E-ISSN: 2707-8396
P-ISSN: 2707-8388
JCEA 2023; 4(1): 21-29
Received: 11-11-2022
Accepted: 17-12-2022

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Performance evaluation of hydrated lime pretreated crumb rubber modified asphalt concrete using superpave mix design

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Abstract
Performance and durability of asphalt pavement is an alarming issue due to time to time increase in demand of high quality road. On the other hand currently number of discarded waste tire is increasing and becoming an environmental concern globally as well as in Ethiopia. This study was conducted to evaluate performance of Hydrated Lime pretreated crumb rubber modified asphalt concrete by dry Fatigue Life, Also rutting test was performed using Double Wheel Track (DWT) with specimens produced by slab compactor. The TSR value decreased for addition of more than 3% CR whereas the value improved with addition of HL. As per the DWT test result smaller rate of rutting and final rut depth compared to control mix obtained using 1% CR with and without HL and 3% CR with HL. The minimum to maximum value of resilient modulus for all mix was obtained as 765 to process. A 12.5 mm Nominal Maximum Aggregate Size and 1609 MPa and 226 to 385 MPa at temperature of 25 C and 40 bitumen with penetration grade of 80/100 was used to prepare all mix. Crumb Rubber (CR) 100% passing 1.18 mm sieve with 1, 3 and 5% by total mass of aggregate and also 2.5% Hydrate Lime (HL) was proposed to pretreat crumb rubber. A total of 70 specimens were prepared using gyratory compactor to determine Moisture Susceptibility, Resilient Modulus and °C respectively. Resilient modulus of mix increased except for 5% CR regardless of temperature and HL. Also resilient modulus of CR mix improved with addition of HL. Fatigue life Increased for mix with up to 3% CR replacement of aggregate whereas the value decreased for both temperature of 25 °C and 40 °C for further increment in CR.

Keywords: Superpave, crumb rubber, resilient modulus, fatigue life and rutting

Introduction

Durability and performance of asphalt pavement becomes a critical issue especially in developing countries like Ethiopia. Asphalt concrete with flexile pavement type has been used for many decades as a pavement surface or wearing course. However, the main challenges on this type of pavement are occurrence of distresses before completion of estimated design period. The major distresses are permanent deformation (rutting), fatigue cracking under traffic movement and environmental influence (Habte, 2021) [6]. Researchers in road industry have been investigating to find an alternative ways for developing sustainable asphalt pavement, among the research area applications of waste rubber in asphalt pavement. Crumb rubber has two major benefits, i.e improving mechanical properties of pavement and creating environmental sustainability by recycling of discarded tire (Mashaan., *et al*. 2012) [15]. Number of waste tires are increasing globally, it is estimated that annually 1.2 billion of waste tire rubber produced worldwide after reached the end of their useful lives.

CR modified asphalt mixtures provided smoother ride and reduced noise compared to conventional asphalt mixtures, beside with better skid resistance and winter maintenance. When CR added to conventional asphalt materials penetration, ductility and phase angle of conventional asphalt decreases, whereas softening point, elastic recovery, viscosity, complex modulus and rutting of conventional asphalt increase with addition of CR (Cong. *et al*. 2013, Weidong, 2007 and Thodesen, 2009) [16, 3, 2]. CR can be utilized in HMA concrete using two different processes (wet and dry) (Hassan and Airey, 2014) [8]. In wet process fine size rubber is blended with hot bitumen to produce rubberized bitumen before blended with aggregate, where as in dry process relatively coarse sized CR substitutes a portion of the mix aggregate causing the rubber to function essentially as an elastic aggregate within the mixture and intended to carry stresses induced by the traffic (Rahman, *et al*. 2010) [10].

In wet process, the asphalt binder rheological properties can be modified much effectively than the dry process, as the crumb rubber particles directly interact with it (Moreno, *et al*., 2013) [14]. Although its consumption of large waste rubber, dry process (partial replacing of aggregate with CR) made CR modified mix showed less performance than conventional and wet process (partial replacing of bitumen with CR) originated mix. One of the major difficulties of CR modified mix is their continuing loss of cohesion resulting in detaching of aggregates and lower durability (Stempihar, 2018) [18]. Due to rapid increase in urbanization there is increase in number of vehicle near future and consequently tremendous number of discarded tire rubber expected to be produced in Ethiopia (Kotresh and Belachew, 2014) [11], waste tires are distributed almost everywhere commonly along road side, around garage public and private working compound and home with a little service, but mostly disposed as useless waste. However despite the increase number of waste tires in Ethiopia the application of waste crumb rubber for pavement modification is uncommon and only a few researches were recently conducted on this area using the wet process and Marshal Mix design method.

General objective

The main objective of this study is to conduct a laboratory-based research study that evaluates the performance of hydrated lime pre-treated crumb rubber modified asphalt concrete using superpave mix design system.

Method

This section deals with sample source, material collection, estimation of the asphalt performance grade, conduct quality test for Virgin aggregate, and standard and techniques used for material characterization, and mix design procedure.

Sampling and Data Collection

Bitumen binder with penetration grade of 80/100 and coarse and fine aggregate was obtained from Addis Ababa City Roads Authority batching plant located around Akaki Kality Sub - City. Appropriate sample of fine waste CR was collected from bridge stone tire retreading factory in Addis Ababa. The big size and any debris from the collected CR was manually removed by hand and separated by sieving. The size of crumb rubber used for this study was less than 1.18 mm. Also 2.5% total aggregate weight of hydrated lime (HL) was used for pretreating CR. Gradation of aggregate was done by wet sieve analysis to separate the particle less than 75 micrometer, blend aggregate was prepared and 12.5 mm nominal maximum aggregate size (see Figure 1) was selected that satisfy the superpave specification or requirements of HMA.

Sample size and sampling techniques

For control mix 0% HL and 0% CR was used, modified mix specimens were prepared by adding 1, 3 and 5% of CR by total weight of aggregate with and without HL. The optimum content of 2.5% hydrated lime with total weight of aggregate which demonstrated a significant enhancement on the mechanical property and resistance of the mixture to rutting, moisture damage and fatigue cracking was selected for this study for pretreating CR. A total of 70 gyratory compacted specimens with different height based on specification of each test were prepared including OBC determination, control mix and modified mix performance tests and 14 slab compacted specimens (300*400*50mm) were produced using electro- mechanical slab compactor for rutting test.

Fig 1: Aggregate from stockpile and blend aggregate prepared in lab

Sample preparation using superpave mix design

Careful material selection and volumetric proportioning is the primary approach in superpave mix design. First selection of appropriate binder performance grade (PG) meeting AASHTO M-320 requirements is undertaken. Secondly, a combined aggregate with a nominal aggregate size in the range of 4.75 -
19.0 mm is taken. The third step is the selections of design binder content by using superpave gyratory compactor. Finally, moisture sensitivity of the asphalt is evaluated in accordance with AASHTO T283. The asphalt concrete mix (control and modified) performance was also determined using appropriate asphalt pavement tester.

Control mix

A mixture of asphalt binder, coarse and fine aggregate without addition of modifier is a control asphalt concrete mixture for this study. Initially aggregates was separately heated at temperature of 165 °C for overnight, the binder also heated at 160 °C for 2 hours before mixing with aggregates. Five asphalt binder contents 4.80, 5.05, 5.55 and 6.05% of total mix were selected to determine optimum bitumen content. Several trial mixes were prepared by using proposed binder content. The mix was set for short term aging of two hours at a temperature of 150 °C before compaction. Selection of design asphalt binder content was obtained based on 4% air voids specimens at design number of gyration (N, design).

Crumb rubber modified mix

The CR modified asphalt concrete mix of this study was divided into two, i.e CR mix with HL and without HL. For CR modified mix without hydrated lime pure CR mass was used and primarily mixed with dry aggregate partially replacing aggregate size less than 1.18 mm. Percentage crumb rubber used was 1, 3 and 5% (by total dry aggregate weight). The bitumen content used to prepare CR modified mix was 5.5%, 6.2% and 7.0% for 1, 3 and 5% CR respectively. Then aggregate - crumb rubber mix was heated with a temperature of 165 °C. Then heated bitumen added on it to prepare the intended mix, this is applied for each CR percentage. High- speed automatic laboratory mixer was used to carefully blend the mixture for 5 minutes. For CR with hydrated lime mix, first CR was blended thoroughly with 2.5% HL in dry condition as shown on the Figure 2, this blend was added in to automatic mixer and heated with 165 °C for one hour, then about 20% of corresponding heated bitumen was added and mixed with CR- HL blend, this is intended to create a coat between CR and HL, then heated aggregate and remaining 80% bitumen was added, finally the mixture was properly mixed for 5 minutes by automatically laboratory mixer with the same temperature. This is applied for each crumb rubber percentage to be used. In all mix type one mix was prepared to determine the maximum specific gravity (AASHTO T 209). Two mixes was prepared for gyratory compaction (AASHTO T 312). See Figure 3. Similar procedure was applied to prepare mix and produce specimen for rutting test using electromechanical slab compactor as shown on Figure 4.

Fig 2: CR and HL blending process

Fig 3: Specimen preparation using Automatic Laboratory Mixer and Superpave Gyratory Compactor

Fig 4: Specimen preparation using Electromechanical Slab Compactor for rutting test

Asphalt concrete performance test Indirect Tensile Strength Test

The indirect tensile strength of HMA is very important parameter since it highly correlates with fatigue cracking and permanent deformation (rutting) of the bituminous mixture. Indirect Tensile Strength (ITS) test has been used broadly in flexible pavement design. Currently the most commonly used test method for evaluating moisture susceptibility of asphalt mixes is the SHRP‟s Superpave system adopted AASHTO T 283-03 method entitled as: Resistance of Compacted Bituminous Mixtures to Moisture Induced Damage““ the Modified Lottman test, AASHTO T 283, has been shown to be reasonably reliable and has widely gained recognition in the paving industry and was used for this study as well. The test result was reported as the ratio of tensile strength of the conditioned subset to that of the unconditioned subset. This ratio is called the “tensile strength ratio” or TSR. Superpave requires a minimum TSR of 80 percent. Lower values are indicative of mixtures that may exhibit stripping problems after construction.

Rutting test using Double Wheel Tracker

Permanent deformation or rutting is the accumulation of small unrecoverable strain caused by consolidation and/or lateral movement of the HMA pavement under repeated traffic load and high temperature. The Double Wheel Tracker developed in Italy by Controls Group was used for this study to determine the rutting performance of all mix by using standard procedure on AASHTO T 324 (see Figure 5). In the standard test submerged specimens compacted using multi slab electromechanical compactor to a 7 percent air voids and a rubber wheel dimension of 400* 300mm with an applied load of 705 N was used.

Fig 5: Double Wheel Track (DWT)

Indirect Resilient Modulus Test

Resilient modulus or dynamic stiffness evaluates the performance of compacted mix to recover under repeated dynamic load with constant compressive stress without the sample reaching failure conditions (Hassan *et al.*, 2019) [7]. It measures the load-distribution ability of the bituminous layers; these forces may be responsible for fatigue cracking, the test is conducted in very short time and non-destructive (Mashaan *et al.*, 2013) [13]. In this study indirect tensile resilient modulus test was conducted using 15 KN capacity Universal Testing Machine (UTM) as shown on Figure 6. The test was performed in accordance with ASTM D 4123-1987 with controlled stress mode. The following test parameters were used:

- Constant load pulse set to 10 to 50% of ITT
- Test temperature 25 °C and 40 °C
- Load rise time set to 125 ms
- Pulse repetition periods of 1000 ms
- Peak recoverable horizontal deformation was set to 5 µm

Actuator Load cell

composed of a semi-sinusoid completed by a different curve that represents the unloading phase was selected, loading rise time set to 100 ms with a rest period of 400 ms. The stress amplitude was kept constant and corresponding deformations were recorded at different times. The load was applied until the sample fractured along the vertical diameter.

Specimen LVDT-1 LVDT-2

Result and Discussion

Analysis and interpretation of bitumen binder

As per the test result bitumen binder collected for this study has a specific gravity of 1.03 g/cm3, flash point 283 °C and 87 dmm of penetration. The physical properties of bitumen binder were as summarized on the Table 1, however, the conventional

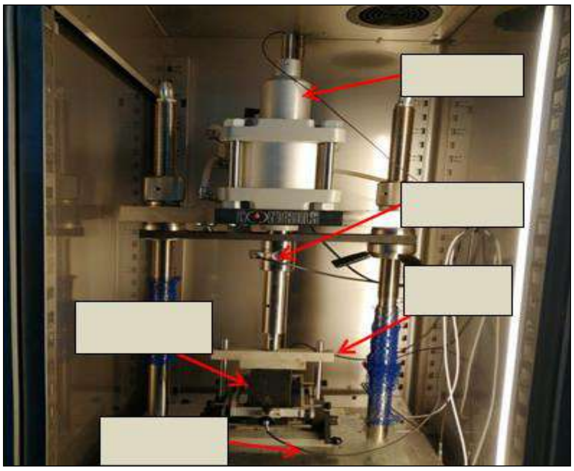

Fig 6: Universal Testing Machine (UTM)

Indirect Tensile Fatigue Test

One of the main distresses in asphalt pavements is the fatigue failure of the asphalt pavement, which is driven by the loading repetition. Universal Testing Machine (UTM) as shown on Figure 6 was used to determine the fatigue life characteristics of control as well as modified mix using AASHTO TP8-94 standard test method. The test was conducted at two different temperatures (25 and 40 °C), haversine loading pattern test such as penetration couldn`t related to the field, as a result further experiment was performed on the same bitumen binder to determine the rheological property.

Table 1: Conventional test results for bitumen

Test Conditions	Unit	Result	Specification
Penetration grade test at 25 °C	d_{mm}	87	80 min, 100 max
Flash point	°C	283	225 min
Specific gravity at 25 °C	g/cm^3	1.025	10.1 min

Superpave Performance Grade

The viscoelastic material property of binder significantly affects its properties depending on working environment and loading condition. Superpave mix design system uses the most updated testing method to determine highly dependency of bitumen on temperature. In this study bitumen binder predetermined penetration grade of 80/100 was also used to check the PG. Complex modulus (G*) and phase angle was used as a major parameter to determine PG of the current binder by performing DSR test. The experimental results obtained for original and RTFO aged indicates that the bitumen binder fulfills the minimum AASHTO M-320 criteria of complex modulus to phase angle ratio at frequency of 10 rad/s as shown on Figure 7. The minimum G*(complex modulus) for original binder should be 1 kPa to assure against tenderness mixture while for aged binder the minimum is 2.2 kPa to indicate the resistance of permanent deformation.

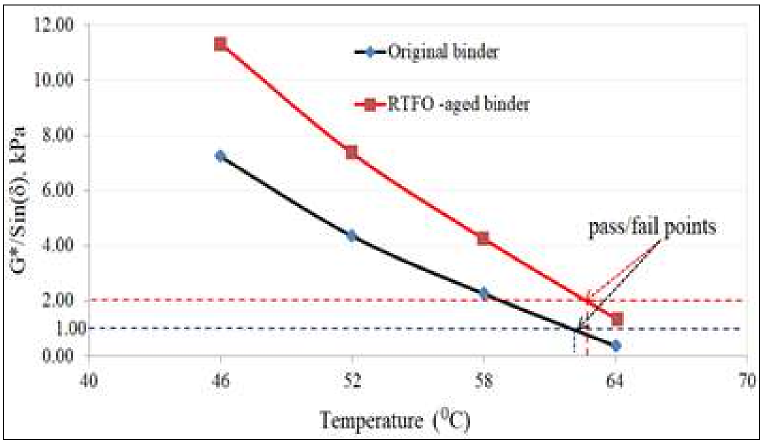

Fig 7: Performance Grade test result for bitumen

The same bitumen binder was checked for the performance grade varying temperature from 46 to 64 °C with 6 °C increments. The bitumen binder performs well and result indicates pass for 46, 52 and 58 °C, but value of complex modulus (G*) less than 1 kPa for original binder and below 2.2 kPa for RTFO aged after a temperature of 61.7 °C and 62.8 °C for original and RTFO aged binder respectively. Area of the study which is Addis Ababa has a consecutive seven day hottest average air temperature of 27.7 °C with standard deviation of 0.71 °C, for which the seven day average maximum pavement temperature calculated as 52.02 °C with 98% reliability. From linear viscoelastic characterization and following the Superpave performance grade system, the equivalent PG for 80/100 penetration bitumen of this study was found as PG 58-LL, it was used to represent bitumen binder used for all asphalt concrete mix of this study.

Aggregate property test results

For this study physical properties of aggregates were selected based on superpave mix design criteria as per Super-pave Series No. 2 (SP-2, 1996). As per SHRP, aggregate consensus and source properties are a function of traffic level and examined accordingly for a standard traffic of 10 million ESAL. Physical property test results are as presented on the Table 2.

Table 2: Physical property test results for aggregate

Property	Standard	Result	Specification
Los-Angeles Abrasion (%, max)	Ashto T 96-94	14	< 35 to 45%
Soundness (% max)	Aashto T 104	15	< 20%
Sand Equivalent,%	Aashto T 176	53.6	> 45
Water absorption (%)	Aashto T 85	0.51	
Bulk Specific Gravity	Aashto T166	2.736	

The gradation of an aggregate is the most important property that an aggregate can contribute to the performance of an asphalt pavement. The aggregate used for the mix design should fulfill the volumetric properties. After washed sieve analysis the percentage of aggregate passing a sieve size is plotted against the sieve opening size raised to the 0.45 power. For the present study single design aggregate was determined from trial percentage and mathematical blending of three different aggregate designated as A, B and C. From three curves the trial blend or combination meeting the criteria for 12.5 mm nominal maximum aggregate size was selected by trial percentage and mathematical blending. The design single aggregate blend meeting the Superpave gradation criteria was obtained by combination of 40% aggregate A, 32% aggregate B and 28% aggregate C by total mass of dry aggregate used for asphalt mix (see Figure 8).

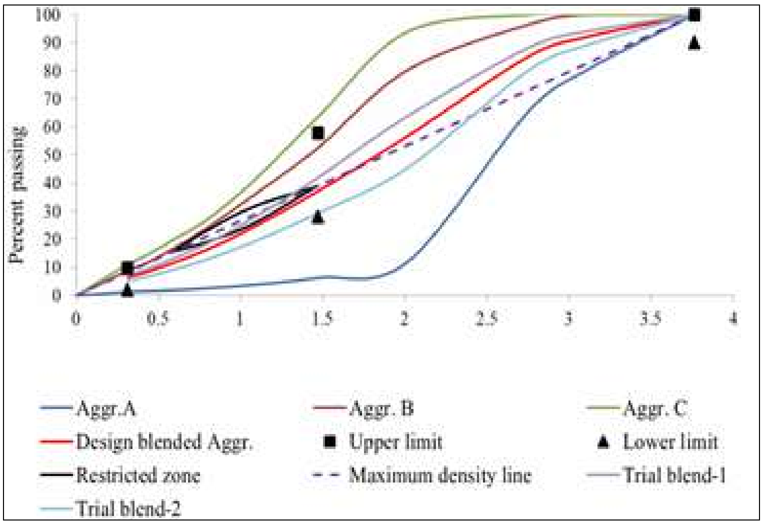

Fig 8: Aggregate gradation curves

Volumetric properties and selection of design bitumen binder

Two specimens are compacted using superpave gyratory compactor for the selected trial blend at four different bitumen binder contents and mixture properties are evaluated for each, the gyratory densification data was recorded at Nini (8 gyrations), Ndes (100 gyrations) and Nmax(160 gyrations). The response of the mixture's compaction and volumetric properties such as% Va, % VMA, % VFA and dust proportion was was as presented on Table 3. The value of design binder content is 5.0% corresponding to 4% air voids at 100 design gyrations for 10 million ESAL.

Table 3: Volumetric properties for trial bitumen binder

% Bitumen	% G_{mm} at N_8	% G_{mm} at N_{96}	% G_{mm} at N_{152}	$V_{a\%}$	VMA,%	VFA,%	DP
4.8	83.6	94.8	96.4	5.2	15.89	67.28	1.06
5.05	84.7	96.1	96.5	3.9	16.47	76.31	1.01
5.55	86.3	96.8	98.08	3.2	16.8	80.95	0.92
6.05	87.8	97.9	98.95	2.1	17.45	87.96	0.84

It was also observed that other mix properties were found to satisfy the Super-pave mix design criteria. The results of Superpave mix properties at design binder content of 5.0% are given in Table 4.

Table 4: Superpave criteria for selection of optimum bitumen content

Mixture properties	Results	Superpave criteria
Va	4	4
VMA	16.3	12min
VFB	73.5	65-75
Dust proportion	1.03	0.6-1.2
% Gmm at Nini = 8	86.6	< 89
% Gmm at N max = 160	95.7	< 98
Gmb	2.432	

Indirect Tensile Strength test result

In total 7 different types of mixtures were examined. The Indirect Tensile Strength (ITS) and TSR value for control and CR modified mixtures with and without HL was presented on Figure 9. The ITS for control mix was obtained as 1123 kPa and 972 kPa for unconditioned and conditioned case respectively. Except for 1% CR mix with and without HL and 3% CR with HL, decrease in ITS value than control mix was observed for the rest mix. The highest value of ITS which is 1251 kPa was obtained with 1% CR + 2.5% HL unconditioned case. The smallest value of ITS which is 585 kPa was found using unmodified 5% CR for conditioned case.

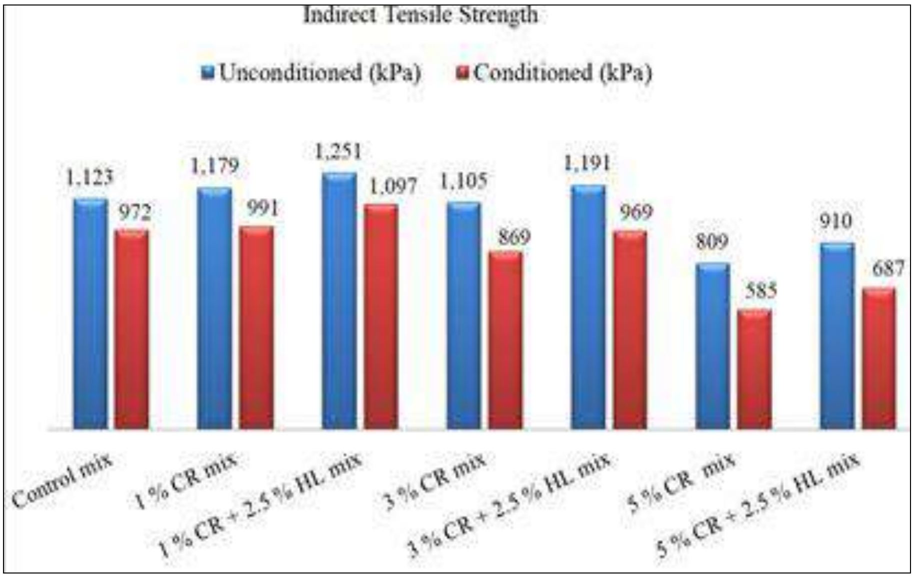

Fig 9: Indirect tensile strength (conditioned and unconditioned) of the mixtures

As per the result unconditioned ITS for all mix exceeded conditioned mix with TSR value > 70%, all mix fulfilled the minimum TSR value of 80% set by superpave excluding three mixes (3% CR mix without HL and 5% CR mix with and without HL). Indirect tensile strength of CR mix increased with addition of HL regardless of conditioning. This is mainly because hydrated lime improved bond between three ingredients (aggregate-CR-bitumen) because of its high adhesive properties which gave more strength to mix (Arabani, *et al.*, 2017). Therefore as per the ITS test result 3% CR can be an optimum content for moisture susceptibility of asphalt concrete.

Rutting test result

Rate of rutting and final deformation of all mix after 10000 cycles or 20000 wheel passes was recorded by DWT computer to evaluate characteristics of mix at 60 °C. As per the DWT test result, there is no sudden change in the rate of deformation for all mixes (see Figure 10). The rate of rutting and final deformation was 0.63 mm/hr. and 3.51 mm for control mix respectively, the value increased with percent crumb rubber with highest rate of rutting and final deformation of 1.22 mm/hr and 6.78 mm respectively, on the other hand decrease in rate of rutting and final deformation after 20000 wheel passes was obtained using HL with the smallest value recorded at 1% CR with HL. The use of fine sized crumb rubber in dry process has enhanced the rutting performance of asphalt mix for 1% and 3% CR content due to combined effect of binder modification and formation of elastic aggregate, i.e higher number of cycles needed to be applied to the crumb rubber modified mixture for it to reach the same target rut depth as the conventional mixture.

As per the test result blending of CR with hydrated lime lowered the final rut depth for all mixes of this study.

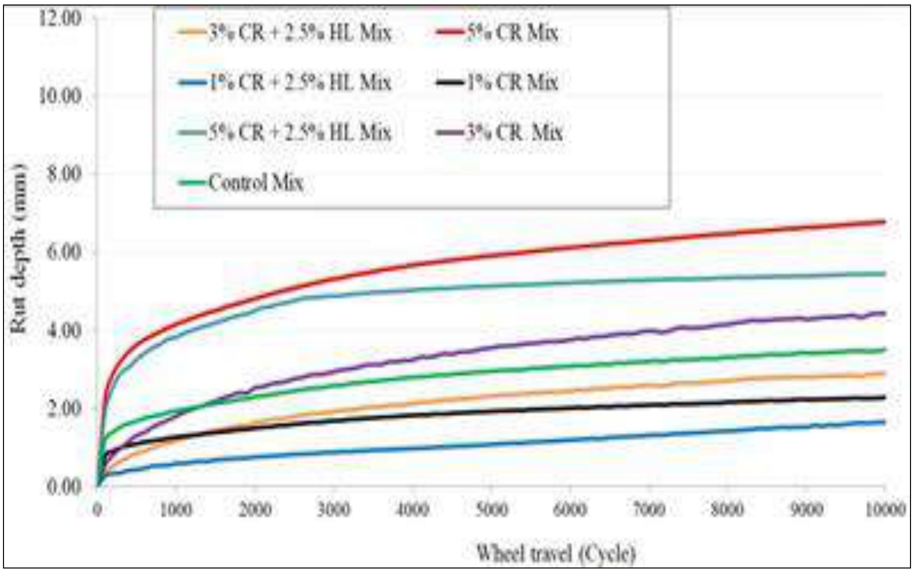

Fig 10: Double wheel track rutting test result for all mix

The strong bond created between aggregate, bitumen and CR due to high binding properties of hydrated lime which results stiffer mix, however the improving effect decrease with increase in% CR due to high flexibility of mixes for additional CR. The disadvantage of CR modified mix is its difficulty during compaction, because it expands and stacks on mould during extruding of specimen, also the specimen is highly flexible regardless of addition of hydrated lime. In this study modified mix containing 1% and 3% CR with HL performed better in rutting resistance compared to conventional mix for the same traffic loading and cycles; addition of HL has also positive effect on rutting resistance. It can be said that inclusion of fine rubber as additional aggregate in dry process was found to increase resistance to permanent deformation.

Indirect Tensile Resilient Modulus test result

The ITRM test was performed on specimen with 150 mm diameters and 65 mm average thickness, the test temperature was at 25 °C and 40 °C. Increase in resilient modulus than control mix was observed excluding using 3% CR without HL and 5% CR with and without HL at a test temperature of 25 °C (sees Figure 11). However at 40 °C higher resilient modulus than control was obtained for all mix except 5% CR with and without HL. As per the ITRM test results adding a larger amount of crumb rubber such as 5% in dry process decreased the resilient modulus of the mixtures regardless of temperature. On the other hand for all mixes containing a blend of CR and HL, an increase in resilient modulus observed. This is mainly due to excellent binding properties of hydrated lime which makes strong mix.

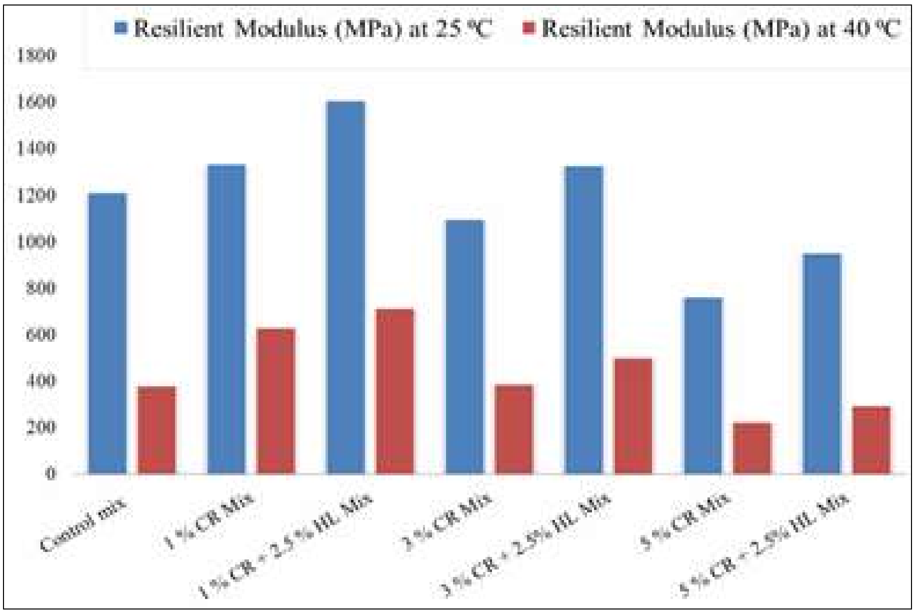

Fig 11: Resilient Modulus for all mix at 25 °C and 40 °C Crumb rubber service double functions, primarily

It act as portion of the aggregate component of the mix but exhibit greater elastic recovery characteristics. Secondly, they modify bitumen binder properties partially through a rubber-bitumen interaction. Another related function of adding crumb rubber in asphalt concrete mix had increased resilient modulus due to high elasticity as stated by many researchers (Xiao, *et al*,. 2009) [4]. For CR modified mix mostly the strain is recoverable indicating that the mixture‟s lower stiffness and higher flexibility under repeated traffic loading. In this case higher strain energy can be absorbed by CR and less stress on pavement surface. Asphalt mix modified with fine rubber had the highest modulus than coarse and medium size, which is supposed to have been caused by the rubber-bitumen interaction. An excellent bonding property of hydrated lime also further improved the CR mix in dry process and resulted strong mix (Takallou, *et al*. 1988) [9].

Indirect Tensile Fatigue (ITF) test result

Fatigue test procedure can be used to evaluate the relative performance of an asphalt concrete mix under repetitive dynamic load which is an input for estimating the structural performance in the road. The fatigue test result of all mix at temperature of 25 and 40 °C under 2500 N pulse repetitive load was as plotted on the Figure 12. The plot shows a number of pulses recorded when the specimen resilient modulus reduced to 50%, the test continued until the specimen fractured; during this condition a trend of rapid. The number of pulse repetition to cause failure of the control mix was obtained as 15,173 and an increase in load repetition that cause failure was observed with increase in CR mix than control mix except for 5% CR and 5% CR + 2.5% HL for both temperature. On the other hand decrease in number of load repetition to cause failure was observed with increase in temperature from 25 °C to 40 °C for control and all CR mix regardless of hydrated lime.

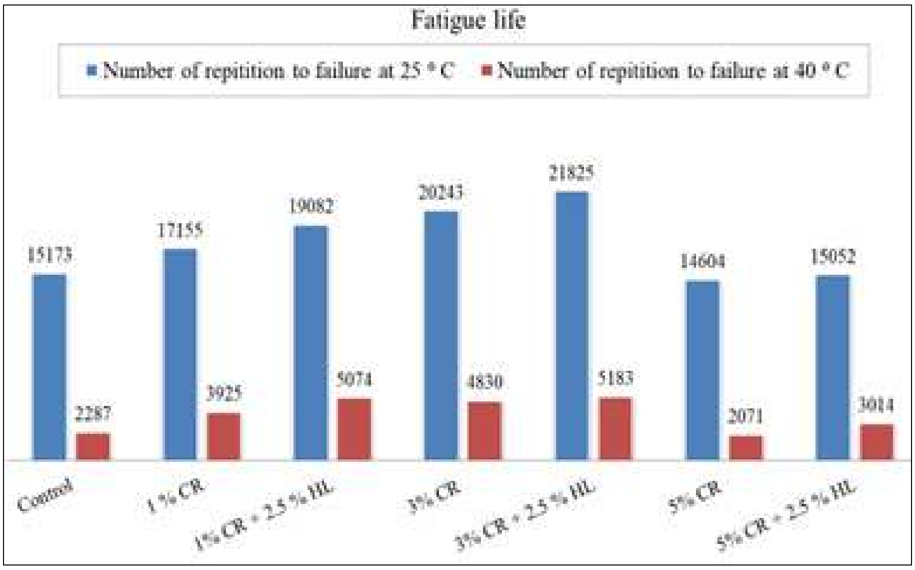

Fig 12: Fatigue Life for all mix at temperature of 25 °C and 40 °C

The fatigue life gets increased for CR mix containing HL than without HL due to high adhesive property of hydrated lime that created strong bond between aggregate-CR and bitumen (Kabir, 2008) [10]. On the other hand both resilient modulus and fatigue life value negatively affected by rise in temperature as result of viscoelastic property of bitumen binder which gets softer for high temperature, the effect is significant for high crumb rubber mix greater than 3% which consumes more bitumen and also high CR result in extremely flexible mix under loading.

Conclusion

Based on the test result the major findings of this study can be concluded as follow:

- According to DSR result the performance grade of bitumen binder for all mixes was found as PG 58-LL
- As per ITS test result, all mix fulfilled the minimum TSR value of 80% set by superpave, except 3% CR mix without HL and 5% CR mix with and without HL. TSR value of CR mix was improved with addition of HL.
- The rate of rutting and final deformation was 0.63 mm/hr. and 3.51 mm for control mix respectively, the value increased with percent CR on which highest rate of rutting of 1.22 mm/hr and final deformation of 6.78 mm found for 5% CR without HL.
- On the other hand decrease in rate of rutting and final deformation after 20000 wheel passes was obtained using HL with the smallest value recorded at 1% CR with HL.
- Increase in resilient modulus than control mix was found for all mix excluding 3% CR without HL and 5% CR with and without HL at 25 °C.
- Addition of high amount of CR such as 5% in dry process decreased the resilient modulus of the mixtures regardless of temperature. The resilient modulus for all mix get decreased with increase in temperature from 25 to 40 °C and, whereas the resilient modulus of CR mix improved with addition of HL.
- The increase in fatigue life than control mix was obtained with up to 3% CR replacement of aggregate for both temperature (i.e 25 °C and 40 °C). For further percent increment in CR the fatigue life decreased, this could be due to over flexibility of mix for additional CR.
- Furthermore the increase in temperature results in flexibility of bituminous mix due to viscoelastic property of bitumen.

Recommended Future study area

Future likely research can be very comprehensive given different bitumen binder, aggregate crumb rubber and also design method. The indirect tensile test underestimates the resilient modulus and fatigue life of an asphalt concrete mix, future study using more advanced laboratory equipment with different pulse load, loading duration and temperature will be also appreciated.

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