EFFECT OF LIME AND EVOTHERM ON BITUMENOUS MOISTURE RESISTANCE

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Abstract: *Moisture damage is defined as loss of mechanical characteristics of material resulting from the presence of water in the bituminous mixes. This phenomenon aggravates various distresses causing loss of assets in the pavement maintenance and rehabilitation. The most traditional technique adopted to mitigate moisture damage is addition of the additives in bituminous mixes. This study evaluates the use of hydrated lime and Evotherm on the moisture susceptibility of the bituminous mixes. Hydrated lime is used as antistripping agent which changes the surface chemistry of the aggregate and results in the stronger adhesion between aggregate and binder.Warm Mix Asphalt (WMA) have privilege of preparing high quality mixes at lower mixing and compaction temperatures. Evotherm is a WMA additive which maintains the required workability even at lower temperatures. This study focuses on evaluating the combined effect of temperature and pressure on moisture resistance of bituminous mixes. The bituminous mix specimen were prepared with 100 mm diameter mould using viscosity grade (VG-20) bitumento the targeted air voids of 7±0.5%. The prepared specimens were subjected to two different conditioning process i.e. AASHTO T-283 (24 h freeze-thaw effect) and Moisture Induced Sensitivity Tester (MIST). Moisture susceptibility was conducted by comparing the results of Indirect Tensile Strength (ITS) test and Retained Marshall Stability (RMS) of the bituminous mixes blended with and without additives. The results show that there is a marked increase in the performance of the mixtures with the additives.*

Keywords: *bituminous mixes, indirect tensile strength, moisture resistance, moisture induced sensitivity tester, pressure, temperature*

1. INTRODUCTION

1.1 General

The global increase in the traffic volume has raised the need for better performing pavements. Proper performance of the bituminous pavement is expected when all the pavement layers and subgrade supports the traffic load throughout its life span. In late 1970s and early 1980s it has been recognised that the moisture has the detrimental effect on the bituminous pavements. Moisture damage is defined as loss of mechanical characteristics of material resulting from the presence of water in bituminous mixes. Moisture damage can be generally classified into two mechanisms: (a) loss of adhesion (b) loss of cohesion. The loss of adhesion is due to water entering between the bitumen and aggregate and stripping away the bitumen film. The loss of cohesion is due to softening of bituminous mixes.

Cohesive and adhesive failure occurs due to the nature of mastic and relative thickness of the binder around the coarse and fine aggregate. Cheng et al. (2002) used micromechanics to assess the "thickness" of the bitumen film at which adhesive failure gives way to cohesive failure. Figure 1.1 is a plot of the cohesive and adhesive bond strength determined from cohesive and adhesive surface energies versus thickness of the bitumen binder or mastic. The theory essentially states that bituminous mixes with thin bitumen films fail in tension by adhesive bond rupture, while those with thicker bitumen films fail because of damage within the mastic as opposed to interfacial debonding. The thickness that differentiates these two types of failures is dependent on the rheology of the bitumen, the amount of damage the bitumen can withstand prior to failure, the rate of loading and temperature at the time of testing.

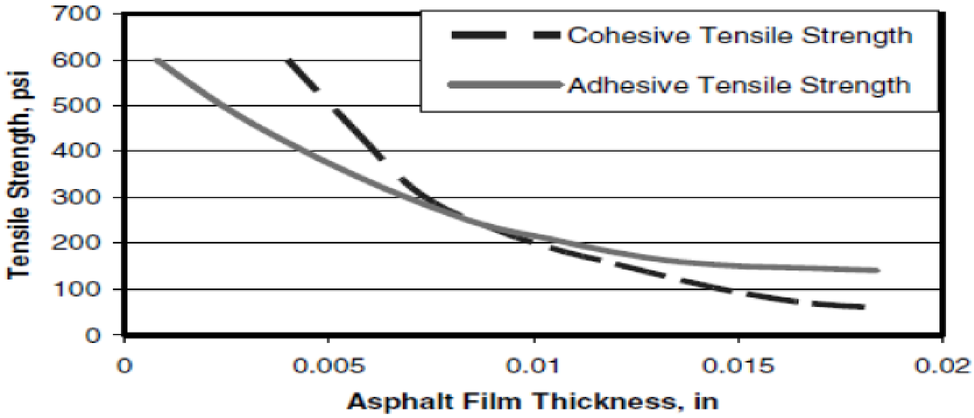

Figure Number 1. Adhesive Vs. Cohesive bond failure in bituminous mixes (Source: Cheng et al. 2002)

1.2 Fundamental Concept of Moisture Damage

It is well known fact that the entry of water cannot be avoided in the pavements. Thus, before going deep into the mechanism of moisture damage, it is necessary to understand the sources of ingress and egress of water into pavements. The presence of water is due to infiltration, melting of ice during freeze and thaw, capillary action and change in the ground water table. The above mentioned are only the primary sources of entry of water in the pavement, however; cracked and damaged shoulder also contribute to ingress of water. Figure 2 shows the possible sources of entry of water in pavement.

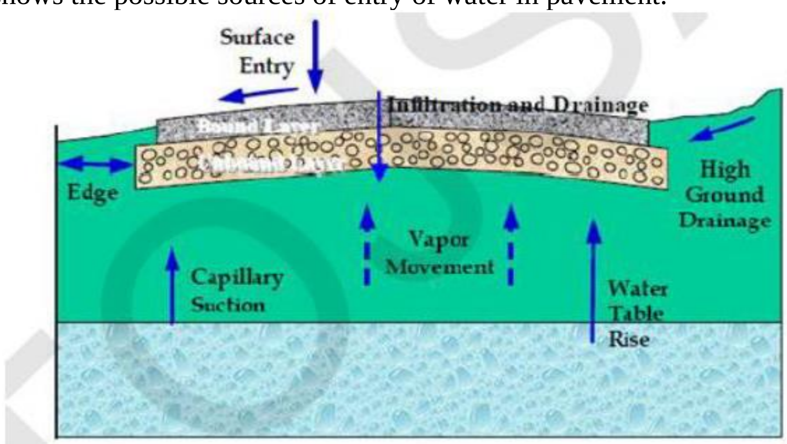

Figure Number 2. Possible sources of water in pavement (Source: Yilmaz and Sargin, 2012)

1.3 Need for the Study

As mentioned above, moisture induced in the pavement will lead or accelerate the deterioration process. Moisture damage is not taken as design parameter but its evaluation is important as it can reduce the strength and affect durability during the life of the pavement. As thequantification of such type of distresses is very difficult because of the induced action of temperature and pressure this type of damage should be better taken care.

Ministry of Roads Transport and Highways (MoRTH, 2013) follows the AASHTO T-283 test to assess the moisture damage of the bituminous mixtures used in India for pavement construction. A test followed to assess moisture damage has to satisfy the real field conditions i.e., in the presence of moisture; movement of traffic over the pavement; and other climatic factors. Temperature is also a main factor which affect the behavior of bituminous mixtures in terms of moisture damage. But the freeze and thaw effect which is followed in AASHTO T- 283 method does not take account the above factors. It considers only the freezing and thawing of bituminous mixtures these effects in the wearing course that occurs in real field. The sentence "Marshall Samples used in the AASHTO T-283 test should have air voids of 6.5 % to 7.5 %" in the AASHTO T283 test protocol make sense that the test is performed on the bituminous mixtures at the initial stage of construction. But the pavements can be affected by moisture at any time after construction; even at the stage with 4±0.5 % air voids. Considering all the above discussed factors, this study tries to analyse the moisture effect on the bituminous mixtures due to freeze-thaw effect and MIST conditioning. The main focus of the study is to assess the moisture susceptibility of bituminous mixes prepared with 7±0.5% air voids and including parameters such as pore pressure and temperature.

2. LITERATURE REVIEW

Bose et al. (2005) investigated the moisture damage to bituminous pavement and effect on field performance with case studies. In this, field observations of five sections are documented in detail with complete details of pavement layers and recommendations for the distresses occurred in respect to the moisture damage. From their studies, it is observed that the failure of bituminous layers is due to water entrapment between granular and the bituminous layer and due to the percolation of water into lower layer through the poorly compacted surface course. On the other hand, most aggregates have an attraction for both bitumen and water.

Huang et al. (2005) studied the effect of adding hydrated lime prior to mixture preparation and performed freeze thaw cycle to evaluate moisture resistance of bituminous mixes. Their study depends on the mainly on two aggregate types i.e. limestone and granite. In addition they also carried out study on oxidative aging due to addition of hydrated lime and model ketone. After freeze thaw cycling the specimen was subjected to selective solvent extraction to isolate the polar organic materials strongly adsorbed on the aggregate surface. They reported that the composition in the bitumen-aggregate interface may change due to repeated freeze thaw cycling.

Kim et al. (2008) evaluated the effect of adding hydrated lime on moisture susceptibility using performance testing. Hydrated lime is added into the mixture in two forms: (i) 1% dry lime; (ii) various concentration of lime slurry. In order to evaluate the performance of the bituminous mixes, Hamburg wheel tracking test and Asphalt Pavement analyser was conducted. AASHTO T-283 is used as a conditioning process using 6 cycles of freeze thaw. Testing data and analysis shows that hydrated lime contributed to moisture damage resistance due to synergetic effect of mastic stiffening, toughening and advanced bonding characteristics. Results shows that the hydrated lime interfacial bond strength between the aggregate and the binder in addition to acting as a mineral filler to stiffen the binder. The major outcome of their study is the way of adding the hydrated lime. They found that dry lime is probably more effective in improving themoisture damage resistance than treating aggregate with lime slurry.

Cheng and Huang (2008) evaluated the moisture damage using Simple Performance Test(SPT) and Superpave Indirect tensile Test (IDT). The objective was to study the effect of SPT and IDT combined with MIST and Freeze-Thaw (FT) conditioning to characterise the lab measured moisture damage. Coarse gravels at different angularity levels (100, 50 and 0% fractured surface counts) were used to produce mix with similar aggregate gradation and amine based anti-strip additive. The specimens were condition using (i) one cycle of FT, (ii) two cycles of FT, (iii) 500 cycles of MIST and (iv) 1000 cycles of MIST. The dynamic modulus, Superpave IDT creep, resilient modulus and strength test were performed on conditioned and unconditioned specimen.

Gorkem and Sengoz (2009) investigated the effect of polymer modified bitumen and the hydrated lime on the stripping and moisture damage in bituminous mixes. The main objectiveof their study was to predict the effect of the additives such as hydrated lime, elastomeric (SBS) and plastomeric (EVA) polymer modified bitumen (PMB) on the stripping potential and moisture susceptibility characteristics of HMA containing different types of aggregates (basaltlimestone aggregate mixture and limestone mixture).

Pinkham et al. (2010) investigated the effect of MIST conditioning on the moisture damage of hot bituminous mix which uses the pore pressure with various cycles and temperatures, aparameter that influences the moisture damage in bituminous pavements. They reported that MIST is recently developed technology that applies alternating pressure and vacuum cycles to submerged bitumen samples to mimic hydraulic scouring. The objective was to differentiate six bituminous mixes used by Maine Department of Transportation in terms of their moisture susceptibility using the MIST technology and field cores. They concluded that the MIST conditioning process does cause moisture damage to the samples in a manner that mimics hydraulic scouring.

Alavi et al. (2011) evaluated the effect of adhesion properties and moisture susceptibility of WMA. In WMA mixes, the reduced production temperatures can affect the drying of the aggregate before mixing, the development of adhesion at the bitumen–aggregate interface, and binder stiffness. Their objective was to identify the significance of these factors and to define their relative contribution to mixture resistance to moisture damage. To evaluate the contribution of bitumen binder–aggregate adhesion, the bitumen bond strength (BBS) test was performed on dry and moisture-conditioned samples. They made recommendations for incorporation of these new test methods into current WMA mixture design specifications. It was stated that both BBS and dynamic modulus testing indicated that specific WMA additives could improve the mixture's moisture resistance and could offset any negative effects from the reduced production temperatures on moisture susceptibility. They reported that, selecting appropriate warm mix additives during the mix design process can help mitigate potential moisture damage associated with WMA.

3. METHODOLOGY

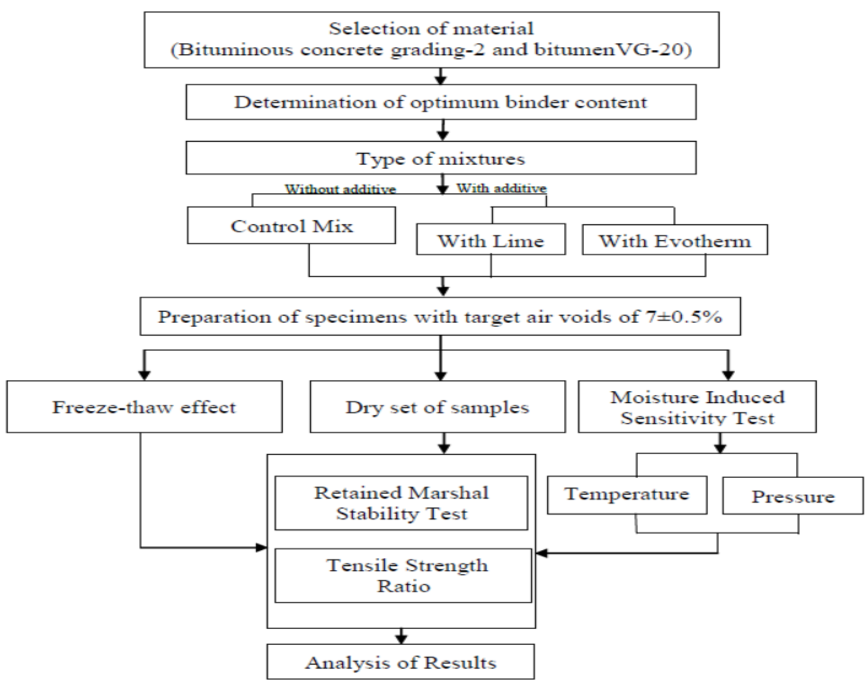

Figure Number 3. Methodology adopted

3.1 Sample preparation

Sample were prepare to a targeted air voids content of 7%. The samples were categorised into two sets: one belonging to dry process and other to the conditioned process. Each sample set was then tested to determine the Retained Marshall Stability (RMS) and Indirect Tensile Strength (ITS). The test matrix adopted in the study is shown in Table 1

Table Number 1. Test Matrix

Serial Number	Variable	Description
1	Aggregate gradation	Bituminous concrete grading 2
2	Bitumen grade	VG-20
3	Air voids	7%
4	Conditioning process	Dry, AASHTO T-283, MIST
5	MIST temperature	40 °C, 50 °C, 60 °C
6	MIST pressure	40 psi (276 kPa), 50 psi (345 kPa), 60 psi (414 kPa)
7	Performance indicator	TSR, RMS

3.2 Moisture Susceptibility Tests Methods

The bituminous mix specimens prepared in the laboratory were subjected to two different conditioning processes including:
(i) AASHTO T-283, and
(ii) Moisture Induced Sensitivity tester (MIST).
The conditioned specimens were then tested for performance including tensile strength ratio and retained Marshall stability.

3.2.1 AASHTO T-283

AASHTO T-283 test is a common method followed in India to evaluate the moisture susceptibility of the bituminous mixes in which the freeze and thaw effect is followed to condition the samples. Followed by saturation of the sample a partial vacuum such as 70 kPa or 525 mm Hg was applied for a short time such as 5 to 10 min. The degree of saturation was determined by dividing the volume of the absorbed water by the volume of air voids and the result was expressed as a percentage. It was ensured that the degree of saturation is in between 55 to 80 %. If the degree of saturation is less than 55%, the procedure was repeated by beginning with using a slightly higher partial vacuum. If the degree of saturation is more than 80%, the specimen is considered to be damaged and was discarded. For specimens with 70 to 80% saturation were selected and each specimen was wrapped with a plastic film and placed in a plastic bag containing 10 ± 0.5 mL of water and sealed. The plastic bags were placed in a freezer at a temperature of -18 ± 3 °C for 24 ± 1 hours. The specimens were then placed in a water bath maintained at 60 ± 1.0 ºC for 24 hours. As soon as the specimens are placed in the water bath, the plastic bag and film were removed from each specimen. The samples subjected to conditioning were removed from the water bath and placed in water bath maintained at 25 ± 0.5 ºC for 2 hours.

3.2.2 Moisture Induced Sensitivity Tester

Proper testing and screening of bituminous mixes for moisture susceptibility is a crucial requirement for designing high-performing, longer-lasting pavements. Moisture Induced Sensitivity Tester simulates bituminous pavement stripping mechanisms, which are due to water and repeated traffic loading. MIST uses the cyclic pore pressure and temperature for evaluation of the damage caused in bituminous pavements. The number of cycles were fixed at 3500 which is the default value with varying temperature and pressure. The temperature is varied from 40 °C to 60 °C at the interval of 10 °C. In similar manner, pressure is varied from 40 psi (276 kPa) to 60 psi (414 kPa) at interval of 10 psi (69 kPa). The specimen after conditioning were subjected to indirect tensile strength and Marshall stability test. It was ensured that the conditioned specimens were dried for atleast 24 h such that the water trapped inside the specimens were completely drained out.

3.2.3 Indirect Tensile Test

The tensile properties of bituminous mixes are of interest to pavement engineers because of the problems associated with cracking. Although bituminous mixes are not nearly as strong in tension as it is in compression, tensile strength of this mixes are important in pavement applications. The ITS is used to determine the tensile properties of the bituminous mixture which can further be related to the cracking properties of the pavement. A higher tensile strength corresponds to a stronger cracking resistance.

3.2.4 Marshall Stability test

This test is done to determine the Marshall stability of bituminous mixture as per MORTH (2013). The principle of this test is that Marshall Stability is the resistance to plastic flow of cylindrical specimens of a bituminous mixture loaded on the lateral surface. It is the load carrying capacity of the mix at 60 °C and is measured in kg. In this test compressive loading is applied on the specimen at the rate of 50.8 mm/min till specimen fails. The temperature 60 °C represents the weakest condition for a bituminous pavement.

4. DATA ANALYSIS

For the present study the optimum binder content is found to be 5.7%. The specimens were prepared for targeted air voids of 7±0.5% for that number of blows were found out to be 31.

4.1 Tensile Strength Ratio Results

4.1.1 Effect of pressure

Tensile strength ratio (TSR) is a measure of water sensitivity. A higher TSR value typically indicates that the mixture will perform well with a good resistance to moisture damage. The higher the TSR value, the lesser will be the strength reduction by the water soaking condition, or the more water-resistant it will be.

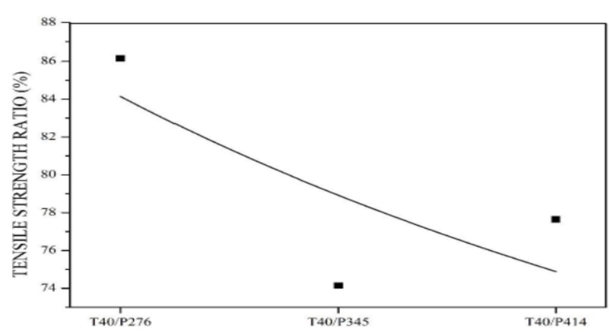

Figure Number 4. Variation of TSR at 40 °C for different pressure in MIST conditioning for the control mix

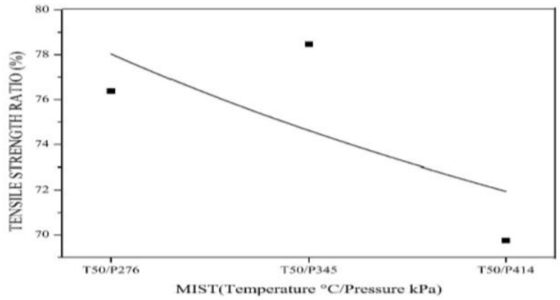

Figure Number 5. Variation of TSR at 50 °C for different pressure in MIST conditioning for the control mix

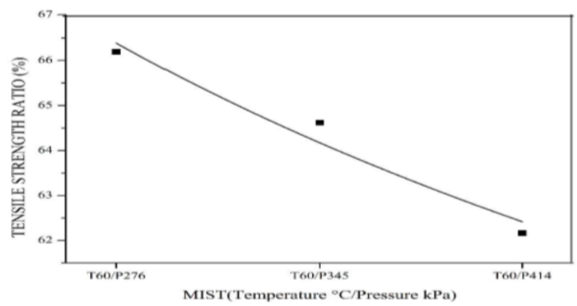

Figure Number 6. Variation of TSR at 50 °C for different pressure in MIST conditioning for the control mix

As stated by Varveri et. al (2014), the tensile strength ratio decreases with the increase in the temperature and pressure. As shown in Figure 4, there is a decrease in the tensile strength ratio with increase in conditioning process. This decrease is abrupt for initial increase in pressure and after that it increased. This increase is due to huge variability in the tensile strength of the tested sample. The TSR is more than 80% at a conditioning pressure of 276 kPa.

Further increase of pressure beyond 276 kPa resulted in TSR values less than 80%. Also in Figure 5 tensile strength ratio first increased and then decreased which is not expected trend as in both there is an increase in conditioning pressure. Figure 6 follows the conventional trend of strength decrease with the increase in conditioning pressure as suggested by Varveri et al. (2014). This shows that the influence of pressure is significant on the TSR.

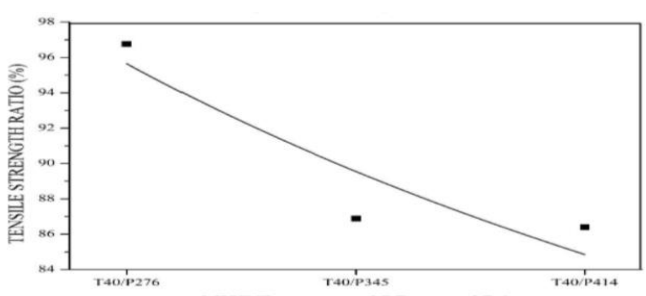

Figure Number 7. Variation of TSR at 40 °C for different pressures in MIST conditioning for the mix with Evotherm

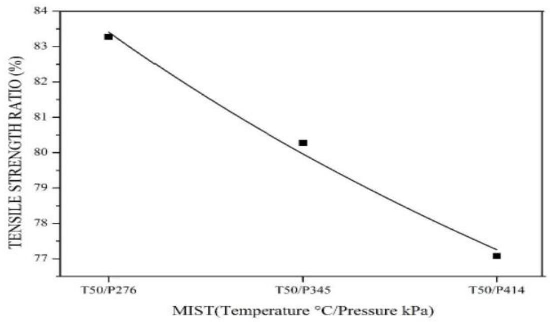

Figure Number 8. Variation of TSR at 50 °C for different pressures in MIST conditioning for the mix with Evotherm

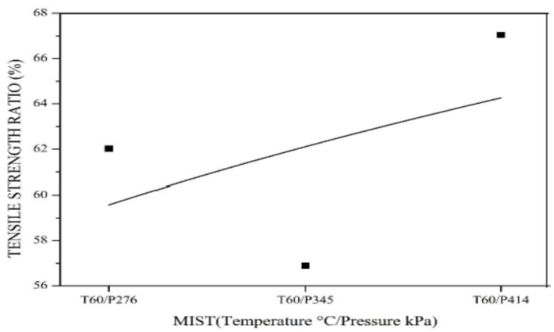

Figure Number 9. Variation of TSR at 60 °C for different pressures in MIST conditioning for the mix with Evotherm

As seen from Figure 7 and 8, when Evotherm is added as an additive, TSR is decreased with increase in conditioning pressure. In figure 9, even though there is an initial decrease in TSR with increase in conditioning pressure, later the TSR increased beyond a conditioning pressure of 345 kPa.

5. CONCLUSION

Based on the results obtained from laboratory experiments on moisture susceptibility of bituminous concrete prepared at 7% air voids and conditioned through freeze-thaw and MIST conditioning process, the following conclusions are drawn based on retained Marshall stability and tensile strength ratio tests:
Within the MIST conditioning process, the tensile strength ratio and retained Marshall stability decreased with increase of both temperature and pressure. The effect of temperature is more significant than the effect of pressure. However, the effect of pressure is more significant for tensile strength ratio at higher temperatures. The tensile strength ratio and retained Marshall stability significantly increased for the mixtures blended with additives. The tensile strength ratio is higher for bituminous mixes with lime as additive when compared to bituminous mixes with Evotherm. It is important to note here that Evotherm being a WMA additive the internal friction in bituminous mixes with Evotherm additive might be lower than the bituminous mixes with lime. The retained Marshall stability of bituminous mixes showed the same trend as that for the tensile strength ratio and retained Marshall stability of the bituminous mixes with lime is higher than the bituminous mixes with Evotherm additive at all temperatures and pressures

considered in the study. It is important to note that in a retained Marshall stability test, bituminous mixes are subjected to compressive forces whereas in the case of indirect tensile strength test, bituminous mixes are subjected to tensile forces. The tensile strength ratio obtained from AASHTO T-283 conditioning is higher for bituminous mixes with lime followed by the bituminous mixes with Evotherm and bituminous mixes without any additive.

6. REFERENCES

[1] *Ameri, M., Kouchaki, S., and Roshani, H. (2013). "Laboratory evaluation of the effect of nano-organosilane anti-stripping additive on the moisture susceptibility of HMA mixtures under freeze–thaw cycles." Construction and Building Materials, 48, 1009-1016.*

[2] *Alavi, M. Z., Hajj, E. Y., Hanz, A., and Bahia, H. B. (2011). "Evaluating adhesion properties and moisture damage susceptibility of warm-mix asphalts bitumen-bond strength and dynamic modulus ratio tests." Transportation Research Record: Journalof the Transportation Research Board, 2295-06, 44–53.*

[3] *Behiry, A. E. M. (2013). "Laboratory evaluation of resistance to moisture damage in asphalt mixtures." Journal of Ain Shams Engineering, 4, 351-363.*

[4] *Bose, S., Sridhar, R., Kamaraj, C., Sharma, G., and Kumar, G., (2005). "Investigation of moisture damage to bituminous pavement and effect on field performance-case studies." Central Road Research institute, New Delhi, 437-451.*

[5] *Buchanan, M., Moore, V., Mallick, R., O'Brien, S., and Regimand, A. (2004)."Accelerated Moisture Susceptibility Testing of Hot Mix Asphalt (HMA) Mixes."83rd Transportation Research Board Annual Meeting, 12, 67-72.*

[6] *Chen, X., and Huang, B. (2008). "Evaluation of moisture damage in hot mix asphalt using simple performance and superpave indirect tensile tests." Construction and Building Materials, 22(9), 1950-1962.*

[7] *Cheng, D., Little, D. N., Lytton, R. L., &Holste, J. C. (2002). "Use of surface freeenergy properties of the asphalt-aggregate system to predict moisture damage potential." Journal of the association of asphalt paving technologists, 71, 59-68.*

[8] *Cheng, J., Shen, J., and Xiao, F. (2011). "Moisture susceptibility of warm-mix asphalt mixtures containing Nano sized hydrated lime." Journal of Materials in CivilEngineering, 23(11), 1552-1559.*

[9] *Cucalon, L. G., Yin, F., Martin, A. E., Arambula, E., Estakhri, C., and Park, E. S.(2015). "Evaluation of moisture susceptibility minimization strategies for Warm-mix Asphalt: Case Study." American Society of Civil Engineers, 28(2), 1-9.*

[10] *D'Angelo, J., and Anderson, R. M. (2003). "Material production, mix design, andpavement design effects on moisture damage." Moisture Sensitivity of AsphaltPavements: A National Seminar, 187-201.*

[11] *Ghabchi, R., Singh, D., Zaman, M., and Tian, Q. (2013). "Application of Asphaltaggregates Interfacial Energies to Evaluate Moisture-induced Damage of Warm Mix Asphalt." Procedia-Social and Behavioral Sciences, 104, 29-38.*

[12] *Gorkem, C., and Sengoz, B. (2009). "Predicting stripping and moisture induced damage of asphalt concrete prepared with polymer modified bitumen and hydrated lime." Construction and Building Materials, 23(6), 2227-2236.*

[13] *Goh, S.W. and You, Z. (2011). "Moisture damage and Fatigue Cracking warm mix asphalt using a simple laboratory setup." Construction and Building Materials, 28(2), 236-247.*

[14] *Hesami, S.A., Roshani, H., Hamedi, G.H., and Azarhoosh, A. (2013). "Evaluate the mechanism of the effect of hydrated lime on moisture damage of warm mix asphalt."Journal of Construction and Building Materials, 47, 935–941.*

[15] *Huang, S. C., Robertson, R. E., Branthaver, J. F., and Claine Petersen, J. (2005)."Impact of lime modification of asphalt and freeze–thaw cycling on the asphalt–aggregate interaction and moisture resistance to moisture damage." Journal of materials in civil engineering, 17(6), 711-718.*

[16] *Ibrahim, M. A., Al-Qadi, I. L., and Trepanier, J. S. (2015). "Mitigation of moisture damage in Asphalt Pavements: Testing techniques and additives/modifierseffectiveness". Construction and Building Materials, 84, 437-443.*

[17] *Indian standard paving bitumen – specification, IS 73, Bureau of Indian Standards, New Delhi, 2013.*

[18] *Kim, Y. R., Lutif, J. S., Bhasin, A., and Little, D. N. (2008). "Evaluation of moisture damage mechanisms and effects of hydrated lime in asphalt mixtures throughmeasurements of mixture component properties and performance testing." Journal of Materials in Civil Engineering, 20(10), 659-667.*

[19] *Leatherman, K., and Willis, J. (2015). "Effect of warm mix technologies and testing protocol on moisture susceptibility of asphalt mixtures." Transportation ResearchBoard 92nd Annual Meeting, (13-4673), 87-98.*

[20] *Lee, J. S., and Kim, Y. (2014). "Performance-Based Moisture SusceptibilityEvaluation of Warm-Mix Asphalt Concrete through Laboratory Tests."Transportation Research Record: Journal of the Transportation Research Board, (2446), 17-28.*