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Performance Evaluation of Cold Recycled Asphalt Mixes at Different Temperatures and Loading Rates

Tahir Sultan[1], Mumtaz Ahmed Kamal[1] and Abid Latif[2]

1. *Department of Civil Engineering, University of Engineering & Technology, Taxila, Pakistan.*
2. *Department of Civil Engineering, University College of Engineering. & Technology, BZU, Multan, Pakistan.*

* **Corresponding Author:** E-mail: *tahir.sultanch@gmail.com*

Abstract

Nowadays recycling is one of the most advance and interesting technique for the rehabilitation of road pavements. In recent years the increased interest in this process, has led to the development of various alternative methods for the recovery and the reuse of road bituminous materials. Cold recycling allows the recovery of bituminous material from an existing pavement without the addition of heat, whilst ensuring the strength of high quality bound base layers. Resilient behavior, rutting resistance and moisture susceptibility of five different cold recycled asphalt mixes have been investigated using UTM-5P. RAP was used as controlled mix to compare with four other mixes having variable binding material types and percentages. Mixes were evaluated at 40 °C and 50 °C under varying loading conditions of 150 ms and 450 ms. Resilient modulus decreases with increase in type and time of loading for all mixes. Both emulsified bitumen with cement and 100% RAP, and 100% RAP performed excellently during Indirect Tensile Strength (ITS). Foam and emulsified bitumen, steel slag and marble waste were used as binders. Cold recycled asphalt mixes can be successfully used as stabilized base course.

Key Words: Creep stiffness; Cold recycled pavements; UTM 5P; Static creep test; Repeated load indirect tensile test.

1. Introduction

Asphalt overlay, reconstruction and cold in place recycling with foamed asphalt are three different rehabilitation approaches whose energy consumption analysis show that they are most beneficial techniques towards pavement rehabilitation procedures [1]. While cold in place recycling employs the most modest energy as compare to other rehabilitation alternatives under lesser extent trafficked roads. Aggregate haulage distance played a crucial role for entire energy consumption comparison of these alternatives. But depth for cold in-place recycling samples can be anticipated efficiently by using rut depth prediction model (RDPM) having a base of grey modeling irrespective of dry and wet examining conditions [2]. Grey modeling and its mathematical model are used for testifying the accuracy in predicted rut depth. The RDPM was modeled utilizing the rut depth information by using asphalt pavement analysis (APA).

Performance of recycled asphalts and virgin asphalts are examined in [3] for airport pavement. Laboratory based experimental consequences demonstrated that recycled asphalts accomplish better properties comparatively long-term aging for surface course in airport pavement. Bituminous mixes with high percentage of reclaimed asphalt pavement (RAP) were applied in highway section rehabilitation. Mechanical attributes of this mixture is demonstrated in [4] by analyzing the RAP variability effectiveness and assuring the stiffness modulus, fatigue behavior, cracking behavior and indirect tensile strength.

A mixture of natural aggregates and RAP with their different percentages greatly affect the pavement performance for their sub-based layer [5]. This investigation in [5] is accomplished on basis of LWD and FWD analysis and the final results are compared with mixture samples containing only natural aggregates RAP variety and potential for high share recycling are the main problems that arise at termination of Porous Europium Mixes (PEM) lifecycle. Two-layer porous asphalt (TLPA) is resulted by PEM RAP recycling. In this case, RAP variability in this TLPA should be examined by different methodologies. This results in attaining an acceptable stage of surface performance [6]. Slurry micro-surfacing meliorates road safety because of its ability to allow for better surface evenness and skid resistance. Diluting tire/pavement dissonance, furbishing up skid resistance, contributing tires-crumb-rubber as a recycling substantial, varnishing surface cracking and decreasing atmospheric emissions utilizing cold technique are investigated in detail to analyze better results and comparisons [7].

RAP preparation processes and recycled asphalt mixes are crucial parameters in manufacturing process. When a tolerable size diminution and separate processes are utilized with 50% recycling proportion and rich stage of RAP incorporation during production process, then better mixing varieties could be achieved. Moreover mix design stipulations can be more easily attained and the binder of concluded mixed variety minor older at high degree of temperature [8].

Investigation is served by using four-point bending tests. Results shows that mixture of raw aggregate skeleton, steel slag and bituminous compounded with RAP laid out better fatigue characteristics and performance [4, 9]. Consequences of partial- and fully substitutes for granular stuff by RAP and hot mix asphalts (HMA), are evaluated. Concluded outcomes indicate that most prominent ITS and MR values would be received under both dry and wet situations for 100% replacement [10].There are some methods utilized for asphalt recycling; hot in-place, hot in-plant and recycle as an unbound stuff. Experimental results in [9] demonstrated that hot in-place reprocessing is slightly better than hot in-plant reprocessing for contributing more cumulative energy demand (CED) and global warming potential (GWP) saving. Moreover asphalt reprocessing is environmentally more beneficial over asphalt reusing. However environmental performance could be improved by some possibilities categorized as logistic, technical and organizational [11].

Usage of two different mix design processes for scheming bituminous pavement mingles with foamed bitumen, is assessed in [12]. Results showed that these two adapted processes depicted unique mix components contempt utilizing same RAP origin. To integrate RAP with asphalt mix intent, the residual binder's quantity and quality is a critical factor to know. If characteristics of both virgin and residual binders are evaluated using both formal and Superpave approaches, and residual binders are mixed with different ration of virgin binder, then results shows that blend properties depend upon individual characteristics of binders. Moreover increase in stiffness of binder is directly proportional to increase in RAP binder [13].

Bitumen binder mixes with 2% to 3% recycled material and 1% to 2.5% of hydraulic binder with 0.5% steps are tested in [10] and effectuate of two types of binding agents (Portland cement and formed bitumen) are examined. Impression of binder substances on atmospheric evacuated content, Marshal Constancy and MR at 25 °C for recycled mixes are studied. Laboratory testing results depicted that recycled base track meets demanded both physical and mechanical characteristics and moisturizing opposition, when foamed bitumen of 2.5% and Portland cement of 2.0% are utilized [14].

The indirect tensile strength, fatigue performance, moisturizing resistance and high temperature stability of asphalt emulsion cold recycled mixes could be improved by mixing together the aged asphalt, cement and RAP. Stress and strain concentration in the interphase among the aggregate and virgin asphalt could be reduced by mixture of aged asphalt and RAP [15]. Different damaging test results for major highway reconstructed by cold in-placed recycling in Iran are exhibited in [16] under five years of valuation. This investigation manifested the pavement status and remaining life estimation for rehabilitation applying cold in-place recycling for period of five years.The cement and the bitumen of the mix figures a resilient mastic able to contribute substantial fatigue resistance characteristics to the conglomerate. The effect of crumb rubber admitted in 100% RAP cold mixes tied with bitumen emulsion and cement is investigated in [17].

When Cold asphalt emulsion mixture (CAEM) is mixed with virgin aggregate, cement and rice husk ash, and then sampled mixture is submitted to compression delay for approximately 24 hours, healed at 25 °C for approximately 8 days and cured to entire curing situation, then last cured sample satisfies at least 3 KN of stability. Moreover the enhanced durability for room temperature is observed more prevailing because of dehydration as compared to cement contents [18].

2. Experimental Program

The key objectives of the study are as follows;

- To sort out the potential uses of Cold Recycled Asphalt.
- Develop a methodology to evaluate the Cold Recycled Asphalt mixes.

The cold recycled samples used in our research consist of the RAP (Reclaimed Asphalt Pavement) 100%, cement (2%), lime (2%) and bitumen (2%). All the moulds were prepared by using different binding materials according to modified Marshall Methods. To evaluate the mechanical properties of molded samples, various tests were performed on UTM 5P at different temperatures and speed of loading (pulse width). Elastic behavior and permanent deformation were measured by UTM 5P (Universal Testing Machine).

2.1 Preparation of Samples

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 carried out and found in the ranges of Type B Gradation of Asphalt Cold Recycling manual MS-21. The oversized material greater than 25 mm was removed from RAP. The bitumen content of the RAP was determined using ASTM D2172. The marshal samples of RAP were prepared as following.

- With 2% of binder i.e. emulsified, foamed bitumen, cement with stabilizing agent in it i.e. Ordinary Portland Cement.

Methodology of research work and preparation of samples had been shown in Fig. 1 and test samples are shown in Fig. 2. Detail of the mixes is given below in table 1.

Table 1 Detail of Mixes

Sample Type	Description
A	Foam Bitumen + Cement 2% + RAP 100%
B	Emulsified Bitumen + Cement 2% + RAP 100%
C	Emulsified Bitumen + Cement 2% + RAP 90% + Steel Slag 10%
D	Emulsified Bitumen + Cement 2% + RAP 90% + Marble Waste 10%
E	RAP

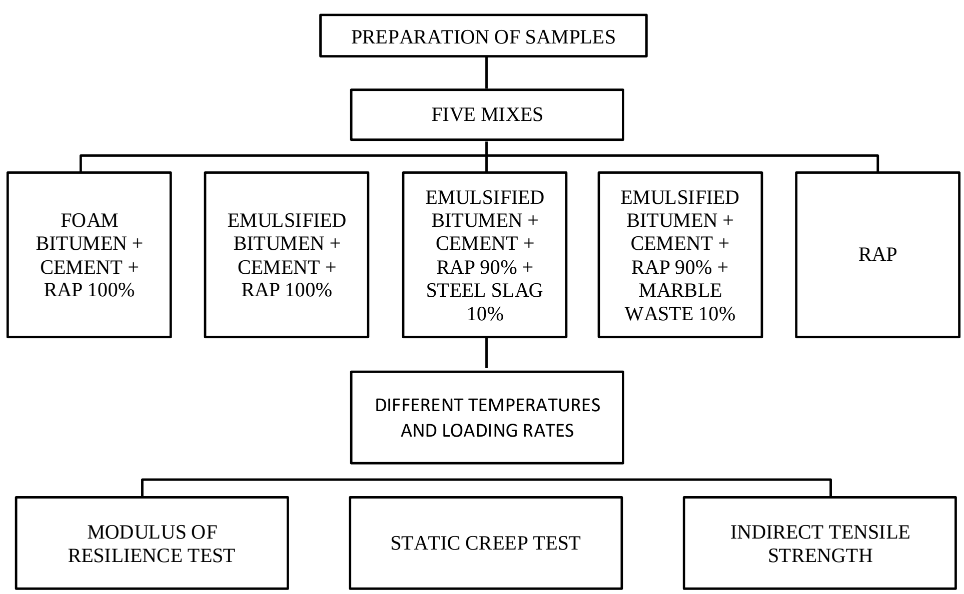


Fig.1: Flow sheet showing sample type and testing conditions

(a) (b) (c)

(d) (e) (f)

Fig. 2: (a) Test Samples for Repeated load Indirect Tensile Test (b) Emulsified Bitumen (c) RAP + Filler + Cement (d) Rap + Filler in un mixed form (e) Marshal Compactor for Compaction of Samples (f) Laboratory Marshall Samples

2.2 *Tests*

2.2.1 Repeated Load Indirect Tensile Test (MR Test)

Elastic theory based design procedures require the elastic properties of pavement materials input parameters. Resilient modulus of asphalt mixtures, an important parameter which helps in the calculation of elastic properties, is measured by the repeated load indirect tensile mode. Most of the paving materials being not flexible practice some permanent deformation after each load repetition. However, if load intensity is kept less as compared to stiffness of the material, the deformation under each load repetition is nearly recoverable, proportional to the load and can be considered as elastic.

Repeated load indirect tensile Test allows cylindrical specimens to be prepared by compacting in the mould or by coring from site. The test specimen is kept short so that it is convenient when coring from the site. The load to be applied is lower as compared to other tests. Under compressive loading, the test offers a convenient means of applying tensile stress.

Five pulse indirect tests were done according to ASTM D4123. The moulds were mounted in the indirect jigs. Diametric loading was applied to the specimen. The recoverable deformation was measured from the axis at 90° to the applied force. The value of poisons ratio was taken as 0.4, because the strain was not measured along the axis of load. To know about the behavior of foam bitumen, emulsified bitumen, and cement as binding material in CIPR mixes testing were conducted on different loading frequencies (pulse width PW) and temperatures as mentioned in testing flow sheet as Fig 1. The testing parameters that were kept constant for emulsified and foam bitumen have been mentioned below.

Table 2. Testing Conditions for Modulus of Resilience Test

	Category	Questions
1.	Condition Pulse Count	5
2.	Loading Cycles	1200
3.	Condition Pulse Period	2000 ms
4.	Test Pulse Period (ms)	1000 ms
5.	Peak Loading Force (N)	300 N
6.	Estimated Poisson ratio	0.40
7.	Temperature	40°C & 5°C
8.	Total Pulse Width	1000 ms
9.	Pulse Width	500 ms
10.	Peak Loading	300
11.	Poisson Ratio	0.40

Similarly testing conditions for cement and lime CIPR mixes had been mentioned below:

The specimen skin and core temperature were anticipated with the help of transducers in the dummy specimen. Pulse width represents the time of loading on the actual pavements. In testing assembly of UTM-5P, sample i.e. Marshall mould was placed in a traverse direction as shown in Fig 3.

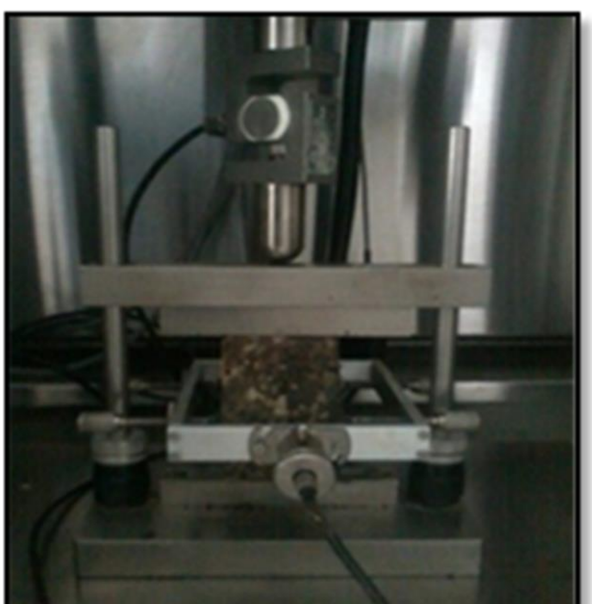


Fig. 3 Sample orientation for MR test

2.2.2 Repeated Uniaxial Load Strain Test (Creep Test)

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. Permanent deformation results in the complete failure of pavements, so there is always a need to measure the rut resistance of pavements to calculate its remaining life. Tests used to evaluate the resistance of asphalt mixes against flow are mainly Marshall Test, static creep test, dynamic creep test and the wheel tracking test. In this research, resistance to permanent deformation of recycled mixtures was evaluated by using Static Creep Test. This test was performed to determine the resistance to permanent deformation of asphalt mixes subjected to uni-axial repeated load. The specimen was subjected to repeated applications of load .The uniaxial deformations were calculated by using electric displacement transducers with data acquisition system and measured at regular periods of load applications up to the end of test. The axial stress, test temperatures and duration of tests depend upon loading conditions and pavement temperatures. The deformations were measured using two linear variable transducers placed entirely opposite to each other. These deformations were measured in the axis of stress application. Testing conditions for CIPR samples using emulsified bitumen, foam bitumen and cement as binding material are mentioned below:

Table 3 Testing Conditions for Repeated Load Uniaxial Strain Test

S.No.	Conditions	Values
1.	Loading Stress (kPa)	100
2.	Temperature^{O}C	40°C, 55°C
3.	Pulse Width (ms)	500
4.	Peak Loading Force (N)	300 N
5.	Loading Pulse Period (ms)	1000 ms

In testing assembly of UTM-5P, sample i.e. Marshall mould was placed in a longitudinal direction as per standard ASTM D4123 which is shown in Fig 4 and repeated load of defined magnitude and frequency was applied and the strain was calculated after the completion of loading cycles.

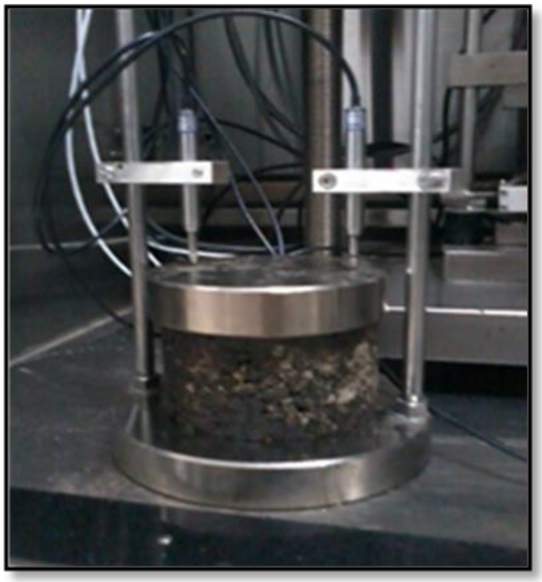


Fig. 4 Sample orientation for static creep test

3. Results and Discussion

3.1 Modulus of Resilience Test

Sample type and testing conditions for Modulus of Resilience are shown in flow sheet (Fig. 1). Testing results of resilient modulus test are shown in table 4

Fig.5-9 depict relationship between resilient modulus and different mixes at different temperature & pulse width.

Table 4 Results of Resilient Modulus Test (MPa)

Sample Type	40 °C		55 °C	
	150 ms	**450 ms**	**150 ms**	**450 ms**
A	3608.5	2607.2	2259.2	1988.8
B	2163.8	1435.5	1444.2	788.8
C	701	561	414	384
D	1500	1585	794	478
E	2211	1348	1635	1138

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 four 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.

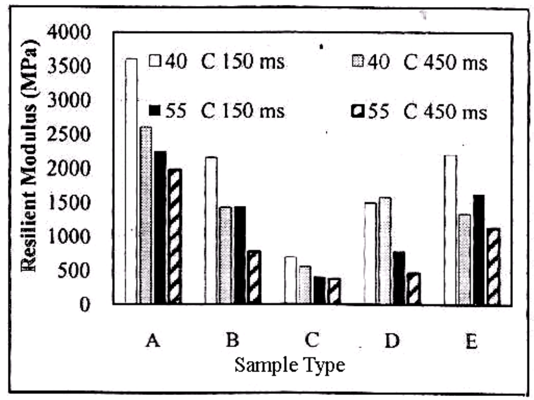


Fig. 5 Relationship between resilient modulus and different mixes at different temperature & pulse width

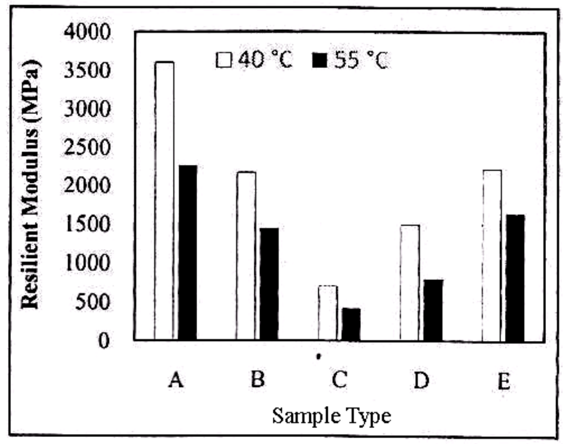
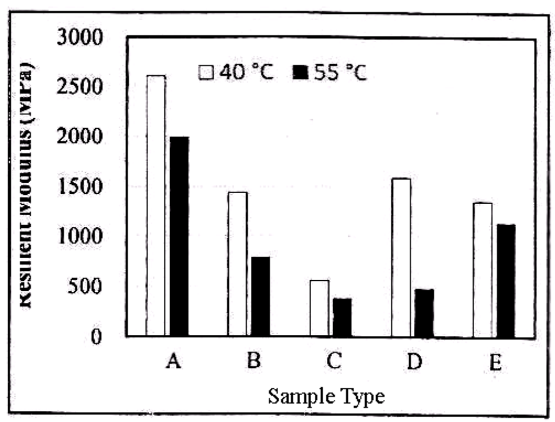


Fig. 6 Relationship between resilient modulus and different mixes at different temperature and constant PW of 150ms



PW of 150 ms

Fig. 7 Relationship between resilient modulus and different mixes at different temperature and constant PW of 450ms

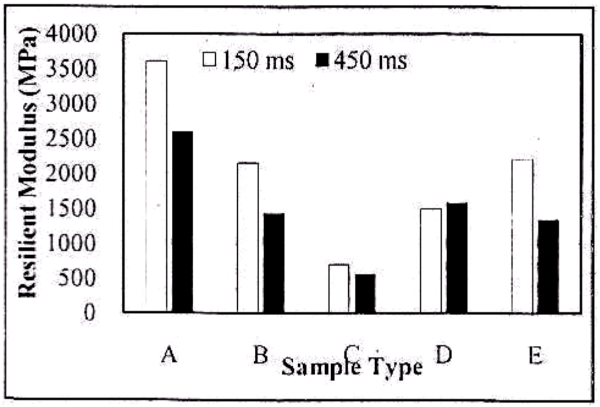


Fig. 8 Relationship between resilient modulus and different mixes at different PW and constant temperature of 40 °C

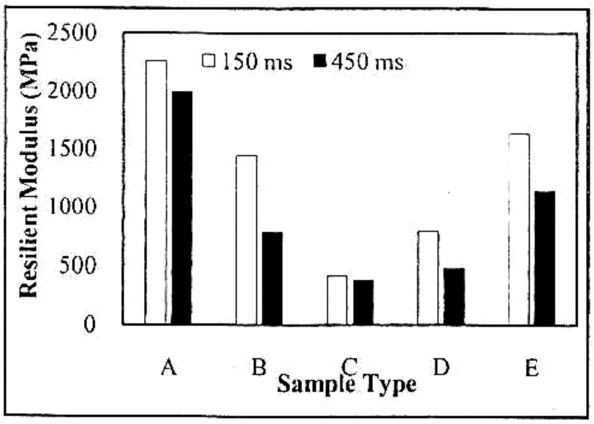


Fig. 9 Relationship between resilient modulus and different mixes at different PW and constant temperature of 55 °C

3.2 Static Creep Test

Testing results of static creep test are shown in table 5. Fig.10-14 depict relationship between creep stiffness modulus and different mixes at different temperature & pulse width.

Table 5 Results of Creep Stiffness Modulus

Sample Type	40 °C		55 °C	
	150 ms	**450 ms**	**150 ms**	**450 ms**
A	19.	10.3	13.2	6.8
B	14.	10.2	12.3	5.1
C	9.4	13.9	23.8	16.4
D	15.5	20.9	15.2	7.4
E	14.0	20.5	12.0	4.8

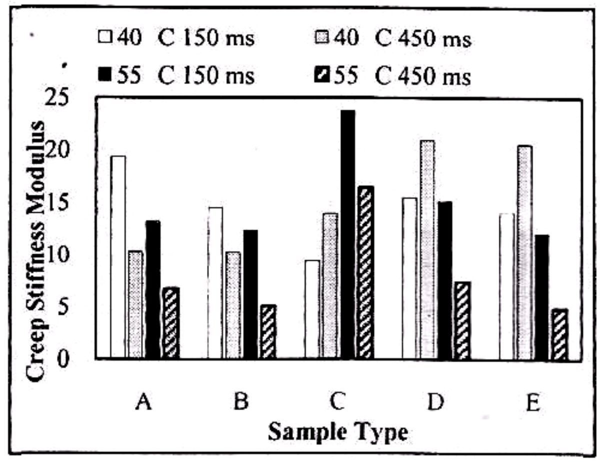


Fig.10 Relationship between creep stiffness modulus and different mixes at different temperature & pulse width

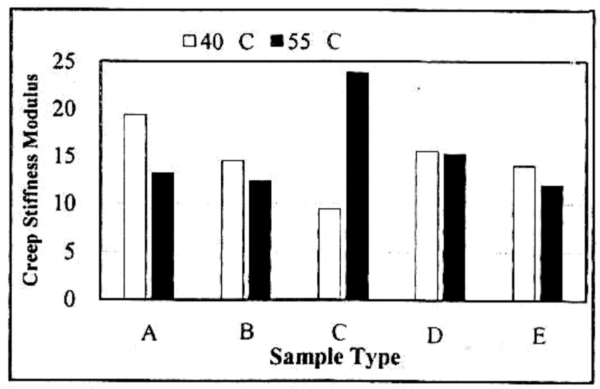


Fig.11 Relationship between creep stiffness modulus and different mixes at different temperature and constant PW of 150ms

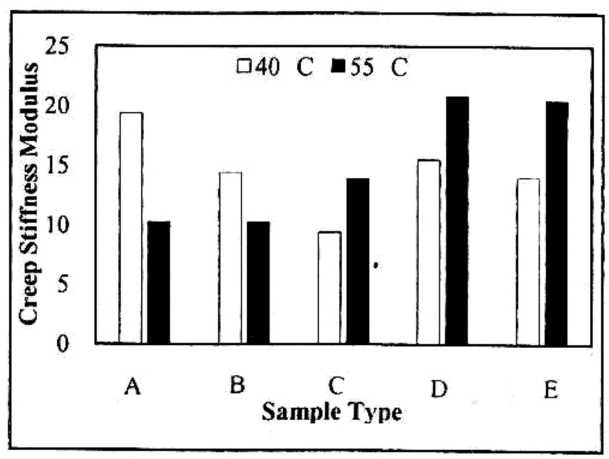


Fig.12 Relationship between creep stiffness modulus and different mixes at different temperature and constant PW of 450ms

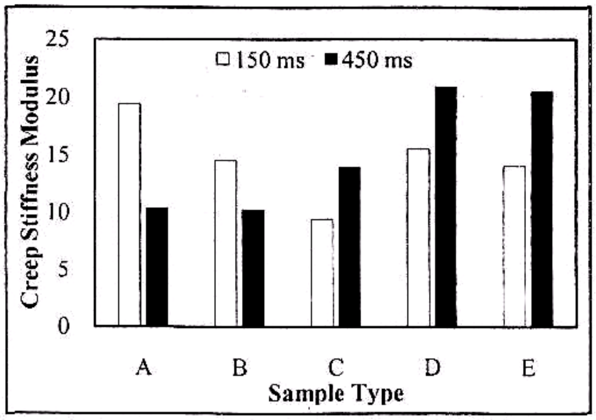


Fig.13 Relationship between creep stiffness modulus and different mixes at different PW and constant temperature 40 °C

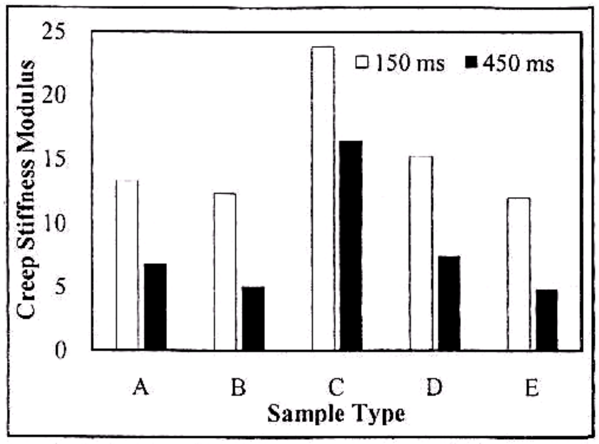


Fig.14 Relationship between creep stiffness modulus and different mixes at different PW and constant temperature 55 °C

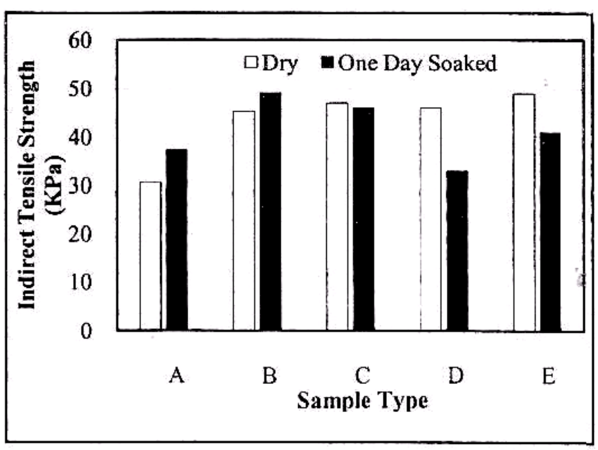


Fig.15 Relationship between ITS and mixes for both dry and wet conditions.

3.3 Indirect Tensile Strength

Testing result of ITS test are shown in table 6 and Fig. 15 shows the relationship between ITS and mixes for both dry and wet conditions.

The Indirect Tensile strengths of all the three mixes is less than the specified for the asphaltic layer, and out of five mixes the mix containing 100% Recycled Aggregate has high tensile strength.

Table 6 Results of ITS Test

Sample Type	Dry	One Day Soaked
A	30.7	37.4
B	45.2	49.1
C	47.0	46.0
D	46.0	33.0
E	49.0	41.0

4. Conclusions

- 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.

- Modulus of resilience decreases with increase in the temperature and pulse width for all the mixes.

- 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 five 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.

5. Recommendations

- CIPR 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.
- For the pavement susceptible to fatigue cracking the cold recycling should consist of 100 % RAP.
- The cold mix (Specimen A) 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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