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Study On Engineering Characterization Of Sulfur Modified Bituminous Binders

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Abstract
Increased heavy traffic loads and associated tyre contact pressure with poor climatic conditions, fatigue, and rutting effects have generated interest in modified bituminous binders as a consequence of increased demand for bituminous flexible pavement. Various customised binders are now widely accessible across the world. To increase the binder's performance, these modifiers significantly alter the rheological and morphological characteristics of the binder, as determined by rheological and morphological testing methods rather than traditional techniques. Using a Dynamic Shear Rheometer, this study intends to enhance the rheological features of unaged and aged samples of these two binders by changing the typical viscosity grade VG 30 bitumen and adding industrial sulphur from the local market (DSR).

An attempt has been made to identify the essential conditions for binder development, such as mixing/blending time and temperature, using the rheological parameters of phase angle and complex modulus in order to assure adequate adjustment. Bituminous mix fatigue and rutting resistance will be affected by this improvement in the future. Sulphur modification of bitumen was performed at four distinct mixing temperatures: 1000C, 1100C, 1200C, and 1300C, as well as five different mixing times: 5 minutes, 10 minutes, 15 minutes, 20 minutes, and 30 minutes. The ideal adjustment standard was determined using unaging and ageing parsimony for five sulphur levels of 1%, 2%, 3%, 4%, and 5% by weight of the bitumen.

Key words: Bitumen, Rheology, Viscosity, Elasticity, Phase angle, Complex Shear Modulus.

1. Introduction

In India, bitumen grading is based on a penetration test, which is used to determine the hardness or softness of bitumen at a temperature of 25°C but does not show bitumen behaviour (viscous/elastic) at that temperature. To achieve great pavement performance, a large volume of money is invested in highway building. However, the pavement is suffering from changes in the weather and high traffic loads, all of which have a direct impact on the pavement's longevity and performance. Fatigue cracking in cold climates and rutting in hot summers are the two most typical issues with bituminous pavement performance. As a result, pavement distress need immediate attention, which is critical and cannot be delayed.

On a hot summer day, the average road surface temperature is 60°C to 70°C. At this temperature, bitumen softens and begins to penetrate and push under laden truck tyres, causing rutting and corrugations in the highway pavement's wheel tracks. However, as the temperature drops or the environment becomes colder, bituminous pavements become too brittle, and fatigue fractures appear when they are overloaded. Fatigue is the outcome of repetitive traffic loads causing cumulative harm.

The goal of this study is to see if a changed binder may help flexible pavements function better. Using 60/70 penetration grade bitumen treated with sulphur, the Marshall Test characteristics of bituminous concrete mixtures were determined. To investigate the influence of sulphur as a modifier in bituminous mixtures at varied concentrations. The dynamic shear rheometer (DSR) is used to determine the rheological properties of bituminous binder across a wide temperature and rate of loading range. Comparing the rheological characteristics of original and modified bitumen at high, medium, and low temperatures. Sulphur's impacts on bitumen modification in terms of flow, amplitude sweep, frequency sweep, temperature sweep, creep response, and creep recovery were investigated. The effects of ageing on rheological characteristics were investigated utilising a Rolling Thin Film Oven (RTFO) and a Pressure Aging Vessel (PAV).

2. Materials Used

Aggregates

Construction aggregate, also known as sand, gravel, crushed stone, slag, recycled concrete, and geosynthetic aggregates, is a broad category of coarse- to medium-grained particulate material used in construction. Aggregates are the world's most mined materials. Aggregates are a component of composite materials like concrete and asphalt concrete, and they act as reinforcement to increase the overall strength of the composite material. Aggregates are extensively employed in drainage applications such as foundation and French drains, septic drain fields, retaining wall drains, and roadside edge drains due to their comparatively high hydraulic conductivity value compared to most soils. Aggregates are also utilised as a foundation material for roads and railroads. In other words, aggregates are employed as a low-cost extender that combines with more costly cement or asphalt to produce concrete, or as a sturdy foundation or road/rail base with predictable, consistent qualities (e.g., to help avoid differential settling under the road or structure).

Aggregates used in concrete pavements

Bitumen(grade 60/70)

In certain natural deposits, bitumen is a sticky, black, and very viscous liquid or semi-solid. It's also a by-product or residue of fractional distillation of crude oil. Bitumen is largely made up of highly condensed polycyclic aromatic hydrocarbons, which comprise 95% carbon and hydrogen (87 percent carbon and 8% hydrogen), as well as up to 5% sulphur, 1% nitrogen, 1% oxygen, and 2000 ppm metals. Also known as bitumen, it is a mixture of 300 to 2000 chemical components, with an average of 500 to 700. It is crude oil's heaviest percentage, with the greatest boiling point (525°C). Mangalore Refinery and Petrochemicals Limited (MRPL) supplied 60/70 penetration grade bitumen for the project.

Bitumen of 60/70 penetration

Sulphur modifier

The use of sulphur modified bitumen can increase the performance of asphalt concrete pavements. The viscosity grade of bitumen binder employed in this study was (VG-30), which is the most often employed for intermittent temperature. The second stage in bitumen modification is to find an appropriate modifier after deciding on the basic bitumen. Sulphur was employed to compare the rheological characteristics of the generated binder with the mix design in this investigation.

Elemental Sulphur

Preparation of Sulphur Modified Bitumen

The following blending sequence was used to modify bitumen materials with sulphur:

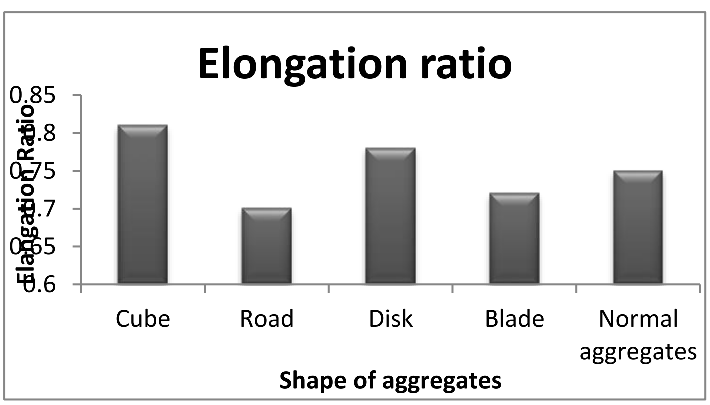
1. Bitumen binder was cooked in an oven to at least 140 degrees Celsius.
2. The stainless steel cylindrical container for mixing, with a capacity of 1kg, was cleaned and stored at a temperature of at least 140oC in the oven.
3. 500 gm of asphalt was weighed into the container, followed by the quantity of additive needed to achieve the appropriate additive-to-asphalt ratio.
4. By total weight of bitumen, five blends were made with 2 percent, 3 percent, 4 percent, 6 percent, and 8 percent sulphur, respectively.
5. Using a heater, the mixing temperature was maintained at 100°C for the first batch of sample preparation.
6. With the assistance of a glass rod, the stirring was begun manually, and the prepared amount of additive was progressively added to the beaker while stirring.
7. The stirring was kept going for another 10 minutes.
8. The ready-to-use sulphur-modified bitumen was utilised to create the test sheets, which were then utilised to create DSR specimens of various diameters using specific tools.
9. The optimal percent of modifier is calculated based on the rheological parameters.

The aforementioned technique was then repeated for creating samples with the optimal percent of modifier at various blending temperatures of 95 o C, 105 o C, 115 o C, 125 o C, and 135 o C.

Experimental results

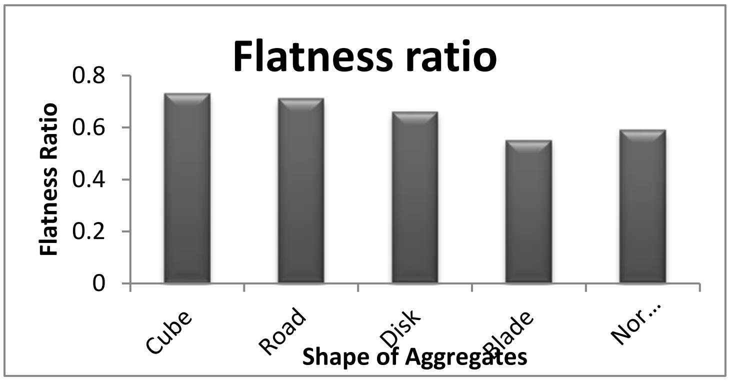
Aggregate Geometric Characteristics from direct measurements

Elongation Ratio for various shapes of aggregates



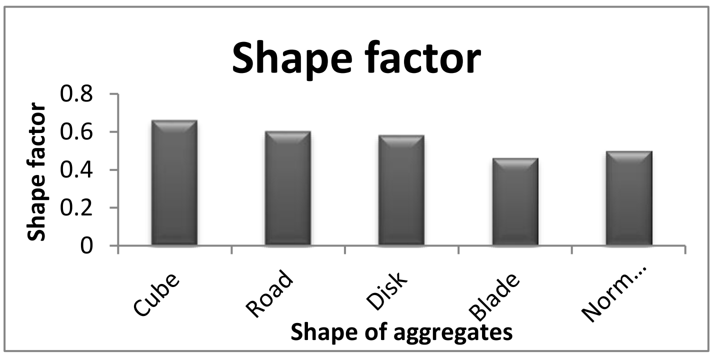
Comparison of elongation ratio values\

Flatness ratio

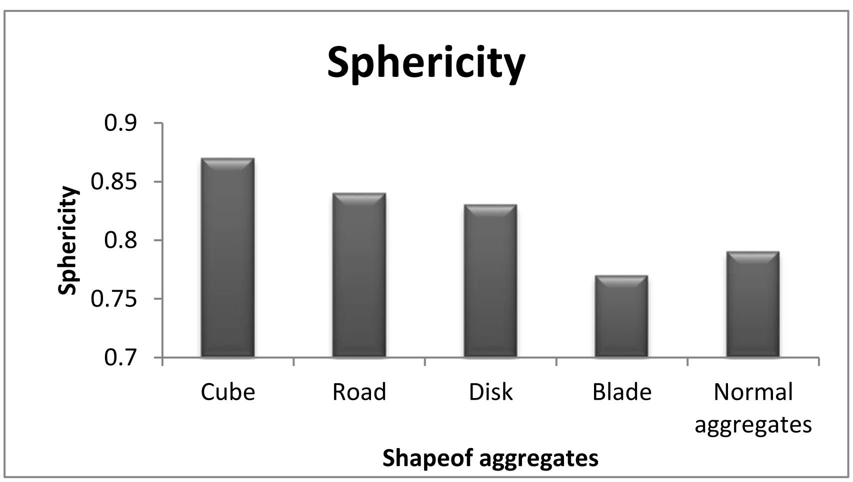


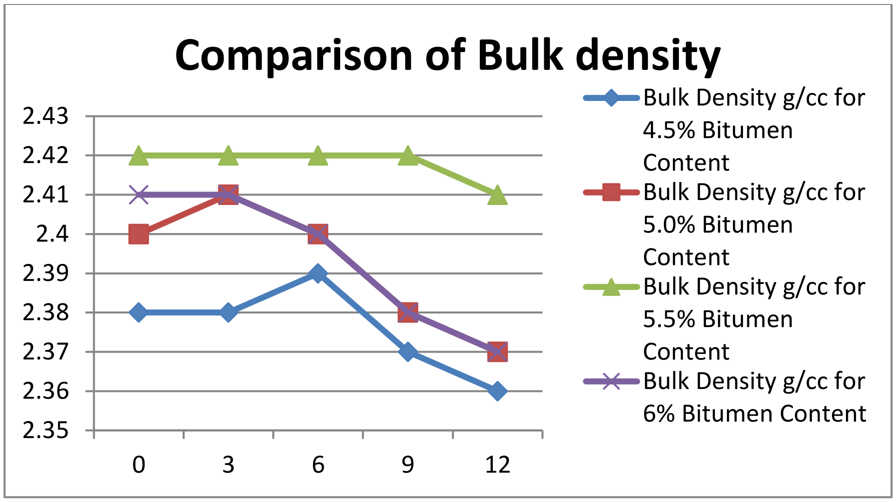
Comparison of flatness ration

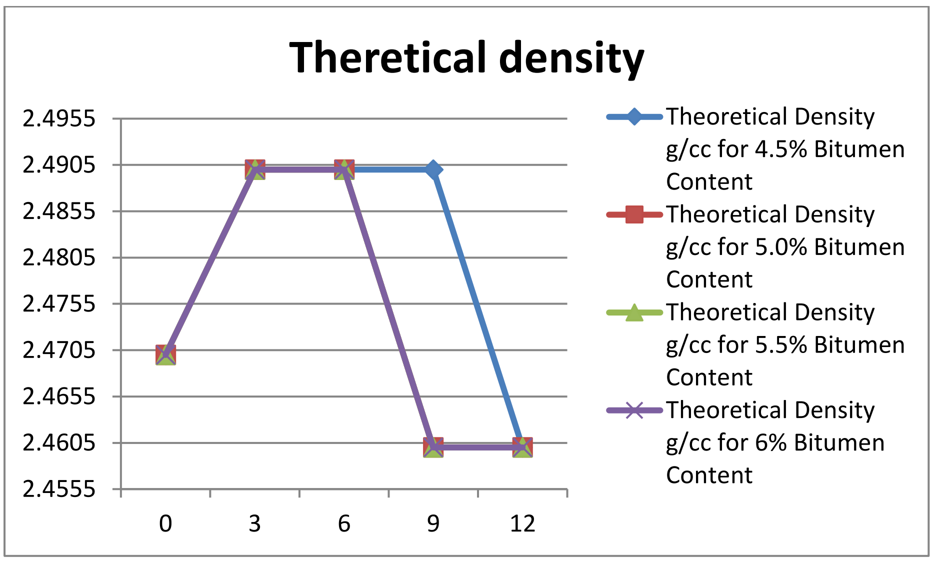
Shape factor test results

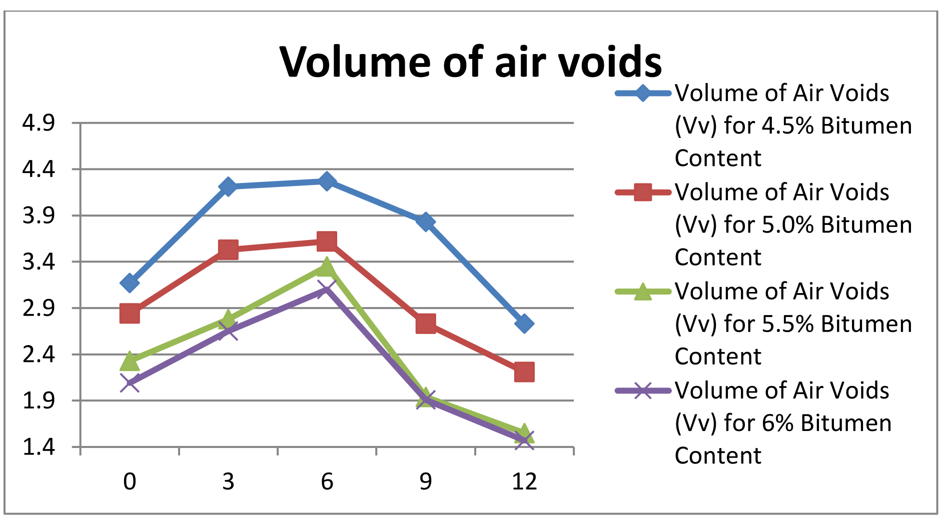


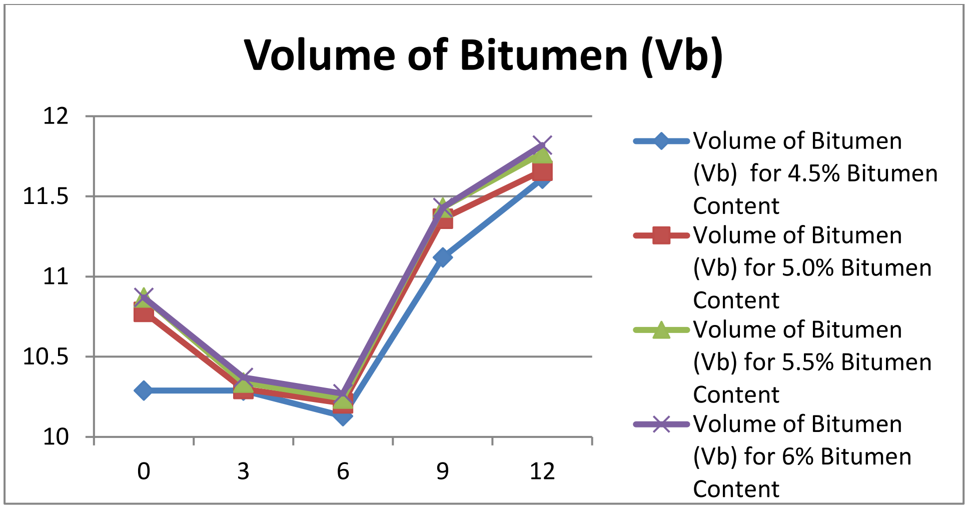
Comparison of shape factor

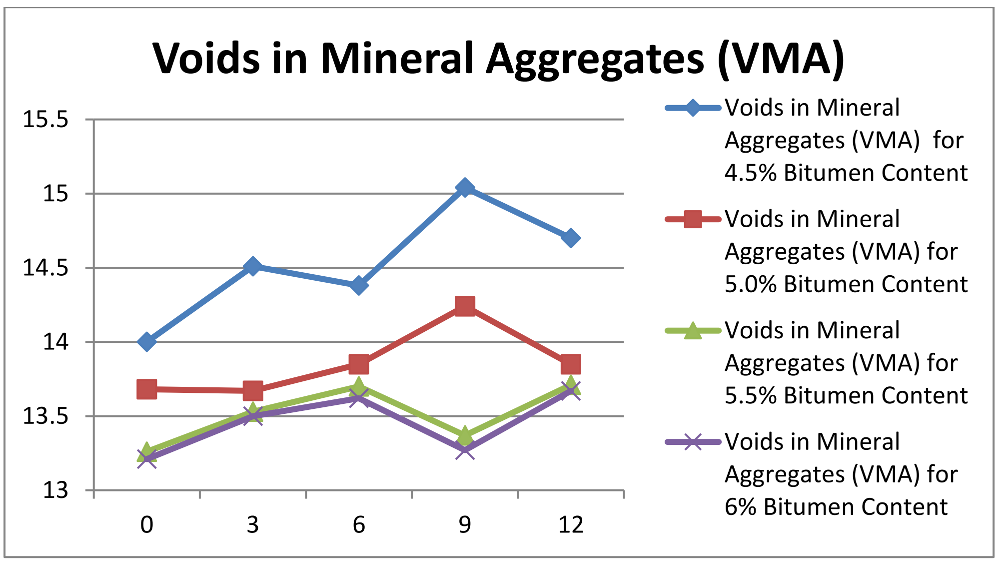


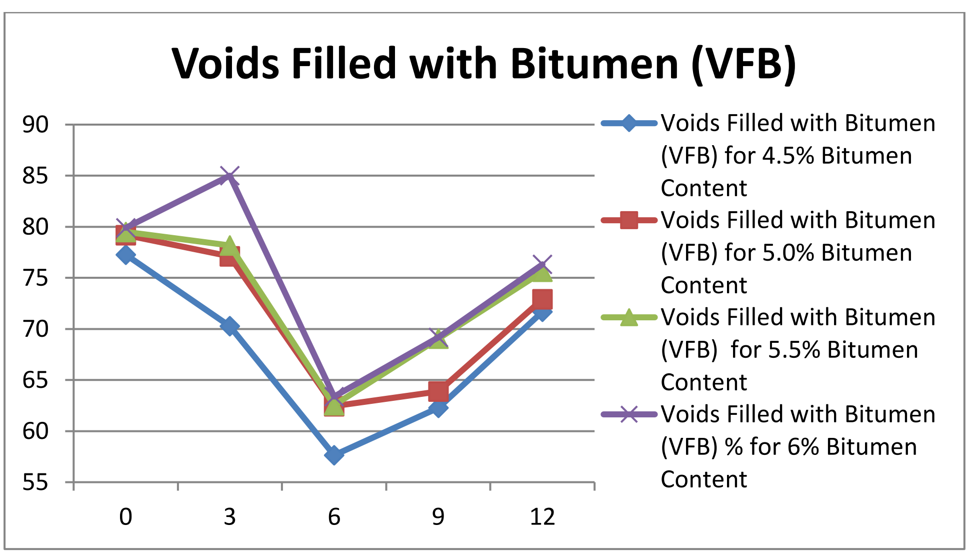

Comparison of Bulk density
2.43
2.42
2.41
2.4
2.39
2.38
2.37
2.36
2.35
0
3
6
9
12
Bulk Density g/cc for 4.5% Bitumen Content
Bulk Density g/cc for 5.0% Bitumen Content
Bulk Density g/cc for 5.5% Bitumen Content
Bulk Density g/cc for 6% Bitumen Content

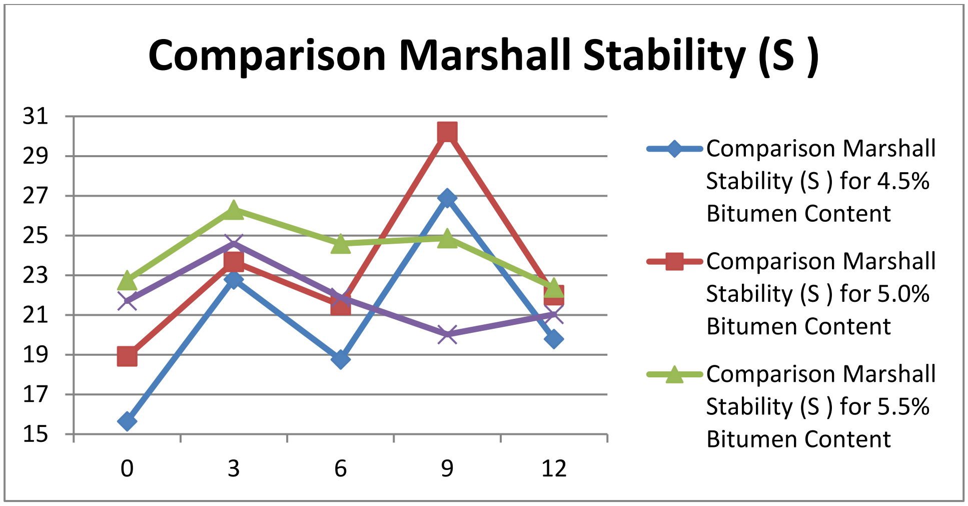

Theretical density
2.4955
2.4905
2.4855
2.4805
2.4755
2.4705
2.4655
2.4605
2.4555
0
3
6
9
12
Theoretical Density g/cc for 4.5% Bitumen Content
Theoretical Density g/cc for 5.0% Bitumen Content
Theoretical Density g/cc for 5.5% Bitumen Content
Theoretical Density g/cc for 6% Bitumen Content

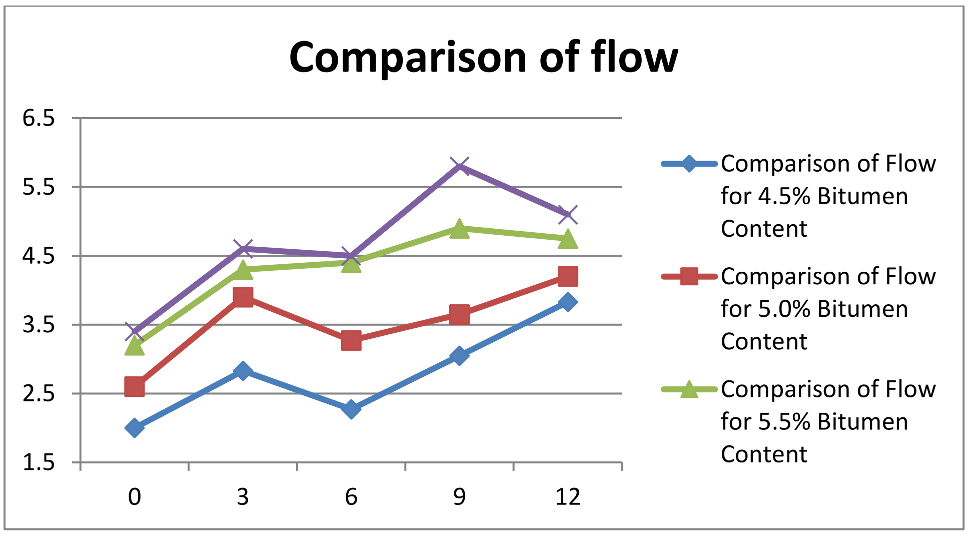

Volume of air voids
4.9
4.4
3.9
3.4
2.9
2.4
1.9
1.4
0
3
6
9
12
Volume of Air Voids (Vv) for 4.5% Bitumen Content
Volume of Air Voids (Vv) for 5.0% Bitumen Content
Volume of Air Voids (Vv) for 5.5% Bitumen Content
Volume of Air Voids (Vv) for 6% Bitumen Content

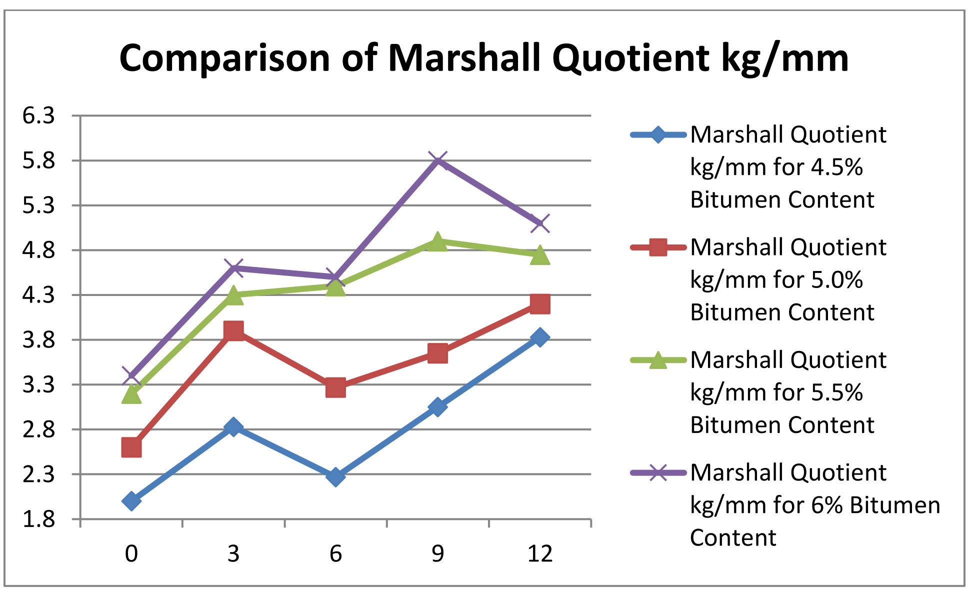

Volume of Bitumen (Vb)
12
11.5
11
10.5
10
0
3
6
9
12
Volume of Bitumen (Vb) for 4.5% Bitumen Content
Volume of Bitumen (Vb) for 5.0% Bitumen Content
Volume of Bitumen (Vb) for 5.5% Bitumen Content
Volume of Bitumen (Vb) for 6% Bitumen Content


Voids in Mineral Aggregates (VMA)
15.5
15
14.5
14
13.5
13
0
3
6
9
12
Voids in Mineral Aggregates (VMA) for 4.5% Bitumen Content
Voids in Mineral Aggregates (VMA) for 5.0% Bitumen Content
Voids in Mineral Aggregates (VMA) for 5.5% Bitumen Content
Voids in Mineral Aggregates (VMA) for 6% Bitumen Content


Voids Filled with Bitumen (VFB)
90
85
80
75
70
65
60
55
0
3
6
9
12
Voids Filled with Bitumen (VFB) for 4.5% Bitumen Content
Voids Filled with Bitumen (VFB) for 5.0% Bitumen Content
Voids Filled with Bitumen (VFB) for 5.5% Bitumen Content
Voids Filled with Bitumen (VFB) % for 6% Bitumen Content


Comparison Marshall Stability (S)
31
29
27
25
23
21
19
17
15
0
3
6
9
12
Comparison Marshall Stability (S) for 4.5% Bitumen Content
Comparison Marshall Stability (S) for 5.0% Bitumen Content
Comparison Marshall Stability (S) for 5.5% Bitumen Content


Comparison of flow
6.5
5.5
4.5
3.5
2.5
1.5
0
3
6
9
12
Comparison of Flow for 4.5% Bitumen Content
Comparison of Flow for 5.0% Bitumen Content
Comparison of Flow for 5.5% Bitumen Content


Comparison of Marshall Quotient kg/mm
6.3
5.8
5.3
4.8
4.3
3.8
3.3
2.8
2.3
1.8
0
3
6
9
12
Marshall Quotient kg/mm for 4.5% Bitumen Content
Marshall Quotient kg/mm for 5.0% Bitumen Content
Marshall Quotient kg/mm for 5.5% Bitumen Content
Marshall Quotient kg/mm for 6% Bitumen Content

The parameters of bulk density, theoretical density, volume of air voids, volume of bitumen, VMA, VFB, and Marshall are discussed in this section. For 4.5 percent, 5 percent, 5.5 percent, 6 percent, and 6.5 percent bitumen content, stability, flow, and Marshall Quotient values were analysed for sulphur modified bituminous mix in varying proportions of 3 percent, 6 percent, 9 percent, and 12 percent for 4.5 percent, 5 percent, 5.5 percent, 6 percent, and 6.5 percent bitumen content, as shown in Table 4 and Figs 1 to 8. All of these characteristics are indicative of how well a bituminous concrete mix performs in the field. The following considerations are offered in light of the utility of the addition of modifiers. The above results show that as the percentage of sulphur (modifier) increases, the Marshall stability values and bulk density values increase and decrease, with the highest stability at 30.22 kN for 9 percent sulphur at 5% bitumen content and the lowest density at 2.42 g/cc for plain and modified bitumen at 3 percent, 6 percent, and 9 percent sulphur addition at 5.5 percent bitumen content. The volume of air voids (VMA) decreases as the theoretical density remains constant, but the volume of bitumen (VFB) decreases.

Conclusions

On the basis of observation and analysis of Marshall Test properties using sulfur, the flowing conclusions are drawn.

1. The Marshall Stability value is found maximum of 30.22 kN for 9% sulfur at 5% bitumen content which is more than plain bitumen.
2. The bulk density is also found maximum having 2.42 g/cc for plain and modified bitumen at 3%, 6% and 9% addition of sulfur at 5.5% bitumen content.
3. It is also observed that air voids decrease, which is required for better strength and service life of the pavement and the VFB is increased by addition of bitumen.
4. As per MoRTH, Optimum Binder and modifier content is found to be 5% and 9% respectively.
5. Modification of Bituminous concrete mix has resulted in maximum stability with less bitumen content, which solves the world oil crisis.

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