

Experimental Investigation to Find Transition Temperature of VG-30 Binder

D. Latha, V. Sunitha, Samson Mathew

Abstract—In India, most of the pavement is laid by bituminous road and the consumption of binder is high for pavement construction and also modified binders are used to satisfy any specific pavement requirement. Since the binders are visco-elastic material which is having the mechanical properties of binder transition from visco-elastic solid to visco-elastic fluid. In this paper, two different protocols were used to measure the viscosity property of binder using a Brookfield Viscometer and there is a need to find the appropriate mixing and compaction temperatures of various types of binders which can result in complete aggregate coating and adequate field density of HMA mixtures. The aim of this work is to find the transition temperature from Non-Newtonian behavior to Newtonian behavior of the binder by adopting a steady shear protocol and the shear rate ramp protocol. The transition from non-Newtonian to Newtonian can occur through an increase of temperature and shear of the material. The test has been conducted for unmodified binder VG 30. The transition temperature was found in the unmodified binder VG is 120°C. Therefore, the application of both modified binder and unmodified binder in the pavement construction needs to be studied properly by considering temperature and traffic loading factors of the respective project site.

Keywords—Unmodified and modified binders, Brookfield Viscometer, transition temperature, steady shear, shear rate protocol.

I. INTRODUCTION

CURRENTLY, the majority of the Indian roads is flexible pavements. Flexible pavement is preferred over cement concrete roads since they have a great advantage that these can be strengthened and improved in stages with the growth of traffic. Another major advantage of these roads is that their surfaces can be milled and recycled for rehabilitation. The flexible pavements are less expensive than rigid pavement with regard to the initial investment and maintenance. A bituminous layer consists of surface course, base course, and sub base course resting over the sub-grade.

The bitumen from the different sources possessing the same penetration value at the specified temperature may exhibit entirely different viscous characteristics at the application temperatures. These tests, therefore, may need intensive correlation with fundamental property like viscosity. Viscosity is the resistance offered by the liquids for its motion and it is the general term for consistency. The degree of fluidity of binder at the application temperature greatly influences the strength characteristics of the paving mixes. High or low

viscosity during mixing or compaction will result in lower stability values. At low viscosity, bituminous binder simply lubricates the aggregates instead of coating a thin film over. At high viscosity resists the compaction effort and mix results in heterogeneous character exhibiting low stability values. Thus, measurement of viscosity at the application temperature is very much essential. The conventional type of measurement of viscosity involves the determination of transpiration time to flow certain quantity of flow under certain test condition. These methods give viscosity in seconds, specifying the apparatus with which it is measured. Brookfield Viscometer measures the viscosity directly in centipoises. The test procedure is very simple to conduct. With the thermosel accessories, viscosity can be determined to any desired temperature. Present studies made use of this one.

Air blown, blended asphalt and petroleum pitch were tested at different aging conditions. The temperature at which the material exhibited shear rate independent viscosity was taken as the transition temperature. The transition temperature varied with processing method and aging conditions. It was seen that blended asphalt exhibited a greater increase in apparent viscosity during aging when compared to air blown asphalt, whereas air blown asphalt showed a greater shift in transition temperature for the same aging conditions [1].

Malkin reviewed that the origin of the non-Newtonian viscosity is related to shear induced structure transformations. This statement should be considered in two different senses. Initially the structure less elastic fluids (polymer melts) with random distribution of segments of flexible chains in space (at rest), shear-induced transformations consist in a modification of a relaxation spectrum [3]. Mturi et al. discussed the limitations of rotational viscometry, especially when used for the determination of viscosity measurements for shear-thinning modified binders, as well as the advantages of Dynamic Shear Rheometry (DSR) as an alternative method of viscosity measurement [2]. Nikhil and Lokesh found that the viscosity of different grade bitumen will increase with the inclusion of fibers. Steel wool gives good results with respect to increase in viscosity [5].

II. RHEOLOGICAL BEHAVIOR OF BITUMEN

Measuring rheological properties were introduced in large scale to the paving industry by the U.S. To study the rheological properties, or visco-elastic behavior, of the binder are the important keys to understanding and predicting pavement performance over a wide range of climatic, environmental, traffic and loading conditions. Range and degree of stiffness, elasticity, and relaxation times tell a great

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deal of the binder performance when measured over the working temperatures

One important factor related to the performance of asphalt pavement is the transitory nature of asphalt as the temperature is varied. As the binder temperature changes from higher to lower value, one can observe the transition from Newtonian to visco-elastic fluid, viscoelastic fluid to viscoelastic solid and finally to a glassy solid [1]. Dedier Lesueur et al. studied about the viscoelastic properties of asphalt cement and its thermal properties was studied with Mettler, TA 2000 B differential scanning calorimeter. They concluded that a viscoelastic property of asphalt is bimodal and they are governed by solid and continuous phases [4]. Canestraril et al. found that the effect of wax on mixing and compaction temperatures ($T > 100^{\circ}\text{C}$) was evaluated using viscosity tests. A Dynamic Shear Rheometer (DSR) and a Bending Beam Rheometer (BBR) were used to investigate the rheological properties of the base and the WMA binder at midrange and low service temperatures (from 18°C to 37°C) [10]. Thodesen et al. studied the effect of crumb rubber on binder viscosity and given that the asphalt binder viscosity is of great importance during the production process of hot mix asphalt mixture as typically asphalt plants will store binders between 149°C and 177°C [6]. Kanmani et al. carried out the study on petroleum pitch from crude sources such as Basrah Light, Arab Msix and Arab Light and they are subjected to steady shear for 99 min at temperatures ranging from 70 to 120°C for different shear rates. Each of these materials exhibited different stress overshoot and decay during steady shear depending on the temperature and shear rate [11]. The binder durability was evaluated by considering the ageing resistance (RTFOT) [8].

A. Temperature

One of the most obvious factors that can have an effect on the rheological behavior of a material is temperature. Some materials are quite sensitive to temperature, and a relatively small variation will result in a significant change in viscosity. Others are relatively insensitive. Consideration of the effect of temperature on viscosity is essential in the evaluation of materials that will be subjected to temperature variations in use or processing like binders in bituminous mixture for road pavement. Viscosity of the warm asphalt binders was measured at 135°C , the standard test temperature and at 120°C , which is the mixing temperature generally used for warm mix asphalt [7].

B. Shear Rate

Non-Newtonian fluids tend to be the rule rather than the exception in the real world, making an appreciation of the effects of shear rate a necessity for anyone engaged in the practical application of rheological data. When the sample is subjected to a variety of shear rates in processing or use, it is essential to know its viscosity at the projected shear rates. If these are not known, an estimate should be made. Viscosity measurements should then be made at shear rates as close as possible to the estimated values. Zero shear rate limiting viscosities of synthetic binders was studied in [9].

C. Time

The time elapsed under conditions of shear obviously affects Thixotropic and Rheopectic (time-dependent) materials. However, changes in the viscosity of many materials can occur over time, even though the material is not being sheared. Aging phenomena must be considered when selecting and preparing samples for viscosity measurement.

III. BROOKFIELD VISCOMETER

Rotational Viscometers are normally used for characterizing the response of the material in the Newtonian/non-Newtonian regime encountered during the mixing and compaction temperature range. In a typical rotational Viscometer, the inner cylinder/spindle rotates and the outer container is stationary. The accuracy of transition temperature depends on the accuracy with which apparent viscosity can be measured.

Viscosity test for all binders are performed using a Brookfield Viscometer available at the Transportation laboratory, NIT, Tiruchirapalli. A rotational Viscometer (model HADV2T) with supporting Rheocalc T software is used throughout the study and test setup of Brookfield Viscometer is shown in Fig. 1.



Fig. 1 Brookfield Viscometer test setup

IV. TEST PROTOCOL FOR FINDING TRANSITION TEMPERATURE

A. The Protocol I: Shear Rate Ramp

In this Protocol, the temperature was kept constant and only the angular velocity was changed at a constant rate. The materials were sheared with an angular velocity increment of 0.02 rpm/s. A pre shearing for 5 min at a constant angular velocity was carried out before the sample subjected to the shear rate ramp. The preshearing was done by starting angular velocity. This protocol has been followed from [1].

B. Protocol II: Steady Shear Protocol

In this protocol, the material was sheared at a constant angular velocity at a specified temperature for 10 min. The angular velocity was selected such that the torque was maintained in such a way that it should not below 10% and should not exceed above 100% .

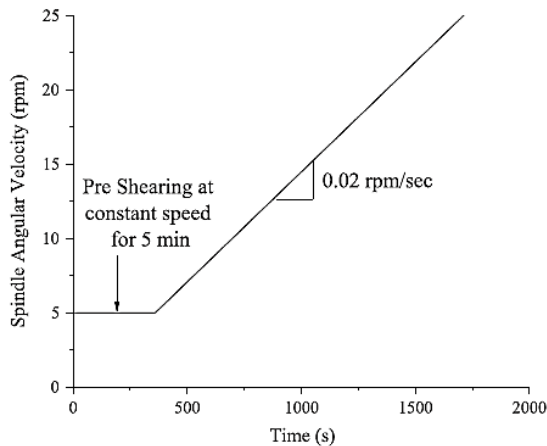


Fig. 2 Representation of Protocol I: Shear Rate ramp [1]

TABLE I
TEST CONDITIONS FOR PROTOCOL I

Test Temperature (°C)	Angular velocity range (RPM)
90	5-8
95	5-15
100	10-30
105	13-30
115	15-30

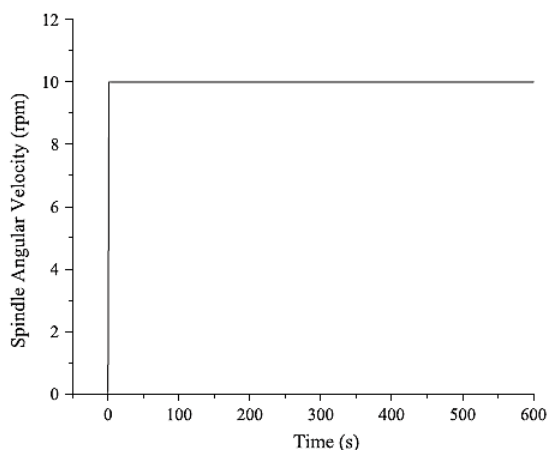


Fig. 3 Representation of Protocol II: Steady shear protocol [1]

TABLE II
MATERIALS AND TEST CONDITIONS FOR PROTOCOL II

Temperature range (°C)	Spindle angular velocity (rpm)
100, 105, 110, 115, 120, 125	10
100, 105, 110, 115, 120, 125, 130	20

V. DATA COLLECTED

TABLE III
PROPERTIES OF MATERIALS AS PER IS: 73

Penetration value (mm)	Softening point (°C)	Ductility(cm)
66	47	56.75

The transition from non-Newtonian to Newtonian can occur through an increase of temperature and shear of the material.

The Protocol I was designed in which at constant temperature, the material was subjected to shear rate ramp. Next, the material was subjected to a constant angular velocity at constant temperature and the transition temperature was identified. The choice of this protocol was based on the results obtained from protocol I.

A. Protocol I: Shear Rate Ramp Protocol

It is interesting to find the transition temperature as a result of shear rate history. The protocol I was designed to quantify such influences. In this protocol, the material was sheared for a constant angular velocity increment of 0.02 rpm/s and at a constant temperature. The temperature at which the apparent viscosity remains constant with increasing shear rate was taken as non-Newtonian to Newtonian transition temperature.

The characterization of bitumen as a yield stress fluid is given in the literature. Benallal found a yield stress for asphalt, whose behavior could be described by a Bingham model. The yield stress was linked to the paraffinic part existing in the asphalt [12]. This yield stress decreased with temperature due to the melting of the crystallized fraction. To quickly estimate the lowest stress from which the bitumen flow, successive stress steps has been applied at 22°C. According to this test, the bitumen is a yield stress fluid, whose yield value at 22°C is between 0.1 and 1 Pa. The evolution of viscosity as a function of shear rate for several temperatures, ranging from 22 to 90°C shows that the maximum shear rate reached was around 100s⁻¹. Above, samples started to tear. At low shear rate (typically, less than 10⁻³ s⁻¹), a yield stress is more visible at high temperatures because, at 22°C or 30°C, it appears at a much lower shear rate (less than 10⁻³ s⁻¹). At high temperatures (70 and 90°C), the measured torque of rheometer was always higher than its minimum value. Whatever the temperature, in the range of explored shear rates, the bitumen can be accurately described by a Bingham model:

$$\eta = \eta_0 + \frac{\sigma_y}{\dot{\gamma}} \quad \text{For } \sigma > \sigma_y$$

where η_0 is the Newtonian viscosity and σ_y the yield stress.

The variation of apparent viscosity as a function of shear rate for VG 30 at 90, 95, 100, 105 and 115 °C is shown in Fig. 4 and it is seen that the binder exhibits shear thinning behavior when tested at unaged condition in the temperature range 90-115°C as seen in Fig. 1. For G 30 unaged binder at 90 °C, the apparent viscosity shows only the shear thinning region between 5 and 7 s⁻¹. At 95°C the shear thinning region lies between 5 and 14 rpm. At 100 °C the binder exhibits two regions from the shear rate 10 to 14s⁻¹ the viscosity decreases to shear thinning region and then constant viscosity value 25 Poise which is the infinite shear viscosity of VG 30 binder at 100°C. At 105°C the shear thinning region lies between 14 and 20 s⁻¹ and attained infinite shear viscosity 13 Poise up to 30s⁻¹. Fig. 4 gives the result that the apparent viscosity decreases with increasing shear rate and increase in temperature and the material exhibited a constant value at higher temperature.

The viscosity of unaged VG 30 binder as a function of shear rate at 115 °C in Fig. 4 remained constant (1758centipois) thus showing Newtonian response response at 115 °C.

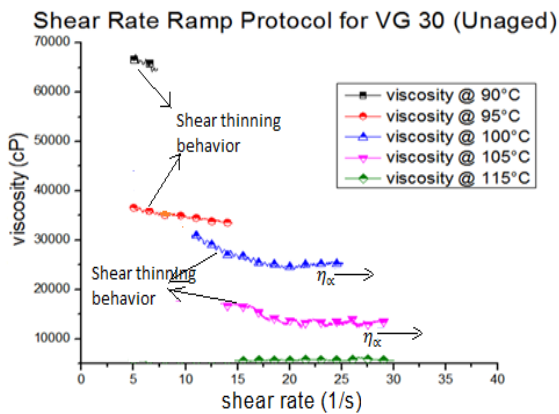


Fig. 4 Shear Rate Ramp Protocol: Viscosity Behavior of VG 30 binder

B. Protocol II: Steady Shear Rate Protocol

The binder in protocol I was subjected to an angular velocity increment and hence the transition temperature obtained from these protocols depended on the shear rate history. In protocol II, the material was sheared under a constant spindle angular velocity and apparent viscosity was measured as a function of time. The experiments were conducted for two different spindle angular velocity as shown in Table II at a specific temperature. If the apparent viscosity values obtained from two different spindle angular velocities at a specific temperature were equal with no stress overshoot, the binder exhibited shear rate independent viscosity and hence response was taken as Newtonian.

For determining the apparent viscosity of the binder required during mixing and compaction, the protocol suggested by asphalt Institute NCHRP report 648 was used and this was a steady shear protocol. In this protocol, the material is subjected to five minutes of preshearing under a constant spindle angular velocity and the average of the apparent viscosity measured in the subsequent three minutes of shearing at the same angular velocity is taken as the apparent viscosity of the binder at that temperature.

Fig. 5 shows the apparent viscosity as a function of time for unaged VG 30 binder for different temperature and spindle angular velocity at 15 rpm and 20 rpm respectively.

In the 20 rpm plot, at 130°C, apparent viscosity of unaged VG 30 binder is approached to constant value 657Centipoise (Fig. 6).

Fig. 7 shows the apparent viscosity as a function of time for unaged VG 30 binder at a different temperature and angular velocity. It was seen that the unaged VG 30 binder exhibited Newtonian behavior at 120°C since at that temperature the apparent viscosity is the shear rate independent.

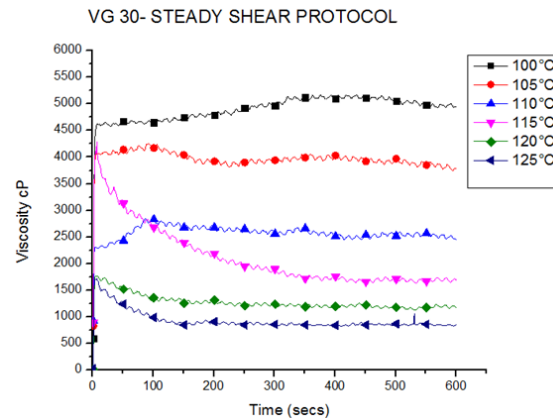


Fig. 5 Steady Shear Protocol: Viscosity Behavior of VG-30 at 10rpm

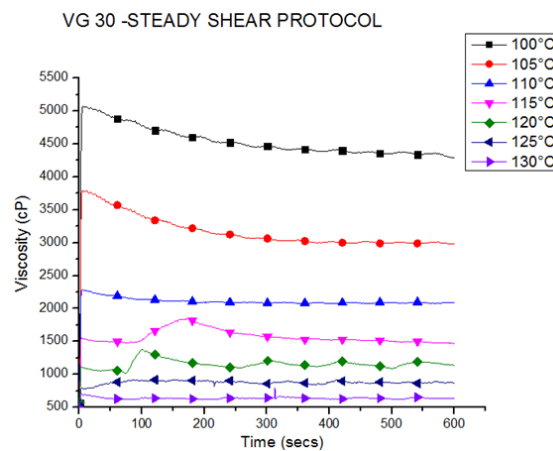


Fig. 6 Steady Shear Protocol: Viscosity Behavior Of VG-30 @20rpm

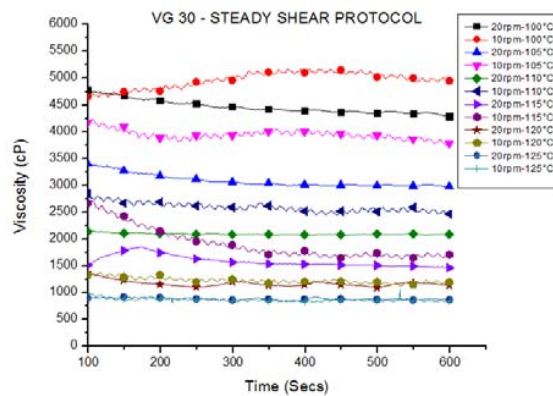


Fig. 7 Viscosity Behavior of VG-30 binder

VI. CONCLUSION

This experimental investigation focused on finding non-Newtonian to Newtonian transition in unmodified binder VG 30. Two different protocols were used for this experimental investigation. The temperature at which the material exhibited shear rate independent viscosity with no stress overshoot was taken as the transition temperature. The material showing Newtonian response at a specific temperature during the

mixing operation during hot mix asphalt laying might not show the same response at the same temperature during compaction [1]. In protocol I, the binder at constant temperature was subjected to angular velocity increment and protocol II, the material was sheared under a constant angular velocity and temperature. The difference in transition temperature obtained from protocols I and II characterize the shear rate history influence.

The unmodified binder VG 30 unaged condition shows transition behavior at 120°C

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