Experimental study to compare the effects of Gradation, Additives and Filler Materials on performance of CIR Mixes

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Abstract: Road transport is one of the major components in economic and social development of a country, especially in developing countries like Pakistan. In Pakistan, 95% of the total freight movement throughout the country takes place through roads. Infrastructure development is one of the costlier processes and consumes a lot of national budget and then to maintain the infrastructure, again a considerable budget is required. There are various maintenance and rehabilitation techniques developed so far, with the modernization and new construction mechanical instruments and machines developed, cold recycling is a new, environmentally friendly and cost effective rehabilitation technique. The performance of Recycled mixes is still unknown as the recycled pavements behaves differently at different temperatures and in different regions of the world. Laboratory investigation of various stabilizing agents and recycling agent and amount of RAP and New Aggregates to be used is yet to be analyzed. Hence this research work is a step forward to investigate the laboratory performance of fillers and stabilizing agent on the properties of Cold Recycled mixes. Anionic emulsified bitumen is used as recycling agent and OPC is used as Stabilizing agent with certain amount of steel slag and marble waste is used as fillers in place of RAP in this research, and their performance is compared by Modulus of Resilience, Uniaxial Repeated Load Test (Static Creep) and Indirect Tensile strength Tests. The mixes containing 100 % RAP shows high Modulus of Resilience but mixes containing steel slag showed more resistance to permanent deformation in Uniaxial Repeated Load Strain test.
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1. Introduction

When the pavement undergoes cracking or the pavement approaches its terminal capacity or it is required to be upgraded to accommodate the increased traffic volume, pavement rehabilitation is normally considered. Pavement with proper design and quality construction and routine maintenance do require little rehabilitation. However in actual the required maintenance is often carried out, making it necessary for the concerning authorities to rehabilitate the pavements sooner or later.

Transportation system is the backbone of the economy of any country. The proper functioning of transportation engineering depends on the excellent road network and its design, execution and maintenance. The economic development of any region/country is conditioned with the development in transportation facilities and its functionality.

Pakistan, with a population of more than 180 million people, has a reasonably developed transport infrastructure. Road transport is the backbone of Pakistan's transportation network with 95 % of the total freight movement. 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. (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.

1.1. Recycling:

Recycling of pavement is one of the several rehabilitation alternatives. Road pavement Recycling is the process of road rehabilitation which reuses the existing materials with in the pavement layers by remixing and adding strengthening agents to form a new durable layer.

Recycled pavement material after processing becomes a usable mixture of aggregate and asphalt binder. Recycling of flexible pavements is a valuable advancement in the field of pavement engineering due to economical and environmental reasons [1–3]. So, application of RAP materials in asphalt mixtures has been preferred in many countries.

Over the last three decades several recycling techniques, such as hot recycling, hot in-place recycling, cold recycling, cold in-place recycling, and full depth reclamation, have evolved. In-place recycling technique is more advantageous technique because it not only reduces the use of new materials but also reduces harmful emissions, traffic delays, and energy associated with the convey and production of these materials.

1.1.1. Cold Recycling:

In Cold recycling (CR) the RAP is recycled without using heat during the recycling process. Reclaimed asphalt pavement (RAP) can be used as an aggregate in the cold recycling of asphalt paving mixtures in one of two ways. The first method (cold mix plant recycling) involves a process in which RAP is combined with new emulsified/foamed asphalt and a recycling agent, sometime also with virgin aggregate to fulfill the gradation requirements, and mixed at a central plant or a mobile plant to produce cold mix base mixtures. The second method involves a process in which the blacktop pavement is recycled in-place, where the RAP is combined with new emulsified/foamed asphalt and/or a recycling agent, possibly also with virgin aggregate to fulfill the gradation requirements, and mixed at the pavement site, at either partial depth or full depth, to produce a new cold mix pavement.

Figure 1: Cold In Place Recycling using Cold Recycling Train.

1.2. Problem Statement:

Heavy loading and extreme temperatures in most part of Pakistan causes premature failures in Flexible pavements, as a result a considerable cost factor for road construction authorities is consumed in maintenance and reconstruction works.

Cold Recycling is an economic rehabilitation technique, but:

- 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.
- While cold recycling technologies are well established, still additional pavement performance information is required, particularly, regarding the % of RAP that can be added and its relationship with the fatigue endurance, creep resistance and durability.
- In addition, there is a need to assess whether RAP can be used in wearing surface cold mixes.
- And the effect of various emulsions/stabilizing agent and filler materials on the strength properties of the cold recycled pavements.

1.3. Objectives of Research:

The research objectives are to explore different cost effective, having improved pavement performance, environment friendly additives and fillers to be used in CIPR.

- To study the performance of CIR pavements with different fillers and additives.
- To compare the Performance of Fillers and Additives by MR Test, Indirect tensile Strength Test, Static Creep Test.
- To study the effects of CIPR on the environment.
- To study the future prospects regarding sustainable development of cold in-situ recycling techniques in Pakistan considering the changes that can be made to design, material selection, and construction to improve the performance of future recycled pavements.

2. Literature Review

2.1. Background:

Pavement recycling is not a new concept; it was evolved in 1970s, when the interest in pavement recycling was aided by an oil embargo, which drove asphalt prices higher. Modernization in the development of heavy duty equipments and construction procedures has been a part of the recycling evolution. Interest was revoke in the early 2000s in pavement recycling as the hot mix asphalt industry once again faced rapidly rising asphalt costs along with diminishing supplies of high quality aggregate.

The use of RAP in asphalt mixes helps reduce costs, conserves asphalt and aggregate resources, and limits the amount of waste material going into landfills. The Asphalt contained in old pavements is an additional valuable resource. The Aged asphalt may have lost some of its original properties, but when it combines with the new asphalt it again serve as an effective binder, hence reducing the amount of new asphalt required.

In recent years, foam Asphalt technology has increasingly gained acceptance as an effective and economical stabilization technique mainly because of its improved coating capabilities and aggregate penetration [4]. Also in recent areas extensive research has been conducted for the application of other waste material such as steel slag in broad areas of road construction and recycling [5]. Steel Slag contains significant amount of free iron which gives the material high density and hardness and make it as a suitable aggregate [6]. In addition to Steel Slag other waste materials such as marble waste, fly ash, GGBS and glass waste have been used in the pavement recycling and re-construction.

2.2. Pavement Recycling Research History:

Murphy and Emery (1996) modified the CIR mixes by adding 25 % additional new aggregates in the mix as compared to conventional CIR mixes, which include high residual Asphaltic Content, fine milled mix. This addition of new aggregates increases the pavement thickness from 20 t o25 % thereby increasing the pavement structural capacity. The study also deduced that CIR gave approximately 30 to 60 % as compare to other rehabilitation methods [7].

Kazmierowski et al (1999) compared the performance of Hot in Place and Cold in Place Recycling based on Ten year performance data in Ontario. Their study revealed that CIR is more advantageous over HIR. The constrained observed with CIR was that it can only be applicable in summer. The CIR is superior in terms of saving to road users, material transportation and environmentally friendly [8].

Lewis et al (1999) studied the characteristic of CIR process in detail by using Cement, Bitumen Emulsion and Foam Bitumen. The study revealed that using 2-3% cement by weight of Aggregates good recycled layer could be achieved. In recycling with Bitumen Emulsion 5% of the total mass is used. However, the most environmental and structurally improving process is recycling by using Foam Bitumen. FB is added in the range of 2 to 3% with 1 to 2 % cement. The paper concludes that the development of modern equipment has given choices of rehabilitating un-surfaced, lightly trafficked and bus/city highways, by applying easy to use method. Cost saving in excess of 20 % is possible with Cold Recycling [9].

Forsberg et al (2002) compared the two different Recycling Agents in their research. The samples were prepared using gyratory compactor of Conventional CIR using 1.5 % bitumen emulsion and New Engineered CIR using 3% bitumen emulsion with engineered chemistry. Different test were performed, and the samples with new CIR showed superior performance in terms of raveling, thermal cracking and moisture vulnerability tests. Falling Weight Deflectometer (FWD) testing conducted on the both type of pavements showed that pavement prepared with new CIR has higher modulli then Conventional CIR. ITS testing results showed that the section constructed with new CIR should be more resistant to thermal cracking. The initial cost of the New engineered CIR were 10 % higher than Conventional CIR, however, improved binder content and the reliability of engineered are expected to give overall lower life cycle cost [10].

Niazi et al (2009) study the use of additives, Portland cement and lime in CIR mixes. They compare the effects of Portland cement, hydrated lime and lime slurry on the performance/properties of CIR mixes. They concluded that addition of both lime and Portland cement, in cold recycled mixes, can increase the marshall stability, modulus of resilience, tensile strength, creep stiffness and resistance to stripping. They recommended the use of Portland cement as comparatively the cement added mixes shows better results than the other two, hydrated lime and lime slurry, additives [11].

Ameri et al (2012) evaluated the effect of steel slag, as a substitute of virgin aggregate in CIR mixes, on the mechanical properties of CIR mixes. They prepared two types of mixes containing 20% and 10% of the two types of new aggregate i.e. Steel Slag in accordance with Asphalt institute CIR grading requirements. They found that addition of steel slag in the cold recycled mixes enhances its marshall stability, modulus of resilience, tensile strength, resistance against moisture damage and resistance to permanent deformation. They also recommended the uses of anionic bitumen with steel slag as an aggregate [12].

3. Methodology

To achieve the purpose of research the steps of study are as follows.

4. Materials

4.1. Aggregates

The Rap for the research was taken from Sahiwal – Okara Section of National Highway N-5 in Punjab, Pakistan. The gradation of the RAP was determined. The gradation was found in the ranges of Type B Gradation of Asphalt Cold Recycling manual MS-21. The oversized material greater then 25mm was removed from the RAP then the marshal samples were prepared according to the gradation given in Table 1 and shown in Figure 2. The bitumen content of the Rap was determined using ASTM D2172. Three types of marshal samples were prepared i.e. Samples containing 100% Recycled aggregates, Samples containing 10% Steel slag by replacing finer contents of RAP and 90% Recycled aggregate and sample containing 10% Marble waste in addition to 90% Recycled aggregate.

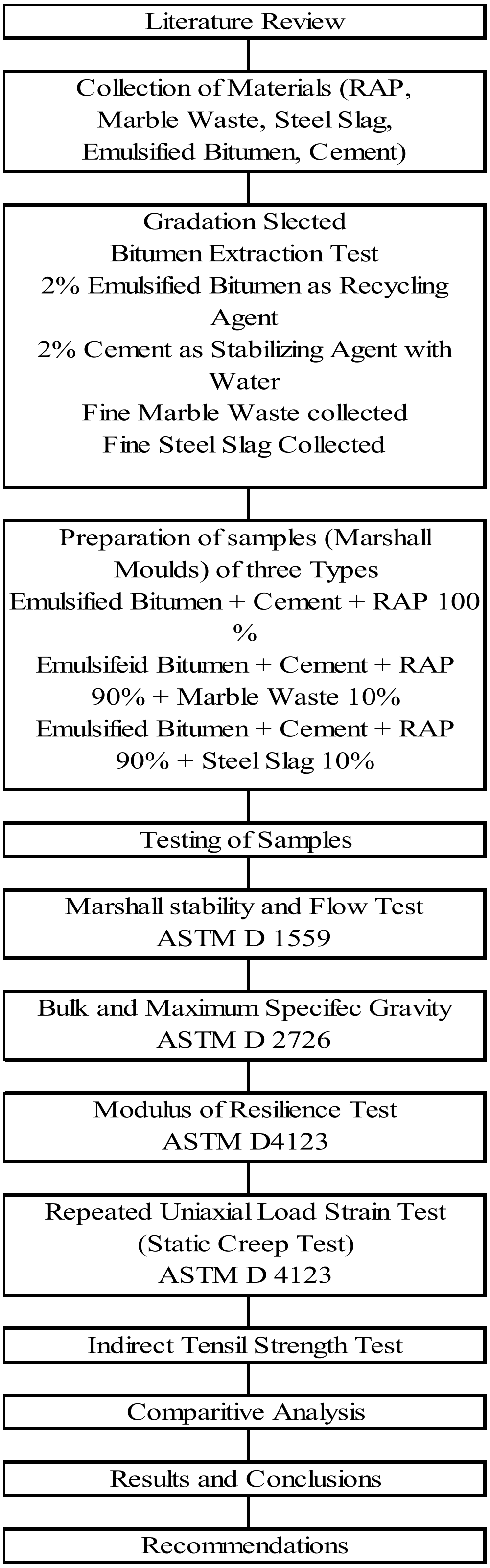


Figure 2: Flow chart of the Research work

Table 1. Adopted Gradation for the mixes.

Sieve No:	% Passing	% Retained	Comm. %
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%	

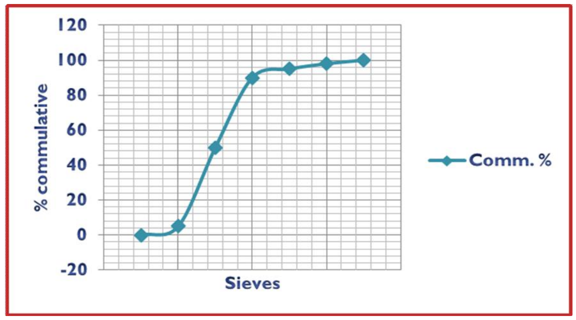


Figure 3: Gradation of the Cold Recycled Mixes

Figure 4. Marble Waste used in Research

Figure 5. Crushed Steel Slag

4.2. Bitumen Emulsion

Selection of bitumen emulsion is important because of compatibility issues with the aggregates and its gradation. Bitumen emulsions have positive or negative electric charges they can show different characteristics while blended with aggregates. In this study anionic (RS-I) bitumen emulsion is used. Table 2 enlist the specification of the used bitumen.

Table 2. Physical properties of Bitumen emulsion.

Properties	RS-1
Residue	55 - 62 %
Saybolt Furol viscosity	20 Sec. – 30 Sec. @ 25 °C
Particle size	5 – 6 microns
Nature	Anionic (Alkaline)
Initial set – hours	2

4.3. Active Additive – Portland cement.

Previous research has shown that the use of additives in CIR mixes can improve their performance. In this study Ordinary Portland Cement (OPC) 2 % by weight of the aggregate, was selected as an active additive.

4.4. Mix Design

There is no universally established mix design practice for cold mix recycling. The amount of new binder required for cold recycling mixes ranges from 0.5 to 3 percent for emulsified asphalts [13]. In this study the bitumen extraction test was carried out on RAP and 3.2% of bitumen content was found. The amount of new binder added is 2% with 2% of ordinary Portland cement. The 2% of water was also added for proper mixing. The Marshall Samples prepared are shown in the Figure 6.

Figure 6. Laboratory Marshall Samples

4.5. Testing Matrix

The tests conducted in this Research and the testing conditions are given in Table 3.

Table 3. Testing, Conditions of Tests

Tests	Marshal Stability and Flow Test ASTM D1559	MR Test ASTM D4123				Static Creep Test ASTM D4123				Indirect Tensile Strength Test	
Conditions	Standard	Temperature				Temperature				Standard	
		40 C		55 C		40 C		55 C		Dry	One Day Soaked
		Pulse width		Pulse width		Pulse width		Pulse width			
		150 ms	450 ms	150 ms	450 ms	150 ms	450 ms	150 ms	450 ms		

5. Results and Discussion.

5.1. Bitumen Extraction Test:

First of all, Bitumen Extraction Test Was carried out, according to standard procedure of ASTM D 2172. The percentage of the binder in the RAP is as follows:

- Wt. of Rap = 1kg
- After extraction = 0.968 kg
- % of Bitumen = 3.2 %

5.2 Marshall Stability and Flow Test:

Marshall Stability and Flow test (ASTM D 1559), bulk sp. Gravity and air void content, of the all three types of mixes was performed. The Results are shown in Table 4.

The air void content of all the samples of three types is between 9-14%. The Stability and flow value of all the mixes are less than the required, samples containing Steel Slag showed comparatively better stability and flow.

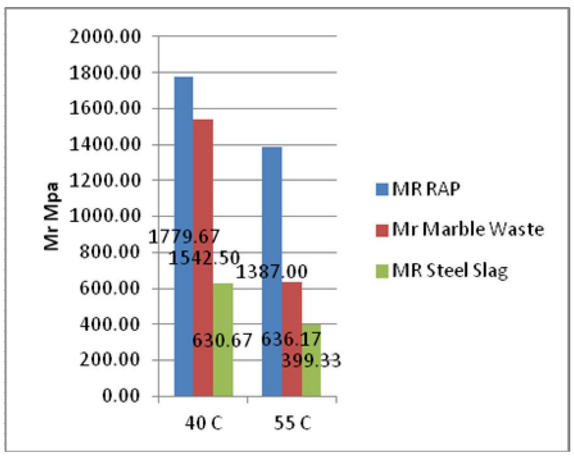
5.3. Modulus of Resilience (Mr) Test.

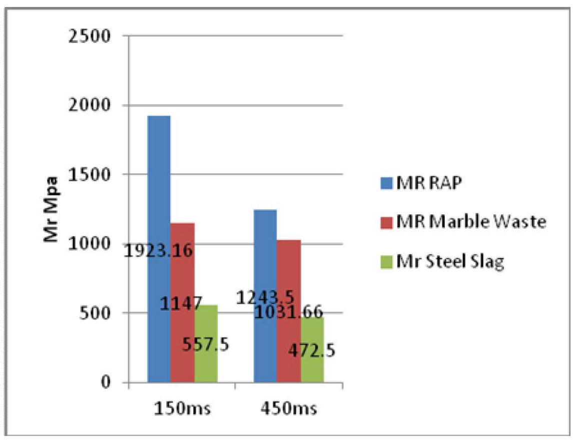
Resilient modulus is most important parameter used in the mechanistic design of the flexible pavements. Resilient modulus of all the bituminous mixes in this research was determined in accordance with ASTM D 4123 method. For each type of mixes and testing condition three samples were tested using the UTM-5P machine. The Conditions are given in table 3. The Pulse period was 1000 ms and the peak loading force for all the samples was 300 N. The results of the Mr tests are shown in the figures 7-9.

Table 4: Marshall Stability and Flow Test results.

Marshall Stability and Flow Test

Sample type	Eb. Cont. %	Cement Cont. %	Gmm	Gmb	Va %	Vol of Absorb Water cm^3	S Deg. of Saturation %	Stability Kg	Flow 0.25mm	Standards for heavy traffic	
Emul. Bitumen+Cement +RAP 100%	2	2	2.48	2.14	13.37	12	89.7	270	6.3	340 kg	8-16mm
	2	2	2.42	2.17	10.29	9	87.5	250	6.1	340 kg	8-16mm
Emul. Bitumen+Cement +RAP 90%+ Marble Waste 10%	2	2	2.48	2.23	10.21	7	68.5	260	5.7	340 kg	8-16mm
	2	2	2.53	2.18	13.91	10	71.9	255	5.6	340 kg	8-16mm
Emul. Bitumen+Cement +RAP 90%+ Steel Slag 10%	2	2	2.55	2.19	14.31	14	97.8	270	5.4	340 kg	8-16mm
	2	2	2.58	2.17	16.02	16	99.9	290	6.1	340 kg	8-16mm





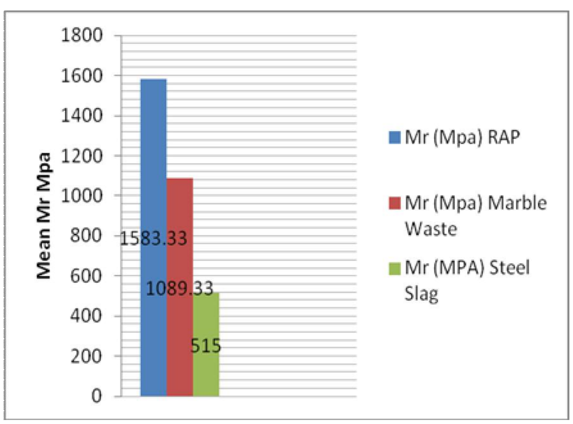


Figure 9: Average Mr of the Three Mixes

5.4. Repeated Uniaxial Load Strain Test (Creep Stiffness):

The repeated uniaxial load strain test is used to measure the strain (Permanent Deformation) and Creep Stiffness of the mixes. The test is carried out according to the standard ASTM D 4123. The Samples are placed horizontally and repeated load of defined magnitude and frequency is applied and the strain is calculated after the completion of loading cycles. The results of this test are shown in terms of Creep Stiffness and Accumulated strain in Figures 10-16 and 17-18 respectively.

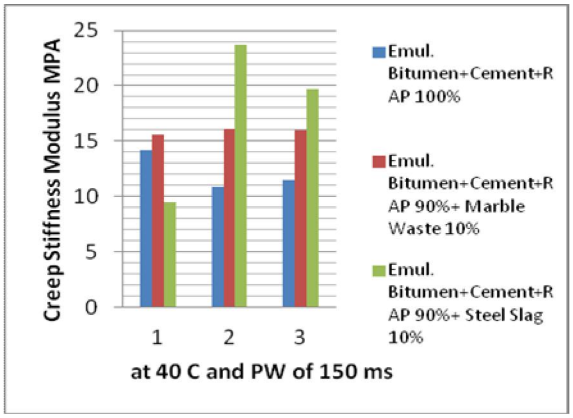


Figure 10: Creep Stiffness of the mixes at 40 C and pulse width of 150 ms

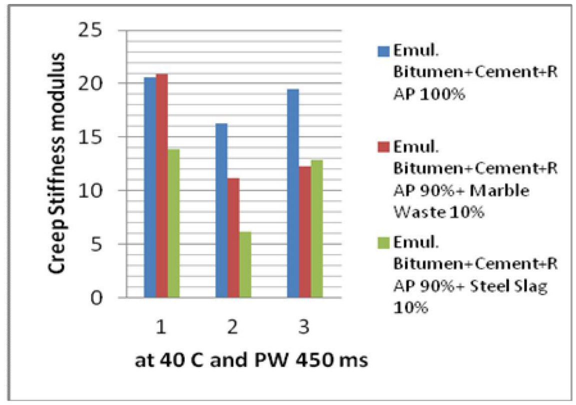


Figure 11: Creep Stiffnes of the mixes at 40 C and 450ms pulse width

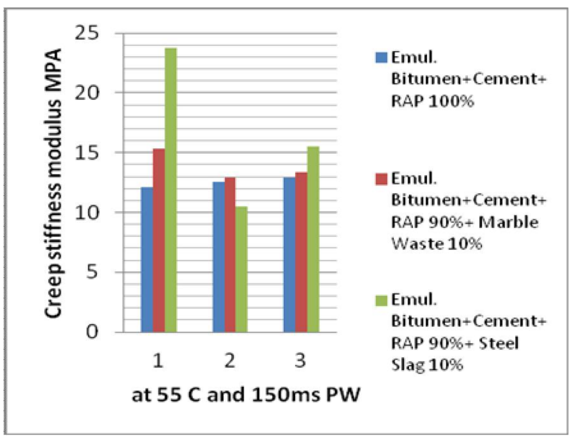


Figure 12; Creep of the mixes at 55 C temperature and 150 ms pulse width.

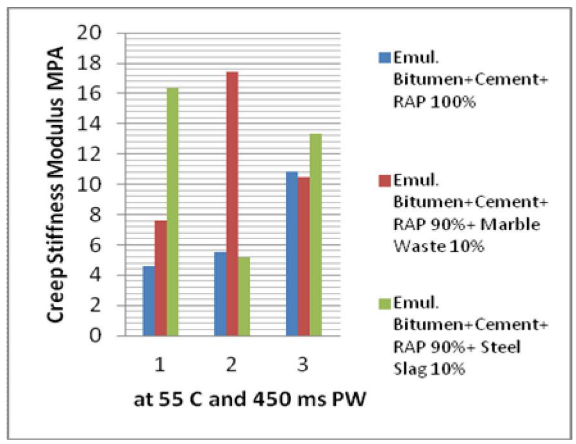


Figure 13; Creep of the mixes at 55 C temperature and 450 ms pulse width.

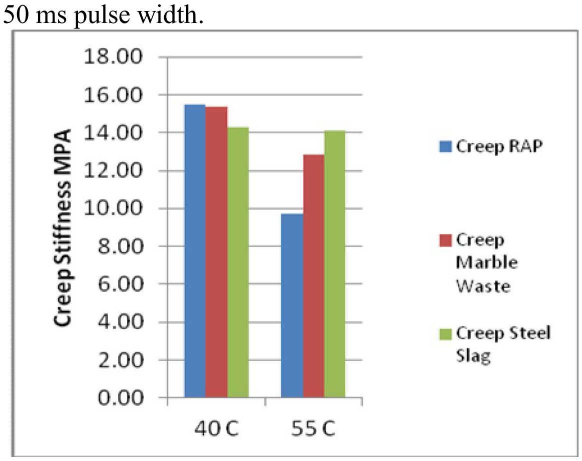


Figure 14: Mean Creep Stiffness of the mixes at 40 and 55 C

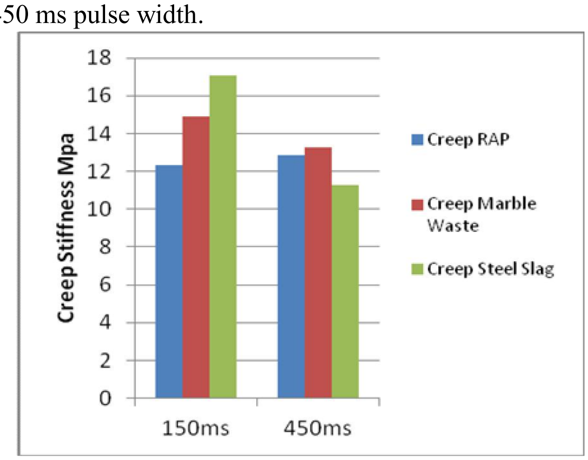


Figure 15: Mean Creep Stiffness of the mixes at 150 and 450 C

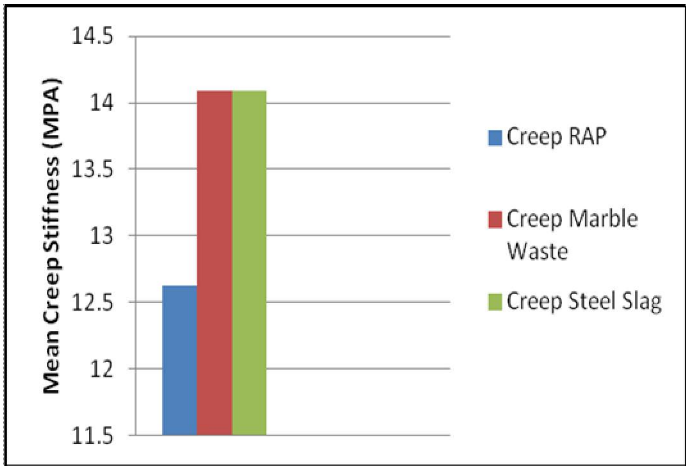


Figure 16. Mean Creep Stiffness Modulus values comparison

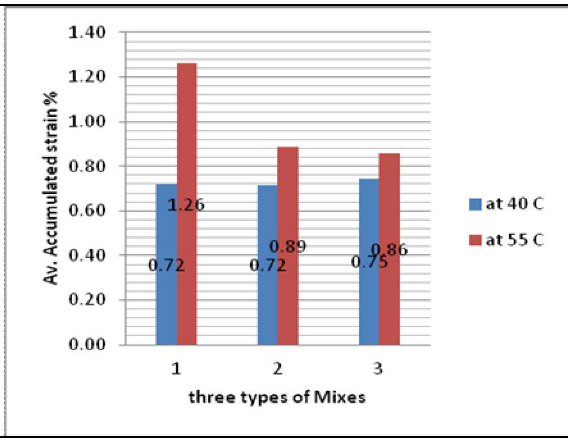


Figure 17. Av. Acc. Strain of the three types of mixes at 40 and 55 C

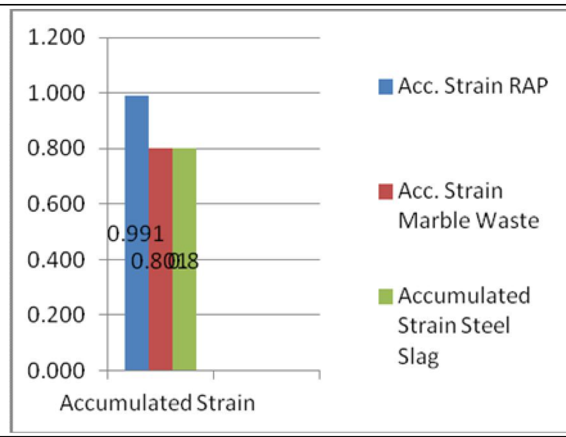


Figure 18. Comparison of Avg. Acc. Strain values of the mixes.

5.5 Indirect Tensile Strength Test (ITS):

The standard ITS test is used to test the Marshall samples in both dry and soaked conditions. The ITS is determined by measuring the ultimate load to failure of a briquette that is subjected to a constant deformation rate of 50.8 mm/minute on its diametrical axis. To determine the soaked ITS, soak the samples for 24 hours in water at 25°C ± 1°C, after removing the samples are surface dried and tested. The ITS test results are given in Table 5 shown in figure 19.

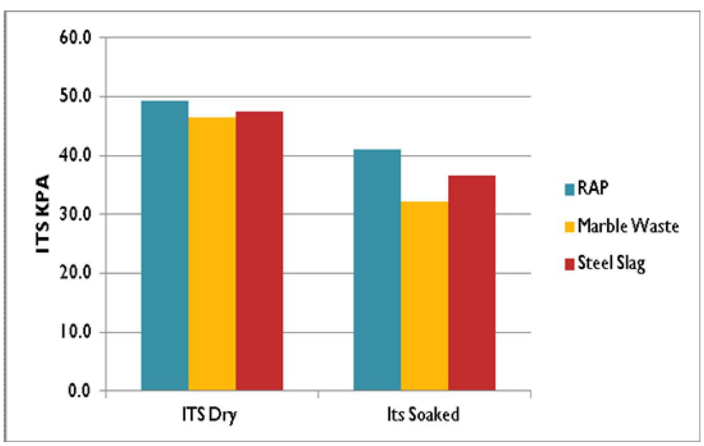


Figure 19: Comparison of ITS values of all the mixes in both Dry and Soaked conditions.

Table 5. Results of the ITS test.

Indirect Tensie Strength Test									
Sample type	Dia of Specimen mm	Height of Specimen mm	Volume mm3	Mass of specimen gram/lb	Bulk Density Kg/m^3	Temp	Load KN	ITS Kpa	Condition
Emul. Bitumen+Cement +RAP 100%	101.6	63.5	510.438	1096	85887	32C	5	49.4	ITS Dry
	101.6	64	506.451	1093	86326.3	32C	4.2	41.1	Its Soaked
Emul. Bitumen+Cement +RAP 90%+ Marble Waste 10%	101.6	70	463.041	1114	96233.5	32C	5.2	46.6	ITS Dry
	101.6	68	476.659	1128	94658.8	32C	3.5	32.3	Its Soaked
Emul. Bitumen+Cement +RAP 90%+ Steel Slag 10%	101.6	66	491.104	1101	89675.6	32C	5	47.5	ITS Dry
	101.6	65	498.659	1090	87434.5	32C	3.8	36.7	Its Soaked

6. Conclusion

- The Results of 5 Pulse Indirect Tensile Modulus of Resilience test shows that the Mixes with 100 % Recycled Aggregate have high Mr. as compared to the other two cold mixes and Steel Slag has the lowest. So for cold recycling use of any other waste product is not helpful in achieving high strength.
- It means that for pavement susceptible to fatigue cracking the cold recycling should consist of 100 % RAP.
- But in the case of Repeated Uni. axial Load Strain Test, Creep Stiffness i.e., resistance against permanent deformation is high for mixes containing Steel Slag and Marble waste. So these fillers can be used in cold recycling to produce stabilize bases, which are not directly in contact with the tire.
- The Marshall Stability and Flow value of all the three type of mixes is less than the required for the pavements designed for heavy traffic intensity. And for all the three mixes values are closed to each other.
- The Indirect Tensile strengths of all the three mixes is less than the specified for the asphaltic layer, and out of three mixes the mix containing 100% Recycled Agg. has high tensile strength.
- The low Modulus of the Mixes containing Marble waste and Steel Slag are due to the improper bonding between the emulsion and the Marble and Steel Slag. Due to the incompatibility of the chemical properties between emulsifier and filers.
- At higher temperatures and Pulse width, both the Modulus of Resilience and Creep stiffness decreases for all the three mixes.
- Over all the cold recycling is 40% less costly than other major rehabilitations, and can be used as stabilized asphalt treated base on roads.
- The cold recycling is an environmental friendly technique. As use of the new aggregates is reduced, Haulage is drastically reduced; the overall energy consumption is also significantly reduced.
- The cold recycling process produces a thick bound stabilize layer that are homogenous and do not contain weak interfaces, hence the structural number of pavement is increased.
- One of the most important benefits of cold recycling is the high level of traffic safety. The full recycling train can be accommodated in one single lane and the remaining lanes can be remained operational during the rehabilitation.

7. Recommendations

- Cir using Emulsified Bitumen and OPC is easy to use and modern road rehabilitation technique, as well as cost effective. So it should be used in Pakistan.
- After the cold recycling the newly produced layer should be used as Stabilized Base. The wearing course of 2.5-5 inches should be laid over it.
- The cold recycled mixes containing fillers Marble waste and steel slag can be optionally used in the roads having light traffic intensity.

- The cold mix containing 100 % recycled aggregate should be used with 2 % cement as for fatigue cracking they have the highest resistance i.e. Modulus of resilience.
- The use of Emulsified Bitumen and filler in Cold Recycling is recommended for the areas of low and moderate temperatures.
- Further research on other stabilizing agents such as Emulsifying bitumen's and Foam Bitumen should be carried out.

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References

1. Kennedy TW, Tam WO, Solaimanian M. Optimizing use of reclaimed asphalt pavement with the Superpave system. J Assoc Asph Pavement Technol 1998;67:311–33.
2. Basic asphalt recycling manual, Asphalt Recycling and Reclaiming Association, PUB:NHI 01-022, Annapolis, Maryland; 2001.
3. Cold mix recycling, general technical specifications. Ministry of Road and Transportation of Iran Deputy of Education, Research and Technology, No. 339; 2006.
4. Hamad Al Abdul Wahab, Mirza g. Baig, Isam A. Mahmoud, Hisham M. Kattan "Study of Raod bases Construction in Saudi Arabia using foam asphalt" Construction Building Materials (2011), doi:10.1016/j.conbuildmat.2011.05.010.
5. Huang Y, Bird R, Heidrich O. A review of the use of recycled solid waste materials in asphalt pavements. Resour Conserv Recy 2007;52:58–73.
6. Kandhal PS, Hoffman GL. Evaluation of steel slag fine aggregate in hot-mix asphalt mixtures. Transport Research Rec 1997;1583:28–36.
7. Dnaiel T. Murphy and Jhon J. Emery (1996). "Modified Cold in Place Asphalt Recycling", paper from Transportation Research Record 1545.
8. Tom Kazmierowski, Pamela Marks & Stephen Lee (1999). "Ten year performance review of in situ Hot Mix recycling in Ontario" Paper No. 99-0409, Transportation Research Record 1684.
9. AJN Lewis and DC Collings (1999) presented research paper on "Cold In Place Recycling – A relevant process for road rehabilitation and upgrading" at 7th Conference on Asphalt Pavements for South Africa.
10. Forsberg Erland Lukanen & Todd Thomas (2002). "Engineered Cold In-Place Recycling project" paper No. 02-2731, Transportation Research Record1813.
11. Y. Niazi, M. Jalili, "Effect of Portland cement and lime additives on properties of cold in-place recycled mixtures with asphalt emulsion" Construction and Building Materials 23 (2009) 1338–1343.
12. Mahmoud Ameri, Ali Behnood "Laboratory studies to investigate the properties of CIR mixes containing steel slag as a substitute for virgin aggregates" Construction and Building Materials 26 (2012) 475–480.
13. Asphalt cold – mix recycling. The Asphalt Institute Series, No. 21; 1983.

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