International Journal of Research (IJR) Vol-1, Issue-6, July 2014 **ISSN 2348-6848**

Fatigue Behavior of Chemically Treated Bituminous Concrete Mix

Anil Kumar S[1] and Vijaya Kumar H A[2]

[1]PG Student, Dept. of Civil Engineering, GEC, HASSAN
VTU, Belgaum. Karnataka, India, [1]E-mail:anilsullia19@gmail.com
[2]Associate Professor., Dept. of Civil Engineering, GEC, HASSAN

Abstract:

. Design, construction and maintenance of roads are given prime importance in the development of the infrastructure of a country. High traffic intensity in terms of overloaded commercial vehicles, significant variations in daily and seasonal temperature and extreme environmental conditions are responsible for early development of distress symptoms like rutting, cracking, bleeding, and shoving and moisture damage of bituminous surfacing. The development of distresses in the pavements with the conventional mixes reveals the need for use of improved materials and techniques for design specifications based on performance tests. The performance tests are those tests which simulate the field conditions and measure the response of the bituminous mix in terms of stress, strain and deflection.The present investigation was carried out to propose the use of chemical. Chemical were mixed to bituminous concrete by wet process to get modified mix. Marshall Method of mix design was adopted to find out the optimum bitumen content. Marshall specimen were prepared for bitumen content of 5.0,5.5,6.0,6.5 and 7.0 per cent by weight of aggregate with 0.1% of chemical by weight of bitumen. Bulk density, Marshall Stability, Flow, Air Voids(Vv), Voids in Mineral Aggregates (VMA), voids filled with bitumen (VFB), Retained stability, Indirect Tensile Strength and Tensile Strength Ratio (TSR), Stripping, Fatigue life and deformations were determined and compared with neat bituminous concrete mixes. The Marshall Stability, Retained stability, Indirect Tensile Strength (ITS), Tensile Strength ratio, fatigue life values for modified mix was increased, similarly stripping of bitumen and rutting deformation decreased considerably as compared to conventional mix.

Keywords: Marshall Stability, Air Voids(Vv), Voids in Mineral Aggregates (VMA), voids filled with bitumen (VFB), Retained stability, Indirect Tensile Strength, Tensile Strength Ratio (TSR), Stripping, Fatigue life.

1. INTRODUCTION

Fatigue cracking, called alligator cracking and associated with repetitive traffic loading, is considered to be one of the most significant distress modes in flexible pavements. The fatigue life of an asphalt pavement is directly related to various engineering properties of typical hot mix asphalt (HMA).

The complicated microstructure of asphalt concrete is related to the grada-tion of aggregate, the properties of aggregate-binder interface, the void size distribution, and the interconnectivity of voids. As a result, the fatigue property of asphalt mixtures is very complicated and sometimes difficult to predict. Understand-ing the ability of an Asphalt pavement to resist fractures from repeated loading condition is essential for developing superior HMA pavement designs. Previous studies have been conducted to unders-tand the occurrence of fatigue and how to extend pavement life under repetitive traffic loading. However, reaching a better understanding of fatigue behaviour of asphalt pavements continues to challenge researchers worldwide, particu-larly as newer materials with more complex properties are being used in the field.

Bituminous Mixes are most commonly used all over the world in pavement construction. About 98 % of the paved roads in India have flexible paveme-nts,within which are included surfacing of various types and thickness. Bituminous surfaces properly constructed and maintained are quite satisfactorily under normal conditions. Various studies were under taken to improve the strength characteristics of bituminous surfaces. They are by modifying grade, aggregate gradation mix proportion, and adding different additives to the bitumen. For special applications where traffic is extremely heavy, stiffer mixes are required which can have larger fatigue life and more resistance to pavement deformation. It has been seen from various literature reviews that strength of paving mixes can be enhanced by using modified binders. Such binders also improve temperature susceptibility and help eliminating some common problems like bleeding of binder during peak summer temperature as well as stripping of aggregates in moisture prone areas. Keeping this facts in minds it was felt that efforts can be made to use some modifier material or bitumen additive. This scheme is an attempt to incorporate the bitumen additive "chemical" in (60/70) VG 30 grade bitumen and study the various parameters of bitumen and bituminous mixes.

1.1 CHEMICAL MODIFIED BITUMEN.

Chemical nanotechnology allows water proofing of soils and aggregate surfaces permanently and acts as a bonding agent to asphalt. This is the most significant develop--ment in the last 50 years which will improve the quality of road building with reduced maintenance cost. The technology addresses the critical subsurface drainage problems in road making and repairs.

It also addresses the following issues:

- Zycosoil is a water soluble reactive organosilane compound and offers:
- Permanent water repellent nano layer on all types of soils, aggregates and other inorganic road construction materials.
- Reaction leads to permanent nano siliconization of the above surfaces by converting the water loving silanol groups to water repellent siloxane (Si-O-Si) bonds.

1.1.1 Technical specifications

- Colour: Clear to pale yellow
- Solid content: 41 + / - 2 %

- Solvent: Ethylene glycol
- Flash Point: 80^0 C
- Viscosity (25^{o}C): 200-800 cps
- Solubility: Forms water clear solution and soluble in asphalt.

1.2 OBJECTIVES OF THE PRESENT WORK

The objectives of the present work involves

1. Determination of various physical properties of the bitumen modified bitumen and aggregates used for Bituminous Concrete (BC) mix.
2. Marshall Specimens were prepared by varying the binder content. These specimen are analysed for the Marshall Stability, Marshall Flow, Retained Marshall stability index, Density, Voids in mix, Voids filled with bitumen and stability-flow. The Optimum bitumen Content for the mix with and without chemical is determined.
3. The laboratory performances of the Bituminous Concrete (BC) mixes are checked by moisture susceptibility, rutting and repeated load tests. Moisture susceptibility tests include the evaluation of Indirect Tensile Strength, Tensile strength ratio. The rutting studies include determination of rutting depth by using Immersion Wheel Tracking Device (IWTD). Repeated load tests are carried out to determine resilient modulus, fatigue life using accelerated loading instruments. Tests are carried out on Marshall Specimens with and without chemical at unsoaked condition for different stress levels and compared

2. LITERATURE REVIEW

Audrey R. Copeland (2007) [1] flexible pavement failures are typically classified as stability (load) or durability related failures. Moisture damages are signified by loss of strength or durability in a flexible pavement due to the effects of moisture and may be measured by the bituminous mixture's loss of mechanical properties. The integrity of a bituminous concrete pavement depends on the bond between aggregate and binder. Moisture in the form of liquid or vapour can degrade this bond and lead to the first stage of failure which is deterioration of the binder-aggregate bond or "stripping" followed by the second stage which is premature failure of the pavement structure. Moisture damage is a complex process that is influenced by material factors, their combinations, construction and external effects such as environment and loading. These factors influence physical properties of a bituminous mixture such as air void content, mechanical strength and stiffness.

Kandhal, P.S.et al. (2008) [2] the most common water movement is upward from under the pavement by capillary action, this is due to poor sub base or sub grade that lack proper characteristics such as permeability that can lead to improper drainage. Thus, the sub surface is saturated with moisture that can migrate upwards to the asphalt-aggregate mixture temperatures are the critical factors affecting the performance of the asphalt mix in terms of both fatigue and rutting.

Shivangi Gupta et al. (2009) [3] Showed the superiority of SBS modified mixes over the conventional mixes. Thus polymer modified mixes may be recommended for national highways where traffic volume is substantially high. The strength parameters like tensile strength, Marshall Stability values of the SBS modified mixes were higher by 21 percent and 25 percent than conventional mixes. Higher tensile strength ratio is observed polymer modified mixes which indicate better cohesive strength of these mixes as compared to conventional mixes. An increase of 2 to 2.5 times in resilient modulus of polymer-modified mixes was observed as compared to conventional bituminous mix. The fatigue life of SBS Modified mix was 2.1 to 2.4 percent higher than the conventional mix. For the constant number of cycles, at the constant temperature, crack length was higher for conventional mix than SBS modified mix.

Sangita et al. (2011) [4] the effect of waste polymer modifier (nitrile rubber and polythene) on various mechanical properties of the bituminous concrete mixtures was evaluated. Various test results on 60/70 bitumen and aggregate satisfied the specified limits. Marshall Stability and retained stability tests confirmed the optimum WPM content to be 8%. The WPMB mix containing 8% WPM showed significant improvements in various properties of the bituminous concrete mixture. The higher values of Marshall Stability and retained stability indicated increased strength and low moisture susceptibility.

Taher M.A. Al-ani (2009) [5] the study shows that adding the Rubber-Silicone to asphalt binder have the following effects on the performance of asphalt mixture:

Increasing the Marshal stability, air voids, and reducing the flow and bulk density compared with the original mix. Increasing the flexibility properties of the mix and this appears from reducing the permanent deformation at test temperature (60^{0}C), the reduction percentage is about (30% to 70%) compared with the original mix without adding Rubber-Silicone. Study the effect of Rubber-Silicone on the performance of asphalt mixture at low temperature.

Sandhya Dixit (2013) [6] showed that the properties of bitumen such as penetration softening point improved with the addition of the waste fibre. There is a significant decrease in penetration values for modified blends, indicating the improvement in their temperature susceptibility resistant characteristics. From the Marshall Test results, it is concluded that the Marshall Stability value increases with an increase in bitumen content from 5% to 5.5% then it decreases. Also higher value of Marshall Stability was found for a modified mix as compared to an unmodified mix.

Ashok Pareek et al. (2012) [7] the results of the experimental study showed that performance of Polymer Modified Bitumen is better than that of conventional bitumen (60/70) which shows, Polymer modified bitumen is found to have a high elastic recovery, better age resistance properties, Marshall Stability of the mix increased by 27%, rutting resistance, indirect tensile strength and Resilient modulus of the polymer modified bitumen is significantly higher.

3.MATERIALS AND METHODS

3.1 TYPES OF MATERIALS SELECTED

3.1.1 Bitumen

The bitumen used in this study was tested in the laboratory. The physical properties such as Penetration, Ductility, Softening Point and Specific Gravity were evaluated and the results are tabulated in Table 3.1.

Table 3.1: Physical Properties of (60/70) VG 30 Penetration Grade Bitumen

Property Tested	Test Method	Results
Penetration (100 gram, 5 seconds at 25^{0}C) (1/10th of mm)	IS 1203-1978	63
Softening Point , ^{0}C(Ring & Ball Apparatus)	IS 1205-1978	49
Ductility at 27^{0}C (5 cm /minute pull), cm	IS 1208-1978	90
Specific Gravity	IS 1202-1978	1.00
Flash point, ^{0}C	IS 1448 (P:69)	220
Fire Point, ^{0}C	IS 1448 (P:69)	250

3.1.2 Aggregates

Table 3.2: Properties of Aggregates

Property Tested	Test Methods	Results	MoRT&H (2001)
Aggregate Impact Value	IS:2386 (IV)	23.5%	24% maximum

Los Angeles Abrasion Value	IS:2386 (IV)	14.2%	30% maximum
Water Absorption Value	IS:2386 (III)	0.84%	2% maximum
Specific Gravity	IS:2386 (III)	2.69	2.5-3.0
Combined Flakiness and Elongation Index	IS:2386 (I)	28.2 %	30% maximum

Aggregates having sufficient strength, hardness, toughness, specific gravity and shape are chosen. The properties of aggregates used in the present study are tabulated in Table 3.2.

3.1.3 Aggregate Gradation Adopted

Table 3.3: Aggregate Gradation of Bituminous Concrete Mixtures Selected

Grading	1	
Nominal Aggregate size	19mm	
Layer Thickness	50mm	
IS Sieve (mm)	Cumulative % by weight of total aggregate passing	Adopted
26.5	100	100
19	79-100	90
13.2	59-79	69
9.5	52-72	62
4.75	35-55	45
2.36	28-44	36
1.18	20-34	27
0.6	15-27	21
0.3	10-20	10
0.15	5-13	9
0.075	2-8	5
BitumenGrade(pen)	60/70(VG30)	

Aggregate grading that satisfied the requirement of the Ministry of Road Transport and Highways (MoRT&H, 2004) specification for midpoint gradation for Grading-I of Bituminous Concrete were selected and are tabulated in Table 3.3.

3.1.4 Modifier

Table 3.4: Properties of Chemically Modified Bitumen

Property used	Percentage 0.1% chemical addedto 60/70) VG 30 Grade Bitumen	Requirements of (as per IRC: SP:53-2010)	Test Method
Penetration at 25^0 C	55	50 to 90	IS 203-1978
Softening point (^{0} C)	56	55min	IS 1205-1978
Ductility (cm)	Above 100	+40	IS 1208-1978
Specific Gravity	1.03	-	IS 1202-1978

The chemical used in the present study is Zycosoil supplied by M/S. Zydex Industries.

3.1.5 Mineral filler

The filler material used in the study is stone dust and cement. Of the 5 per cent filler, 3 per cent stone dust and 2 per cent cement is used.

Table 3.5: Mineral filler Gradation for Bituminous Concrete Mix

IS Sieve (mm)	Cumulative % passing by weight of total aggregate
0.6	100
0.3	95-100
0.075	85-100

3.2 DESIGN OF BITUMINOUS CONCRETE MIX

The properties of any bituminous mix like stability, bulk density, air voids, are mainly dependent on the gradation of aggregates, binder content and its type, the type of compaction and compaction temperature. Marshall's Method of mix design as per ASTM D-1559 was adopted for this study. The Marshall Test specimens were prepared by adding 5.0, 5.5, 6.0, 6.5, and 7.0 per cent of bitumen by weight of aggregates.

3.2.1 MARSHALL STABILITY TEST

The Marshall method uses standard test specimen of height 64mm and diameter 102mm.

The specimens are prepared by adopting a standard procedure for heating, mixing and compacting the mixture. Compaction is done by imparting 50 or 75 blows on each side of the specimen. 50 blows are used for medium traffic roads and 75 blows are used for heavily trafficked roads. The specimen was kept in thermostatically controlled water bath maintained at 60 ±1^{0}C for 30 to 40 minutes. These are called unconditioned specimens. The principal features of the method are a density-voids analysis and a stability-flow test of compacted specimen and the specimen were taken out, placed in Marshall Test head and tested to determine Marshall Stability value which is a measure of strength of the mixture. It is the maximum resistance in kN. The volumetric properties of conventional bituminous mixes as well as chemical.

Table 3.6: Properties of Bituminous Concrete Mix to determine Optimum Bitumen Content using Marshal Stability without chemical

S. No.	**Property Tested**	**Bitumen content by the weight of aggregates**			
		4.5%	**5%**	**5.5%**	**6%**
1	Marshall stability (kN)	18.28	18.86	18.67	17.01
2	Flow value(mm)	2.11	2.28	3.07	4.08
3	Bulk Density (gm/cc)	2.392	2.393	2.392	2.391
4	Vv (%)	4.57	3.88	3.23	2.57
5	VFB (%)	69.28	74.59	79.42	84.03
6	VMA (%)	14.88	15.28	15.7	16.11
7	Marshall stability cond. (kN)	16.15	16.78	16.34	15.15
8	Retained stability(%)	88.36	88.93	90.6	89.05
9	OBC (%)	**4.96**			

Table 3.7: Properties of Bituminous Concrete Mix to determine Optimum Bitumen Content using Marshal Stability with chemical.

S. No.	**Property Tested**	**Bitumen content by the weight of aggregates**			
		4.5%	**5%**	**5.5%**	**6%**
1	Marshall stability (kN)	19.24	22.36	19.02	17.16
2	Flow value (mm)	2.11	2.24	3.4	4.25
3	Bulk density (gm/cc)	2.391	2.404	2.399	2.396
4	Vv (%)	4.65	3.77	3.30	2.79
5	VFB (%)	68.90	74.68	78.61	82.55
6	VMA (%)	14.95	14.88	15.45	15.95
7	Marshall stability cond.(kN)	18.08	21.63	17.45	16.59
8	Retained stability (%)	93.97	96.73	91.74	96.67
9	OBC(%)	**4.93**			

Table 3.8: Comparison of Volumetric Properties of BC Mixes with and without chemical using Marshall Test

Property Tested	**without chemical OBC**	**With chemical @OBC**	**Requirements of BC mixes (MoRTH,2001)**
Marshal stability (kN)	18.821	21.920	9
Bulk density (gm/cc)	2.392	2.402	–
Vv (%)	3.935	3.890	3 to 6
VFB (%)	74.160	73.870	65 to 75
VMA (%)	15.248	14.889	Min 14
Retained stability (%)	88.880	96.340	Minimum 75

Fig.3.1 (a-g) Comparison of Marshal Values of BC mixes (with and without chemical).

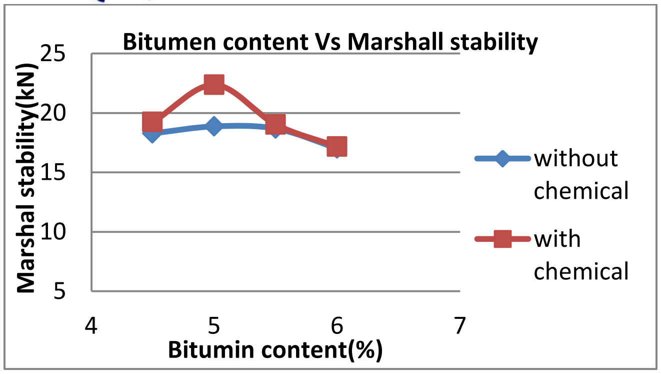

Fig.3.1 (a)

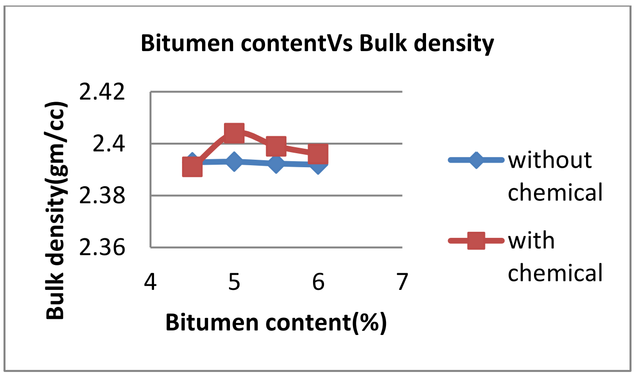

Fig.3.1 (b)

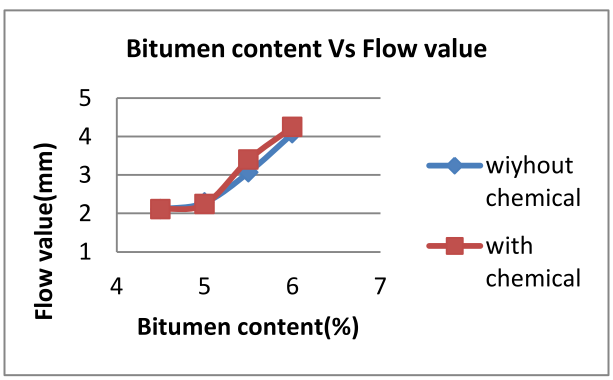

Fig.3.1(c)

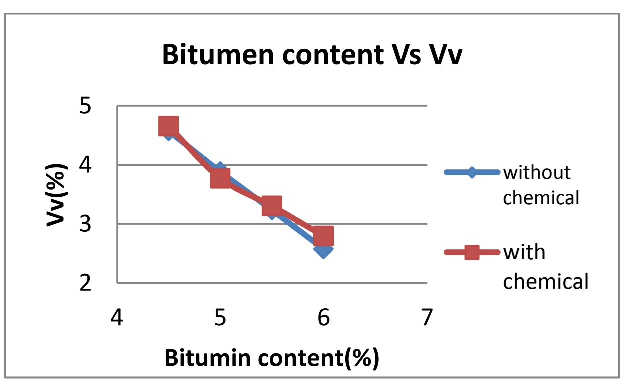

Fig.3.1 (d)

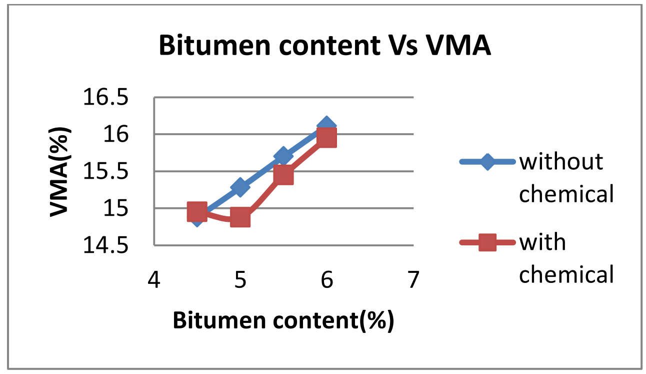

Fig.3.1 (e)

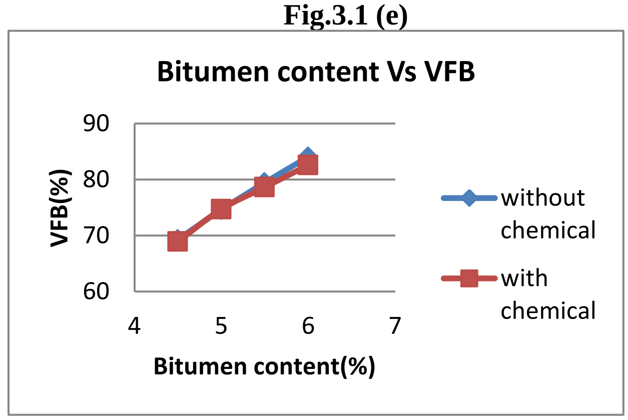

Fig.3.1 (f)

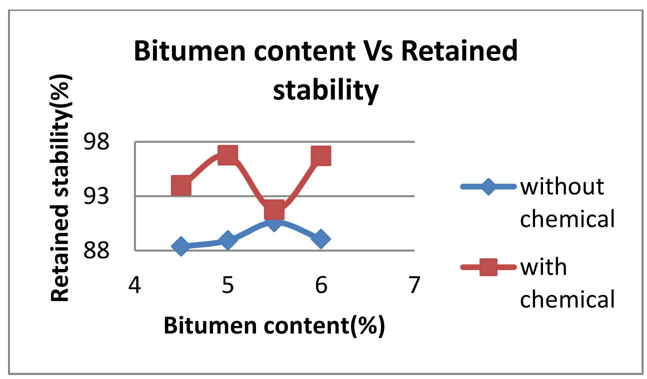

Fig. 3.1(g)

3.3 INDIRECT TENSILE STRENGTH (ITS)

The specimens were brought to temperature of 25 ±1^{0}C, by keeping them in water bath maintained at test temperature for 2 hours. These specimens are called as **unconditioned specimens.** The specimen were placed in plastic bags containing 10 ±0.5 ml of water and sealed and kept in freezer at temperature of -18 ±3^{0}C for 24 ±1 hours. The specimens were then kept in water bath for 24 ±1 hours maintaining 60 ±1^{0}C temperatures. This complete process is called freeze and thaw cycle. These specimens are called as conditioned specimen.

Table 3.9: Indirect tensile strength and tensile strength ratio for BC mix @ OBC

Sl. No	Bituminous concrete mix.	Indirect tensile strength(MPa)		Tensile strength Ratio (%)
		unconditioned	conditioned	
1	Without chemical	1.16	0.96	82.70
2	With chemical	1.28	1.18	92.18

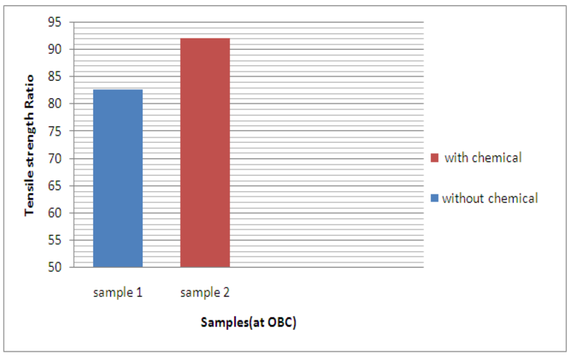

Fig .3.2 Tensile strength ratio with chemical and without chemical

3.4 RUTTING STUDIES

Rutting characteristics is studied using Immersion Wheel Tracking Device (IWTD). The wheel tracking device consists of a loaded wheel and a confined mould in which 600mmX200mmX50mm specimen of BC is rigidly restrained on all sides. A motor and a reciprocating device give the wheel to and fro travel of 600 mm. The stress that the wheel applied on the specimen is 0.68MPa. The depth of impression (or deformation) was recorded at mid-point by means of 2 LVDTs (Linear Variable Differential Transducers) fixed on either side of the wheel. The slabs are compacted with static compression machine to achieve a compaction level of 6-7% air voids in the mix. From the binder content versus air voids graph, the binder content corresponding to 7% air voids is found. Corresponding to this binder content, using the binder content versus unit weight graph, the unit weight is found. The aggregates required for the rutting sample is taken by measuring the required quantities according to the adopted gradation. The aggregates are heated to 160ºC and then the bitumen heated to 160ºC is mixed with the aggregate and chemical mix. This bituminous mix is compressed in a sturdy steel mould using a static compression machine to the required density and thickness. After 24 hours of casting the slab is placed in the machine and tested. The slab is subjected to reciprocating load repetitions for 10,000 passes and the depression on the beam surface is recorded. Water was applied externally to the specimen. Two samples, one without chemical and one with chemical content i.e. 0.1% by weight of the bitumen were prepared and tested. A plot of number of passes versus deformation in millimetre is plotted for both mixes.

Table 3.10: Rutting Specimen

No. of passes	Deformation (mm)	
	Without chemical	With chemical
0	0	0
1000	0.8	0.3
2000	1.9	0.8
3000	3.0	1.3
4000	3.7	1.8
5000	4.1	2.2
6000	4.5	2.5
7000	4.9	2.9
8000	5.2	3.0
9000	5.9	3.5
10000	6.7	3.8

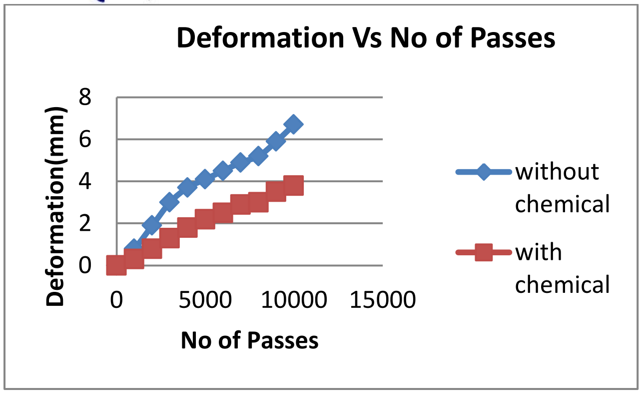

Fig.3.3 Comparison of Sample with Chemical and Without Chemical

3.5 REPEATED LOAD TEST

Repeated Load Test was conducted using Fatigue Testing Machine developed by Bangalore University and Manufactured by Spranktronics. ASTM D4123 (Indirect Tension Test for Resilient Modulus of Bituminous Mixtures) procedure modified by Bangalore University was adopted for this test. The specimen was placed in the specimen holder diametrically and the top plate was placed over it. It was held in position by adjusting the horizontal clamps. Then the holder was kept exactly at the centre with respect to the loading shaft.

Then the controlling system was switched on and two horizontal and two vertical LVDTs were fixed. V1, V2, H1 and H2 were made zero by fine adjustment. Load is also set to zero.From the software part we can give the peak load, frequency, rest period etc and also control the shaft movement. Then the load actuation was stated.The loading was stopped automatically when the required criteria is reached or when the specimen fails. The load applied and the deformations at specific intervals will be stored in a notepad file by the software which can be used for further calculation.

Repeated load test was conducted on the both modified and conventional mix at optimum binder content with the applied load as 10 per cent, 20 per cent and 30 per cent of the ultimate Indirect Tensile load and frequency 1 Hz. The rest period selected is 0.9 sec. The test was conducted at40^{0}c. Three specimens were tested for each case.

Table 3.11: Repeated load test results of BC mix@40^{0}c

Stress levels	ResilientModulus (M_R), (N/mm²)	Fatigue life (No of cycles)
without chemical		
10%	936.01	1239
20%	1001.30	909
30%	1118.77	666
With chemical		
10%	1311.06	1613
20%	1249.32	1187
30%	1384.69	802

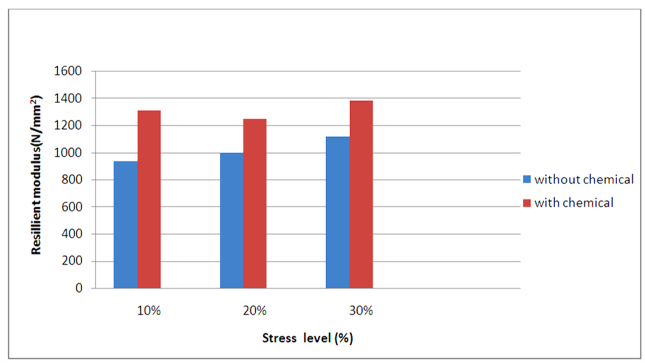

Fig. 3.4 Comparison of resilient modulus for BC mix with and without chemical at different stress level

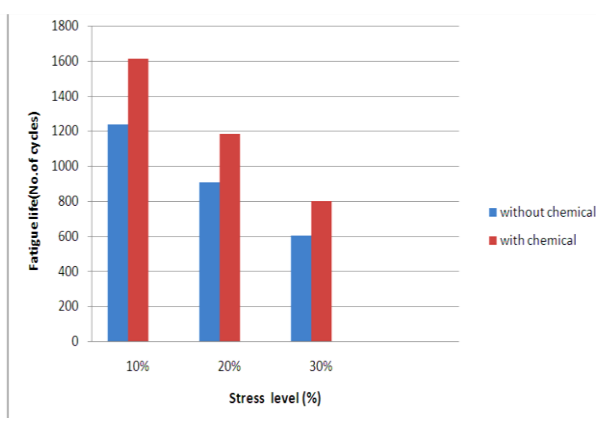

Fig. 3.5 Comparison of Fatigue life for BC mix with and without chemical at different stress level

CONCLUSIONS

The results of the experimental study show that performance of chemically modified bituminous concrete mix is better than that of conventional bituminous concrete mix. Following conclusions can be drawn from this study:

- The Marshall stability value increased by 17 percent with 0.1 percent of chemical as compared to the BC mix without chemical.
- The flow value is within the limits (2 to 4 mm) for this modified mix as per MoRTH specifications.
- The Retained stability value increased by 9 percent with 0.1 percent of chemical as compared to the BC mix without chemical.
- Indirect tensile strength value for unconditioned sample increased by 10 percent for the BC mix with 0.1 percent of chemical. Similarly for conditioned samples ITS values increased by 22 percent as compared to the conventional mix.
- The Tensile strength ratio for sample with chemical was found to be 92.18% and which is higher than the samples without chemical is 82.70%. This indicates that mixes with chemical are not susceptible to moisture.
- Rutting depth after 10000 wheel passes was found to be decreased from 6.7mm to 3.8 mm for chemically modified bituminous mix.
- It was observed that BC mix with 0.1% of chemical gives more Resilient modulus compared to conventional mix. Nearly 30% of Resilient modulus of BC mix can be increased by adding 0.1% chemical by weight of bitumen.
- It was observed that BC mix with 0.1% of chemical gives more fatigue life compared to conventional mix. Nearly 25% to 30% of fatigue life of BC mix can be increased by adding 0.1% chemical by weight of bitumen.
- It is concluded that chemically modified BC mix is showing better results as compared to conventional mix hence it is suggested to use for the construction of Flexible pavement.

REFERENCE

[1]. Aurdrey, R. and Copeland. (2007): "Influence of Moisture on Bond Strength of Asphalt-Aggregate Systems", Vanderbilt University

[2]. Kandhal, P.S., Sinha, V.K., and Veeraraghavan, A., (2008): "A Critical Review of Bituminous Paving Mixes Used in India", Journal of the Indian Road Congress, Volume 69-2, pp: 541.

[3]. Shivangi, G. and Veeraragavan, A., (2009): 'Fatigue behavior of polymer modified bituminous concrete mixtures', Journal of the Indian Roads congress, March, 2009.

[4]. Sangita, Tabrez Alam Khan,Sabina & D.K. Sharma "Effect of waste polymer modifier on the properties of bituminous concrete mixes" Construction and Building Materials, 25 (2011) 3841–3848.

[5].Taher M.A. Al-ani (2009)"Modification of Asphalt Mixture Performance by Rubber-Silicone Additive" Anbar Journal of Engineering Sciences 71 AJES, Vol. 2, No. 1.

[6].Sandhya Dixit, Prof. Deepak Rastogi (2013) "Studies on the Improvement of Characteristics of Bitumen with Use of Waste Plastic" International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 3.

[7]. Ashok Pareek,Trilok Gupta and Ravi KSharma (2012) "Performance of polymer modifiedBitumen for flexible pavements" int. J. Struct. & civil engg. Res. Vol.1.

[8]. Ministry of Road Transport and Highways, "Specification for Roads and Bridge Works", (2004): New Delhi

[9]. IS:2386 (Part I) 1963, "Methods of Test for concrete-Part I Particle size and shape", Bureau of Indian Standards, India.

[10]. IS:2386 (Part I) 1963, "Methods of Test for Aggregates for Concrete-Part 1 Particle Size and Shape", Bureau of Indian Standards, India.

[11].IS:2386 (Part III) 1963, "Methods of Test for Aggregates for Concrete-Part 3 Specific Gravity, Density, Voids, Absorption, Bulking", Bureau of Indian Standards, India.

[12].IS:2386 (Part IV) 1963, "Methods of Test for Aggregates for Concrete-Part 4 Mechanical Properties", Bureau of Indian Standards, India.

[13]. IS:1202-1978, "Methods for Testing Tar and Bituminous Materials; Determination of Specific Gravity", Bureau of Indian Standards, India.

[14]. IS:1203-1978, "Methods for Testing Tar and Bituminous Materials; Determination of Penetration", Bureau of Indian Standards, India.

[15]. IS:1205-1978, "Methods for Testing Tar and Bituminous Materials; Determination of Softening Point", Bureau of Indian Standards, India.

[16]. IS:1208-1978, "Methods for Testing Tar and Bituminous Materials; Determination of Ductility", Bureau of Indian Standards, India.

[17]. ASTM D 4867 – 09 "Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures", ASTM, USA.

[18]. ASTM D 6927 – 06, "Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures", ASTM, USA.

[19]. ASTM D 6931 – 07, "Standard Test Method Indirect Tensile (IDT) Strength of Bituminous Mixtures", ASTM, USA.

[20]. Kadiyali, L.R., and Lal, N.B. (2005): "Principles and Practices of Highway Engineering", Khanna Publishers.