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TO REVIEW EFFECT OF WARM MIX ADDITIVES AND LOADING RATE ON RUTTING OF WARM MIX ASPHALT PAVEMENT

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ABSTRACT

Warm mix asphalt (WMA) technologies are of classified in two major types such as wax-based and chemicalbased. The prior additives at temperature of mixing and compaction completely melt in the binder and thus construction work enable at low temperature.While in case of chemical additives fraction between binders and aggregates minimize and thus provide same results during construction. It is well known that during construction technologies of WMA showed tendencies for increased rutting because of reduced ageing.However, in trails of laboratory better performance revealed by wax-based additives at pavement service temperature , the wax crystallizes and provide enhanced stiffness to the mastic. At pavement service temperatures the WMA visco-elastic response effect by wax presence and the related temperature sensitive properties (crystallization and melting). This study mainly examined on such type of problems for wax and chemical based additives along with a control hot mix asphalt (HMA) binder. The Study showed three essential results. During first result, binder'srheological response is characterized, in second the rutting and third result showed the calculation of mixtures mechanical properties. It is concluded that mixture of bitumen's having wax based additives showed better rutting resistance characteristic below temperature of 40^0C. Same response given inthe range of 40–50 ◦C temperature while more prone to rutting at the temperature above 50 ◦C as compared to mixture of HMA. More ever high rutting was shown consistently in WMA mixture with chemical additives.

Keyword's

Warm mix asphalt,Wax based, Chemical based, rutting, visco-elastic response, reduced ageing

I. INTRODUCTION

The compaction and mixing temperature of bituminous pavement was reduced by usingwarm mixed Asphalt (WMA) up to 30^{0}C (IRC SP 101 2014).Additives of WMA were categorized in two groups which are chemical based and wax based additives.The viscosity of binders was reduced by both additive but in various ways. For example, binders surface tension was reduced with addition of in Newtonian regime which reduced friction between aggregates and binders (Bower 2011). Wax-based additive composed of long chain hydrocarbons which offered low viscosity at mixing and compaction temperature as compared to conventional binder (Jamshidi *et al.* 2013). More ever, every additives reaction with binder was in unique way which effected the WMA performance in different ways. When mixture of Bitumen's was produced with binder of WMA, two concerns raised. First one, effect of reduced ageing because of low mixing and compaction temperature, while secondly one, the effect of warm mix additives on binders.

Reduced aging rate was investigated in laboratory and field studies in WMA binders (West *et al.* 2014). Reduced ageing cause lower resistance to rutting and high resistance to fatigue characteristics as compared to Hot mix asphalt (HMA). (Xiao *et al.* 2009, Qin *et al.* 2012, Hasan *et al.* 2013). In addition, Materials performance to fatigue and rutting based on the uses of warm mix additive. The main aim of this paper is to know the effect of two warm mix additives additive and loading rate on rutting of WMA pavements i.e. Evotherm and Sasobit in which former related to chemical base additive while latter one related to wax based additives. At laboratory scale, various WMA mixtures rutting performance was reported under different studies.The measurement of rutting in bituminous mixture was done by using repeated creep and recovery and wheel tracker test (Zelelew *et al.* 2013, Toraldo *et al.* 2013). From repeated creep and recovery test the flow number was obtained which used to measure rutting of bituminous mixture, widely.

Short term-aged materials used in laboratory before application to any rutting tests. According to (AASHTO R 30-2 2006) for Mixture of HMA , the short-term ageing conducted at field compaction temperature of 135^{o}C.Thus, ageing mixtures of WMA temperature more than production temperature was inappropriate. It was suggested that for short term ageing temperature changing must be same to compaction temperature of respective mixture of WMA(Bonaquist,2011). Reduced flow number resulted because of reduced ageing of WMAmixturesas compared to HMA mixture. For WMA mix design (Bonaquist 2011) incorporated flow number as performance criteria for test. Beside ageing, the mixture of WMA rutting properties was also varied with test criteria in the laboratory level/scale. Materials rutting properties was affected by conditions of test such ass loadwaveform, temperature, loading rate and confinement pressure(Hajj *et al.* 2010, Zelelew *et al.* 2013, West *et al.* 2014).

For describing different mixtures of WMA resistance to rutting flow number and Hamburg wheel tracking tests were conducted After testing it was noted that mixture ranking was varied with methods of testing's i.e. repeated creep and recovery and wheel tracking tests (Zelelew *et al.* 2013).various studies was conducted to investigate different WMA filed performance to rutting (Prowell *et al.* 2007, Zhang 2010,Sargand *et al.* 2011, Porras *et al.* 2012, Mohammad *et al.* 2014 ,West *et al.* 2014).During these studies, difference between laboratory predicted and field values of rutting was observed which indicated that laboratory predicted rutting having high values. While behavior of WMA mixture was found same with HMA in field.

Two WMA track tests were prepared with addition of Evotherm mixture rutting was measured application of 5,15,333 ESAL. It was concluded that rut depth of WMA test track was observed 0.2mm lesser or same when compared to HMA test track (Prowell *et al.* 2007). Sargand *et al.* (2011) constructed three WMA sections with Evotherm, Sasobitand Aspha-min to measure the rutting.It was noticed that rutting sign was not found after construction of forty-six months. he improved field performance of WMAsection in rutting might be due to the improved field densityof the mixture. For identical level of compaction of WMA andHMA section, the density of WMA material is expected to behigh due to increased compatibility (Hurley and Prowell 2005,Hurley and Prowell 2006) and this higher density might haveresulted in improved performance. Here, it has to be pointedout that the higher density of the mixture may also affect thelong-term fatigue performance of the mixture.

To predict WMA Pavement rutting behavior simulation were carried out in many study using AASHTOWare mechanistic–empirical (M-E PDG) (M-E PDG 2008), in field data absence (Goh *et al.* 2007, Zhang 2010, Buss and Williams 2012, Podolsky *et al.* 2016). The rut depth based on dynamic modulus, material calibration factors and field or local calibration were based which are predicted from M-E PDG simulation. The material calibration factors usage depend upon repeated creep and recovery test while local calibration factors depends upon field data suggested by Von Quintus, 2012 . The prediction of rut depth accuracy mostly dependent on appropriate calibration factors use.

II. RESEARCH METHODOLOGY

Materials:

Binders: In this study two binders of WMA produced using Sasobit and Evotherm for usage along with one conventional binder i.e. VG30**.** Sasobit and Evotherm was used 1.5% and 0.4% respectively as dose. In this paper WMA binders are named as EVOTHERM-VG30 and SASOBIT-VG30. All the binders were short term ageing which were used for testing.

Bituminous Mixture:

In this Study, aggregates having medium grade were used to produced bituminous mixture. The size of aggregate was kept 13.2mm. Based on above binders three numbers (VG30, EVOTHERM-VG30 and SASOBIT-VG30) of Bituminous mixture were prepared**.** For better understanding mixtures of bituminous prepared with VG30, WMA-EVOTHERM and WMA-SASOBIT binder termed asHMAVG30, EVOTHERM-VG30 and SASOBIT-VG30, respectively. VG30 binder and aggregates having oven dried heated at temperature of 175 ◦C while mixed at temperature of 165 ◦C when preparing of HMA specimens (MoRTH 2013). The ageing that occurred during compaction and mixing at field level , Mixtures of HMA were short term aged at temperature of 135 ◦C for a period of 4h ±5min. Then placed at a compaction temperature of 150 ◦C for 1/2 hours (AASHTO R 30-2 2006).WMA binder and aggregates heated at temperature of 145 ◦C while mixing was done at temperature of 135 ◦Cwhen prepared WMAsamples,WMAbinder and the aggregates were heated to 145 ◦C and mixed at 135 ◦C. Mixtures of WMA were short-term aged at temperature of 117 ◦C for period of 4hr ±5min and compacted directly at this temperature (Bonaquist 2011).

Preparation of Sample:
Shear box compactor was utilized to fabricate the specimens of both WMA and HMA (ASTM D 7981 2015). For HMA and WMA Samples compaction 600 KPa Vertical stress and 4 degrees shear angle was used in box compactor. Beams having size of 450x150x160mm was prepared and for testing sample was sliced. For test of dry wheel tracker sample were sliced from two slabs having size of 300x150x50mm. For conducting tests of repeated creep and recovery, and dynamic modulus three cylinders having size (dia;100mm and Height;100mm were cored from every shear box compacted beam. The samples air voids kept in range of 6±0.5% and 4±0.5% for testing related to rutting and dynamic modulus, respectively. The densification curves of materials used for dynamic modulus test in samples of HMA and WMA was shown in Figure.1.

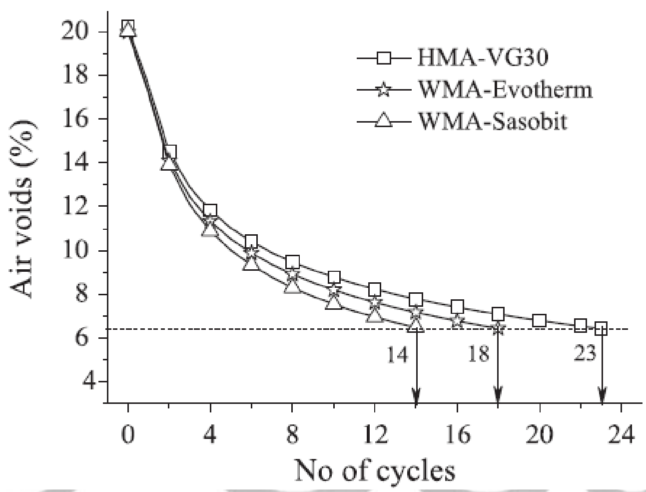

Fig.1 Densification curves of HMA and WMA samples used for dynamic modulus test.

Same vertical force applied on both HMA and WMA should be noted. More ever, it was noted that high resistance to compaction was exhibited by HMA-VG30 mixture to reach the air voids as targeted (Figure 1). In addition, 23 shear cycles required by HMA-VG30 to attain target air voids, but same target air void was attained by WMA-EVOTHERM and WMASASOBIT samples attained in 18 and 14 shear cycles, respectively.

Laboratory Test Methods:

Binders: For Ranking of WMA binders rutting performance according to ASTM D 6373 (2015) The performance grading test was conducted based on $|G*|/\sin\delta$. Short-term ageing specimens were used for conducting of repeated creep and recovery test at various temperatures i.e. 25°C, 35°C, 45°C, 55°C. The test was composed of 25 cycles and after each 5 cycles during loading period stress increased. Stress levels with 1s loading time having various values of 0.104kPa 0.329kPa, 1.04kPa, 3.29kPa and 10.4 kPa (Narayan *et al.* 2016) applied and followed by rest period of 9s, 20s, 20s, 70s and 150 s, respectively.

Mixtures: Dynamic Modulus Test.

In this paper AASHTO TP79 (2010) was used to find the dynamic modulus. The test was conducted at six various temperaturesand ten frequencies i.e. of 5, 15, 25, 35, 45and 55^{0}C and of 0.01, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 25 Hz, respectively.

Dry Rut Wheel Tracker Test:

During this test, the specimen was placed below the wheel load of 700N and load moved to and fro. On wheel axle linear variable displacement transducer was mounted to capture the rut depth on test specimen surface at interval of 4mm. Wheel one to and fro motion considered as one load cycle. More ever, the test was finished at passes of 30,000 or 5mm rut depth which came first.The depth of rut basically depends upon wheel load magnitude and wheel moving speed. To study the behavior ofWMAmixture to different rates of loading, the test was conducted at two different speeds of 26.5 and 12.5 cycles per minute. Two various speed was used during the test i.e. 26.5 and 12.5 cycles/min for examining WMA mixture behavior to various loads of rating.

Repeated Creep and Recovery Test (RCR test).

Asphalt mixture performer was used to conducted RCR test with adoption of two various protocols. The standard flow number test protocol (AASHTO TP79 2010) was first protocol composed of 0.1 s haversine load and 0.9 s rest period. 600kPa deviated stress were applied on specimen at temperature of 50 and 60^{0}C.The permanent strain was computed at the end of each cycle by measuring the displacement of actuator. When 0.1s time varying load applied on material, the loading was insufficient due to haversine loading nature to capture to capture the real-time traffic loading condition in standard flow number test protocol (Hajj *et al.* 2010). During 2nd protocol test was conducted under confinement pressure by applying trapezoidal load in this this paper (Gayathri *et al.* 2016), which composed of repeated trapezoidal waveform loading with 1 s loading time and 2 s recovery period. The 600kPa deviatoric stress applied with 40 kPa confinement. The loading time was kept constant at 0.8s while deviatoric stress increased at a rate of 5860 kPa/. The sample was unloaded with same rate of loading. Figure 2 clearly shown load waveform which was used for testing. With interval of 0.001s the deformation was noted, and strain was calculated. For sample HMA-VG30, Figure 3 revealed measured strain at50 ◦C .Testing of all materials was conducted at40, 50 and 60 ◦C while for WMA-SASOBIT testing was conducted at additional temperaturesof 30, 35 and 55 ◦C.

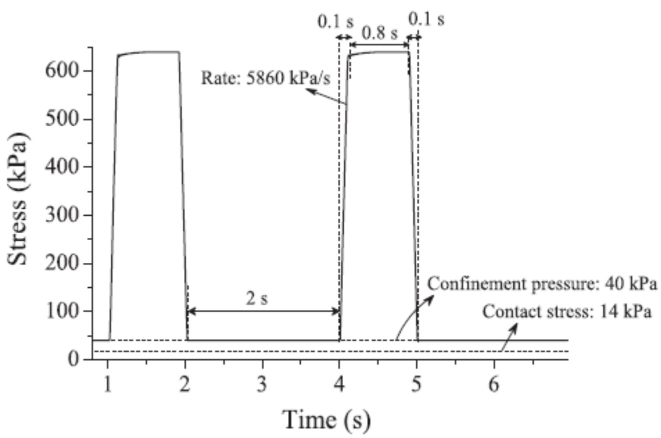

Fig 2. Repeated creep and recovery test – Loading waveform.

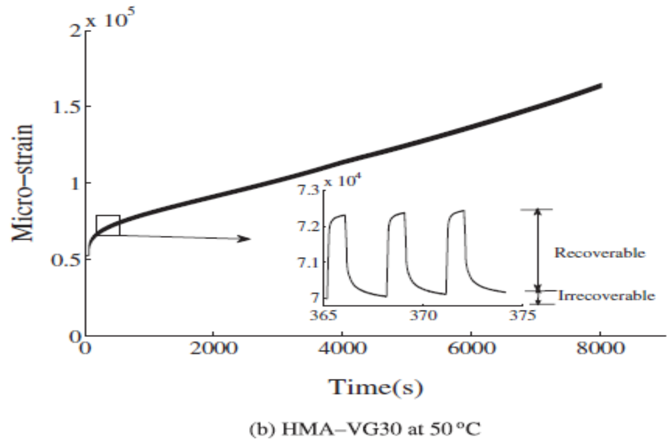

Fig 3. Repeated creep and recovery test – Trapezoidal loading

III. Results

Binder characterization: Performance Grading

For all three binders Table 1 showed dynamic modulus (|G∗|), phase angle (*δ*) and the temperature to |G∗|*/sinδ* of 2.2 kPa was measured.

Table 1. Test results of Performance grading

Sample	64^{0}C		70^{0}C		Temperature corresponding to |G∗|/sinδ of 2.2 kPa (◦C)	Ranking
	|G∗| (Pa)	δ (◦)	|G∗| (Pa)	δ (◦)		
VG-30	5970	85.8	2880	85	72.3	1
SASOBIT-VG30	5090	86.6	2350	86.6	70.6	2
EVOTHERM-VG30	4160	86.6	1990	87.5	66.9	3

It was clear from table the as compared to VG 30, SASOBIT-VG30 and EVOTHERM-VG30 found more susceptible to rutting.

Repeated Creep and recovery test:

Figure 4 showed response of creep and recovery at temperature of 25 and 45^{0}C at stress level of 0.104kPa. It was observed that strain accumulation at 25^{0}C was found less in SASOBIT-VG30 as compared to VG30 while when at temperature 45^{0}C strain accumulation was found high in SASOBIT-VG30 as compared to VG30 . At all levels of stress, The SASOBIT-VG30 binder temperature susceptible behavior was found consistent. While EVOTHERM-VG30 binder strain accumulation found uniformly higher as compared to VG30 binder at all stress levels and temperatures. Figure 5 indicated recovery avg %age for levels of stress i.e. 0.104 and 3.290 kPa. At all temperatures and stress levels, the recovery of EVOTHERM-VG30 binder recovery was found less as compared to VG30 binder while SASOBIT-VG30 binder recovery was affected by temperature and stress magnitude at all stress levels and temperature. More ever at

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0.104 kPa Stress level SASOBIT-VG30 binder showed improved recovery as compared to VG30 and at higher stress level of 3.290 kPa SASOBIT-VG30 binder revealed less recovery.

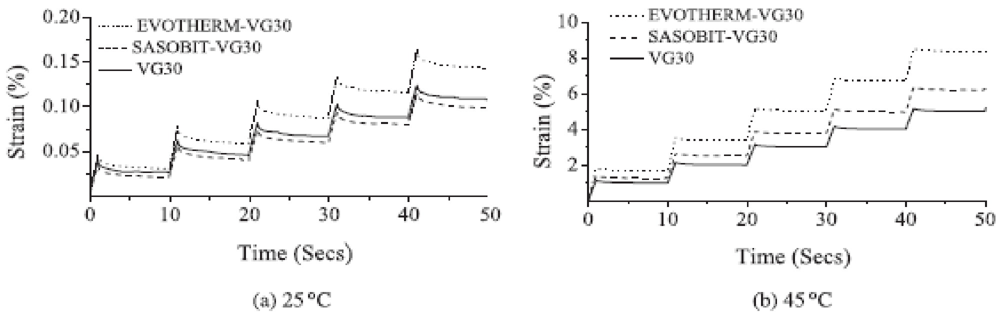

Fig 4 Creep and recovery response at 0.104kPa

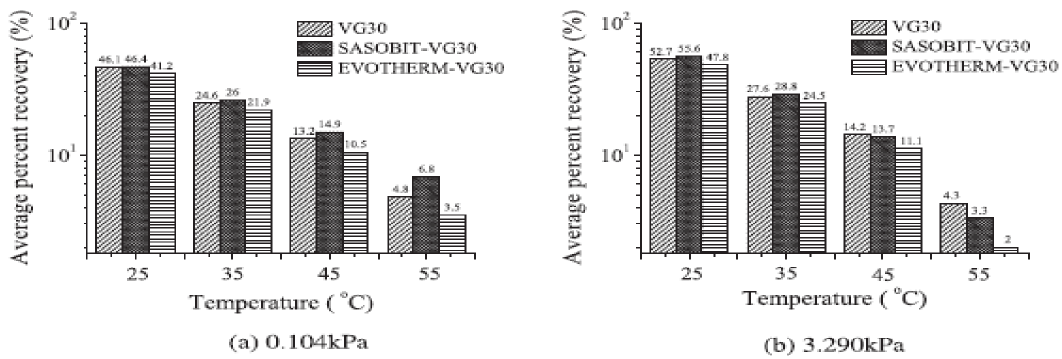

Fig 5 Recovery avg percentage at various temperatures

Ranking of binders at various temperature and stress levels based on recovery percentage was shown in table 2.

Table 2. Ranking of binders based on repeated creep and recovery test results.

Materials	Temperature ^{0}C	0.104kPA	0.329 kPa	1.04kPA	3.29kPa	10.4kPa
SASOBIT-VG30	25	1	1	1	1	1
HMA- VG30		2	2	2	2	2
EVOTHERM-VG30		3	3	3	3	3
SASOBIT-VG30	35	1	1	1	1	2
HMA- VG30		2	2	2	2	1
EVOTHERM-VG30		3	3	3	3	3
SASOBIT-VG30	45	1	1	2	2	2
HMA- VG30		2	2	1	1	1
EVOTHERM-VG30		3	3	3	3	3
SASOBIT-VG30	55	1	1	2	2	2
HMA- VG30		2	2	1	1	1
EVOTHERM-VG30		3	3	3	3	3

From table 2 it was clearly indicated that binder EVOTHERM-VG30 ranked 3 consistently at all temperature and stress level. While ranked 1 at low temperature and ranked as second at high temperature. The change in SASOBIT-VG 30 ranking with change in stress level and temperature was also heighted in table 2. More ever it was also noticed form table 2 that when melting point temperature reached the WMA-SASOBIT was more prone to rutting.

Mixture characterization: Dynamic Modulus

For all mixtures (VG30, EVOTHERM-VG30, SASOBIT-VG30) dynamic modulus was measured at various frequencies and temperature were shown at Figure 6.

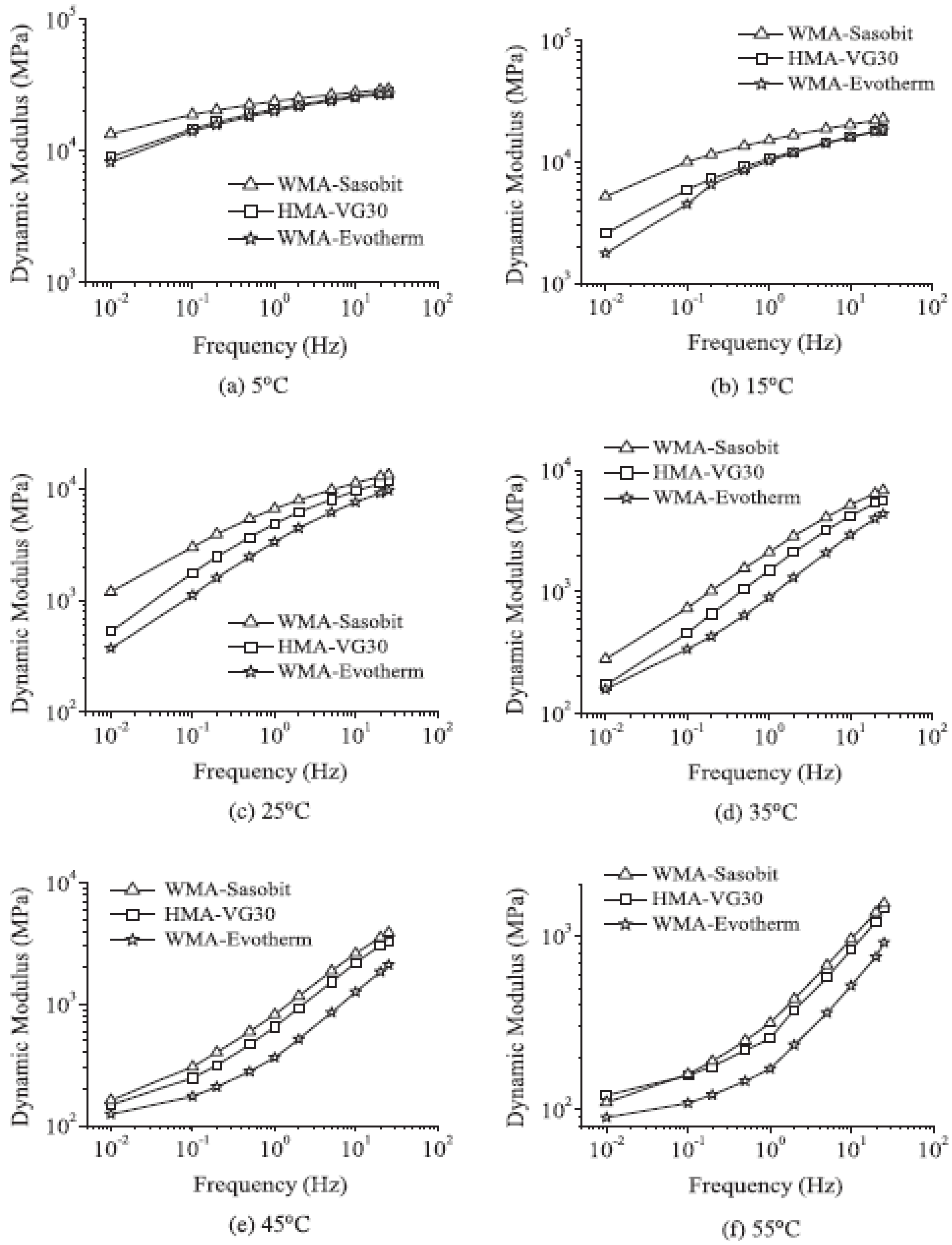

Fig.6 Dynamic Modulus of HMA and WMA Mixtures

From above figure it was indicated that at temperature of 5 and 15^{0}C values of dynamic modulus was found same for WMA EVOTHERM while less values were found at high temperature as compared to VG30. More ever, the difference between WMAEVOTHERM and HMA-VG30 in dynamic modulus were constantlyidentical for various frequencies at any given temperature. Dynamic modulus of WMA-EVOTHERM was reduced due to WMA binder reduced ageing as verified by West *et al.* (2014). To know the effect of warm mix additives at various temperature and frequencies master curve was at 35^{0}C (reference temperature) and was shown in Figure.7. Based on wide range of temperature and frequencies the WMA-EVOTHERM dynamic modulus was observed 30-40% less as compared to VG30. While dynamic modulus variation in WMA-SASOBIT was observed to be dependent on temperature and frequencies.

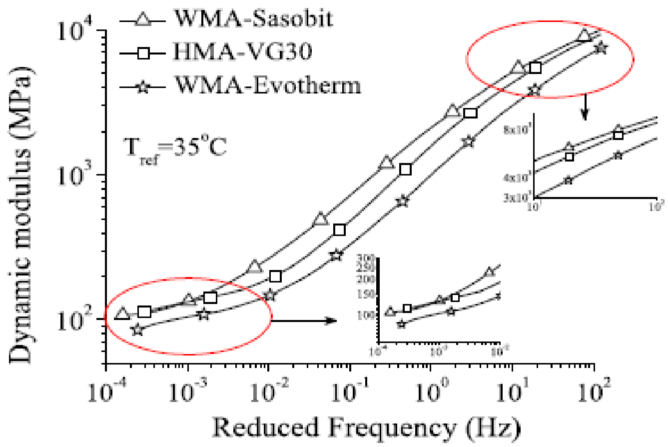

Fig.7 Master Curves

Wheel tracking test:

Profile of rut depth along wheel load for speed level of 12.5 cycles per minute at temperature of 50 and 60^{0}C and 9000Th pass was shown in Fig.8. It was concluded that rut depth at above mentioned temperature was found more for WMA-EVOTHERM as compared to HMA-VG30. More ever low and high rut depth was observed by WMA-SASOBIT at 50 and 60◦C when compared with HMA-VG30. In figure 8, rut depth avg values were determined for all load cycles and utilized in future analysis (BS-EN-12697-22 2003).The For mixtures of HMA-VG30,WMA-EVOTHERMand WMA-SASOBIT average rut depth for two various speed were shown in Fig 9 at 50 and 60 ◦C. Better rut resistance was observed in WMA-SASOBIT as compared to HMA-VG30 followedbyWMA-EVOTHERM for a speed level of 26.5 cycles per minute at both 50 and 60 ◦C.

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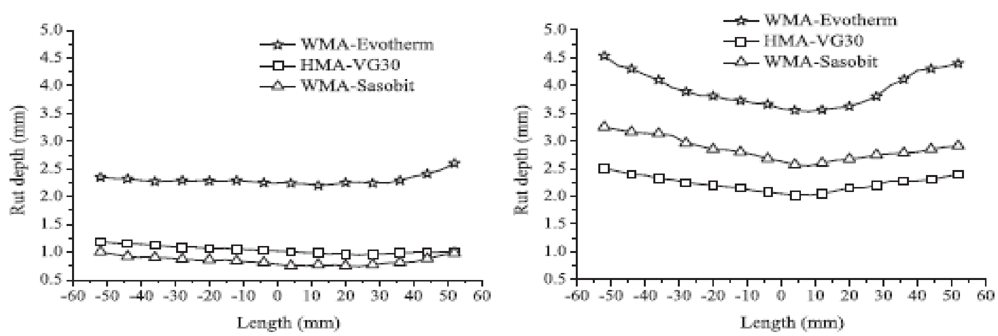
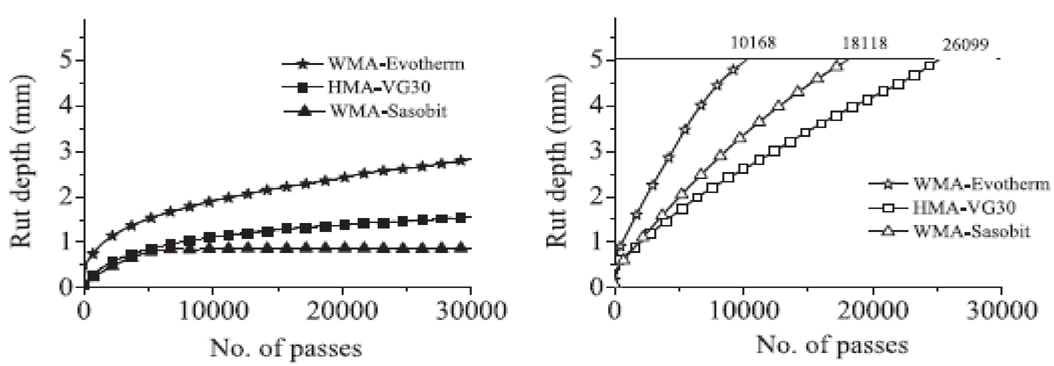


(a) 50 °C, 12.5 cycles/minute, 9000 pass (b) 60 °C, 12.5 cycles/minute, 9000 pass

Fig 8. Rut depth variation along the length of slab



(a) 50°C, 26.5 cycles per minute (b) 60°C, 12.5 cycles per minute

Fig 8. Results of Wheel tracker

Table 3 shown bituminous mixtures rutting performance at the end of 30,000 cyclesor the number of cycles to reach 5mm rut depth, was ranked and noted. WMA-SASOBIT ranking was observed and depend upon rate of loading.

Table.3 HMA and WMA mixtures ranking based on wheel tracking test

Materials	Temperature ^{0}C	26.5 Cycles /Minutes	12.5 Cycles/Minutes
SASOBIT-VG30	50	1	1
HMA- VG30		2	2
EVOTHERM-VG30		3	3
SASOBIT-VG30	60	1	2
HMA- VG30		2	1
EVOTHERM-VG30		3	3

Repeated Creep and Recovery test – Haversine loading

Irrecoverable strain variation was shown in figure 10 with respect to load cycles numbers . Creep curve of three stages was considered i.e. primary, secondary ,and tertiary. WMA-SASOBIT as compared to samples of HMA-VG30 and WMA-EVOTHERM showed longer secondary stage at temperaturesof 50 and 60 ◦C. The cycles number represented by flow number corresponding to tertiary stage starting known from the irrecoverable strain rate of change of slope. Based on flow number, it was concluded that Better rut resistance was observed by WMA-SASOBIT as compared to HMA-VG30 followed by WMA-EVOTHERM at 50 and 60 ◦C.

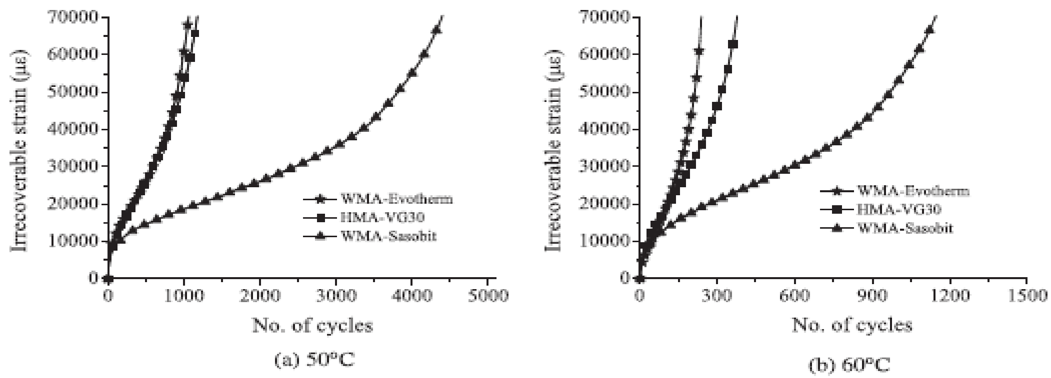


Fig 10. Haversine loading-Creep Curve

Repeated creep and recovery test – Trapezoidal loading:

Figure 11 shown strain value for all three materials due to trapezoidal loading was tested at different temperatures. Better resistance showed by WMA-SASOBIT at temperature of 40^{0}C followed by HMA-VG30 and WMA-EVOTHERM (Figure 11 (a). WMA-SASOBIT and VG30 showed same behavior at temperature of 50^{0}C (Figure 10(b)) and at 60^{0}C, HMA-VG30 showed better rutting resistance as compared to HMA-VG30(Figure 10(c)).

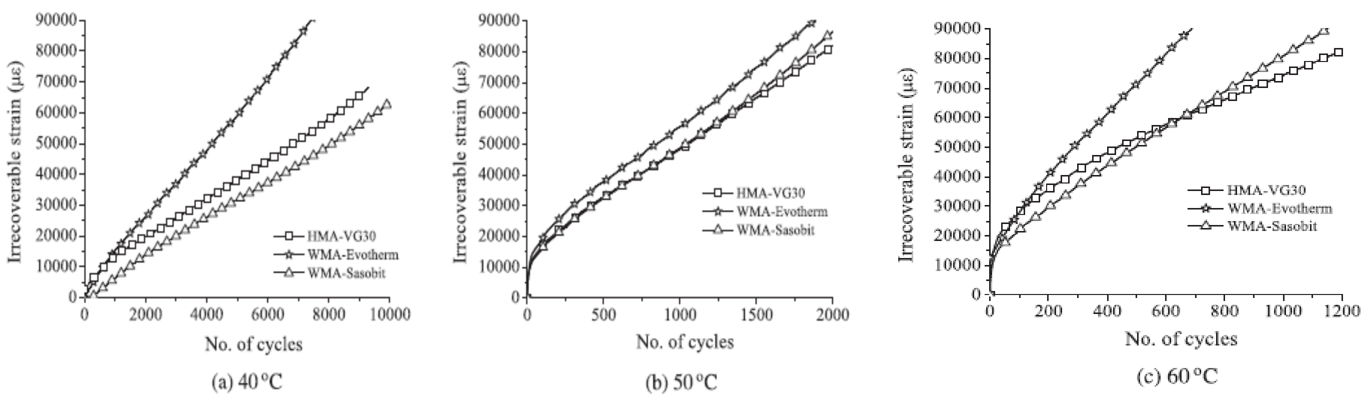


Fig 11 Creep curves- Trapezoidal loading

During repeated creep and recovery test rutting tendency was calculated and strongly based on test method. When mixtures of WMA was tested increased dependency on loading rate was shown by WMA-SASOBIT i.e. dynamic modulus, rut wheel testing with 12.5 cycles/minute and creep and recovery test with trapezoidal loading).Sasobit treated binder response changes with temperature of testing as reported by Roja *et al.* (2015).

Conclusions:

In this paper two WMA technologies (Sasobit and Evotherm) were compared with hot mixture asphalt binder. Using the binders and mixtures experimental work was conducted. The experimental investigation was conducted in such way to capture each sensitive response. It was concluded that repeated creep and recovery test indicated better rutting features of binder (SASOBIT-VG30) at less than 35 degree Centigrade and all stress levels as compared to VG30 binder. While SASOBIT-VG30 at high temperatures and stress level was observed more prone to rutting as compared to VG30 binder. During testing of performance grading SASOBIT-VG30 found to be ranked low when compared with VG30 for rutting at high temperature. Ranking of materials by performance grading test at limited temperature was well known corresponding to failure and not provide any information regarding expected rutting at low pavement temperature. In mixtures of bitumen's of Sasobit, loading and stress rate sensitive response was also observed. For dynamic modulus WMA-SASOBIT sensitive response rate was seen at temperatures more than 45^{0}C especially at low frequencies. More ever shift of 10^{0}C was found during observation of response of WMA-SAOBIT mixture with binder as far as dynamic modulus is concerned. WMA-SASOBIT was observed with high ranking during flow number and rut wheel test at 60^{0}C in terms of performance. Specifications were followed to conduct such type of tests. The WMA-SASOBIT performance was slipped below at temperature of 50 and 60^{0}C from HMA-VG30 in case of trapezoidal loading for flow number and lower loadingrate for rut wheel testing, respectively when loading rate was changes during same tests conduction. Based on various testing protocols it was concluded that WMA-SASOBIT indicated high rutting resistance at low temperature of 40^{0}C as compared to HMA-VG30. More ever, same response was noted between 40 and 50^{0}C and above 50^{0}C HMA-VG30 binder showed less prone to resistance than WMA-SASOBIT.

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