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An Experimental Investigation on Influence of Mixing and Compaction Temperature on Air Voids in Bituminous Mix

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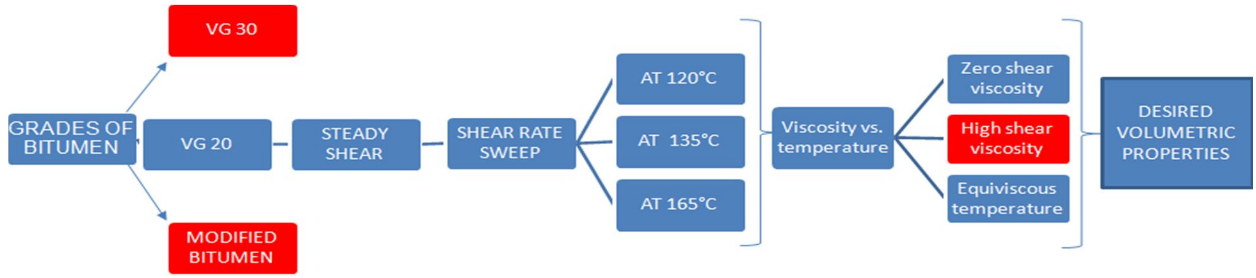
***Abstract:** The air void content and long-term performance of pavements are significantly impacted by the mixing and compaction temperature of bituminous mixtures, leading to potential failures such as premature aging, reduced durability, and issues like fatigue life, raveling, rutting, and vertical consolidation in Hot Mix Asphalt (HMA) pavements. To achieve optimal production and placement of HMA, it is crucial to carefully consider the mixing and compaction temperatures of the binder (bitumen) used. Notably, these temperatures vary based on the grade and origin of the bitumen, as different sources exhibit distinct properties affecting the mixing and compaction characteristics. Selecting an appropriate mixing and compaction temperature is vital to ensure effective aggregate coating and achieve the desired density. This experimental study aims to determine a reliable method for estimating the mixing and compaction temperatures for both modified and unmodified bitumen, thereby enhancing the overall performance and longevity of asphalt pavements.*
***Keywords:** Bitumen, Viscosity, Temperature, Compaction, Equiviscous*

I. INTRODUCTION

The bituminous mix has been using for road construction since 1870's and 70% of pavements are made of bitumen. The mixing and compaction temperature of bitumen is an important factor affecting the performance of the bituminous pavements. To estimate the appropriate temperature, approximations from field experiences are currently used. The mixing and compaction temperature is not identical for all grades of bitumen. Depending on the origin of bitumen, there will be change in properties and this influences the mixing and compaction temperature. The mixing and compaction temperature influences the air voids and causes failures by accelerating the aging and decreasing the durability, affects fatigue life, raveling, rutting and vertical consolidation. The correct mixing and compaction temperature is correlated to the viscosity of the material. If the viscosity of bitumen is high, there will be difficulty in mixing while a low viscosity results in drain down from the mix. Hence an appropriate viscosity has to be determined to be correlated to the mixing and compaction temperature. The mixing and compaction temperature for modified binder is higher when compared with the unmodified binders. Currently, the use of modified binder is about 20% of the total pavement construction. Some recommendations have been made regarding the mixing and compaction temperature. It has been said that the temperature should not exceeds 182°C while mixing and the temperature should be 149°C when discharged from hauling in the case of modified binders.

II. METHODOLOGY

From the common source, required grades of bitumen are chosen. Steady shear and shear rate sweep tests are performed at 120°C, 135°C and 160°C. Corresponding viscosity for each method is determined using various tests such as Equiviscous, Low shear viscosity & High shear viscosity. From the result of various methods, a mould is made and volumetric properties are determined.



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III.EXPERIMENTAL INVESTIGATION

A. Introduction

For determining mixing and compaction temperature the experiments required are

1) *Rotational viscometer*

a) *Introduction:* From the name we can determine that viscometer is an equipment use to determine the viscosity of the material. Viscometer measures both Newtonian and non-Newtonian fluids.

b) *Principle:* From the name we can determine that viscometer is an equipment use to determine the viscosity of the material. Viscometer measures both Newtonian and non-Newtonian fluids.

c) *Methods:* Steady shear: constant shear rate is used; Shear rate sweep: shear rate is varied over a range

d) *Procedure:* Viscometer, thermostat and the computer are connected with each other. The bitumen is placed in the cylindrical container and fixed at the bottom plate of viscometer. The spindle is made to suspend on the hook. The temperature and torque values are fixed and let the bitumen to melt and to reach the desired temperature. The spindle is partially immersed in the cylindrical container to maintain the equilibrium for 5 minutes. Start the viscometer, the spindle will tend to rotate and data are taken. Viscometer works by getting the measurements of the torque on a vertical stand that rotates the spindle in an anti-clockwise direction. The rotation of the spindle is usually proportional to how viscous the sample is.

Fig 1: Viscometer and its methodology

2) *Marshall Apparatus*

a) *Introduction:* The test is intended for the measurement of the resistance to plastic flow of cylindrical specimen of bituminous paving mixture loaded on the lateral surface. The procedure consists of determining the Marshall stability and flow value analysis, property of the mix and maximum binder content. With the help of phase diagram calculations are made.

b) *Procedure:* The Marshall mould of 102 mm diameter and 64 mm height with a base plate and a collar is taken. In concern with mix design grading and mixing have been made and the mix is placed in the mould in three layers and compacted in the rammer of weight 4.5 kg is made to drop from the height of 175 cm. The compaction is made on the other side of the mould by keeping the mould in an inverse manner. Sample is extracted with the help of sample extractor. The mould is placed between the curved path and breaking head. The load is applied on the mould and the value will be displayed in the dial gauge, then the stability and the flow value is measured.

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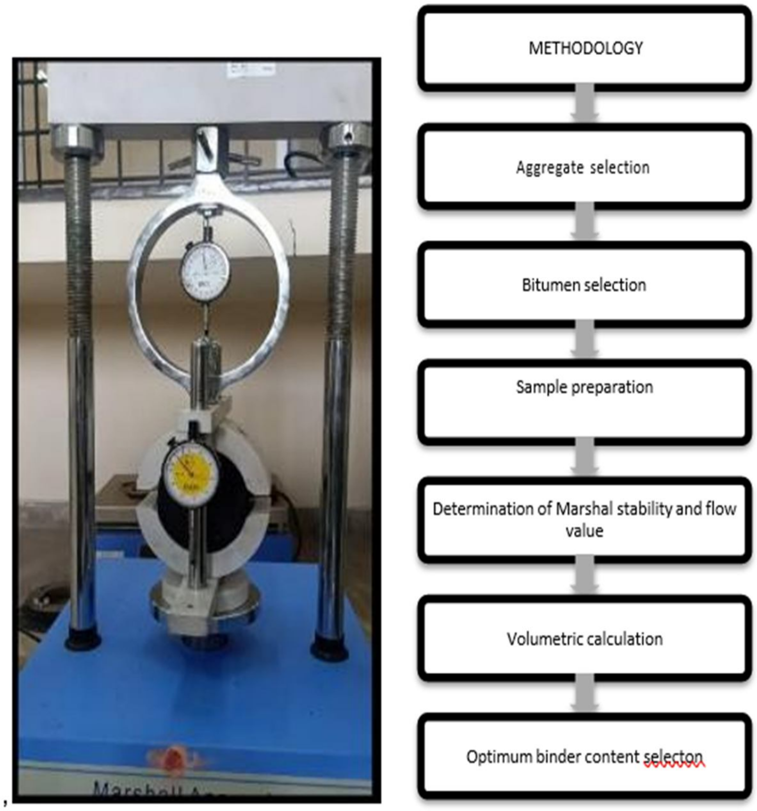

Fig 2: Marshall Apparatus and its methodology

IV. RESULTS & OBSERVATIONS

A. *Shear Rate Sweep*

Three grades of bitumen VG20, VG30 and modified bitumen were taken. A rotational viscometer was used to measure the viscosity. For constant temperature, the shear rate ranges were identified such that torque should not exceed 90% of the capacity of the equipment. Also, the low shear rate corresponding to 10% torque was identified. The shear rate sweep was performed for temperatures namely 120°C, 135°C, and 165°C.

From the obtained data, the graph is plotted from six random viscosity values to its corresponding shear rate.

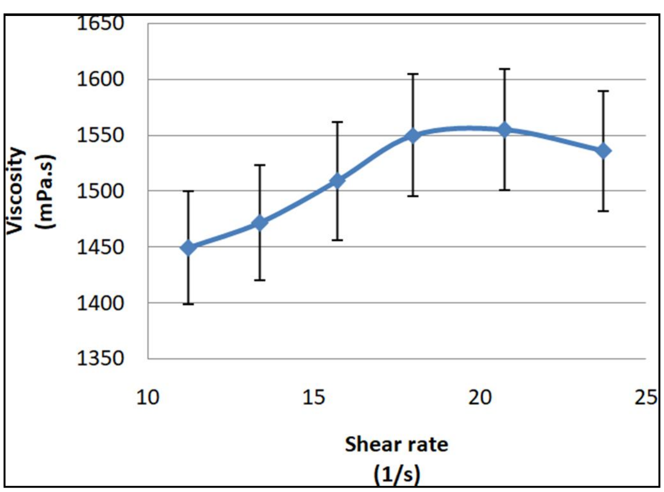

Fig 3: VG20 at 120°C.

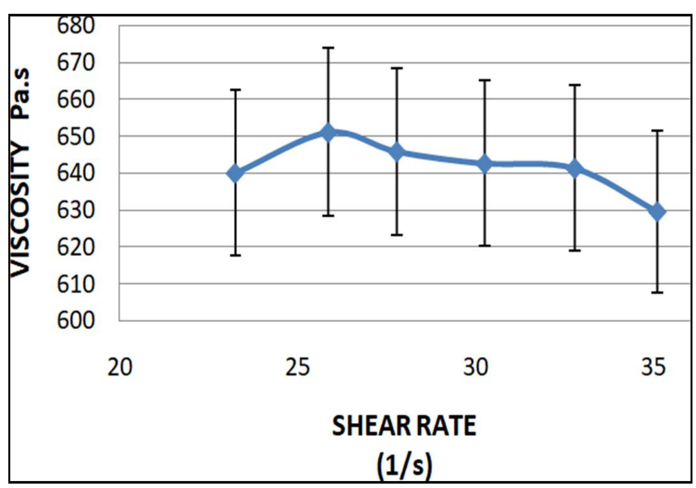

Fig 4: VG 20 at 135°C

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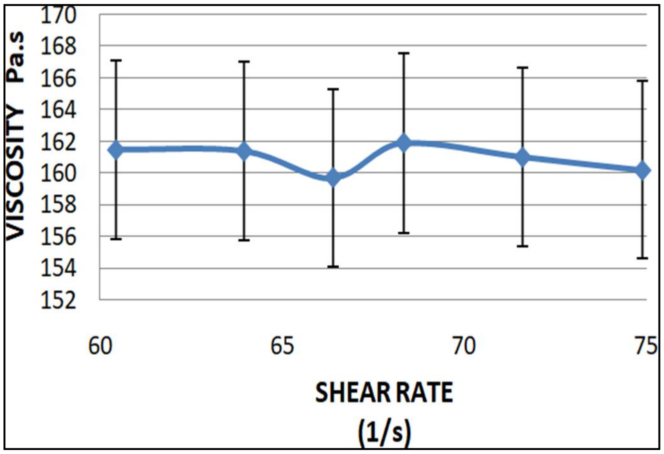

Fig 5: VG20 at 165°C

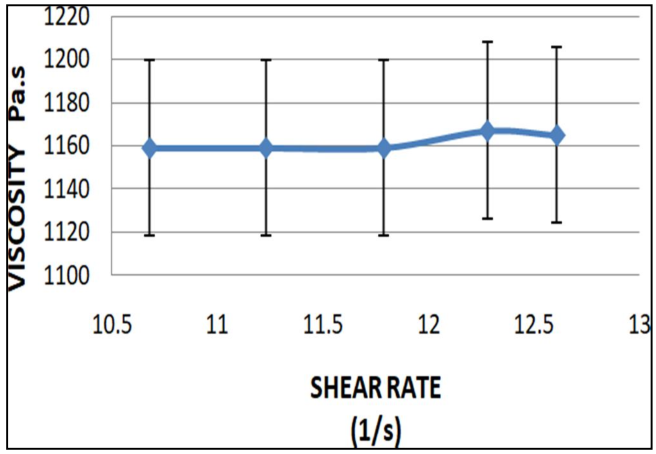

Fig 6: VG 30 at 120°C.

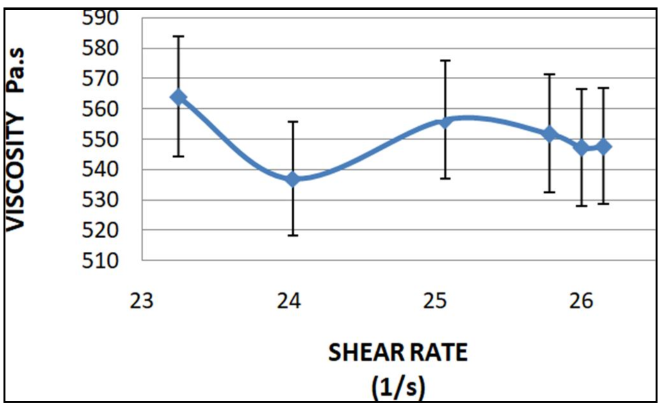

Fig 7: VG 30 at 135°C

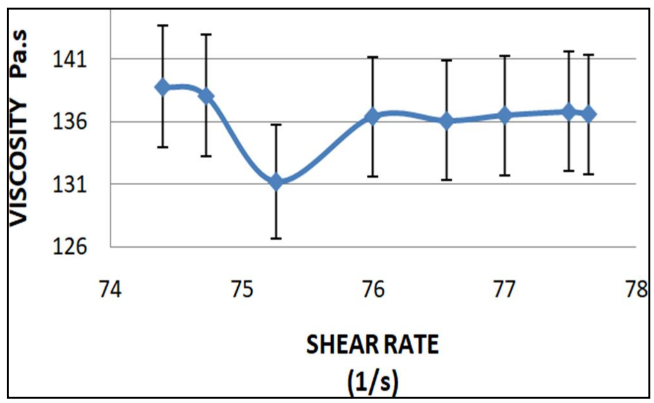

Fig 8: VG 30 at 165°C.

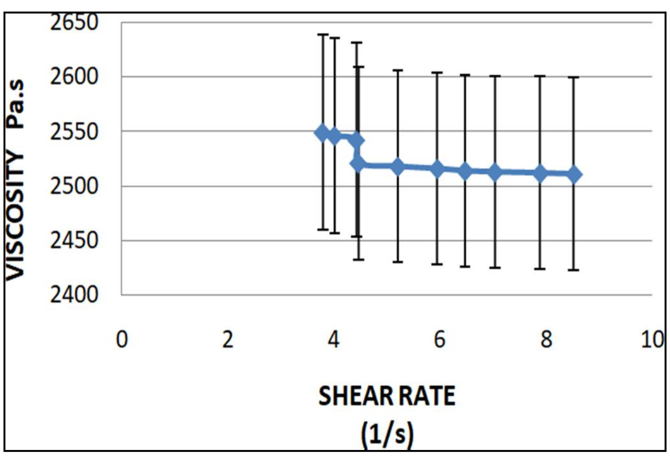

Fig 9: MB at 120°C

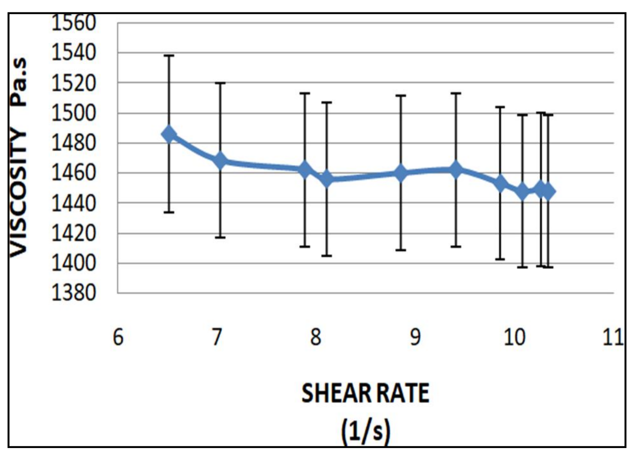

Fig 10: MB at 135°C

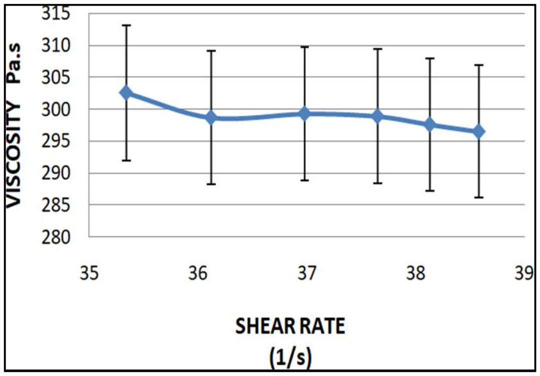

FIG 11: MB AT 165°C

Fig. 3 to Fig. 11 shows the results for the shear rate sweep experiment for bitumen. The repeatability range is also plotted here to estimate the Newtonian behaviour.

The above nine graphs are parts of the graph of viscosity vs. shear rate given below. The curve should fix to certain models. To know which part resembles which models the graph is divided into three parts and named as 1, 2 and 3.

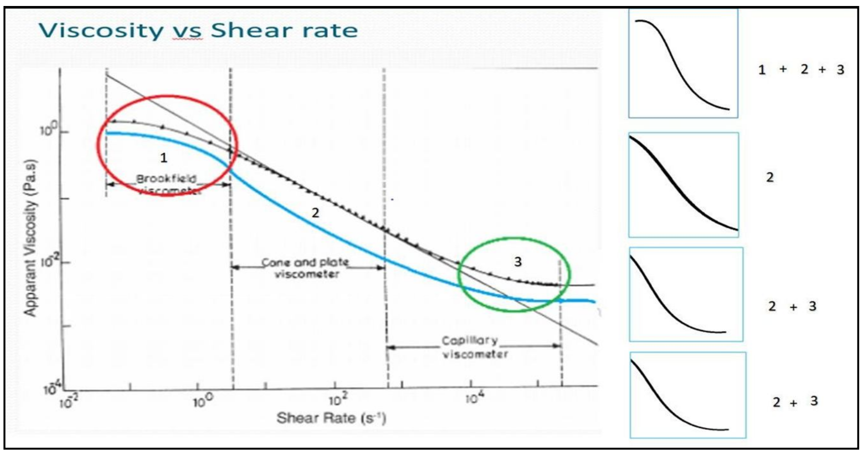

Fig 12: Graphical representation of viscosity vs. shear rate

B. Observation

Bitumen should be changed for every trial because it is sheared in the cylindrical container or else there are more chances for shear failure. Couple of trial is made for accuracy.

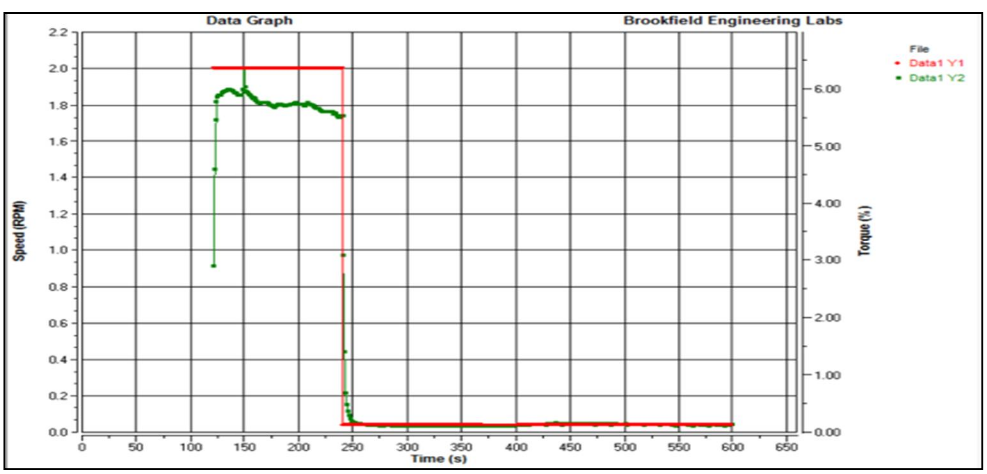

Fig 13: Shear failure

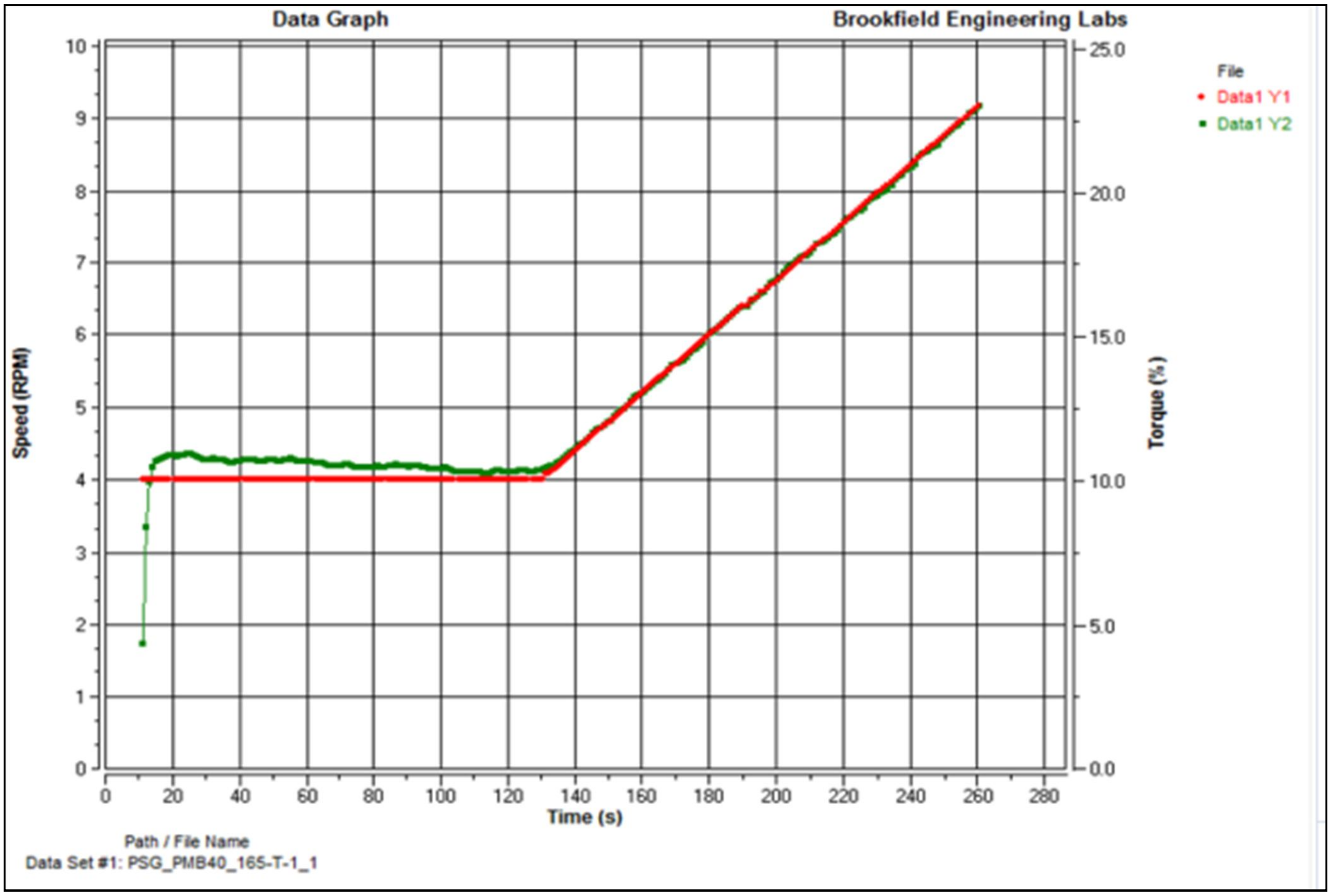

Fig 14: Shear rate sweep

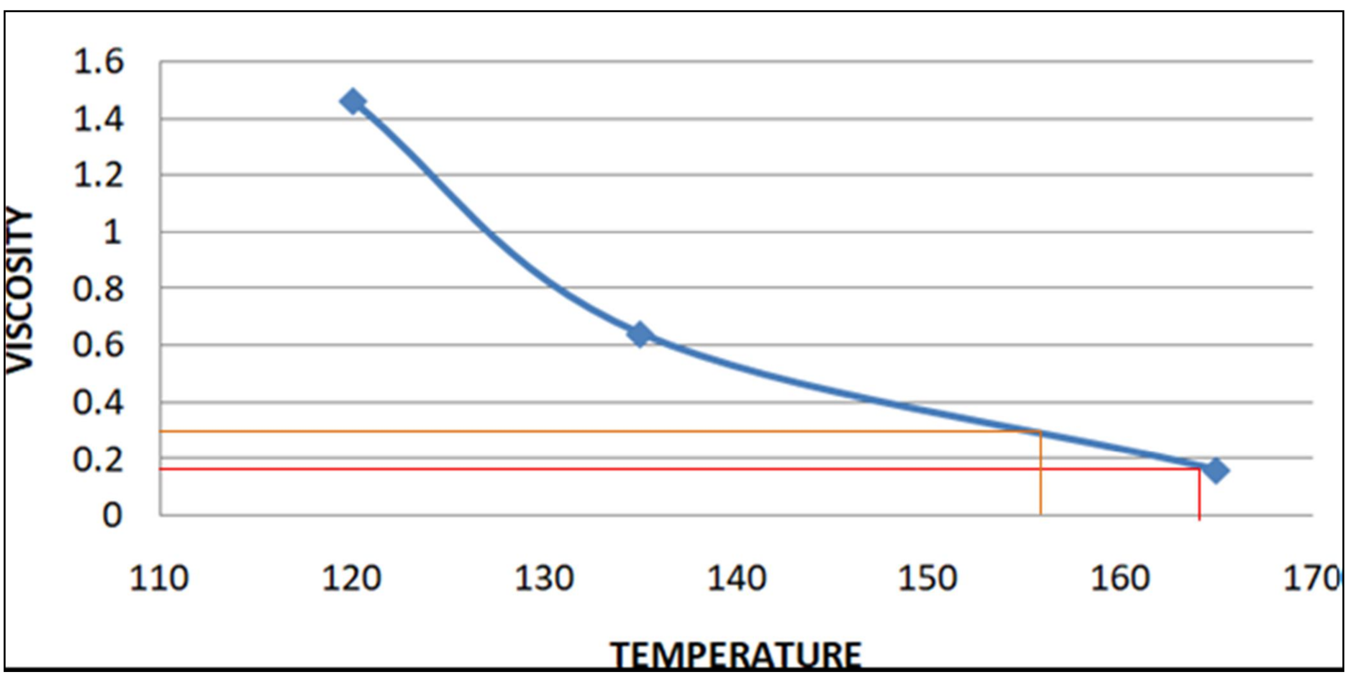

Fig 15: Viscosity vs. temperature graph to determine appropriate mixing and compaction temperature

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V. MIX DESIGN

A. Mix Design

Mix design involves selecting and proportioning materials to obtain the desired properties in the finished construction product. The mix design used in this study is detained as follows.

Mass of the aggregates = 1200 g
% binder content = 4%
Mass of binder content = x
Mass of the bituminous mix = (1200 + x)To quantify the mass of bitumen content
X = 4.5% (1200 + x)
X = 56.54 g

Extra 5% of the material is considered to compensate the losses during mixing and compactionTherefore,
Mass of binder content = 60 g Mass of aggregates = 1260 gMass of bituminous mix = 1320 g

B. Gradation

The gradation of the aggregates has to be determined for the required 1260 g of aggregates. Using sieve shaker, the percentage of aggregate retained on specified sieves are determined and gradation curve is obtained as shown in Fig.11. The mid gradation for the percentages specified in MoRTH for a DBM mix is used here. The appropriate gradation of aggregate is taken with three different percentages of bitumen contents namely, 4, 4.5 and 5%.

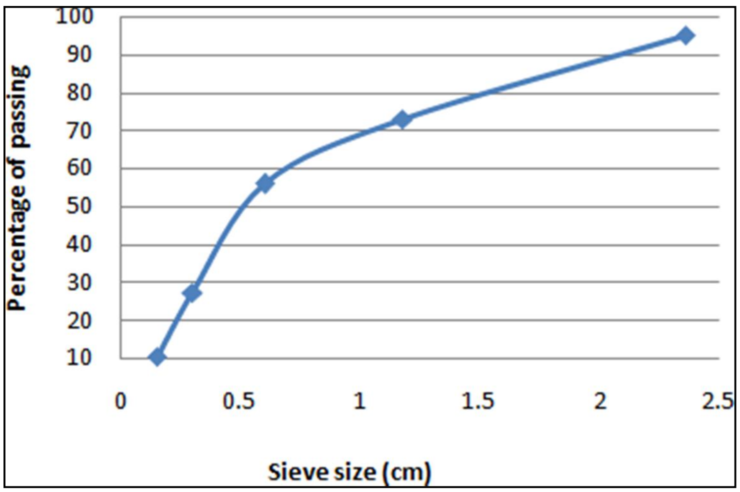

Fig 16: Gradation curve

The mixing and compaction temperature obtained for bituminous mix based on high shear method and low shear methods yield identical values as bitumen exhibits Newtonian behavior for most of the temperatures considered here.

The obtained temperature for

- *Mixing : 164°C*
- *Compaction: 157°C*

With the obtained aggregate gradation and temperatures moulds can be made (Fig. 13) and their appropriate volumetric properties can be measured to compare the variation in volumetric.

Fig 17: Casted bituminous mould

Properties obtained mixes with variation in mixing temperature estimated based on the three methods.

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C. Volumetric Properties

The term volumetric analysis implies the volume occupied by bitumen and aggregate to yield the mixture of desired properties. This is important to consider the durability of the pavement. The Marshall apparatus is used to determine the volumetric properties.

Fig 18: Marshall apparatus

1) *Air Voids (VA):* These are the unoccupied spaces between aggregate and bitumen and occupied by the air. There should be around 2-4% of air voids in order to rectify from the stresses from vehicles. Higher air voids increase the pores and make water to percolate through the voids. The allowed air voids should be 3-5%.

$$Va = 1\text{-}(Gmb\ /Gmm) \times 100$$

2) *Percentage of voids filled with asphalt (VFA):* The volume occupied by the binder is simply called as percentage of voids filled with asphalt. It directly depends on the durability of the pavement. If high VFA, large amount of binder content else vice versa. This helps in decrease of rutting formation.

$$VFA = 100 \times (VMA\text{-}Va)/Va$$

3) *Percentage voids in mineral aggregate (VMA):* It is defined as inter-granular void space between aggregate molecule and compacted paving mixtures. The expected value should be greater than 13.

$$VMA = 100\text{-}GmbPs\ /Gsb$$

4) *Stability:* It is the load taken by the specimen during the failure and the load should not be lesser than 8%.
5) *Flow Value:* Flow value is the deformation during specimen failure. With the help of the dial gauge, the deformation is determined. Here, 0.25 mm will be considered as one unit.
6) *Unit Weight:* Unit weight is defined as the weight per unit volume of the material. Unit weight increases with increase in bitumen content. Once sufficient quantity has been reached, it begins to fall.

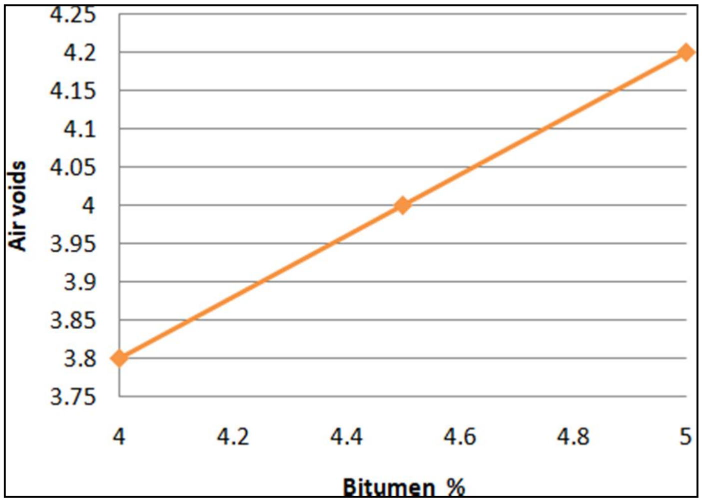

Fig 19: graph plotted for air voids vs bitumen %

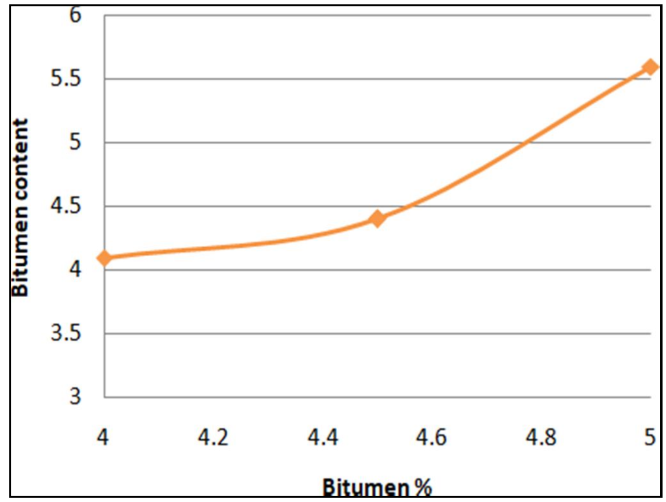

Fig 20: graph plotted for bitumen content vs bitumen %

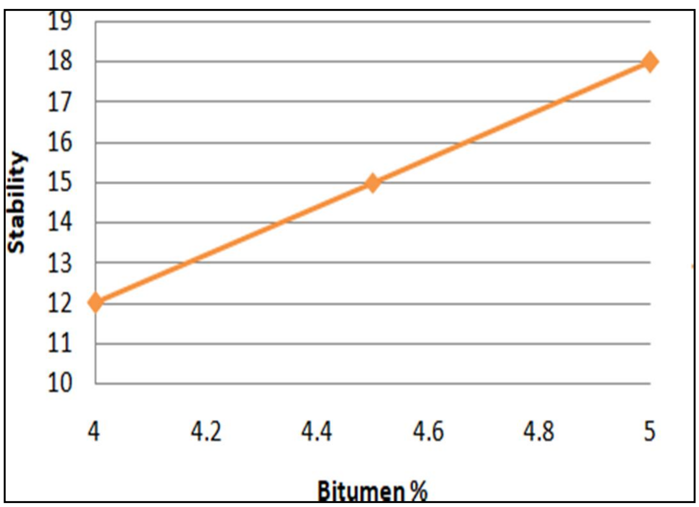

Fig 21: graph plotted for stability vs bitumen %

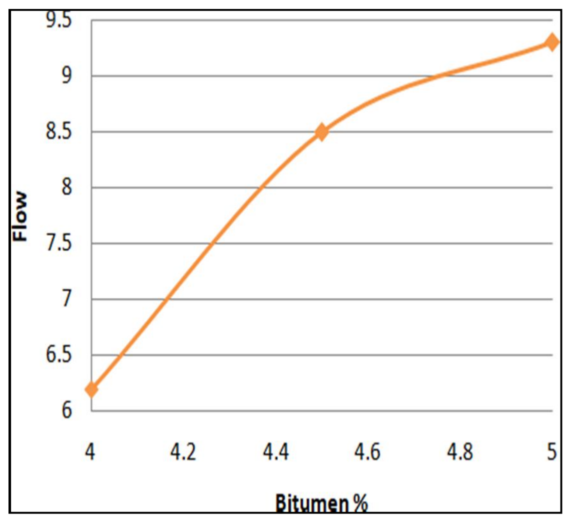

Fig 22: graph plotted for flow vs bitumen %

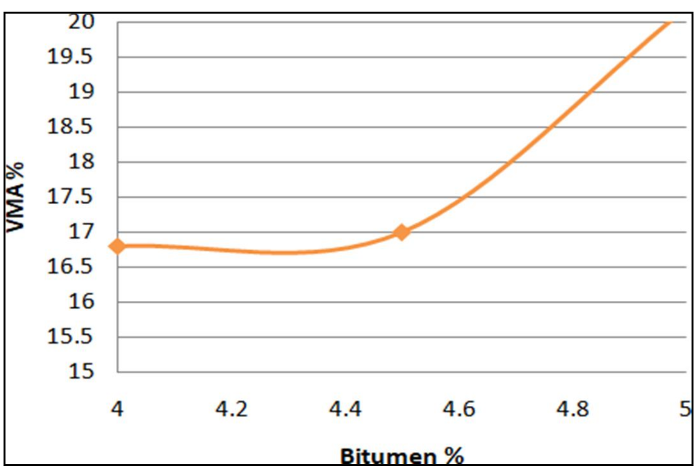

Fig 23: Graph plotted for Vma% vs bitumen %

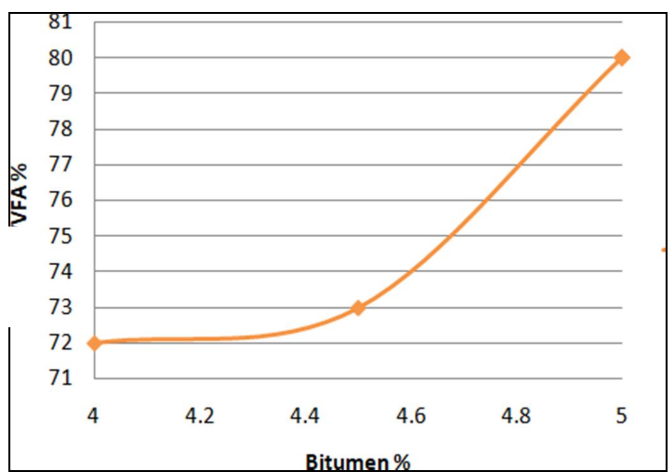

Fig 24: Graph plotted for vfa vs bitumen %

TABLE I
Volumetric Properties

Sl No.	Property	Values Obtained	Specification (Heavy Traffic)
1	Air Voids, %	4	3 to 5
2	Binder Content, %	4.7	4.6
3	Stability, kN	15	>8
4	Flow, mm	8	8 to 14
5	VMA, %	18	>13
6	VFA, %	75	65 to 75

VI. CONCLUSIONS

From the guidance of NCHRP the mixing and compaction temperature of VG20 grade is obtained using equiviscous and zero shear viscosity. The mould is made at mixing and compaction temperatures then the volumetric properties are determined. The volume of air voids is 4% the pavement gets rectify from the stress caused by the vehicle with sufficient bitumen content of 4.7%. The stability is 15 kN much higher than the expectation, where as specified value is 8kN. So it with stand larger amount of weight with very low deformation of 8 mm. The value of VMA is good and value of VFA is excellent, so the pavement made at mixing and compaction temperature will last for decades and obtained volumetric properties lie within the specification, so it should be the best mixing and compaction temperature. This is the field laying mixing and compaction temperature, depends on the distance the temperature may vary.

VII. ACKNOWLEDGMENT

First and foremost, I would like to thank the Almighty God for giving me the power to believe in myself and achieve my goals.
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I extend my sincere thanks to all faculty members, non-teaching staff and my friends for their help and support in completing this project work.

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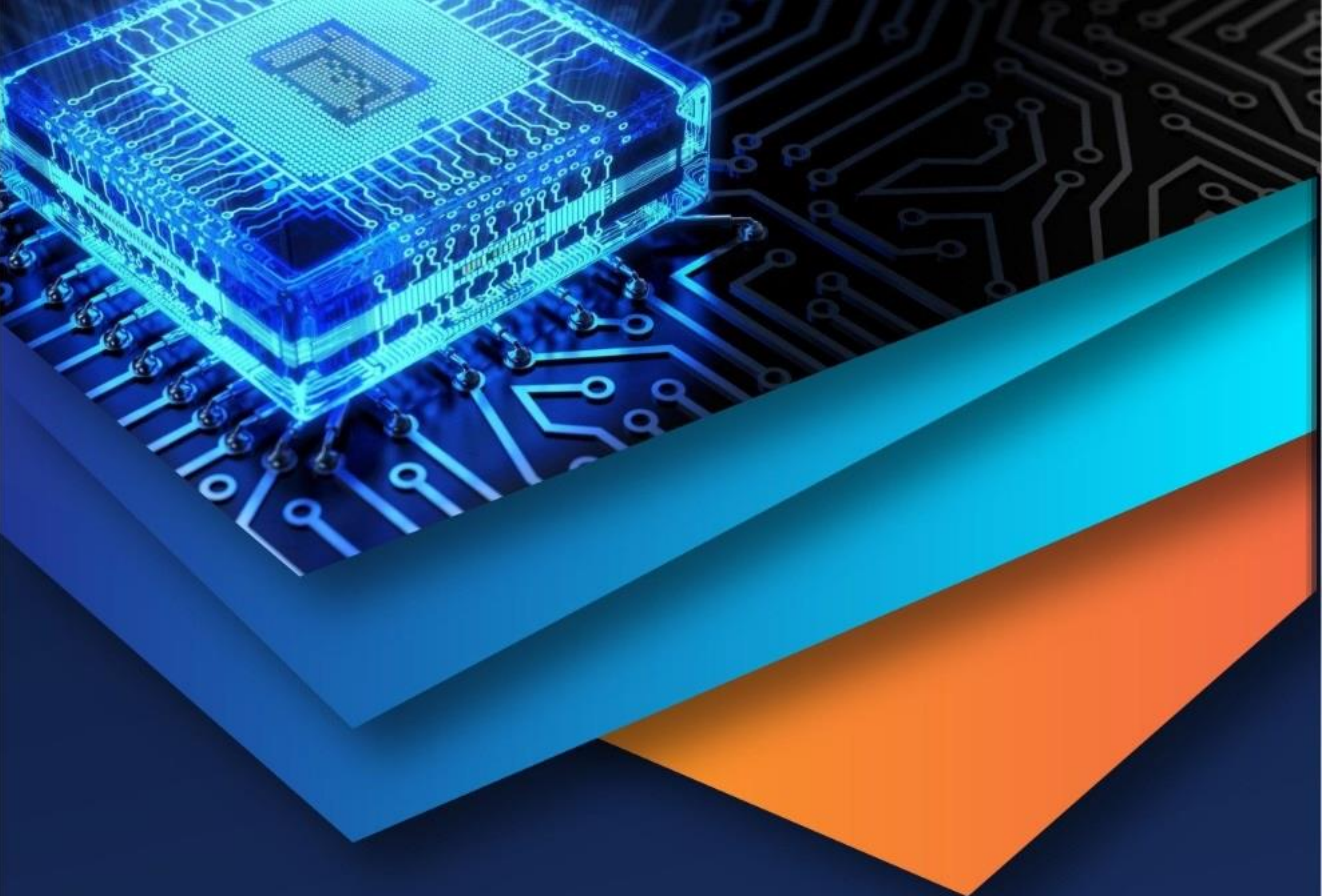

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