	10.33	0.935
	55 C	13.24	0.795	12.40	0.91	6.80	1.855

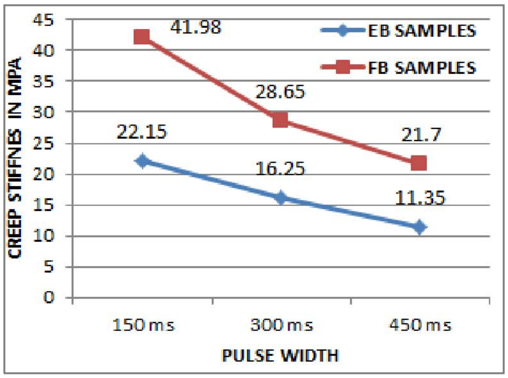

Figure 6. Graph b/w creep stiffness & pulse width at 25 C

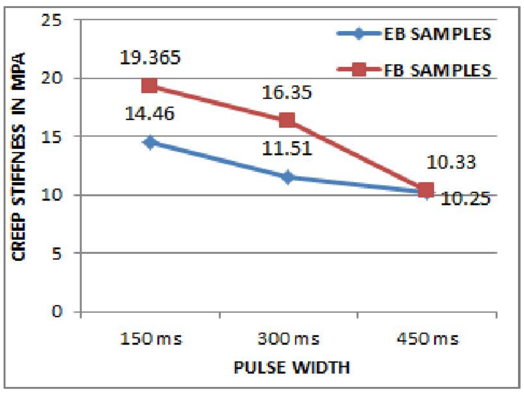

Figure 7. Graph b/w creep stiffness & pulse width at 40 C

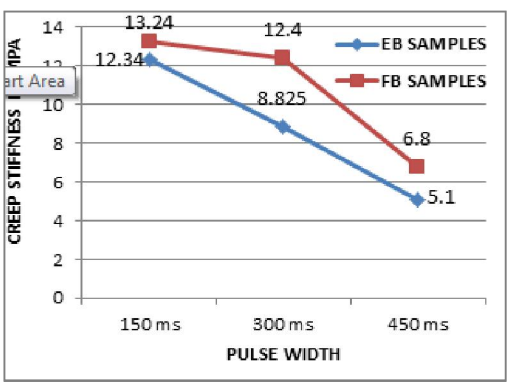

Figure 8. Graph b/w creep stiffness and pulse width at 55 C

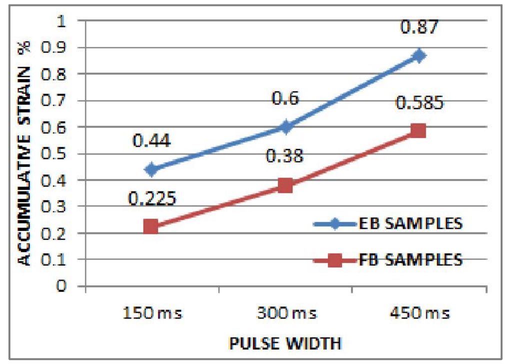

Figure 9. Graph b/w accumulative strain and pulse width at 25 C

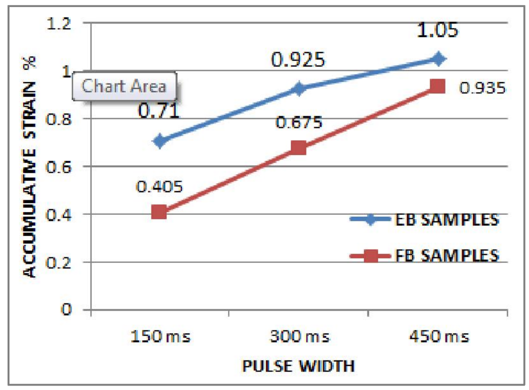

Figure 10. Graph b/w accumulative strain and pulse width at 40 C

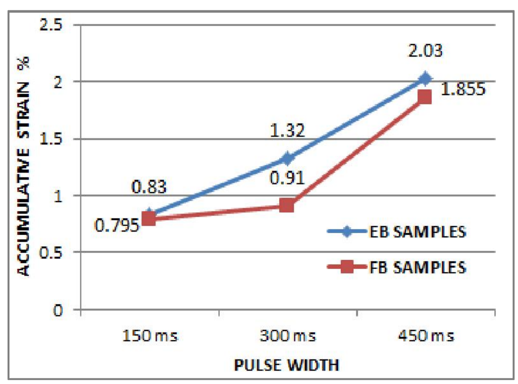

Figure 11. Graph b/w accumulative strain and pulse width at 55 C

5. Conclusions:

- MR modulus of resilience decreases as the temperature increases for both the mixes and at all the Pulse width.
- As the pulse width increases the MR decreases for both the mixes i.e. Foam Bitumen and Emulsified Bitumen Mixes.
- The foam bitumen showed higher Modulus than Emulsified Bitumen Mixes for all the temperature and loading pulse conditions
- The result of Creep stiffness shows that as the temperature increases the value of Creep stiffness modulus decreases considerably.
- For all the three testing temperatures creep stiffness is higher for Foam bitumen mixes.

- Accumulated strain shows the vice versa trend of Creep stiffness for the three testing temperatures as the temperature increases the accumulated strain also increases.
- The mixes containing Foam Bitumen as the recycling agent and 2 % Cement are better rehabilitation option for cold recycling of pavements.
- The MR of Foam bitumen mixes are remarkably high showing their ability and acceptability as a most suitable rehabilitation option.

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