Laboratory Evaluation of Rutting Performance of Asphalt Concrete Mixtures by Crumb rubber modification

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Abstract —One of the most important distresses in flexible pavements is Permanent deformation (rutting). It is a severe problem mostly in those countries having high temperature like Pakistan. Asphalt Rubber (AR) is produced by mixing crumb rubber that is obtained from waste tires with asphalt binder. Mixtures produced with asphalt rubber are one of the substitutes to reduce permanent deformation. It is also one of the most suitable applications to dispose the waste tires. In this study our aim is to compare the rutting behavior of asphalt rubber mixtures with the conventional mixtures. For this study, two aggregate gradations, namely NHA class "A" and NHA class "B" were chosen. Wet process of mixing was used to produce asphalt rubber and Marshall Mix design was used to determine optimum asphalt rubber content. Uniaxial repeated load test (cyclic creep test) and Wheel Tracking Test (WTT) were performed to study the rutting performance of asphalt mixtures. During uniaxial repeated test, temperature was set to 25, 40 and 55 ^{0}C and specimens were tested for a period of 3600 cycles. Stress levels of 100, 300 and 500 kPa were used. Pulse period was selected 2 second and the pulse width was selected 0.5 second. Wheel tracker test was conducted for a period of 10,000 load cycles at three different temperatures 25, 40, and 55 ^{0}C. The testing results of this study confirmed that the use of asphalt rubber to prepared asphalt mixtures increases significantly the resistance to permanent deformation (rutting). This study also concluded that crumb rubber modified bitumen is more effective for coarser aggregate gradation than finer aggregate gradation to increase permanent deformation resistance (rutting resistance).

Key Words — Permanent Deformation, Crumb Rubber Modified Bitumen, Wheel Tracking Test, Uniaxial Repeated Load Test.

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1 INTRODUCTION

The percentage of the asphalt binder in hot mix asphalt (HMA) is reasonably small, but the asphalt binder affects the HMA more than the aggregate because environment affects the asphalt binder more than aggregates.

Asphaltic roads show inadequacy on temperatures, when the temperature is high becomes soft and when temperature is low it cracked. Therefore, it is essential to increase the quality of asphalt binder and quality of asphalt binder can be improved by a material which produces a thicker binder and reduced temperature susceptibility, so that it will improve thermal cracking resistance in the low temperature and rutting resistance in the high temperature.

Used tires gather rapidly and they cannot easily dispose. They generate a severe environmental problem and most of the countries like Pakistan have to go through that problem. Various methods had been deliberated in last few years for improving properties of conventional asphalts, such as the addition of some modifiers is made in order to increase their properties. The use of Crumb Rubber (CR) powder has been a substitute to improve the quality of HMA and, at the same time minimize their environmental influence.

In 1960, Charles McDonnald was the first who make use of CR in asphalt mixtures to increase the performance of HMA [1, 2]. Many studies that had been done in the last several decades indicated that permanent deformations and cracking resistance of asphalt pavement can be increased by mixing crumb rubber powder with asphalt. Furthermore, the thickness of asphalt overlays can be reduced by using rubberized asphalt mixtures [3, 4].

To make asphalt rubber, the crumb rubber is cut and grinded into small sizes and then added into the conventional asphalt binder. In the ambient grinding technique, scrap tire rubber is powdered at or above room temperature. In the cryogenic grinding technique, before grinding liquid nitrogen is used to freeze (-120 ºC) tire chips [5].

Bennert et al., 2004: concluded that the working range of the conventional mixtures expanded because of the addition of crumb rubber and thus results in reduction of fatigue cracking and rutting at low and high temperatures respectively [6].

Viscosity of asphalt binder decreases at high temperatures, as a result the asphalt binder becomes soft and flow easily. Soft asphalt binder forms softer asphalt mixtures, which increases the risk of rutting. However, viscosity of asphalt mixture increases due to the addition of CR which strengthens asphalts at high temperature [7].

Shen et al., 2009: evaluated the effect of surface area of the crumb rubber on the rheological properties of asphalt binder. They concluded that crumb rubber that has greater surface area will have greater complex modulus and greater phase angle [8].

M.A. Kamal et al., 2009: evaluated the performance of asphaltic base and wearing course. In this study four experimental sections were built using Crumb Rubber Modified Bitumen (CRMB) and conventional bitumen on N-5 (Pakistan) under the same environmental and trafficking conditions. They concluded that under the same loading and environmental conditions pavements sections placed with

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crumb rubber modified bitumen showed better performance as compared to the conventional asphalt binder in terms of their pavement deflections and resilient modulus [9].

Liseane P.T.L. Fontes et al., 2009: compare the rutting behavior of conventional mixtures with Asphalt Rubber (AR) mixtures. Two aggregate gradations, namely dense and gap-graded were used in this study. Wet process was used to prepared asphalt rubber. They used two laboratory tests, the Accelerated Pavement Testing Simulator Test (APTST) and the Repeated Simple Shear Test at Constant Height (RSST-CH). The results of their study confirmed that the resistance to rutting is improved when asphalt rubber binder is used. The maximum resistance is offered by the mixtures prepared with gap-graded aggregate gradation [10].

Baha Vural Kok et al., 2011: used ambient crumb rubber and Styrene-Butadiene-Styrene (SBS) for the modification of asphalt binder. First, modified bitumen was evaluated by dynamic shear rheometry, rotational viscometery, and conventional binder tests. Then permanent and fatigue characteristics of HMA including CRMB and SBS modified bitumen were evaluated. The tests results showed that to get the same performance the CR content must be used at much higher than SBS content [11].

Peiliang Cong et al., 2012: study the effects of crumb rubbers contents on the properties of asphalt binders. They concluded that properties of crumb rubbers modified bitumen with grade 80/100 are better than that of modified bitumen with penetration grade 60/80 at low and high temperature [12].

G.H. Shafabakhsh et al., 2014: study the effect of adding CR on the rutting behavior of asphalt mixtures. Wheel track test has been used in order to compare the performance of rubberized asphalt mixtures and conventional asphalt mixtures. In their study they concluded that the use of CR powder produced a considerable decrease in the rate of rutting depth of rubber asphalt mixtures compared to conventional asphalt mixtures [13]

2 OBJECTIVES

Following were the objectives of this study.

- To improve the rutting resistance of asphalt mixtures
- To compare permanent deformation (rutting) behavior of the mixtures with CRMB with its base bitumen penetration grade 60/70 and conventional bitumen with penetration grade 60/70 by varying temperature and stress levels.
- To study the behavior of asphalt mixtures due to addition of modifier.

3 TEST MATERIALS

3.1 Aggregates

Aggregate selection is important for the construction of pavement. In this study aggregates were obtained from a lime stone quarry (Margalla, Pakistan). Two aggregate gradations, NHA-A and NHA-B were selected for this study is given in Table-1 and plotted graphically in figure 1.

3.2 BITUMEN

In this study conventional asphalt binder (60/70) and modified binder (15 % crumb rubber) were used. Properties of conventional and modified bitumen are shown in Table 2.

TABLE 1
GRADATION OF AGGREGATES

Sieve Sizes (mm)	NHA Class A % Passing	NHA Class B % Passing
50	-	-
37.5	-	-
25	100	
19	95	100
12.5	77.2	82
9.5	63	70
6.3	47.2	54.6
4.75	42.5	50
2.36	29	30
1.18	18.5	19.7
0.6	12.1	13.5
0.3	8.5	10
0.15	6.5	7.1
0.075	5	5
Pan	0	0

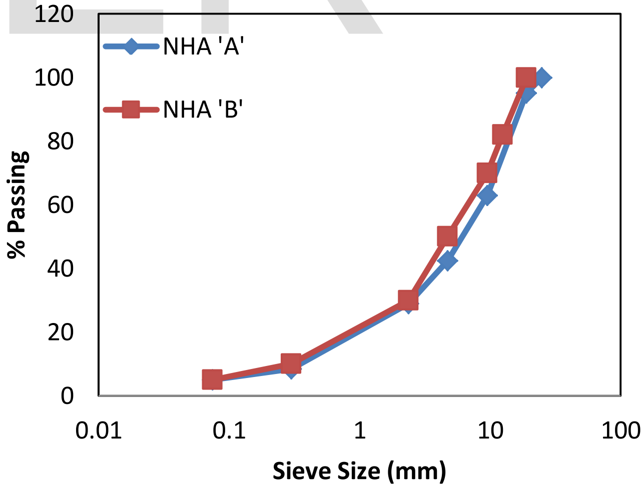

Fig. 1. Aggregate gradation curve

TABLE 2
CONVENTIONAL PROPERTIES OF ASPHALT BINDERS

Sr. No	Description	CRMB (60/70 BASE)	Neat Bitumen "60/70"
	Type	Modified	Neat
1	Ring & Ball Softening Point (^{0}C)	61	49
2	Penetration (mm)	44	67
3	Ductility @ 25 °C (cm)	53	100
4	Elastic Elongation Recovery (%)	82	69

4 EXPERIMENTAL INVESTIGATION

4.1 Bituminous Mixtures Design

In this study, wet process is used to produce asphalt rubber. The ambient grinding crumb rubber was used. Crumb rubber powder (0.60-0.15 mm) was used to prepare asphalt rubber binder. Asphalt rubber is prepared by mixing crumb rubber (15 %) with neat bitumen at a temperature between 175 °C and 185 °C and stirred at a speed of 3000 rpm with high speed mechanical stirrer for about 45 minutes [9]. Optimum Asphalt Rubber Content (ARC) was calculated by using Marshal Mix design method. Optimum conventional asphalt binder content is 4.0 % for NHA class 'A' and 4.3 % for NHA class 'B'. Optimum asphalt rubber content is 4.7 % for NHA class 'A' and 4.9 % for NHA class 'B'.

4.2 Repeated Load Permanent Deformation Test (Cyclic Creep Test)

This test was done by using Universal Testing Machine (UTM–5P). This machine can apply uniaxial cyclic loadings of different amounts. In Uniaxial strain (creep test) test, first we apply a static conditioning stress of 10 kPa to the sample for 100 seconds then measures the accumulated strain due to applied stress. Pulse period of 2000 milli-seconds and pulse width of 500 milli-seconds was used. Specimens were tested at stress levels of 100, 300 and 500 kPa for a period 3600 cycles. Temperature was set to 25, 40 and 55 ^{0}C. As testing of sample continued, accumulated strain was measured using two linear variable differential transducers (LVDTs).

4.3 Wheel Tracking Test

This test was performed according to EN 12697-22 test method using Wheel Tracking Device. The susceptibility of bituminous material to rut under wheel load is determined using the wheel tracking test. Specimens prepared in laboratory or cut from the real pavement can be tested for rutting due to loaded wheel cyclic passes at different temperatures. The apparatus consists of a loaded wheel which passes repeatedly over the sample held securely on a table and an attached device displays rut depth (mm) that occurs at the surface of specimen. Temperature control device is required so that the temperature of the test specimen during testing remains uniform. Test specimens were prepared in the laboratory using Roller Compactor. In this study, a load of 700 Newton (N) was applied. Mixes were tested at temperature of 25, 40 and 55 °C for a period of 10,000 cycles.

5 RESULTS AND DISCUSSIONS

5.1 Accumulated Strain Results

The results of accumulated strain have been presented in table 3 and are shown graphically in figure 2-4 to make a comparison among different gradations, asphalt binder types, different temperatures and at different stress levels.

TABLE 3
PERCENTAGE ACCUMULATED STRAIN OF MIXES

No.	Stress level	Temperature	Accumulative strain (%)			
			NHA-A N.B	NHA-A CRMB	NHA-B N.B	NHA-B CRMB
1	100	25	0.37	0.27	0.43	0.32
2	300	25	0.48	0.36	0.55	0.43
3	500	25	0.97	0.74	1.17	0.95
4	100	40	0.84	0.64	0.91	0.73
5	300	40	1.08	0.84	1.26	1.01
6	500	40	2.867	2.18	3.13	2.56
7	100	55	1.08	0.80	1.13	0.91
8	300	55	2.08	1.6	2.19	1.8
9	500	55	4.3	3.3	4.43	3.77

It has been observed from figure 2-4 that as temperature and stress level increases, permanent deformation increases. Increasing rate in accumulated strain (permanent deformation) was more due to increase in temperature as compared to rate of increase in accumulated strain due to increase in stress level.

5.2 Wheel Tracking Test Results

The results obtained from Wheel Track Test in terms of Rut

Depth (mm) obtained at different temperatures have been shown in figure 5.

Figure 5, shows that rut depth increased with the increase in temperature. Rate of increase in rut depth is more at high temperature as compared to low temperature. Asphalt mixture prepared with NHA-A aggregate gradation and crumb rubber modified bitumen has lowest value of rut depth among all other mixtures.

6. CONCLUSIONS

Overall rutting behavior of mix prepared with neat bitumen was lower as compared to the mix prepared with crumb rubber modified bitumen (CRMB).

Fine graded mixtures (NHA-B) showed more accumulated strain and rut depth than coarse graded mixtures (NHA-A).

Rutting resistance (permanent deformation) of coarse graded mixtures (NHA-A) prepared with crumb rubber modifier bitumen (CRMB) is 25-30 % greater than coarse graded mixtures prepared with neat bitumen.

Rutting resistance (permanent deformation) of fine graded mixtures (NHA-B) prepared with crumb rubber modified bitumen (CRMB) is 10-15 % greater than fine graded mixtures prepared with neat bitumen.

Crumb rubber modified bitumen is more effective for coarser aggregate gradation than finer aggregate gradation to increase permanent deformation resistance (rutting resistance).

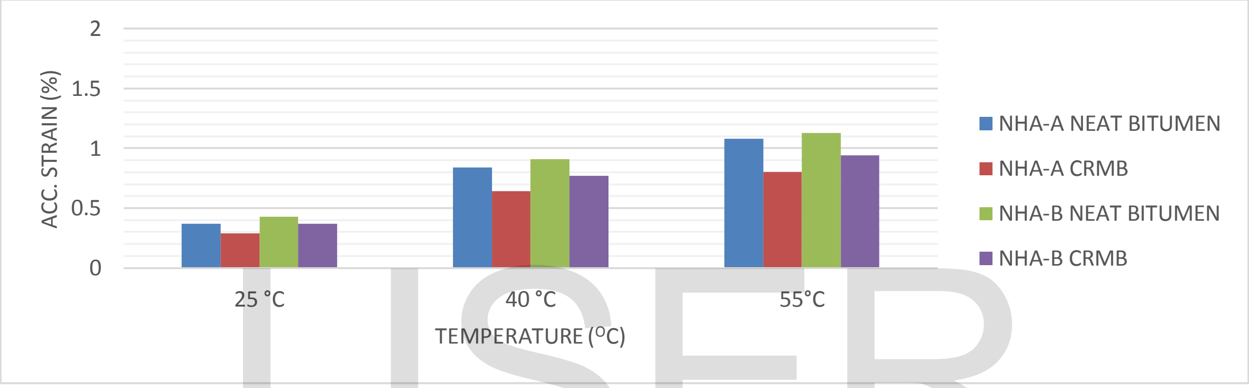

Fig. 2. Accumulated strains of the mixes at 100 kPa

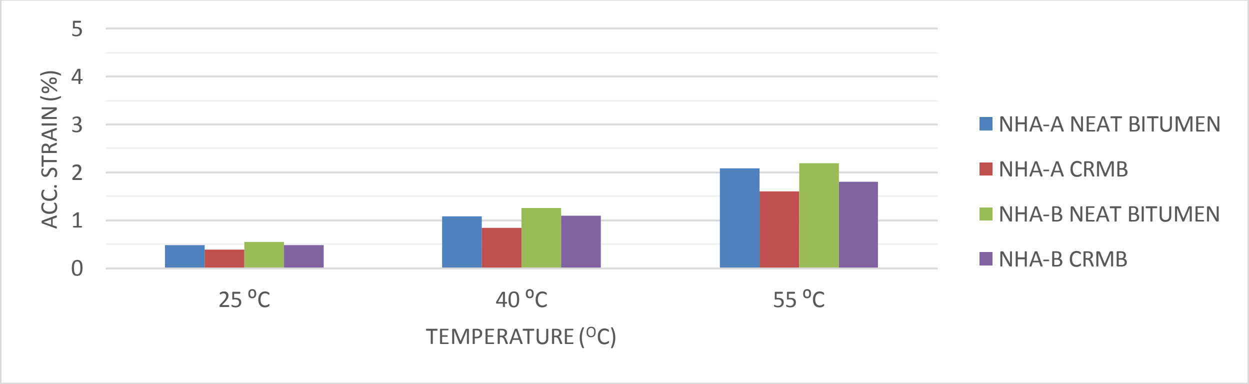

Fig. 3. Accumulated strains of the mixes at 300 kPa

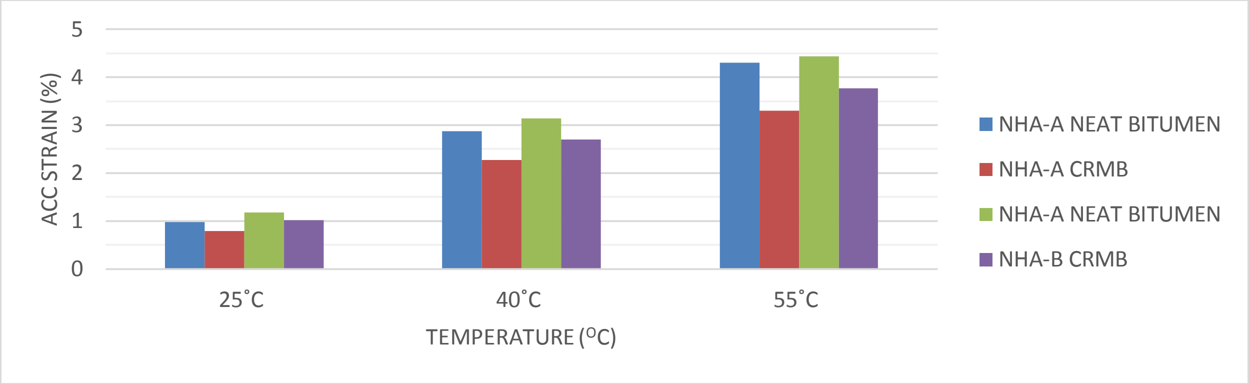

Fig. 4. Accumulated strains of the mixes at 500 kPa

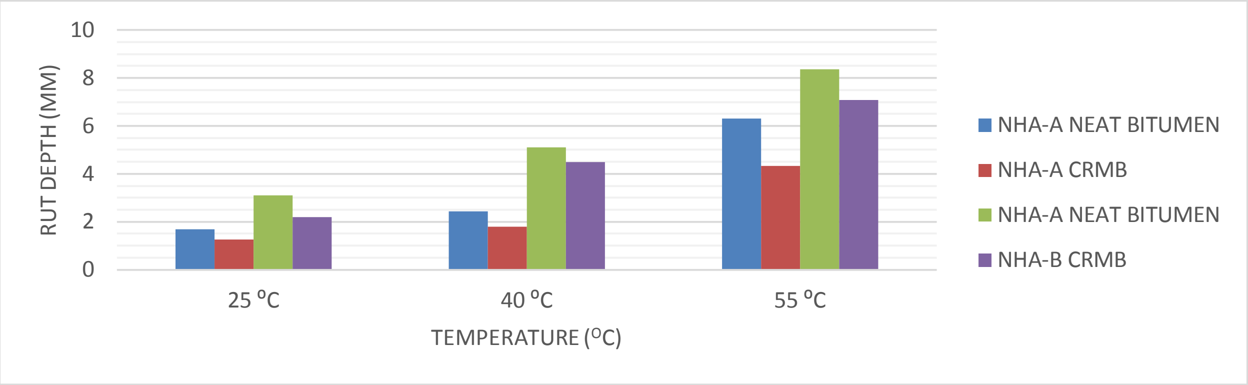

Fig. 5. Rut depth of mixes at 700N

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