Effect of Harder Grade Bitumen (Vg-30 & Vg-40) on the Performance Characteristics of DBM-I Mix

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Abstract: The percentage of air voids in this study was shown to be 4.020 percent and 4.507 percent by VG-30 and VG-40 respectively, which was noticeable in the change between the two binders grades. Stability values of Marshall of VG-40 were always higher than VG-30 despite the fact that both grades showed a similar value of optimum binder content (OBC) of 4.25%. It is interesting to note that VG-40 has reached its optimum stability at a 4.50% bitumen threshold and is better at that mark than VG-30. It was found that stability increased alongside binder content and then started to decrease. When investigating the ideal proportions of binders, the Marshall Mix Design Method of dense bituminous macadam (DBM-I) was used. The paving bitumen of two grades, VG-30 and VG-40, was assessed with respect to its performance functionalities and mix behavior under a heavily loaded media. This was intended to determine the grade that was more resistant and durable. In India, significant highways are commonly built with Dense Bituminous Macadam (DBM) or Bitumen Concrete (BC) with mix of bitumen generally prepared on Marshall method- which is a compromise method which on one hand balances aggregate size gradation and on the other hand the quantity of bitumen. Considering that road infrastructure is the back-bone of transportation and it has a direct impact on the economic might of a nation, the VG upgrading of road infrastructure with higher-performance bitumen grades such as VG-40, would have the potential to ensure road sustainability and endurance of the weight it carries. The Pavement performance was analysed using IIT Pave Software, it was observed that the fatigue and rutting life for VG-30
30.92 msa& 1719.62 msa and VG-40 38.42 msa &2596.96 msa, respectively. Further, a detailed comparative cost analysis was carried out with both bitumen gradeVG-30 and VG-40.It was observed that total construction/cost for VG- 30 2,08,001 Rupees whereas the total cost for VG-40 2,09,876 Rupees respectively. It indicated that there was a very lesser difference in cost with both type of bitumen grades. As per *(IRC: 37-2002)* It was focused that grade bitumen has more stability for Indian climate and traffic conditions. Therefore, the VG-40 grade can be used instead of VG-30 under homogeneous traffic flow conditions.

1. INTRODUCTION

The car industry has been one of the biggest drivers of growth for almost all countries. When we compare modes of transportation as to which is most flexible in regards to the route taken, where you are traveling to or from, how long it takes, and how fast you can get there, then clearly road transportation has more advantages than other forms of transportation (Jain et al., 2013 [1]). As the number of cars on Indian roads continues to grow due to rapidly expanding urban populations and growing industrial and services sectors, India's road space will continue to be at a premium. To accommodate this increasing demand, the infrastructure of India's roads will have to support greater weight and less need for repair (Patele t al., 2014 [2]).

With an estimated annual growth rate of over ten percent for five consecutive years, India has become the second fastest-growing automotive market in the world (Teppala et al., 2014 [3]), and also boasts the second-largest global road network. Consequently, India's transportation system is growing very quickly and this growth includes many high-profile highway construction initiatives such as the development of large sections of expressway networks, national highways, rural routes, and numerous improvements to these facilities which will require great financial investments (Teppala et al., 2014 [3]).

Highways are generally constructed as flexible pavements having bituminous surfacing in India primarily due to the lower cost of construction and easy repair and maintenance on long-term use (Joshi & Patel, 2013 [7]). An average pavement design is not a layer but a system of well thought strata with distinct functions in providing durability and performance. These are the layers that are laid over the natural soil base which is called the subgrade. They all have a combined job to share and carry out the repeated load of vehicle wheels down safely into the embedded soil without hazardous or straining collapse. In that way, highway pavements are an engineered shoe between the moving traffic and earth below, and make a trade-off between economy, safety and service life.

2. LITERATURE REVIEW

Dense Bituminous Macadam is identified as a high strength binder layer and it is meant to be on roads that have experienced a lot of traffic load. Among its strengths is its flexibility in aggregate gradation, in that an engineer may obtain the best mix design without jeopardizing the long-term durability of the produced aggregate. Manufacture of DBM is done per the guidelines of hot mix asphalt (HMA) technology. It entails the mixing of well-graded aggregates to a given bituminous binder in a controlled mixing plant. The two are heated to attain the desired viscosity and moisture level then proportioned and mixed. The resulting mix is hot, which is moved to the site of the construction and is evenly placed in form by use of paving machines. After being spread, the layer is half-compacted to have an even thickness and smooth even layer, and then it is rolled on again to attain a required density. Such a tedious procedure makes sure that the end result of the pavement design can provide not only a stable base but a comfortable ride on top of it. A number of investigations in different parts of the world have studied the work of DBMs, differences in mix design, and optimization of materials, which underscores its flexibility under different climatic and traffic loading conditions.

Investigation of Performance Specifications for Marshall Mixes Using Performance-Based Mix Design Methodology (2024) [4],paper presented a comprehensive study for developing the performance specifications for the Marshall mixes using the performance-based mix design (PMD) methodology. The specification describes the desired levels of fundamental engineering properties for predicting performance during mix design or quality assurance checks at the time of construction design of bituminous concrete mixtures in this study was pursued by performing a combination between volumetric designing and performance-based assessments. In evaluating the durability of the mix, two tests were used, namely: dynamic creep test that measures rutting resistance and indirect tensile asphalt cracking test which measures fatigue cracking resistance. This research was conducted involving a very broad set of variables (five different patterns of aggregate gradation, viz. mid gradation, fine-coarse blend, coarse gradation, coarse-fine blend, and fine gradation, three different groups of binders, PMB-40 VG-30, VG-40). The compaction energy also varied at 5 different levels, with the predetermined blows per face being 35, 50, 75, 90 and 110 blows. Initial investigations were carried out by defining baseline values of rutting and cracking resistance on Marshall-formulated mixes. These standards have been used as a point of reference in measuring performance. Based on this, the study investigated the manner in which particular causes such as aggregate gradation, use of a particular type of binder in Unbounded mixture, as well as the level of compaction influence the performance of bituminous mixtures under stress. Much of the significance in the study was given to the assessment of the correlation between volumetric mix properties, and its ability to correlate with larger performance effects so that correlation between the parameters of the mix design and actual durability against rutting and cracking can be better explored through this study. The performance space diagram (PSD) has also been plotted, portraying the overall performance (acceptable, desirable, or unsatisfactory performance regions) of bituminous mixtures based on rutting resistance and cracking resistance. This paper highlights and advocates the integration of these performance-based specifications into the Marshall mix design specifications to improve pavement characteristics and extend overall service life.

Gupta S. and Duggal A.K. (2022)[5] The purpose of this research into the Marshall Stability and Indirect Tensile Strength (ITS) properties of DBM material made with VG-30 & VG-40 binder was to see if their are any relationships between different Marshall Stability & ITS values when changing binder content in DBM. There were four concentrations of binder use within this study; 4.5%, 4.65%, 4.8% and 4.95%. Data showed that both VG-30 & VG-40 binder exhibited very good Marshall Stability & ITS results at the same binder concentration which was at 4.65%. These results show that the use of Marshall Stability can be used as an indication of ITS values.

Gupta et al. (2016) [6] According to the results of the study on Marshall properties of bituminous concrete specimens, produced using VG-30 and CRMB-55, it has been found that the stability of the bituminous concrete produced by CRMB-55 increased by 15.10% compared to the bituminous concrete produced by VG-30. The void content of the mixes made with CRMB-55 (1.10%) was not significantly different, but the Flows of the same mixes were found to be about 2.7% higher compared to the mixes made with VG-30. In general, the overall characteristics of CRMB-55 were better than VG-30.

Katra et al. (2014) [9] The production of industrial waste (fly ash from a coal fired thermal power plant and waste tyres from vehicles) is a serious problem in India. According to the authors, it is estimated that the fly ash from a coal fired thermal power plant is being produced at an alarming rate, approximately 300 million tons annually. Therefore, fly ash is currently considered to be the largest amount of industrial by-products. The number of motorcycles and automobiles have increased dramatically over time; therefore there are large quantities of waste tyres. In addition, waste tyres are identified as hazardous/solid waste. Furthermore, of the total amount of waste tyres generated, 60% is dumped in illegal manners through uncontrolled urban/rural dumping. These types of disposal create several pollution-related problems including pollution due to air quality from tyre fires and visual/aesthetic pollution. In addition to the need to find technological means to utilize current waste, the authors sought to investigate whether varying levels of fly ash were suitable for incorporation into various percentages of bitumen mixes.

Teppala et al. (2014) [3] The first paper of this study was a scientific investigation of the physical properties of crushed stone aggregate for dense bituminous macadam (DBM) pavement. The Marshall Mix with 0.04 % by weight concentration of CRMB 55 and Zycosoil showed significant improvements in stability, unit weight and flow values compared to the untreated mix. It was concluded that the enhanced stability, unit weight and flow properties led to enhanced compaction properties of the mix and workability during pavement construction. These results are representative of the potential benefits that may occur from using Zycosoil nano technology for formulation of bituminous mixes to improve their performance in pavement construction. Laboratory experiments were carried out to assess the effect of varying concentrations (0.03%, 0.04% and 0.06% by weight of CRMB 55 base binder) of Zycosoil. The Zycosoil additive was added to the binder during heating at 175 °C so that the additive was evenly distributed throughout the binder for all of these test samples. We were able to measure the effects of the different concentrations of Zycosoil on the properties of the resulting DBM mixture by directly adding the Zycosoil to the binder and applying heat to the sample at 175°C.

2.2 DENSE BITUMINOUS MACADAM (DBM-I) GRADATION

There have been two levels of dense bitumen macadam (DBM) created for road construction. With Grading 1, there is an aggregate size at 37.5mm. For grading 2, this has been reduced to 25mm. DBM was chosen to serve as both a binder course and base course; primarily for its durability. It is also ideal for heavy traffic conditions. This makes the engineering selection process easier and allows them to choose a best fit for their needs based on the site conditions or design requirements. Although MoRTH's fixed ratio for fine aggregate will remain the same (between 28 % to 42%) regardless of whether they select either one of these options, it appears the main difference is that while the larger (25 mm to 45 mm) aggregate is permitted when using Grading 1, it does not appear to be permissible when selecting Grading 2.

Table 1:Viscosity Grade (VG) Bitumen Specification in India

Characteristics	VG-10	VG-20	VG-30	VG-40
AbsoluteViscosity,60°C, poises	800-1200	1600-2400	2400-3600	3200-4800
Kinematic Viscosity, 135°C,cSt, minimum	250	300	350	400
Flash Point, °C, minimum	220	220	220	220
Solubility in trichloroethylene, %,minimum	99.0	99.0	99.0	99.0
Penetration at25°C,minimum	80	60	45	35
Softening point, °C, minimum	40	45	47	50
Ductility	75	50	40	25

Table 2:Existing MoRTH Gradations for Dense Bituminous Macadam(DBM)

Grading	1	2
Nominal aggregate size	37.5 mm	26.5 mm
Thickness	75-100 mm	50-75 mm
Sieve, mm	Percent Passing	
45	100	-
37.5	95-100	100
26.5	63-93	90-100
19	-	71-95
13.2	55-75	56-80
9.5	-	-
4.75	38-54	38-54
2.36	28-42	28-42

1.18	-	-
0.6	-	-
0.3	7-21	7-21
0.15	-	-
0.075	2-8	2-8
Bitumen Content, %	Minimum 4.0	Minimum 4.5

2.3 MARSHALMIXDESIGN

A bituminous pavement performs due to a combination of the design elements of the pavement and the current/actual conditions such as traffic loads, weather/climatic conditions and drainage conditions. The strength of material, both in terms of sub-grade support, is crucial to the overall performance of the pavement and its life because it depends on the various layers of pavement that are appropriate based on the type of traffic and climatic conditions (Justo and Khanna, 2010 [24]). Bituminous mixes are composed of well-graded aggregate and a suitable binder that is in the correct ratio. The Marshall Stability Mix Design Method can be used to achieve bituminous mix designs.

2.3.1 Marshall Stability and Flow Measurement

In the Marshall Test, the greatest degree of deformation of the sample specimen occurs at the time that the greatest force has been achieved by the sample, and this is most closely monitored during the development of the Marshall Mix Design. This deformation is called plastic flow deformation and is recorded from the dial gauge using .25mm (.01in.) increments. The dial gauge reading corresponds to the moment that the greatest force has been applied to the ram at which time the sample will be removed. After removal, the sample will continue to be loaded at a constant rate of 50.8mm/min. The greatest force (weight) that the sample can withstand before failing indicates its stability. It should be noted that both the Stability and Flow tests are critical in assessing the performance and quality of an asphalt mix because they provide significant indicators for both load bearing properties and deformation characteristics (NPTEL, 2007 [25]).

2.3.2 Density and Voids of Compacted Mix

To determine the characteristics of a material and its composition plan in order to ensure that the testing process can accurately determine those characteristics of the material, the testing process must be able to replicate all or some of the unique properties of the material. Those include; specific gravity of bulk bitumen (Gb); theoretical specific gravity of bitumen (Gt); percent of the volume of bitumen (Vb); percent of air void (Vv); percent of volume of mineral aggregate (VMA); and finally, percent of the volume of voids filled with bitumen (VFB).

A closer look at every of such parameters will be undertaken as part of the evaluation in order to gain greater understanding of the interplay of these individual properties. The phase relationship between them can be presented in a simple form of a visual representation which can be used to explain the interdependencies between them as shown in Figure 3.1. Analysing the data numerically and with the aid of the diagram, a complete picture of the behaviour of the material can be gained and can then be used to draw more confident results and conclusions.

4. Results and Discussion

4.1 DETERMINATIONOFMARSHALLSTABILITYANDFLOWVALUEAT VG-30 BITUMEN (WITH 4.00 % BITUMEN)

TABLE4.1:CALCULATION OF BULK SPECIFIC GRAVITY (GB)

S.No.	Bitumen Specimen No.	Weight of Marshall Sample (gm)	Bulk Volume (CC)	Gb(gm/cc)	Average (Gb)
1	SpecimenNo.-1	4109	1714	2.397	2.396 (gm/cc)
2	SpecimenNo.-2	4100	1712	2.395	
3	SpecimenNo.-3	4105	1712.5	2.397	

Table4.2:The test results with Different Bitumen Content forVG-30

S. No.	Bitu me %	Gb	Gt	Vv(%)	Vb	VMA (%	VFB (%)	Marsh a Stabili ty (KN)	Flow (mm)	Marshall Quotient (Stability /Flow)
1	4.00	2.396	2.519	4.874	9.369	14.243	65.78	21.59	4.30	5.02
2	4.25	2.408	2.509	4.020	10.004	14.025	71.33	21.08	4.62	4.56
3	4.50	2.401	2.500	3.966	10.561	14.527	72.70	24.25	5.17	4.69
4	4.75	2.392	2.490	3.931	11.107	15.038	73.86	26.04	4.79	5.44
5	5.00	2.386	2.481	3.833	11.661	15.494	75.26	22.42	5.13	4.37

Bed of bituminous concrete mix shall meet certain criteria as shown in Table 4.3 Summeries of standards of NA or MoRTH (5 th revision) of the mix. When such criteria were tested, it was determined that any combination of VG-30 grade bitumen, and a binder content of 4.25 percent was the most appropriate. This percentage has proved as the best since it achieved the mix parameters balance and hence with respect to the specified specifications.

Table4.3MarshallPropertiesofBituminousConcreteMixPreparedUsingVG-30asBinder Material at OBC

S.No.	Marshall Properties	Test Resul Obtained	Requirements as per MoRTH (V Revision)Specifications
1	OBC(%)	4.25	4.0(minimum)
2	Marshall Stability(KN)	21.08	20.25
3	Flow(mm)	4.62	3-6
4	Air Voids(Vv)%	4.02	3.0–6.0
5	VMA%	14.025	12(minimum)
6	VFB%	71.33	65-75

Figure4.1showed the graphically representation of Air Voids and BitumenVG-30.

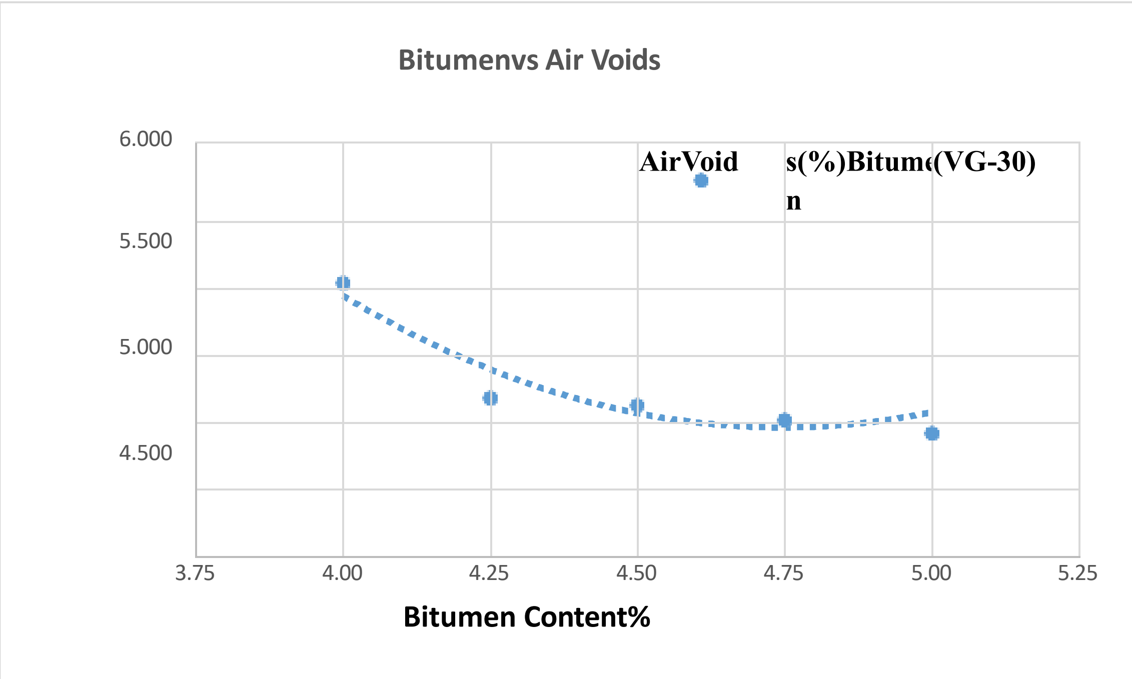

Figure4.1:Graph between AirVoidswithBitumenGradeVG-30

Figure4.2 showed the graphically representation of VMA and Bitumen VG-30.

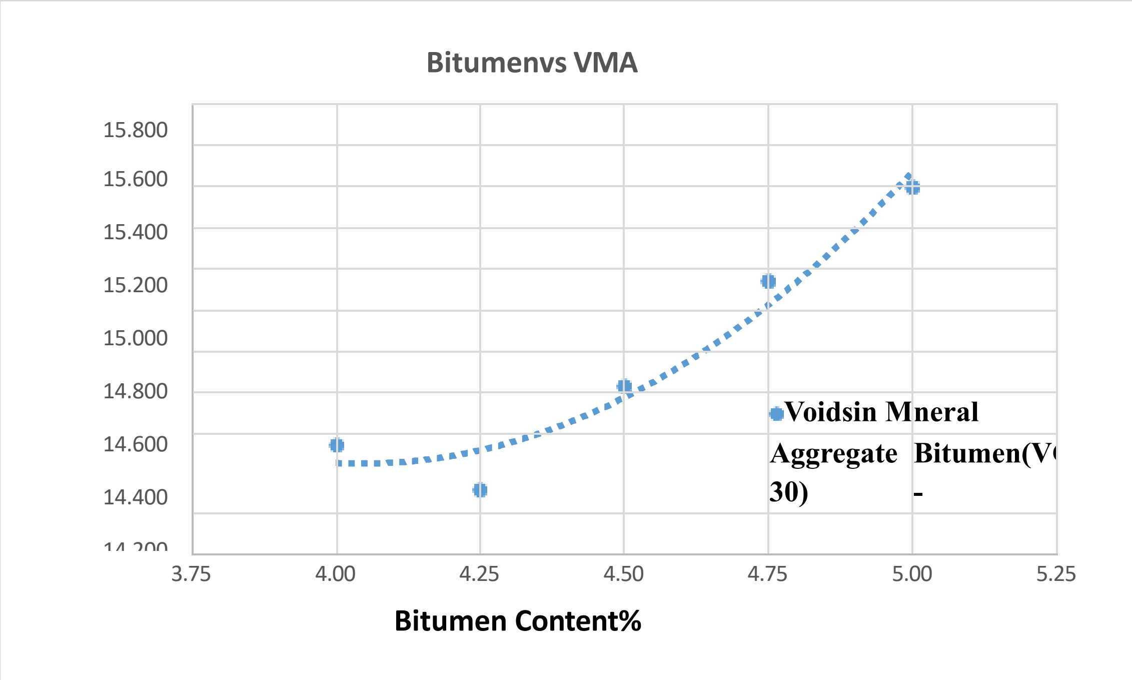

Figure4.2:Graph between VMA with Bitumen GradeVG-30

Figure4.3 showed the graphically representation of VF Band BitumenVG-30.

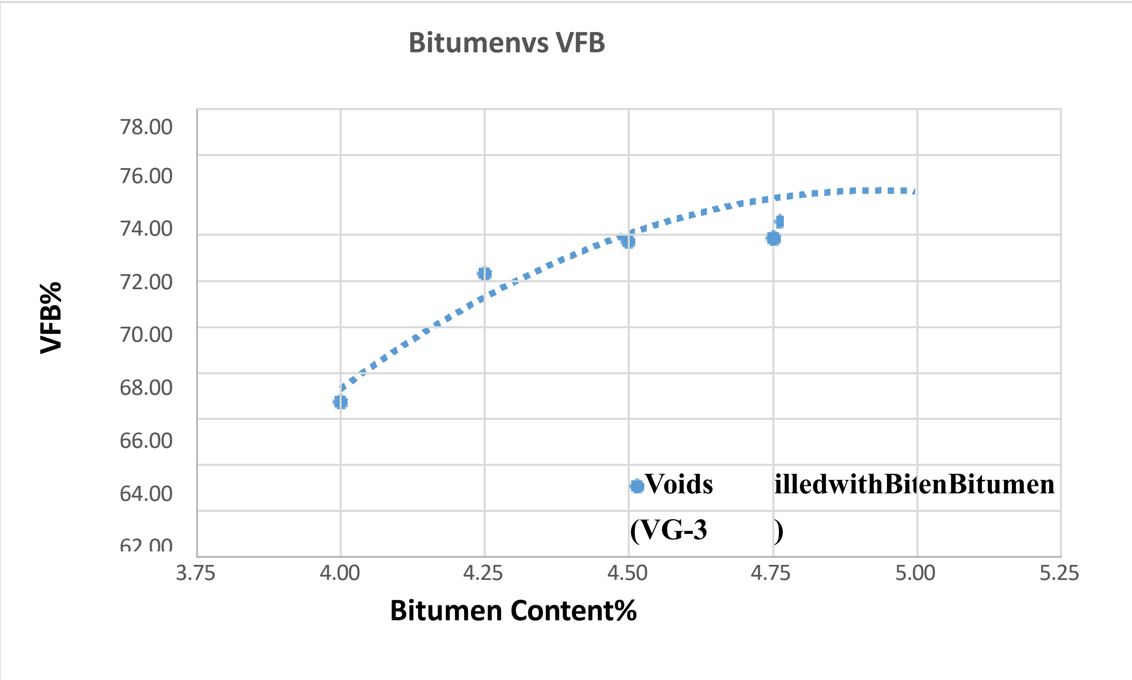

Figure4.3:Graph between VFB with Bitumen GradeVG-30

Figure4.4 showed the graphically representation of Flowand BitumenVG-30.

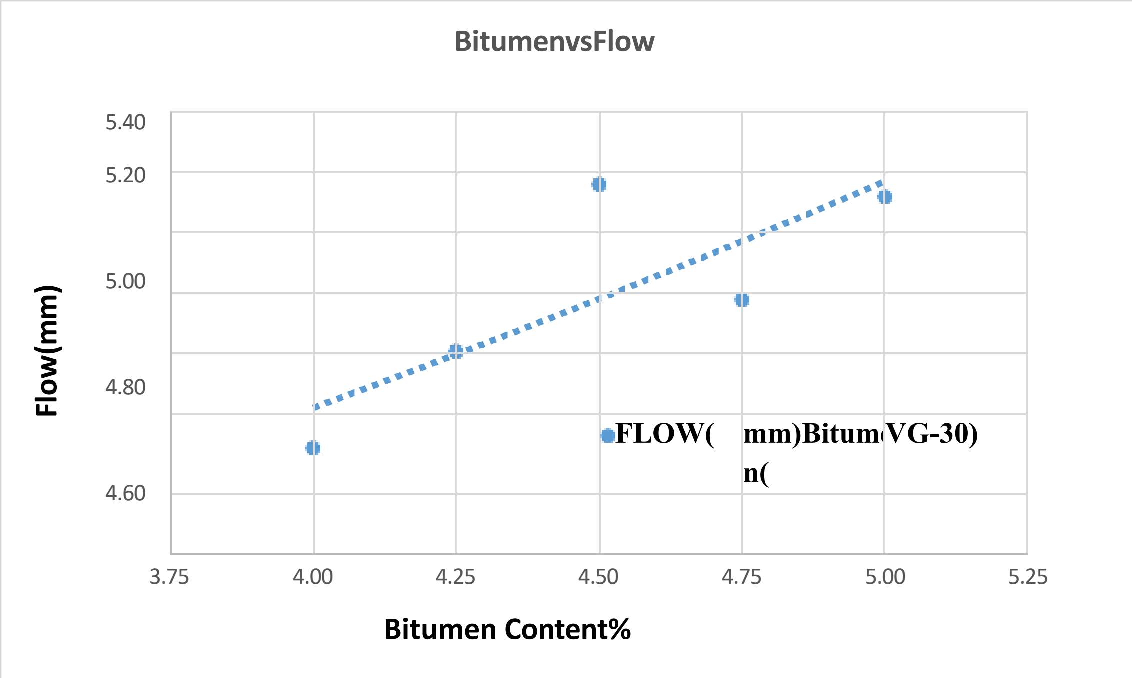

Figure4.4: Graph between Flow with Bitumen GradeVG-30

Figure4.5 showed the graphically representation of Stability and BitumenVG-30.

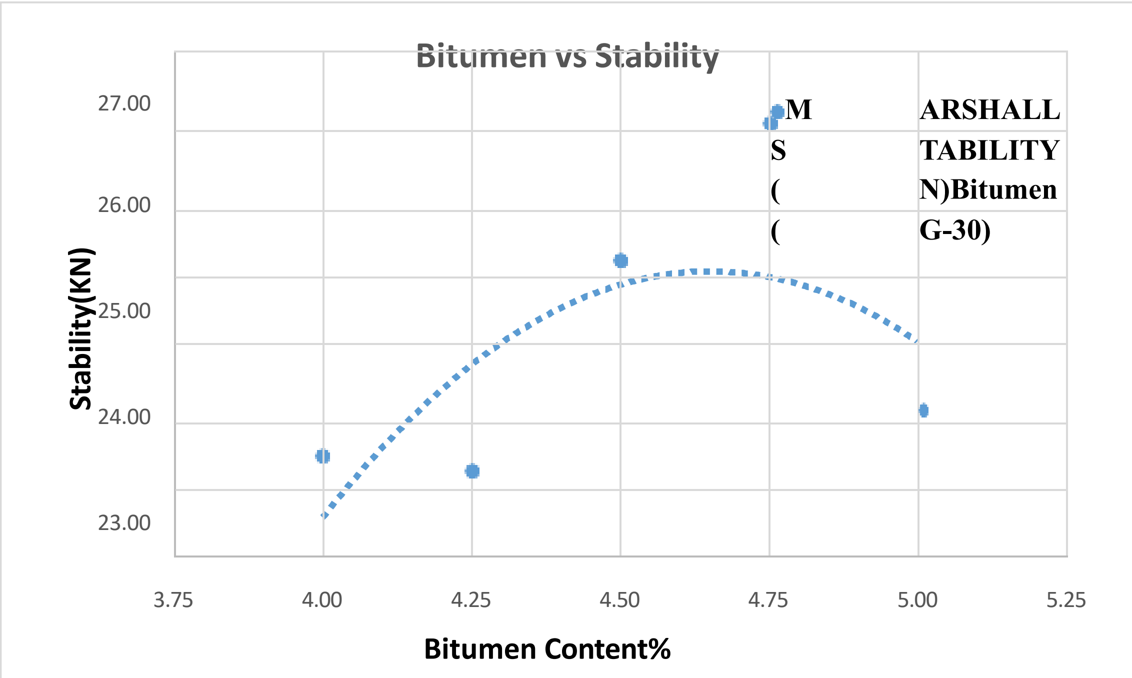

Figure4.5:Graph between Stability with Bitumen GradeVG-30

4.2 DETERMINATION OF MARSHALL STABILITY AND FLOW VALUE AT VG-40 BITUMEN (WITH 4.00 % BITUMEN)

Table4.4:Calculation of bulk specific gravity(Gb)

S.No.	Bitumen Specime No.	Weight of Marshall Sample (gm	Bulk Volume (CC)	Gb(gm/cc)	Average (Gb)
1	SpecimenNo.-1	4177	1720	2.428	2.377 (gm/cc)
2	SpecimenNo.-2	4168.5	1792	2.326	
3	SpecimenNo.-3	4172	1756	2.376	

Table4.5:The test results with Different Bitumen Content forVG-40

S.N 0.	Bitu me %	Gb	Gt	Vv(%)	Vb	VMA (%	VFB (%)	Marsh a Stabilit (KN)	Flow (mm)	Marshall Quotient (Stability/ Flow)
1	4.00	2.377	2.520	5.681	9.221	14.903	61.879	23.45	4.59	5.11
2	4.25	2.397	2.510	4.507	9.880	14.388	68.673	24.26	5.12	4.74
3	4.50	2.403	2.500	3.885	10.488	14.373	72.968	27.58	5.73	4.81
4	4.75	2.393	2.490	3.898	11.025	14.922	73.880	26.64	5.93	4.49
5	5.00	2.380	2.480	4.037	11.542	15.578	74.088	25.62	6.80	3.77

Table 4.6, MoRTH (5 th revision) specification splits such performance as requirements of bituminous concrete mix. It was found that these requirements could best be satisfied when the content of the binder was maintained at 4.25% whilst a number of different proportions of the binder were tested. The analysis also demonstrated that this figure was the optimum binder content of VG-40 grade bitumen since it would guarantee that the mix had suitable combination of strength, durability and stability that were required in the standard.

Table 4.6 Marshall Properties of Bituminous Concrete Mix Prepared Using VG-40 as Binder Material at OBC

S.No.	Marshall Properties	Test Result Obtained	Requirements as per MoRT (VthRevision)Specifications
1	OBC(%)	4.25	4.0(minimum)
2	Marshall Stability(KN)	24.26	20.25
3	Flow(mm)	5.12	3-6
4	Air Voids(Vv)%	4.507	3.0–6.0
5	VMA%	14.388	12(minimum)
6	VFB%	68.673	65-75

However the bitumen volume was 10.004% for VG-30 grade and 9.880% for VG-40 grade bitumen. It directly indicated that as viscosity was higher for VG-40grade, it caneasily filled the air voids and therefore less bitumen volume was required for filling the air voids.

Figure4.6 showed the graphically representation of Air Voids and BitumenVG-40.

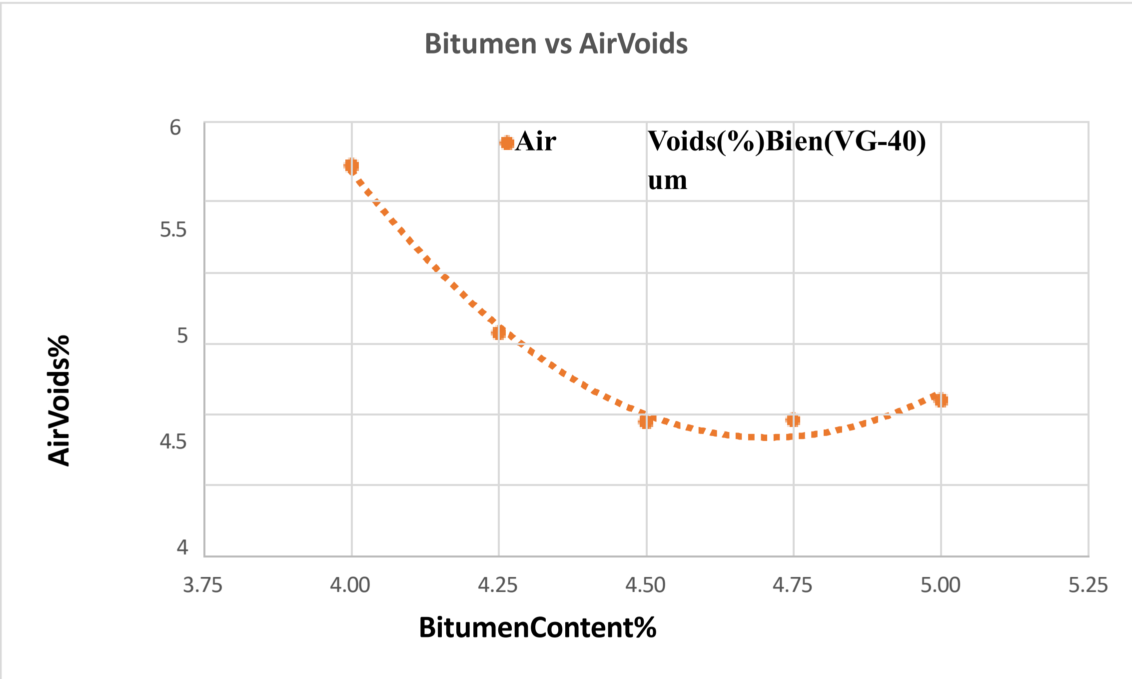

Figure4.6:Graph between Air Voids with Bitumen Grade VG-40

Figure4.7 showed the graphically representation of VMA and Bitumen VG-40.

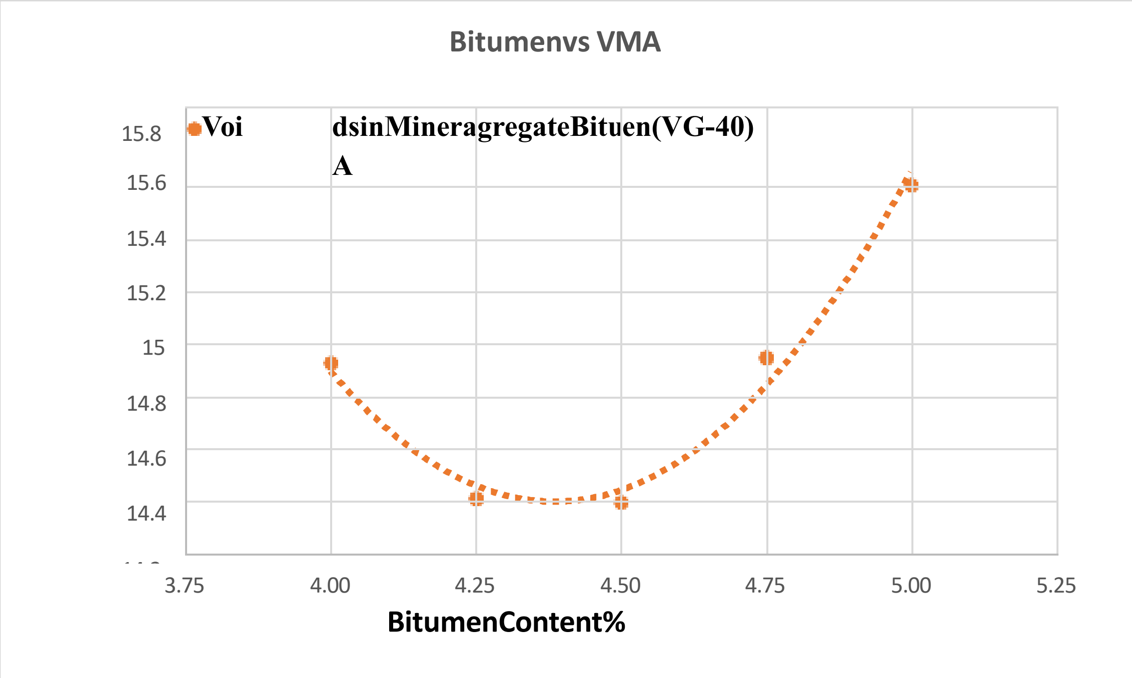

Figure4.7:Graph between VMA with Bitumen GradeVG-40
Figure4.8 showed the graphically representation of VF Band BitumenVG-40.

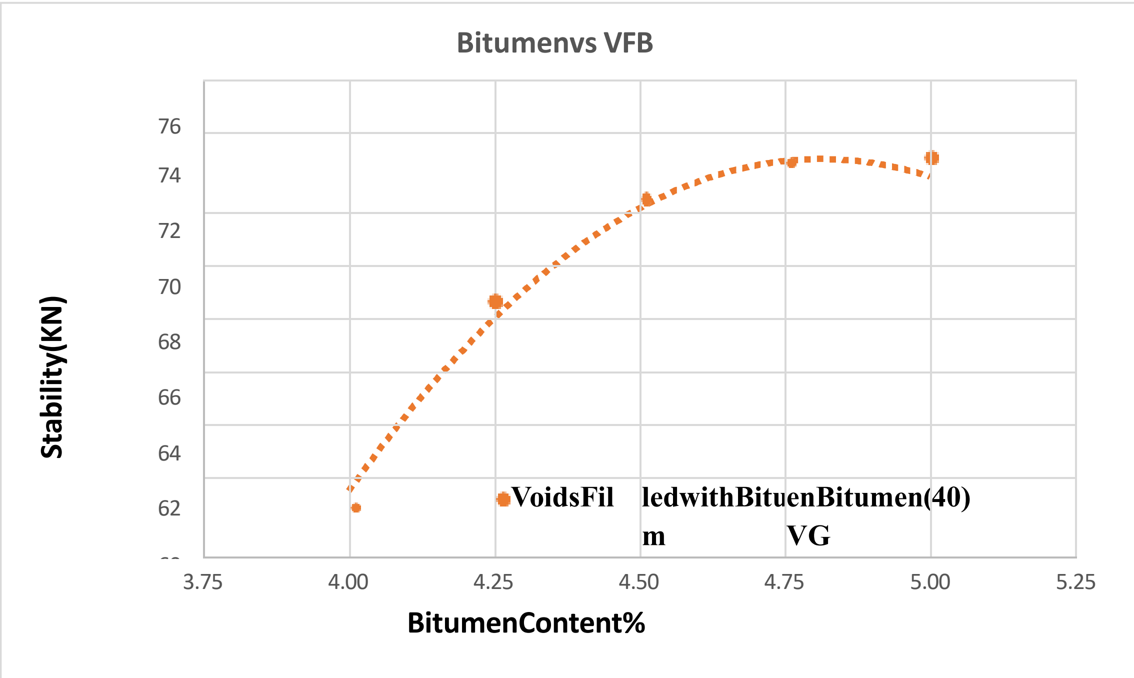

Figure 4.8: Graph between VFB with Bitumen Grade VG-40

Figure4.9showed the graphically representation of Flowand BitumenVG-40.

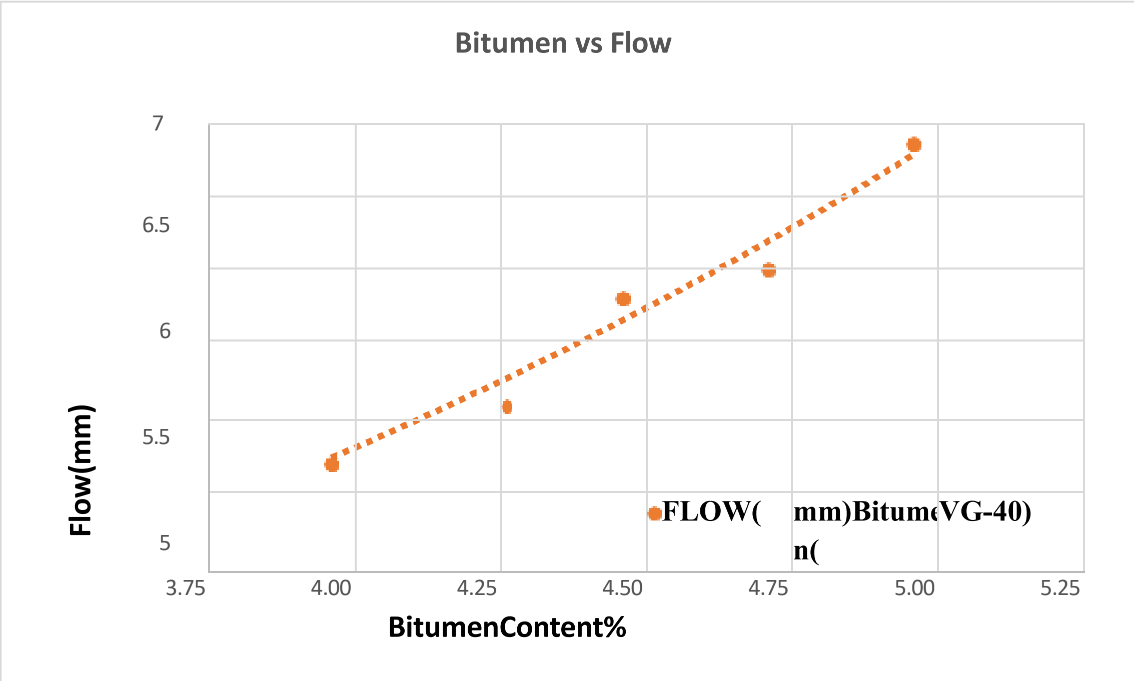

Figure4.9: Graph between Flow with Bitumen GradeVG-40
Figure4.10 showed the graphically representation of Stability and BitumenVG-40.

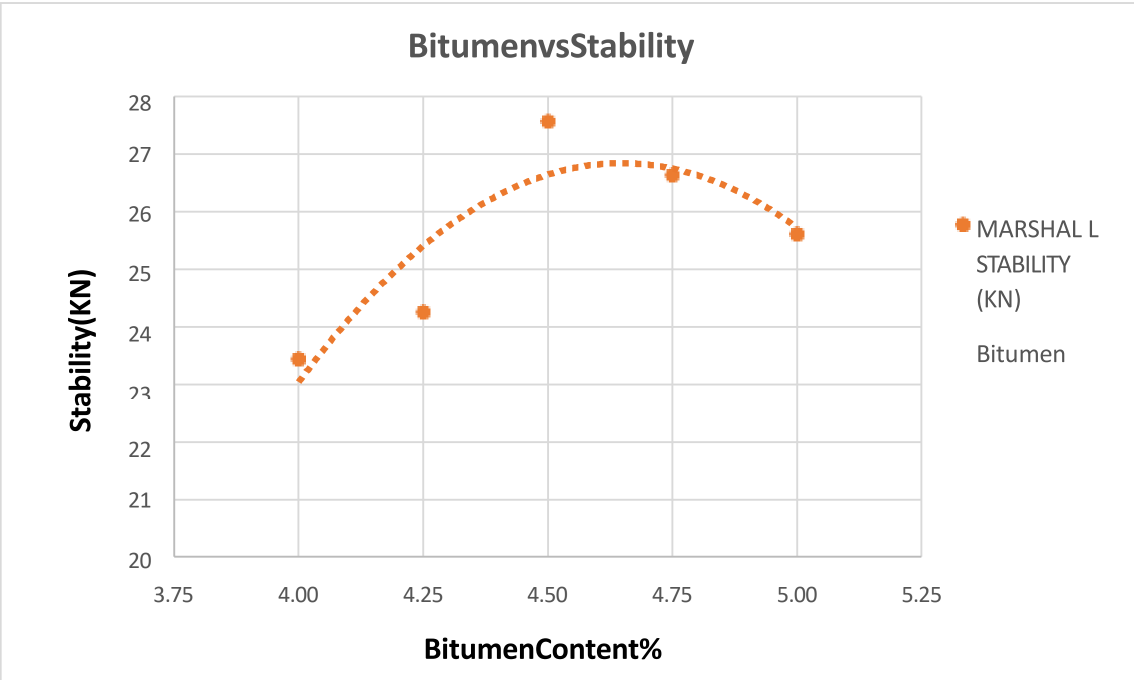

Figure4.10:Graph between Stability with Bitumen GradeVG-40

5. Conclusion

- The volumetric and mechanical properties of Marshall specimens tested at different binder contents (VG-30 and VG-40) reported an optimum binder content (OBC) of 4.25% (in aggregate weight), which matches the specifications of MoRTH (Specification in MoRTH, 2005). The more the bitumen was grown, the higher the Marshall Stability, where VG-40 was superior to VG-30. VG-40 was observed to have a circa 5 percent greater stability at 4.50 percent bitumen content than VG-30.
- The Pavement performance was analyses using IIT Pave Software ,it was observed that the fatigue and rutting life forVG-3030.92msa& 1719.62msaandVG-40 38.42msa&2596.96msa,respectively.
- Cost estimations also done for DBM-IwithVG-30 and VG-40 binder grade. It was found that the total construction cost.
- It was observed that total construction/cost for VG-30 2,08,001 Rupees whereas the total cost for VG-40 2,09,876 Rupees respectively. It indicated that there was a very lesser difference in cost with both type of bitumen grades. As per *(IRC: 37-2018)* It was focused that grade bitumen has more stability for Indian climate and traffic conditions. Therefore, the VG-40 grade can be used instead ofVG-30 under heterogeneous traffic flow conditions.

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