Performance and Comparison of Crumb Rubber Modified and Conventional Mixes Under Varying Temperature and Stress Levels

M.A. Kamal[1], S. Shahid[2], M.U.Arshid[3], I. Hafeez[4]

[2] *Civil Engineering Department, UET Taxila, Pakistan*
[3]usman.arshid@uettaxila.edu.pk

Abstract-Laboratory investigations were carried out in terms of resistance against rutting and assessing resilient modulus of Crumb Rubber Modified Mixes (CRMM) and conventional mixes (60/70 pen) at varying temperatures (55, 40, and 25 °C) and stress levels (500, 300 and 100 kpa). The specimens were tested using UTM (5P) and a comparison of the rutting resistance and resilient modulus (Mr) of both the mixes were made. CRMM showed better performance in terms of rutting resistance and increased resilient modulus compared to that of conventional mixes (CM) under same stress and temperature conditions.

Keywords-Resilient Modulus, Asphalt, Accumulated Strain, Modified Bitumen

I. INTRODUCTION

Quality of bitumen is important in evaluating the properties of bituminous concrete mixes in terms of its performance. In Pakistan, growth of commercial vehicles, uncontrolled axle loads, and substantial changes in daily and seasonal pavement temperatures are accountable for an early breakdown of flexible pavements in most areas of the country. Local refineries meet the current specifications of bitumen. However, mainly the failure of flexible pavements before the expected time is due to the design compatibility of conventional asphalt mixes with the continual application of wheel load under local environmental conditions.

Various studies have indicated that performance of Asphalt mixes can be greatly improved with the introduction of modifiers. It is hypothesized that by improving the binder stiffness at high service temperature and reduced stiffness at lower service temperatures, an improved binder can be developed. Polymers introduced as binders create a lattice within the asphalt by combining small molecules into larger ones. These larger molecule lattices are more stable under high and low temperatures and thus resist thermally induced cracking at low service temperature and permanent deformations and rutting at high temperatures [i] and [ii] reported that hot rolled asphalt surfacing showed improved performance with the addition of organic polymers. While [iii] has also identified beneficial properties of modified bitumen.

One such form of modified bitumen is Crumb Rubber Modified Bitumen (CRMB) also called Asphalt Rubber, introduced in Pakistan by M/s Phoenix Commercial Company (Pvt.) Limited in collaboration with an Indian manufacturer. Full scale trial sections were laid using CRMB and their performance under extreme loading and environmental conditions was studied by [iv]. They reported better performance of CRMM mixes than that of conventional mixes in terms of their resilient modulus and pavement deflection.

Similar findings have already been reported by [v]-[xii] that performance of asphalt mixes with crumb rubber compared to the conventional mix is better.

II. PROBLEM STATEMENT

High traffic intensity of commercial vehicles, overloading, inflated tire pressures, substantial change in daily and seasonal temperatures, low maintenance, limited budgets are few of the problems resulting in premature failure of flexible pavements. Consequently, huge Govt. exchequer is being incurred to keep the road to an expectable service level. National Highway Authority incurred a mammoth expenditure of Rs. 5.951 Billion for operation and maintenance of 9098 km of its network during 2007-08. This includes Rs. 1,417 Million on rehabilitation of 114 km roads, Rs. 1,638 Million on structural overlays, Rs. 1,676 Million on functional overlays of 514 km, Rs. 810 Million on routine maintenance of 8183 km of roads and Rs. 410 Million on highway safety [xiii].

India having the identical environment as in Pakistan has revealed that properties of bitumen and bituminous mixes can be improved to meet the requirements of pavement with the incorporation of certain additives. Crumb Rubber Modified Bitumen is one such effort in this regard which improves complex modulus and elastic response of bitumen at higher temperatures [xiv]. It is the time to adopt alternate technologies to address the frequent pavement failures. The use of modified bitumen has been reported to offer solution to reduce the maintenance rate; consequently, treatments stand for a longer time. Additionally at elevated temperatures bitumen modifier increases the resistance of asphalt concrete against permanent deformation. This could be achieved by either stiffening the bitumen so that total visco-elastic response of the asphalt is reduced with a corresponding reduction in permanent strain or by increasing the elastic component of the bitumen, thereby reducing the viscous component, again resulting in reduction of permanent strain.

III. Experimental Work

A. Aggregate Gradation & Asphalt Content

In this research work, mixes were prepared using aggregate gradation of National Highway Authority (NHA), Government of Pakistan Class-A specification for Wearing Coarse, as shown in Table I. Optimum asphalt contents were worked out using Hot Mix Asphalt Design approach and reported to be 4.2% for conventional mix (60/70 pen) and 4.3% for CRMM [xv].

TABLE I
GRADATION OF AGGREGATES

Sieve Size	%age Passing	JMF Limits	NHA Specs Limits
1”	100	100	100
3/4”	94.6	88.6-100	90-100
3/8”	63.4	57.4-69.4	56-70
No. 4	44.4	38.4-50.4	35-50
No. 8	28.9	24.9-32.9	25-35
No. 50	8.8	4.8-12.8	5-12
No. 200	4.4	2.8-6.8	2-8

Bitumen (60/70 pen and Crumb rubber ranging from 0.15 mm to 0.60 mm particle size were heated to 150 ºC and mixed by wet process at a rate of 15% by mass at a low speed, for about five minutes. The blend was then heated at a temperature between 175 ºC to 185 ºC and stirred at a speed of 3000 rpm with a high speed mixture for about 45 minutes. Heated up to 165 ºC, Crumb Rubber Modified Binder was stirred smoothly to prevent segregation and mixed in a batching plant finally to transport on site. The product was then laid by conventional asphalt paver [iv].

B. Repeated Load Uniaxial Strain Test

Repeated Load Uniaxial Strain Tests were performed as per British Standard Institute to measure the amount of accumulated and resilient strains against repeated loading. The tests were performed using Universal Testing Machine, UTM-5P. Initially, static conditioning stress (10 kpa) was applied to the specimen for a specified conditioning time (100 sec). A fixed time delay was maintained following the conditioning period, during which the applied stress was set to zero. Once the delay time expired, the specimens were then subjected to repeated pulse loading for loading stresses of 100, 300 and 500 kpa against varying temperatures of 25, 40 and 55 ˚C. Pulse period was set as 2000 ms and pulse width of 500ms with terminal pulse count of 1800 [iv].

The accumulated resilient strains were measured against applied stresses and varying temperature conditions. Strains during both the conditioning and pulsed loading conditions were measured along the same axis as the applied stresses using two Linear Variable Differential Transducers (LVDTs).

The tests results were based on an average of three specimens for varying load and temperature conditions both for conventional and CRMB mixes and are shown in Fig. 1.

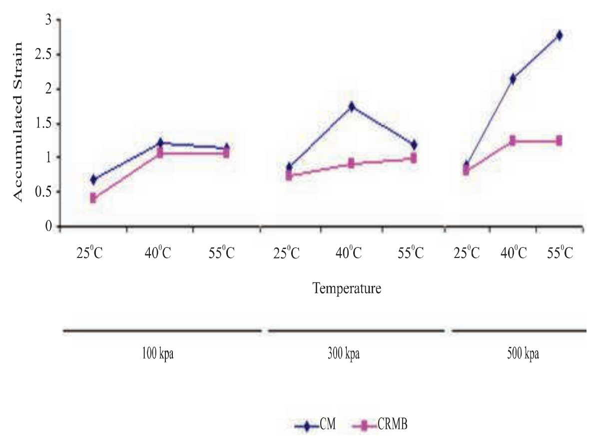

Fig. 1. Accumulated Strains for Conventional Mix (CM) and Crumb Rubber Modified Bitumen (CRMB)

It can be observed from Fig. 1 that CRMB mix showed less accumulated strain at all temperatures and stress level advocating better performance against permanent deformation and rutting. Accumulated strains of CRMB mix was about 55% less than that of the conventional mix (CM) at extreme stress level of 500 kpa and at a temperature of 55 ˚C

C. Repeated Load Indirect Tensile Test

The five pulse Repeated Load Indirect Tensile Test was performed as per ASTM D4123 to determine resilient modulus of bituminous mixtures [xvi]. The test was carried out by applying compressive loads with haversine waveforms, a pulsed diametral loading force was applied to a specimen and the resulting total recoverable diametral strain was then measured onaxes 90 degrees from the applied force.

Tests were performed with five condition pulses for a period of 2000 ms followed by a Peak Loading Force of 100N. The test pulse period was kept as 1000 ms with pulse width of 400 ms. Since strain was not measured on the same axes, therefore Poisson's ratio of 0.4 was assumed to calculate the resilient modulus.

Modulus of Resilience (Mr) is directly associated to the load spreading ability of a material giving a relationship between applied stresses and corresponding strains. It is affected by density, temperature, particle size, shape and gradation as well as lateral confinement. The resilient modulus test is used in structural analysis of layered pavement system and determines the stiffness of pavement materials under stress conditions by simulating wheel loads on pavement.

Tests were performed for combination of varying loads (100, 300 and 500 kpa) and varying temperatures (25, 40 and55 ˚C). Each combination was tested 3 times and average values were taken. In total 27 tests with 9 different loading and temperature combinations were performed.

Average values of resilient modulus of conventional bituminous mix and CRMB against varying loads and temperatures are shown in Fig. 2

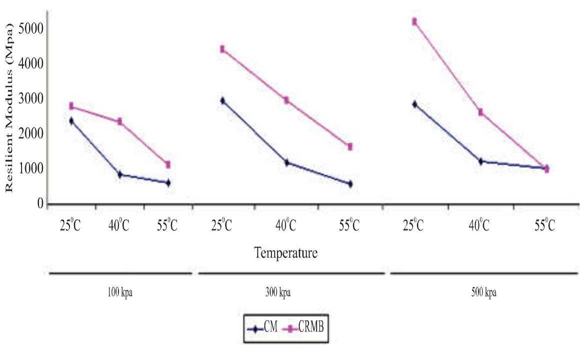

Fig. 2. Resilient Modulus for Conventional Mix (CM) and Crumb Rubber Modified Bitumen (CRMB)

A higher value of Mr for CRMB Mix to that of conventional mix can be observed at the tested temperatures and loading conditions. It can also be observed that resilient modulus values increase with the increase in applied load and decrease with increase in temperature.

I. CONCLUSIONS

Following conclusions have been drawn;

Crumb Rubber Modified mixes showed better performance with lesser accumulated strains at all the tested temperatures and stress levels.

Resilient Modulus of CRMM mixes showed higher values to that of the Conventional mixes at all temperatures and loading conditions.

Overall performance of CRMM was better than that of the conventional mixes in terms of resisting against rutting and higher resilient modulus.

REFERENCES

[i] T. Sharif. "Modified Bituminous Mixes to Minimize Pavement Rutting", Department of Civil Engineering, Highways Group, University of Birmingham, UK. 1992.

[ii] J. H. Denning and J. Carswell "Improvement in rolled asphalt sampling by the addition of organic polymers", TRRL Report, Crowthorne, Berkshire, UK. 1989.

[iii] D. C. Douglas, and H. Zhu. "Asphalt Rubber – An Anchor to Crumb Rubber Markets", Third Joint UNCTAD / IRSG Workshop on Rubber and the Environment, International Rubber Forum, Veracruz, Mexico. 1999.

[iv] M. A. Kamal, F. Shazib, and B. Yasin, "Resilient Behaviour Of Asphalt Concrete Under Repeated Loading & Effects Of Temperature," Journal of the Eastern Asia Society for Transportation Studies, vol. 6, pp. 1329–1343, 2005.

[v] J. Harvey and C. L. Monismith, "Effects Of Laboratory Asphalt Concrete Specimen Preparation Variables On Fatigue And Permanent Deformation Test Results Using Strategic Highway Research Program A-003a Proposed Testing Equipment, "Transportation Research Record, No. 1417. pp. 38-48, 1993.

[vi] W. Daly and I.Negulescu,"Characterization of asphalt Cements modified with Crumb rubber from discarded tires," Transportation Research Record: Journal of the Transportation Research Board, vol. 1583, pp. 37–44, Jan. 1997.

[vii] M. Hossain, S. Swartz, and E. Hoque, "Fracture and tensile characteristics of asphalt-rubber concrete," Journal of Materials in Civil Engineering, vol. 11, No. 4, pp. 287–294, Nov. 1999.

[viii] S. K. Palit, K. S. Reddy, and B. B. Pandey, "Laboratory evaluation of Crumb rubber modified asphalt mixes," Journal of Materials in Civil Engineering, vol. 16, No. 1, pp. 45–53, Feb. 2004.

[ix] Wong, C. Ching. and W. Wong, "Effect of Crumb Rubber Modifiers on High Temperature Susceptibility of Wearing Course Mixtures", Construction and Building Materials, pp. 1741-745. Vol. 21 2007.

[x] W. Haibin, Q. He, Y. Jiao, J. Chen, and M. Hu. "Evaluation of anti-icing performance for crumb rubber and diatomite compound modified asphalt mixture." Construction and Building Materials 107 (2016): 109-116.

[xi] X. Ouming, F. Xiao, S. Han, S. N. Amirkhanian, and Z. Wang. "High temperature rheological

properties of crumb rubber modified asphalt binders with various modifiers." Construction and Building Materials 112 (2016): 49-58.

[xii] K. B. Vural, M. Yilmaz, and M. Akpolat. "Performance evaluation of crumb rubber and paraffin modified stone mastic asphalt." Canadian Journal of Civil Engineering 43, no. 5 (2016): 402-410.

[xiii] Ministry of Finance, Govt. of Pakistan. "Pakistan Economic Survey". 2007-08. Source: http://www.finance.gov.pk/survey_0708.html

[xiv] P. Kumar, H. C. Mehndiratta, Singh, and K. Lakshman, "Rheological properties of crumb rubber modified bitumen-a lab study," Journal of Scientific and Industrial Research (JSIR), Vol 68, No. 9, pp 812-816. Sep. 2009.

[xv] National Highway Authority, General Specification, Ministry of Communications, Government of Pakistan, 2000.

[xvi] ASTM D4123-82 (Re-approved 1995). "Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures", American Society for Testing.