IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 9, Issue 1 (Sep. - Oct. 2013), PP 16-22
www.iosrjournals.org

Rheological Characterization of Bituminous Binder containing Wax based Warm Mix Asphalt Additive

Ambika Behl [1], Prof Satish Chandra[2], Prof V.K Aggarwal[3]
[1] *Scientist, CSIR-CRRI, New Delhi 110025*
[2]*Professor, Department of Civil Engineering, IIT Roorkee, 247667*
[3]*Professor & Head, Dept of Chemical Engg, IIT Roorkee, 247667*

Abstract: *Warm mix asphalt (WMA) has been gaining increasing popularity in recent years due to energy savings and environmental benefits. The mechanism of WMA is to use some additives or technologies to reduce the viscosity of bitumen and to modify the rheological behavior of bituminous binders, and thus improve the workability of the mixture at lower temperature. In this study a paraffin wax based additive Sasobit is used to reduce the viscosity and thus mixing and compaction temperature during hot mix asphalt production. VG 30 grade bitumen binder is used in the present study. Sasobit is added in the dose of 2 percent, 3 percent and 4 percent by weight of binder. Brookfield viscometer is used to determine the viscosity of the binders with and without sasobit at test temperature of 90, 120, 150 and 180^{O}C. Dynamic Shear Rheometer is used to study the Rheological behavior of the modified n unmodified binders. The study shows that the mixing, laying and compaction temperatures can be reduced considerably when sasobit is added to the binder. Laying and compaction temperature can be as low as 80^{O}C with VG-30 bitumen when 4 percent sasobit is added and due to this there will be an overall reduction in quantity of emission of pollutants when the bituminous mix is made at this low temperature.*
Keywords: *Warm Mix Asphalt, Sasobit, Rheology, Characterization*

I. Introduction

The hot bituminous mix industry is constantly exploring technological improvements that will enhance the materials performance, increase construction efficiency, conserve resources, and advance environmental stewardship.

During construction, the temperature must be high enough to ensure the workability of the mix and yet below the temperature at which excessive binder hardening occur. For little or no improvement in workability, increasing the mix temperature often results in increased plant emissions and fumes at the paving site and binder hardening. All around the globe efforts are being put forward to protect the environment. Currently emphasis is on reducing CO_2 emissions in view of reducing greenhouse effect.

Typically, the emissions from hot mix asphalt are classified into two major categories – visible emissions and invisible emissions. Invisible emissions are the emissions that primarily consist of non – condensable volatile organic compounds (VOCs) which precipitate in the production of ground level ozone. The visible emissions consist of fugitive dust emissions generated at the conveyers, stockpiles, and roadways and other heavier hydrocarbons that readily vaporize at temperatures around 150 °C (300 °F). The visible emissions condense in ambient air, absorb to dust and water particles, and have a characteristic fuel odor. In India, the Supreme Court has banned the use of Hot Mix Asphalt (HMA) in metropolitan cities like Delhi to reduce CO_2 emission. With environmental emissions laws forever being tightened by time may be right for India to tilt its way towards environment friendly technologies.

It is logical that one approach to achieving these goals would involve methods to reduce production temperatures of Hot Mix Asphalt. With the decreased production temperature the additional benefit of reduced emissions from burning fuels, fumes, and odor generated at the plant and the paving site as well as comparatively lowers quantities of fuel consumption. The concept of Warm Mix Asphalt has been introduced over the last few years as a means to these ends. Warm Mix Asphalt produced at temperature in the range of 20^{0}C to 50^{0}C lower than conventional hot mix asphalt (HMA).

Current and impending regulations regarding emissions are making it more attractive to consider greater reductions in HMA production temperature. While stack emissions have decreased significantly over the last few years due to improved pollution control features, further reductions in the emission of greenhouse gasses will likely be required in the future. Working conditions in the production and placement of HMA are also important to the industry as improvements lead to an enhanced work environment, higher-quality work, and better employee and workforce retention. Significant HMP temperature reduction would have two benefits for the workforce: it would further reduce fumes in the vicinity of all paving workers and it would make for a cooler work environment.

Several new processes have been developed to reduce the mixing and compaction temperatures of hot bituminous mix without sacrificing the quality of the resulting pavement, these warm-mix technologies were developed in Europe and are now available in India. These relatively new processes and products use various mechanical and chemical means to reduce the shear resistance of the mix or increasing the viscosity of bitumen at construction temperatures while reportedly maintaining or improving pavement performance.

1.1 Advantages of Warm Mix Asphalt

Bitumen is a thermoplastic material and its stiffness is dependent on temperature. Most bitumen used in road construction are thermo visco-elastic in nature. Their visco-elastic behavior is highly dependent on temperature at which they are handled. In a conventional procedure of road construction with conventional binder, the bitumen is heated to a temperature in the range of 150 – 170^{O}C to bring down its viscosity so that it can easily and thoroughly mixed with aggregates. At this temperature, fumes and hydrocarbons released in the atmosphere cause air pollution around the hot mix plant. Use of polymer modified binders requires further increase in the mixing temperature due to their high viscosity.

When using the WMA process instead of the traditional " Hot Mix", the bituminous mixture only needs to be heated to 100-130°C and can be compacted at around 80-100°C. Lower temperatures lead to important energy savings without reduction in quality of different end products properties. Because less energy is needed to heat the bituminous mixture, much lower emission occurs.

Compared to traditional "Hot Mix" the new Warm Mix process is cost effective in production and more environmentally friendly in terms of reduced emission. As such, it represents a huge step forward and a viable future for road production. The goal with warm mixes are to obtain a level of strength and durability that is equivalent to or better than hot-bituminous mix, which leads to following advantages such as:

- Lesser production and laying temperature.
- Lesser emissions (CO_2, CO, NO, etc.,).
- Lesser energy/fuel cost
- Lesser curing time – early opening to traffic
- Other possible benefits
  - Cool weather paving (extend season)
  - Compaction aid for stiffer mixes while achieving the same or better density

1.2 Sasobit®

Sasobit® has been used in three different sizes for WMA pavements. They are pellets, flakes and powder. Sasobit® is a Fischer-Tropsch (FT) wax produced from the coal gasification process and is typically added at the rate of 1.5% by weight of asphalt. Recently it has started production from natural gas using the FT process. In Fischer-Tropsch process, the carbon-monoxide atoms get converted into a mixture of hydrocarbons having molecular chain lengths from 1 to 100 carbon atoms or greater. In this process, white hot coal is treated with a blast of steam. Iron or cobalt act as a catalyst in the reaction. The reaction can be represented as follows: -

$$(2n+1)H2 + nCO \rightarrow CnH(2n+2) + nH2O$$

Sasobit® has a much longer chain length – 40 to 115 carbon atoms and thus has a melting point around 99°C compared to 20 to 45 carbon atoms and a melting point of 50°C to 80°C for generic paraffin wax. Sasobit® forms a lattice structure in the asphalt binder which is the basis for the stability of asphalt that contains Sasobit®. Sasobit® can be added to the asphalt (wet process) or the asphalt mixture (dry process). Sasobit® helps in increasing the compactibility of the mixture and thus creates lower air voids in the specimen when compared to the mixture without any additives. Since Sasobit® can dissolve with the binder at lower temperatures; a high shear mixer is not required at the construction site for mixing the additive with asphalt. Sasobit® forms a homogeneous solution with the base binder after stirring and lowers the viscosity of asphalt. Sasobit® manufacturer claims that a mixing temperature can be lowered by up to 32°C.

II. Objectives And Scope

The objective of this paper is to investigate how a commercially available additive Sasobit can be used to bring down the mixing and compaction temperature of bituminous mixture as compared to the conventional mix. In addition to indicate that how the addition of Sasobit modifies the viscosity and rheological properties of Viscosity Grade 30 bitumen.

III. Review Of Studies

Nazimuddin et al. (10) reported that Sasobit® decreased the rut depth which could justify the increase in high temperature binder grading. Kunnawee et al. (11) reported AC 60/70 binder modified with 3.0% Sasobit® not only improved the compactability but also exhibited a greater resistance to densification under simulated traffic. Gandhi and Amirkhanian (12) demonstrated that two of the three binders maintained the same PG grade with the addition of Sasobit®. Hurley and Prowell (2006) studied the performance of warm mixes and observed improved level of compaction of mixtures by both the Super Pave Gyratory Compactor (SGC) and Vibratory Compactor methods at temperatures as low as 88^0C. It was reported that rutting potential increased with decreasing mixing and compaction temperatures. Wayne Jones presented Warm mix Asphalt as the technology of the future. He reported that despite the nearly 27^0C temperature difference, the same densities were achieved on both the conventional HMA and WMA. Hurley and Prowell conducted laboratory and field studies on use of Hydrated aluminium silicates and Paraffin wax additive as an additive in warm mix. They reported that the addition of hydrated aluminium silicates did not increase or decrease the rutting potential but Paraffin wax additive Sasobit have a significant decrease in the rutting potential of an asphalt mixture. They also reported that the addition of these additives decreases the TSR values. Xiao et al. (2009) deduced that the addition of 1.5 percent Sasobit® will generally allow for mixing and paving temperatures about 20°F to 55°F (depending on the mix and project) lower than those for conventional HMA. This resulted in CO2 emission reductions of around 32percent from direct reductions; plus, another 8 percent reduction from energy savings is possible. They estimated a joint reduction of about 40 percent. Aurilio and Michael (2008) reported a fuel savings of 30 percent on a small Sasobit® project in Ottawa, Ontario.

IV. Experimental

Materials: VG (viscosity grade) 30 grade bitumen was obtained from IOCL Faridabad. Sasobit**®** was procured from the Indian distributor of Sasobit®, and it was used in powder form to modify VG 30 bitumen in three different percentages; 2 %, 3% and 4% by weight of the bitumen.

4.1 Methodology

4.1.1 Preparation of Blends

For this study samples of VG- 30 bitumen are prepared with the above mentioned dosages of the Sasobit® additives. The bitumen was first brought to its flowing state by heating it to a temperature where bitumen is in flowing state, and then the warm mix additives were added as per the dosages selected. Each sample contained 200 gm VG 30 binder. Then selected percentages of warm mix additives were added into the neat binder. After adding the warm mix additive, hand stirring was given for approximately 15-20 min at normal speed. Prepared blends were then stored for further testing.

4.1.2 Characterization of Blends

The viscosity profiles of the binder were measured using the Brookfield Rotational Viscometer; the equipment was used to measure the viscosity characteristics of the neat and modified binder. This study determined influence of the additive on the viscosity of the binder at midrange and high temperatures. The viscosity of each bitumen blends with and without the additives were measured at various test temperatures at a rotational speed of 20 RPM of the Brookfield spindle 27. The viscosities of all the samples were measured at 100ºC, 120ºC, 130ºC and 150ºC. The prepared blends were saved for further research work.

The Viscoelastic response of the modified bituminous binders was evaluated using a Dynamic Shear Rheometer with parallel plate geometry by measuring complex shear modulus and phase angle. Measurements were taken in the temperature range 6^oC to 88^oC. The 25mm steel plate was used, the gap width set was 1mm and all measurements were taken at a frequency of 10 rad/s. The DSR measures a specimen's complex shear modulus (G^*) and phase angle (δ). The complex shear modulus (G^*) can be considered the sample's total resistance to deformation when repeatedly sheared, while the phase angle (δ), is the lag between the applied shear stress and the resulting shear strain. The specified DSR oscillation rate of 10 rad/s (1.59 Hz) is meant to simulate the shearing action corresponding to a traffic speed of about 55 mph (90 km/hr). G^* and δ are used as predictors of HMA rutting and fatigue cracking. Early in pavement life rutting is the main concern, while later in pavement life fatigue cracking becomes the major concern.

V. Results And Discussion

5.1 Effects of Sasobit® content on viscosity

Viscosity is a fundamental characteristic that describes the resistance of fluids to flow. In practice, it is necessary to ensure that asphalt binder has adequate viscosity to ease pumping and able to coat each aggregate particle during mixing. The relationships between viscosity and Sasobit® content of VG 30 binders subjected to different temperatures conditions are shown in Figure 1.

Table 1: Viscosity of VG- 30 bitumen with different percentages of Sasobit®

Sasobit®	Viscosity at 100ºC (cP)	Viscosity at 120ºC (cP)	Viscosity at 130ºC (cP)	Viscosity at 150ºC (cP)
Neat Bitumen VG-30	2525	650	425	150
2% Sasobit®	2625	600	375	125
3% Sasobit®	2800	575	350	125
4% Sasobit®	2975	550	300	95

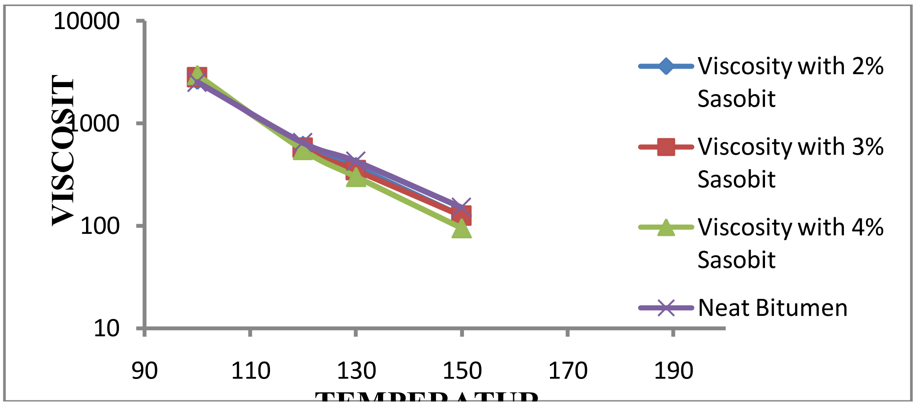

Figure 1: Viscosity graph of VG-30 bitumen with different percentages of Sasobit®

From the results given in table 1 it can be seen that at and below 100ºC, the binders containing Sasobit® increased the Viscosity and with the increasing concentration of Sasobit®, the influence of Sasobit® on the viscosity becomes more significant especially at low temperatures. Beyond 100ºC all binders containing Sasobit® show a decrease in viscosity and with increase in concentration of Sasobit® and the temperature, the viscosity decreases more noticeably which is the potential ability of Warm Mix Asphalt additive.
The reason for increase in viscosity at and below 100ºC is because the melting point of Sasobit® is about 95ºC. The manufacturer also claims that Sasobit® melts between the temperatures of 85ºC to 115ºC.

5.2 Rheology of modified bituminous binders

The DSR measures a specimen's complex shear modulus (G*) and phase angle (δ). The complex shear modulus (G*) can be considered the sample's total resistance to deformation when repeatedly sheared, while the phase angle (δ), is the lag between the applied shear stress and the resulting shear strain. The specified DSR oscillation rate of 10 rad/s (1.59 Hz) is meant to simulate the shearing action corresponding to a traffic speed of about 55 mph (90 km/hr). G* and δ are used as predictors of HMA rutting and fatigue cracking. Early in pavement life rutting is the main concern, while later in pavement life fatigue cracking becomes the major concern.

Figures 2 to 7 shows the Viscoelastic behavior of Sasobit modified binders and the neat binder i.e. VG-30 G' is defined as the ability of the material to store energy in the cycle of the deformation and G'' is the energy dissipated as heat in the cycle. G' and G'' are plotted as a function of temperature at constant frequency of 10 radians/sec in figures 2 & 3.

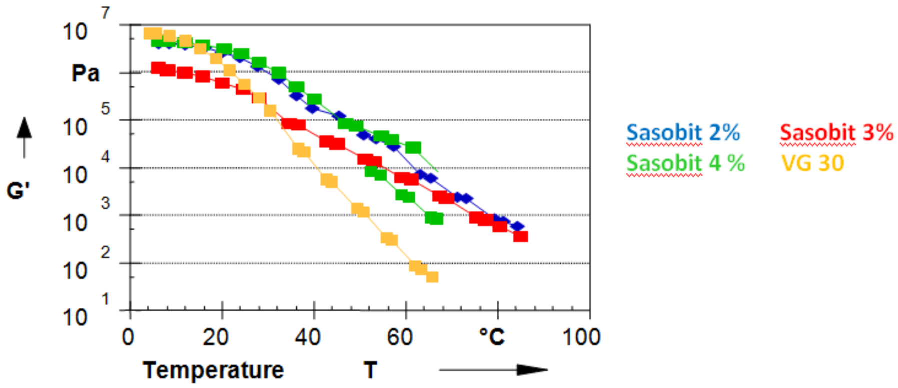

Figure 2: Effect of addition of Sasobit on Storage Modulus

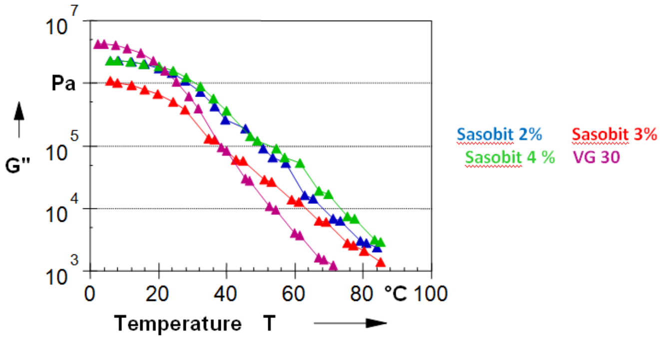

Figure 3: Effect of addition of Sasobit on Loss Modulus

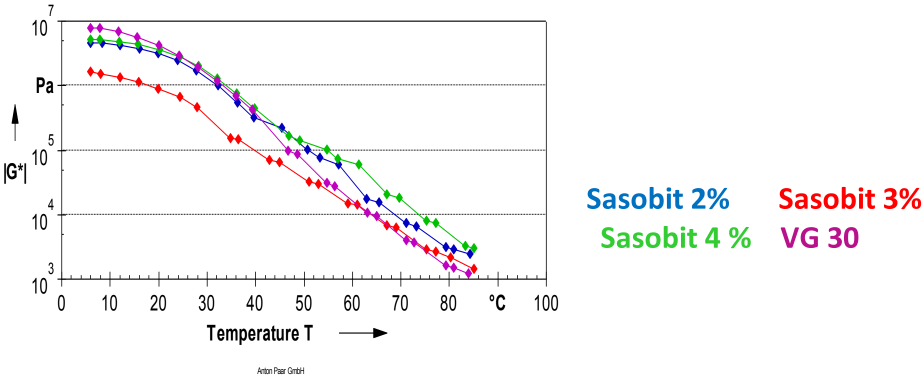

Figure 4: Complex Modulus of neat and Sasobit modified Binders at different temperatures

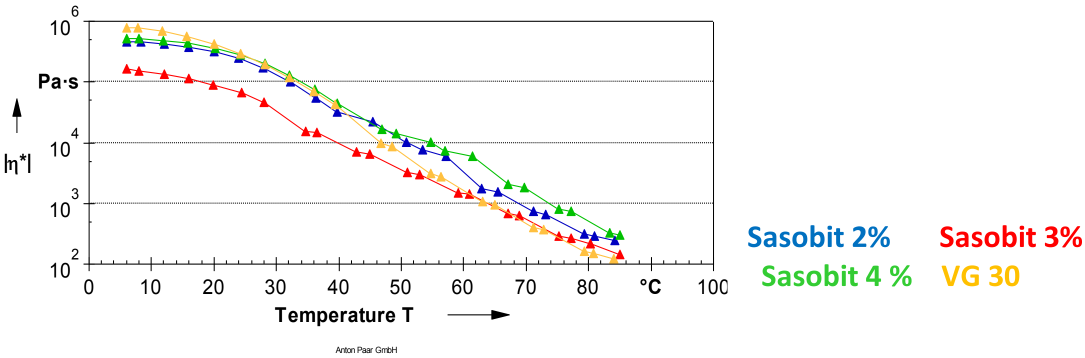

Figure 5: Effect of addition of Sasobit on Complex Viscosity

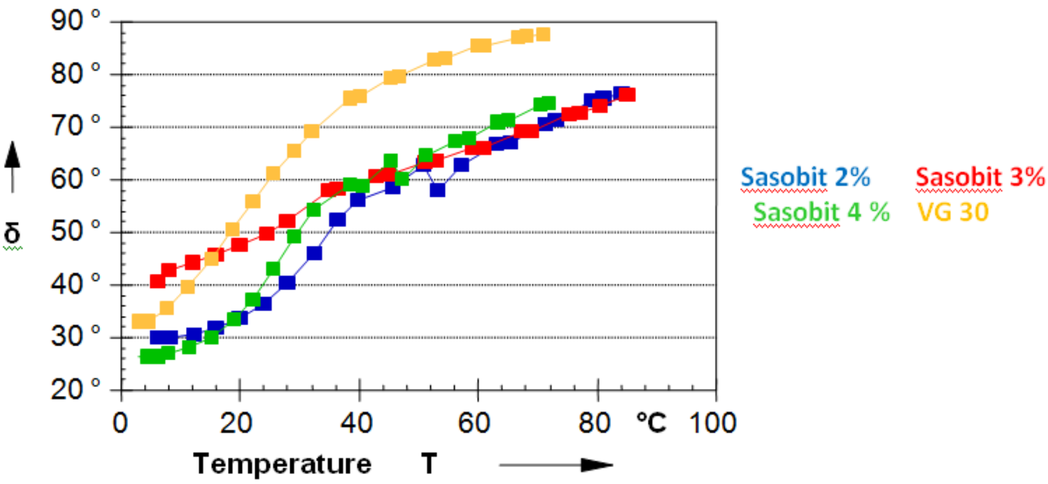

Figure 6: Comparison of Phase Angle of neat and Sasobit modified binder

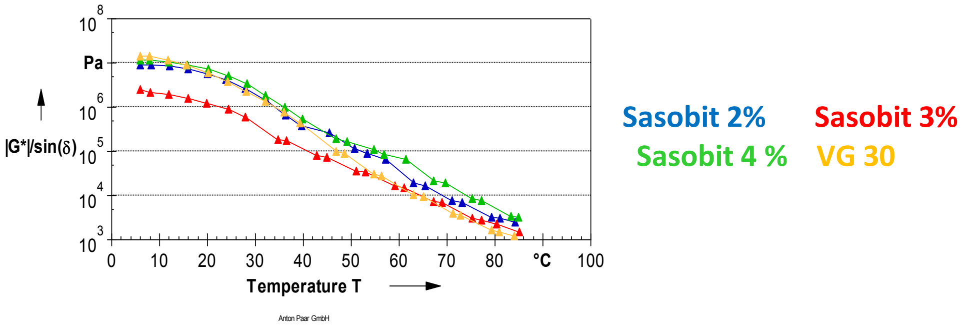

Figure 7: Effect of addition of Sasobit on G*/sin δ

5.2.1 Viscoelastic Response of Binder

Results in figures 2 & 3 show a decrease of G' and G'' moduli with increasing temperatures. But the rheological behavior of Sasobit modified bitumen binder changes after going beyond a temperature of 40^0C, before the temperature of 40^0C the neat bitumen showed higher values for G' and G'' but from 40^0C to 88^0C the sasobit modified binder showed better values for G' and G''. The increase in G' reflects the increase in the stiffness of the bitumen Sasobit blends, compared with that of neat bitumen. But the increase in G'' indicates an increase in the viscous response.

The storage modulus (G') of Sasobit modified binder was higher than neat bitumen as shown in figure 2 after a temperature of 40^0C.It is maximum for the bitumen modified with 4 % Sasobit. The loss modulus (G'') of modified blend was significantly higher than the neat bitumen as shown in figure 3. Higher values of loss modulus indicate more resistance of the binder to permanent deformation. Figure 4 shows almost linear relationship between complex modulus [G*] and temperature. Whereas the trend followed is same i.e. from 6^0C to 40^0C the neat bitumen showed higher complex modulus but from 40^0C to 88^0C the 4% sasobit modified binder showed higher values for complex modulus. Figure 5 shows a similar trend of complex viscosity increase and decrease before and after 40^0C. The complex viscosity reduces with increasing temperatures. Higher modulus at high temperature indicates better resistance to permanent deformation (rutting).

Figure 6 shows that the phase angle (δ) of Sasobit modified bitumen was lower than that of neat bitumen. The phase angle of 4% Sasobit modified bitumen was considerably lower than that of unmodified bitumen. Lower phase angle indicates lower viscous flow and higher elastic response. This indicates that sasobit modified binders have high consistency and elasticity. Figure 7 shows there was an increase in the G*/sinδ parameter of the original binder when the Sasobit was mixed. This indicates that the stiffness of the modified binder increases with the increase in the percentage of Sasobit and decreases with the increase in the temperature.

5.3 Emissions from Warm Mix Asphalt

Many pollutants are emitted in the process of mixing and laying of bituminous concrete for pavements. There are many different types of compounds emitted during the whole process from hot mix plant to the final laying and rolling. In this study the tests were carried out for only few compounds to get a qualitative idea about emissions from the warm mix .The emission test results show that there is considerable amount of reduction in emissions like styrene, xylene, benzene etc when mixed at lower temperature 120^oC as shown in figure 8. There are possibilities of formation of new compounds, each evaporating at different temperature range. Hence further extensive study is required in this area, taking care of all different compounds emitted at various stages, for getting better conclusion

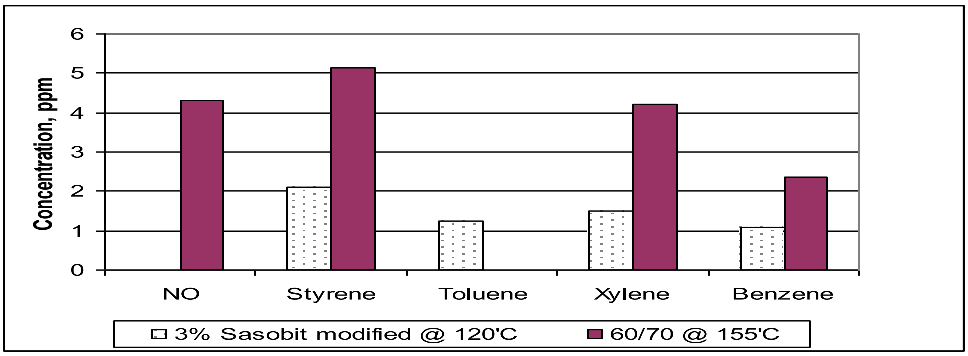

Figure 8: Emission Test Results

VI. Conclusions

Based on the results of the laboratory study the following conclusion can be drawn:

- Viscosity of Sasobit warm mix asphalt is higher at lower temperatures and reduces considerably at higher temperatures, which is desirable.
- It was observed that at 100ºC the Sasobit® increased the viscosity of the binder as its melting point is between 85ºC to 115ºC and beyond 100^0C it reduces the viscosity of binder to a greater extent up till 155^0C.
- Sasobit® modified binder showed better G' and G" values between the temperature range of 40^0C – 88^0Cwhich concludes to the increased stiffness of the binder as well as better viscous response of the binder in that temperature range.
- Improved phase angle and complex modulus values were achieved after addition of Sasobit® to the binder. It shows better resistance to the permanent deformation of the mix as compared to the mix prepared by neat VG 30 binder.
- Though it is obvious that there will be an overall reduction in quantity of emission of pollutants when the mix is made at 120^oC than at 155^oC, in terms of fuel etc., extensive study is required in this area to get better conclusion.

Acknowledgements

The authors are thankful to Dr.S.Gangopadhay, Director, Central Road Research Institute, New Delhi, for his encouragement during the study. The authors do not endorse any proprietary products or technologies mentioned in this paper. These appear herein only because they are considered essential to the objective of this paper.

References

[1]. Newcomb, D "An Introduction to Warm-mix Asphalt", National Asphalt Pavement Association, 2006.
[2]. Ministry of Road Transport & Highways (MORTH) specifications for Road and Bridge Works", 2001, Indian Road Congress, New Delhi.
[3]. "Warm Mix Asphalt Shows Promise for Cost Reduction, Environmental Benefit ": The Asphalt Pavement Association of Oregon held in 2003.
[4]. "Asphalt- Contributing to a Sustainable Future ", Asphalt Review, Volume 24, No.23, December 2005.
[5]. U.S. Department of Transportation Federal Highway Administration (2004), "Warm Mix Technologies and Research ". Accessed in February 17 2012.
[6]. David Jones, Bor-Wen Tsai, and James Signore (2010), Warm-Mix Asphalt Study: Laboratory Test Results for AkzoNobel RedisetTM WMX, University of California Pavement Research Center UC Davis, UC Berkeley
[7]. Wasiuddin, N. M., Selvamohan, S., Zaman, M. M., and Guegan, M. L. T. A. (2007). "A Comparative Laboratory Study of Sasobit® and Aspha-min® in Warm-Mix Asphalt." Transportation Research Board 86th Annual Meeting, Washington DC, United States. [CD-ROM]
[8]. Chowdhury, Arif and Button, Joe. *A Review of Warm Mix Asphalt.* Texas Transportation Institute.Springfield, Virginia : National Technical Information Service, December 2008. Technical report.
[9]. Shu Wei Goh, Zhanping You, Thomas J. Van Dam, "Laboratory Evaluation and Pavement Design for Warm Mix Asphalt", Proceedings of the 2007 Mid-Continent Transportation Research Symposium, Ames, Iowa, August 2007. © 2007 by Iowa State University