

EXPERIMENTAL INVESTIGATIONS OF COIR FIBRE AND CRUMB RUBBER MODIFIED BITUMINOUS MIXES

PROJECT REPORT

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DECLARATION

I, the undersigned, hereby declare that the project report “Experimental Investigations of Coir Fibre and Crumb Rubber Modified Bituminous Mixes”, submitted for partial fulfilment of the requirements for the award of degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Prof. Sai Niveditha M.G. This submission represents my ideas in my own words and where ideas of others have been included. I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/ or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

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CERTIFICATE

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ABSTRACT

A country's road network is essential to its economic growth, social integration and trade. Inadequate transportation facilities may have an impact on a country's socio-economic and cultural development. Increased traffic volume and severe loading conditions in India necessitate massive construction of better, more durable and more effective roads that avoid or reduce bituminous asphalt distress. As a result, in order to increase the performance of flexible pavements, these issues must be addressed. One method for improving pavement performance is to modify the asphalt mixes. Coir fibres of size 6 mm and crumb rubber of size 0.8 mm is used for modification in this study. Marshall stability test was done on the mixes to evaluate the stability and flow values. Volumetric properties of the mixes were also evaluated. Coir fibre and crumb rubber modified mixes shown higher stability values than normal mixes. Target air voids is achieved at 8% coir fibre and 6% crumb rubber content. To understand the moisture susceptibility of the mixes indirect tensile strength was conducted. Tensile Strength Ratio (TSR) of the modified mixes were also higher than normal mixes. It indicates modified mixes were less susceptible to moisture damage. Rut depth of the mixes were also evaluated using Wheel rut testing machine. Modified mixes shown lower rut depth values than normal mixes.

Key words: Coir fibre, Crumb rubber, Marshall stability, Moisture susceptibility, Wheel rut testing

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LIST OF ABBREVIATIONS

APA	Asphalt Pavement Analyser
BC	Bituminous Concrete
BIS	Bureau of Indian Standards
CFMB	Coir Fibre Modified Bitumen
CGS	Centimetre-Gram-Second
CRMB	Crumb Rubber Modified Bitumen
EVA	Ethylene Vinyl Acetate
HMA	Hot Mix Asphalt
MORTH	Ministry of Road Transport and Highways
OBC	Optimum Bitumen Content
PET	Polyethylene Terephthalate
TSR	Tensile Strength Ratio
SBS	Styrene Butadiene Styrene
SBR	Styrene Butadiene Rubber
SDBC	Semi Dense Bituminous Concrete
SMA	Stone Matrix Asphalt
VFB	Voids filled with bitumen
VMA	Voids in mineral aggregates

1. INTRODUCTION

1.1 GENERAL

The second-largest road network in the world is found in India, and more than 98% of it is made up of flexible pavements. Low flexural strength is a characteristic of flexible pavements, which are made up of layers of base, subbase, and surface course. There are many different types of climates, terrains, building materials, and traffic conditions in our nation, both in terms of loads and volumes. In order to provide a smooth riding surface and absorb wear and tear from traffic, bituminous mix is typically utilized as a surface course and wearing course. However, due to repetitive traffic loads, flexible pavements frequently experience issues like cracking (Fig. 1.1) and rutting (Fig. 1.2). Permanent deformation of pavements occurs as a result of that. It occurs due to the inadequate stability, inadequate pavement strength, and improper compaction (Nivas et al., 2018). In order to reduce the damages, higher performance pavements are necessary. As a result, in order to increase the resilience of flexible pavement, the traditional mix must be altered.

There are a variety of asphalt binder additives on the market. Polymers and rubbers were the commonly used modifiers. Polymers includes SBS (Styrene Butadiene Styrene), SBR (Styrene Butadiene Rubber) and EVA (Ethylene Vinyl Acetate). Crumb rubber and natural rubber are the two types of rubbers used in modification. Nowadays natural fibres are also used for the modification of bituminous mixes due to their low cost and environmental friendly recycling.

1.2 PROBLEM STATEMENT

Flexible pavement experiences permanent deformations; therefore, periodic maintenance and rehabilitation are necessary to minimize damages. This is accomplished by applying thin overlays or making quick repairs. In this situation, it is possible to increase road rideability but little consideration is given to structural strength. Pavements of insufficient strength may permanently distort as a result of repeated stresses, or they may permanently fail. It is due to the excessive strain on the pavement layers. Vertical oscillations are caused due to the surface undulations and inconsistencies occurred due to pavement's plastic deformations, which increase fuel consumption, deteriorate vehicle parts, and increase operating expenses. Passengers will experience discomfort as a result of these problems.



Fig. 1.1 Cracking in pavements

(Source: <https://www.capitalgeotechnic>)



Fig. 1.2 Rutting in pavements

(Source: <https://www.researchgate.net/figure/Rutting-distress>)

Several research projects have been focused on the development of modified asphalt materials to enhance the overall performance of pavements throughout the past few decades. To improve the performance of flexible pavement, natural fibres, synthetic fibres, steel slag aggregates etc. have been used for the modification of bituminous mixes. Natural fibres have the potential to be used as an admixture in HMA (Hot Mix Asphalt) mixtures to overcome inherent deficiencies. These fibres are also more sustainable, energy efficient, economical and environmental friendly. Waste tyres are one of the most problematic sources of waste around the world, particularly in our country. At the international level, the supply of discarded tyres is steadily increasing. Every year, 300 million tonnes of discarded tyres are produced around the world (Praba et al., 2020). The proper use of scrap tyres in flexible pavements can result in a reduction in the national stock of scrap tyres. So these tyres can be recycled in the form of crumb rubber. Because of its elastic qualities, rubber modified asphalt incorporates stress absorbing membranes that reduce reflective

cracking. So a study can be conducted to evaluate the performance of pavements with the natural fibres and crumb rubber as additives by varying their respective percentages.

1.3 OBJECTIVES

The main objective of this study is to evaluate the performance of normal and modified mixes under varying percentages of coir fibre and crumb rubber. The specific objectives of the study are as follows:-

- To determine the volumetric properties of normal and modified mixes by Marshall Method.
- To determine the optimum bitumen content, optimum coir fibre content and optimum crumb rubber content from the properties.
- To determine the moisture susceptibility of the optimum mixes.
- To determine the rutting performance of optimum mixes.

1.4 METHODOLOGY

The methodology planned to achieve the mentioned objectives is described given below:

- Study of literature: Background study was conducted to determine the effect of binder additives on the performance of pavement.
- Laboratory study: Material characterization of aggregate, bitumen (VG-30) and modified bitumen were done in the laboratory study. Physical properties of aggregates, bitumen and modified bitumen were determined.
- Preparation of compacted specimens: Cylindrical specimens of height 65 mm and diameter 100 mm is prepared according to BC-1 gradation. Coir fibres and crumb rubber in varying percentage is added to the above mix during mixing.
- Experimental Analysis: Volumetric properties and moisture susceptibility of the mixes were determined using Multiframe digital testing apparatus. Rutting characteristics of the mixes were determined using Wheel rut tester.
- Interpretation of results and discussions

1.5 SCOPE

This thesis includes the study to evaluate the performance of normal, coir fibre and crumb rubber modified mixes using VG-30 bitumen. Gradation used for the surface course is BC-1 gradation. Coir fibres of size 6mm and crumb rubber of size 0.8mm were used. Percentage of coir fibres and crumb rubber powder used were 4%, 6%, 8% and 10%. Volumetric properties, moisture susceptibility and rutting characteristics of the mixes is determined. Fatigue characteristics of the mixes can be investigated in future.

2. LITERATURE REVIEW

2.1 CLASSIFICATION OF BITUMINOUS MIXES BASED ON THE METHOD OF PRODUCTION AND COMPOSITION

Bituminous mixes are classified into the following categories based on the method of production and composition as:

2.1.1 Hot Mix Asphalt

It is the most common mixture used in asphalt pavements. The binder is heated and mixed in a hot mix plant at a certain temperature.

2.1.2 Cold Laid Mix

It is produced at a bitumen mixing plant by mixing the aggregates and bitumen without the application of heat.

2.1.3 Mixed in Place or Road Mix

It is produced by mixing the aggregates and bitumen emulsions on the surface of the streets in reasonable extents by proper street mixing equipment.

2.1.4 Penetration Macadam

It is manufactured by layers of coarse and uniform sized aggregate which is spread and rolled on to the pavement with certain amount of asphalt.

2.1.5 Dense Graded Mixtures

They are used as surface courses in bituminous asphalts and it is again divided into two type's namely dense bituminous macadam and bituminous concrete.

2.1.6 Open Graded Mix

It is a coarse aggregate mix containing a significant quantity of air voids to permit water to drain. High resistance to fatigue, reflection cracking, rutting, and shoving are the features of open graded mixes.

2.1.7 Stone Matrix Asphalt

It is a gap graded bituminous mix which has higher amount of coarse aggregates and binder content along with filler and it provides better stone to stone contact. In eastern Washington State, a study was conducted to compare the long-term performance of a SMA pavement to a hot-mix asphalt (HMA) pavement (Wu et al., 2017). The SMA material outperformed the control HMA material in terms of top-down, bottom-up, and thermal cracking resistance, according to the results of laboratory examinations of the field cores.

The recovered SMA binder outperformed the HMA binder in terms of rutting, fatigue, and thermal fracture resistance, according to the results of tests on the recovered binder, and the SMA mixture showed less aging than the HMA control mixture.

2.2 FIBRE MODIFIED BITUMINOUS MIXES

The main goal of fibre reinforcement in bituminous mixes is to increase strain energy absorption in the bituminous mix and improve tensile strength to the resulting composite in order to prevent crack formation and propagation, which might jeopardize the structural integrity of the road surface. It was assumed that if hot mix asphalt is strong in compression but weak in tension, reinforcing may be added to give the required tensile stress resistance. The cohesion and strength of bituminous mixes may be improved by the addition of fibres because they have higher tensile strength than typical blends (Sani et al., 2011).

2.2.1 Natural Fibres

The five main components of natural fibres are cellulose, hemicellulose, lignin, pectin, and waxy compounds are cellulose and hemicellulose. These fibres are biodegradable, have improved energy recovery, good thermal characteristics, low cost, low density, non-abrasive, and adequate specific strength (Abiola et al., 2014). The natural fibres coir, kenaf, sisal, banana, and jute are frequently utilized.

2.2.1.1 Coir fibres

Coir fibres (*Cocos Nucifera*) is extracted from the outer skin of the coconut and there are two varieties of coir fibre. They are white and brown coconut fibres with the white coir being more flexible than brown coir. White coirs are made from young coconuts and the brown coirs are made from matured coconuts. Brown coirs are thick, strong and abrasion resistant than white coirs.

2.2.1.2 Kenaf fibres

Kenaf (*Hibiscus Cannabinus*) is a type of natural fibre obtained from East Indian hibiscus shrub and it is seen predominantly in India and Pakistan. Kenaf fibres can grow up to 5 metres tall and is of cylindrical shape. Kenaf fibres are strong fibres but they are brittle when broken and have high initial modulus with a little amount of recovered elasticity (Sani et al., 2011).

2.2.1.3 Sisal and Banana fibres

Sisal is a flowering plant that produces a rigid fibre and that is used to make rope and other items. Sisal fibres have high resilience to moisture and heat and it prevents fracture development. These fibres are used as reinforcement for houses in under developed countries. On the other hand banana fibres are the strongest natural fibres and they are durable and also biodegradable.

2.2.1.4 Jute fibres

Jute plants are seen particularly in locations with a lot of rainfall. The advantages of using these fibres include greater strength, biodegradability, great absorbency and environmental compatibility. These fibres contains waxes, sugar, minerals and other substances. According to the research findings of Kumar et al., (2004) revealed that natural jute fibres can replace the synthetic fibres and it provides good adhesion with asphalt.

2.2.2 Synthetic Fibres

The primary polymers, polyethylene, polypropylene and polystyrene shows adhesion properties in their molten state. Mixtures strengthened with nylon fibres increases the fatigue life of a pavement to about 20 to 25 times than with the mixtures without fibres. In road overlays, pavement was strengthened using glass fibres to prevent potholes by reducing the cracks. When the amount of polymer used in the blend is high, the polymer dispersion in the bitumen is also high and it separates when it cools down.

2.2.3 Coir Fibre and Kenaf Fibre Modified Asphalt Mixes

The effect of bulk density, voids in mineral aggregates and Marshall Stability of hot mix asphalt with modified mixes was investigated in a study by Sani et al. (2011). The presence of coir and kenaf fibres increased the stability of ordinary HMA by 3.2% and 9.7% respectively. The mix will become more durable when the density is higher and the air voids is lower. Coir fibre modified asphalt mixes is the densest among the three and the kenaf fibre modified asphalt mixes is having the lowest voids in mineral aggregates.

2.2.4 Natural Fibres as Stabilizing Additives in SMA

Large amounts of coarse aggregate are present in SMA, and these aggregates bond together to build a stone skeleton that resists permanent deformation. Rut resistance and skid resistance are enhanced by the use of large coarse material. With the addition of fibres the optimum bitumen stability can be maintained and can prevent binder drainage during transportation and placement. It effectively fills the spaces between the aggregates and

binds them together due to the high bitumen concentration, increasing its resistance to premature cracking and ravelling. Fig. 2.1 shows the comparison between SMA and conventional HMA. The results of using bagasse and shredded waste plastic to stabilise SMA mixture in flexible pavement were also considered.

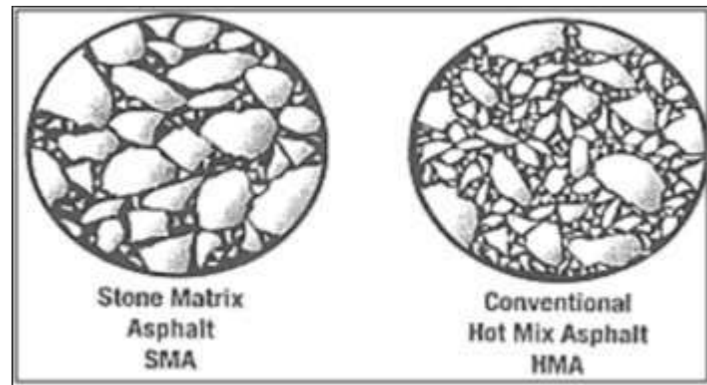


Fig. 2.1 Comparison between SMA and conventional HMA
(Source: Dilkusha and Manikanta, 2018)

Marshall Properties of SMA mixes with different % of fibres as additive was investigated (Dilkusha and Manikanta, 2018). The percentage increase in stability above the control mixture is around 70% and for the SMA mix with other fibres, the increase is around 60%. The presence of the fibres has decreased the flow values and they are within the acceptable specification range. Coir fibre stabilised mixtures shown higher specific gravity than other mixtures and which results in better design of mixes. For coir fibre stabilized mixes, the volumetric characteristics at 0.3 percent fibre concentration shows that air void increases by 11.5%, VMA increases by 2.2%, and VFB reduces by 2.4%. In sisal fibre stabilized mixtures, the percentage changes are 9.25% rise for air void, 5.4% increase for VMA, and 1% decrease for VFB. While in banana fibre stabilised mixes, air voids increased by 8.5%, VMA increased by 5.9%, and VFB decreased by 1%. The introduction of fibers in SMA mixtures increases stability, tensile strength ratio, and index of retained strength.

2.2.5 Marshall Properties of Semi Dense Bituminous Concrete Mixes

In laboratory conditions, Subramani (2012) conducted a study to determine the Marshall properties of SDBC (Semi Dense Bituminous Concrete) mixes. Addition of coir fibres increased the stability value by 1.3 times when compared to the normal mix and the flow value showed an increase of about 1.8 times. Coir fibre of length 15mm was used by Bhavana et al., (2018) to determine the performance of coir fibre modified mixes. The

optimum binder content of the mix reduced to 8.9% and optimum fibre content of the semi dense bituminous concrete mix was 0.3%.

2.2.6 Polypropylene Fibres as Additives to Bituminous mixes

By adding polypropylene fibres to bituminous mixes, the higher stability value and volumetric properties is obtained at 5.33% fibre content and 4.83% binder content (Remadevi et al.,2014). The change of stability and flow parameters enhances bituminous concrete's structural resistance to distresses in flexible pavements.

2.3 CRUMB RUBBER MODIFIED BITUMINOUS MIXES

Crumb rubber from old tyres has been used in pavement construction due to its potential in increasing the performance of asphaltic mixtures. Crumb rubber can be mixed in with aggregates in asphaltic mixes (dry process) or it can be blended with bitumen at a particular temperature (wet process). Factors like the mixing time, temperature, characteristics, and source of the crumb rubber and bitumen type must be taken into account in order to achieve a superior and balanced crumb rubber modified bitumen in terms of high and low temperature properties (Ibrahim et al., 2013).

Marshall Properties and moisture susceptibility of crumb rubber modified asphalt mixes was determined on a study conducted by Palit et al., (2004). Three different types of blend were created by changing the concentration of CR (Crumb Rubber) by weight of asphalt in the blend. Crumb rubber modified mixes shown higher stability values and higher resistance to moisture damage due to its higher tensile strength ratio than normal mixes. Also at lower temperatures, modified binders show higher penetration values, while at higher temperatures, they show lower penetration values.

2.4 RUTTING PERFORMANCE OF MODIFIED MIXES

Rutting is the process of materials moving gradually under repeated loads in the asphalt pavement layers or in the underlying foundation through consolidation or plastic flow, resulting in the development of twin longitudinal depressions under the wheel paths. These depressions or ruts are dangerous for at least two reasons: first, if the surface is impermeable, the rut collects water, which can lead to hydroplaning and is a threat to safety of passengers; second, as the rut depth increases steering becomes more challenging and which increases the risk. A study was conducted using nanopolyacrylate polymer modifier to evaluate the rutting performance of hot mix asphalt mixture (Shaffie et al., 2014). Rutting test was conducted using Asphalt Pavement Analyzer (APA) and the rutting resistance is improved when nanopolymer is added to the binder. In comparison to

normal mixes, modified mixes comprising crumb rubber and waste plastics are less prone to deformation (Chandrawal et al., 2016).

Moghaddam et al., (2014) attempted a study to understand the behaviour of Polyethylene Terephthalate (PET) modified asphalt mixes under static and dynamic loads. The outcomes demonstrated that adding PET can alter the characteristics of an asphalt mixture. While it could not be regarded as a suitable additive for pavements experiencing static loading, it was a superior additive that could significantly improve rutting properties of asphalt mixture under dynamic loading conditions. PET modified mixtures had entirely different behaviors under static and dynamic loadings. Research findings of Shankar et al., (2009) shows that rut resistance of crumb rubber modified bitumen has also been improved with an optimum binder content of 5.67% and there is no loss of strength characteristics in terms of stability and rut resistance.

2.5 SUMMARY OF LITERATURE

The reinforcement of coir and kenaf fibres improved the fatigue life and increased the Marshall stability by 3.2% and 9.7% respectively in a HMA mix. But in the case of coir fibre stabilized SMA mixes, the percentage increase in strength compared to normal mixture is 38% for unconditioned samples and 160% for conditioned samples. While for sisal and banana fibres it is about 35% and 153% respectively. Fatigue lives of CR modified mixes is higher compared to normal mixtures due to other mix parameters such as improved elastic recovery, better ageing characteristics and lower susceptibility to moisture damage. Rutting characteristics of the mixes were also improved after the addition of additives.

3. EXPERIMENTAL METHODS

This chapter provides a description of the methodology, materials used in the study, sample characterization, testing procedure for determining the physical properties of normal and crumb rubber modified bitumen, volumetric tests and the performance test procedures for normal and modified bituminous mixes.

3.1 METHODOLOGY

The flow chart of methodology of the present work is shown in Fig. 3.1.

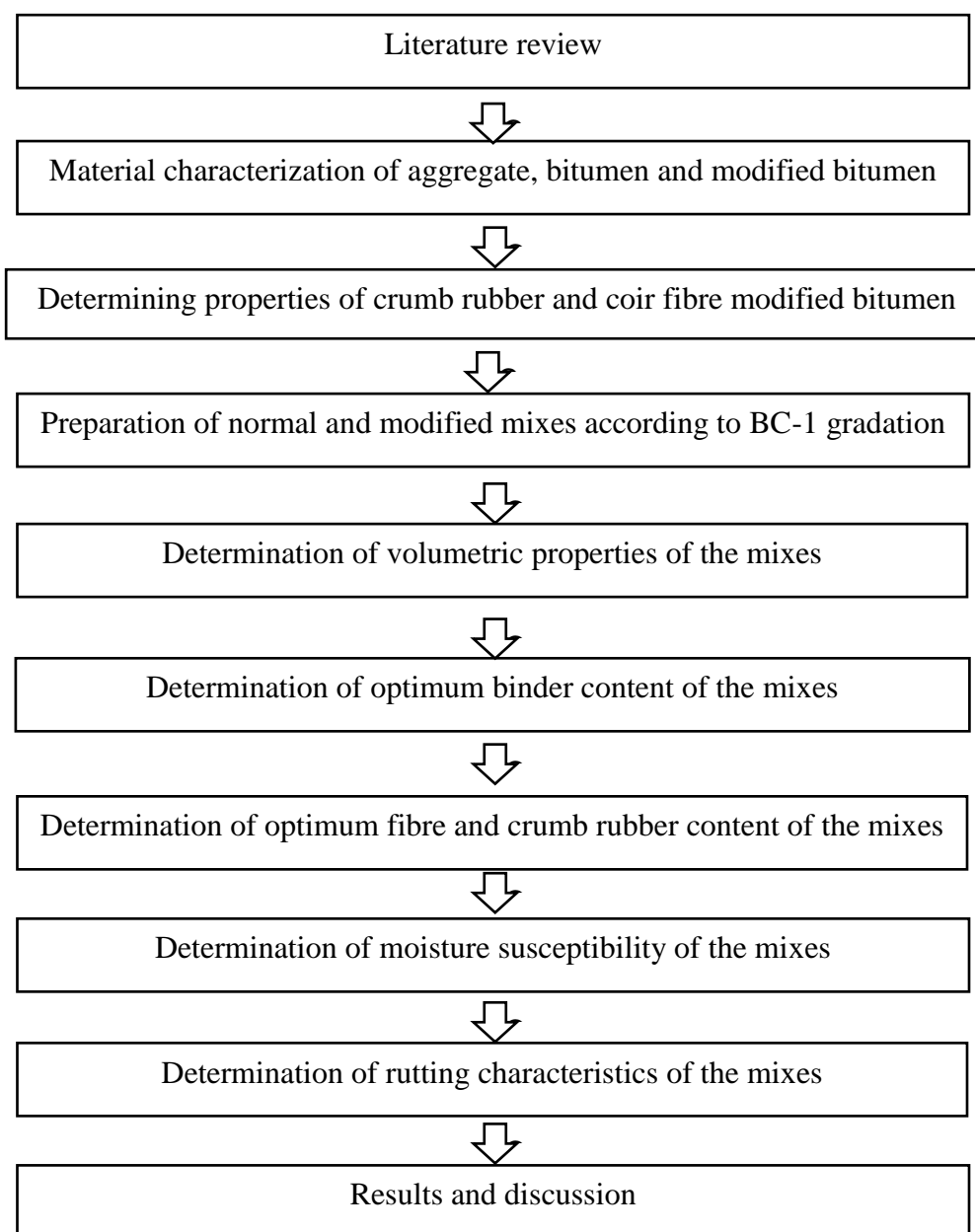


Fig. 3.1 Methodology

3.2 MATERIALS USED

VG-30 was used as binder in this study. Aggregates were collected from Akkavila crushers, Kollam. Coir fibres (Fig. 3.2) were collected from Kollam. Crumb rubber powder (Fig. 3.3) were supplied by Royal rubbers, Angamaly.



Fig. 3.2 Coir fibre



Fig. 3.3 Crumb rubber powder

3.3 PREPARATION OF MODIFIED BITUMEN

In this the VG-30 binder is heated to a temperature of 100°C. Coir fibre and crumb rubber was added into the normal bitumen and the blend is mixed using a mechanical stirrer at 200 rpm for 15-20 minutes. The blending temperature was maintained at 150-160°C.

3.4 TESTS ON BITUMEN

The tests performed on the normal and modified bitumen includes Penetration test, Softening point test, Ductility test, Viscosity test and Specific gravity test according to IS:73-2013, Loss on heating test according to ASTM-D-1754 and Elastic recovery test.

3.4.1 Penetration Test

This test is used to assess the hardness and consistency of bitumen. It is measured with a device known as a penetrometer, which has a 100 g total weight for the needle assembly and a mechanism for releasing and locking in any position. This experiment is carried out at a predetermined temperature of 25 °C.

3.4.2 Softening Point Test

The Ring and Ball test is used to determine a bitumen's softening point. At a specific temperature, a brass ring carrying a bitumen test sample is suspended in glycerin or water. The liquid medium is heated at a rate of 5°C per minute while a steel ball is placed on top of the bitumen sample. The bitumen's softening point is defined as the temperature at which it contacts a metal plate positioned a certain distance below the ring. In general, lesser temperature susceptibility is associated with higher softening points.

3.4.3 Ductility Test

This test is conducted to determine the adhesive property of bitumen and its ability to stretch. The distance in centimeters that a bituminous material will stretch before cracking when two ends of a typical briquette specimen of the material are dragged apart at a specific speed and at a specific temperature is used to determine the material's ductility.

3.4.4 Viscosity Test

Viscosity of a liquid is the property that retards its flow due to internal friction and it is a measure of resistance to flow of the liquid. The Brookfield viscometer is used for measuring viscosity. The principal of operation of the viscometer is to drive a spindle through a calibrated spring. For testing binders, generally spindle number 21 of the viscometer is used. An angular velocity of 20 rpm was selected and based on the torque experienced by the spindle against the angular velocity, viscosity values were calculated

and displayed digitally on the machine. All units of measurement are displayed according to either CGS or SI system.

3.4.5 Specific Gravity Test

The specific gravity of bitumen is a fundamental property frequently used as an aid to classify the binders for use in paving jobs. It is defined as the ratio of the mass of a given volume of the binder to the mass of an equal volume of water, the temperature of both being at 27°C. The apparatus used to determine the specific gravity of bitumen includes specific gravity bottle of 50 ml capacity, weighing balance having least count of 1g and water bath. The bottle is cleaned, dried and weighed along with the stopper (W1). It is then filled with fresh distilled water along with stopper and it is then kept in water container for at least half an hour at a temperature of 27°C. The bottle is then removed and cleaned from outside and the specific gravity bottle containing distilled water is weighed (W2). The bituminous material is heated to a pouring temperature and is poured in the empty bottle. The material is filled up to the half taking care to prevent entry of air bubbles. To prevent the escape of air bubbles, the sample bottle is allowed to stand for half an hour at suitable temperature and then weighed (W3). The remaining space is filled with distilled water at 27°C and is kept in a water container and it is weighed (W4), after being removed from water container. Specific gravity can be calculated using the equation 3.1.

$$\text{Specific gravity} = \frac{(W2 - W1)}{(W3 - W1) - (W4 - W2)} \quad (3.1)$$

3.4.6 Loss on Heating Test

When the bituminous binder is heated, it loses the volatiles and gets hardened. To study the effect of heating, an accelerated heating procedure is adopted. Thin film oven is used for determining this test. About 50 g of the sample is weighed and heated to a temperature of 163°C for 5 hours. After the heating period, the sample is cooled and weighed and the loss in weight is expressed as a percentage by weight of original sample. The residue after heating is subjected to penetration tests and reduction in penetration value is also determined.

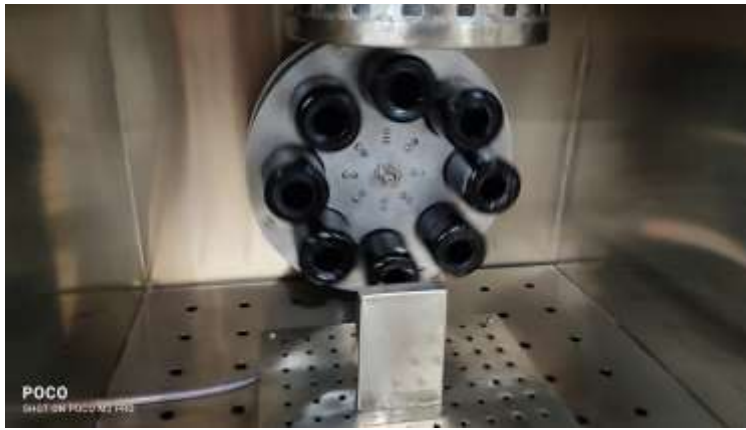


Fig. 3.4 Loss on heating test

3.4.7 Elastic Recovery Test

This is a simple test conducted in a ductility testing machine to assess the quality of the modified bitumen. The elastic recovery is evaluated by comparing the recovery of a thread of modified bitumen after conditioning for one hour at specified temperature. Sample is prepared and conditioned as per ductility test. The test specimen is elongated at a specified temperature to a deformation of 10cm. when the specimen is deformed to 10cm, the specimen is cut into two halves at the midpoint using scissors. Specimen is kept in the water bath for one hour at the specified temperature. After one hour, the elongated half of the specimen is moved back to the position near the fixed half of the test specimen. Thus both the pieces just touches each other. The length of the recombined specimen is measured as 'D' cm. Elastic recovery is calculated using the equation 3.2.

$$Elastic\ recovery\ (\%) = 100 \left(\frac{10 - D}{10} \right) \quad (3.2)$$

3.5 TESTS ON AGGREGATES

The tests performed on the aggregates include Aggregate crushing value test, Aggregate impact value test, Los Angeles abrasion test according to IS: 2386 (Part 4), Shape test according to IS: 2386 (Part 1) and Specific gravity and Water absorption test according to IS: 2386 (Part 3).

3.5.1 Aggregate Crushing Value Test

This test is used to assess the strength of the coarse aggregates used in the pavement under gradually applied load. Aggregates measured to weight of about 3500 g is taken and transferred to the set of sieves arranged in the order of 12.5 mm, 10 mm and pan. After

that the sieves are placed in the mechanical shaker for 10 minutes. Sample retained on the 10 mm sieve was collected. Then a cylinder was taken and empty weight of the cylinder (W1) was noted. Aggregates were then added to the cylinder in three layers and for each layer tamping was done at 25 times. Then weight of the cylinder with aggregates (W2) was noted. Cylinder was placed on position along with plunger on the compression testing machine. After switching on the machine, 40 tonnes of load was applied and release the load after switching off the machine. Transfer the aggregates into 2.36 mm sieve and allow it to shake for 10 minutes on the mechanical shaker. Weight of aggregates retained on pan was noted (W3). Aggregate crushing value was calculated using the equation 3.3.

$$\text{Aggregate crushing value} = \left(\frac{W3}{W2 - W1} \right) * 100 \quad (3.3)$$

3.5.2 Aggregate Impact Value Test

This test is used to evaluate the toughness of aggregates to break down under application of impact. Aggregates measured to weight of about 350 g is taken and transferred to the set of sieves arranged in the order of 12.5 mm, 10 mm and pan and it is then placed in the mechanical shaker for 10 minutes. Coarse aggregates retained on 10 mm sieve was collected. Empty weight of the cylinder is taken (W1) and then the aggregates retained on 10 mm sieve is transferred into the cylinder in 3 layers. Each layer were given a tamping of 25 times. Weight of the cylinder along with the aggregates was noted (W2). Cylinder was then placed in the impact testing machine and 15 blows were given at an interval of not less than 1 seconds. Before applying blows, release the hammer in order to apply the impact load. The aggregates are then transferred to the 2.36 mm sieve and placed in the mechanical shaker. Weight of the aggregates passing through 2.36 mm sieve was noted (W3). Aggregate impact value was calculated using the equation 3.4.

$$\text{Aggregate impact value} = \left(\frac{W3}{W2 - W1} \right) * 100 \quad (3.4)$$

3.5.3 Los Angeles Abrasion Test

This test is used to determine the resistance to wear and tear of aggregates by using an abrasive charge. Choose the grading to be used in the test so that it complies as closely as feasible with the grading to be used in construction. Preferred grade is B. Sieve the sample in a 20 mm, 12.5 mm and 10 mm IS sieves using sieve shaker. Collect the sample retained on 10 mm and 12.5 mm sieve in a separate container and weigh it to 5000 g (W1). Then

the weighed aggregates and abrasive charges are then transferred to the circular drum of Los Angeles machine and fix the cover. The machine should be rotated at a rate of 30 to 33 revolutions per minute. The entire stone dust was sieved on 1.75 mm IS sieve and was placed in mechanical shaker. The material coarser than 1.70 mm size was weighed (W2). Abrasion value is calculated using the equation 3.5.

$$\% \text{ wear} = \left(\frac{W1 - W2}{W1} \right) * 100 \quad (3.5)$$

3.5.4 Shape Test

The shape of aggregate particle is determined by the percentage of flaky and elongated particles contained in it. The evaluation of shape of the particles is made in terms of flakiness index, elongation index and angularity number. The fraction of aggregate particles by weight whose smallest dimension or thickness is less than three fifths, or 0.6 of their mean dimension, is known as the flakiness index of aggregate. This test is applicable to size larger than 6.3 mm. Standard thickness gauge is used to gauge the thickness or least dimension of the aggregate samples. The fraction of particles in an aggregate whose largest size is more than one and a quarter, or 1.8 times their mean dimension, is known as the elongation index. This test is not applicable for sizes smaller than 6.3 mm. Standard length gauge is used to gauge the greatest dimension or length of the aggregate samples.

Samples were sieved through IS sieves of size 63, 50, 40, 31.5, 25, 20, 16, 12.5, 10 and 6.3 mm. A minimum of 200 pieces of each fraction was taken and weighed them. Flaky materials were separated through thickness gauge and the weight of the material was taken. The non flaky materials were separated and weighed to find out the elongation index of these aggregates. Each fraction was gauged on the length gauge in order to separate the elongated materials. Weight of materials retained on length gauge were also taken. Flakiness index and elongation index is calculated using the equations 3.6 and 3.7.

$$\text{Flakiness index} = \left(\frac{\text{Total weight of material passing through thickness gauge}}{\text{Total weight of sample gauged}} \right) * 100 \quad (3.6)$$

$$\text{Elongation index} = \left(\frac{\text{Total weight of non flaky material retained on length gauge}}{\text{Total weight of non flaky sample gauged}} \right) * 100 \quad (3.7)$$

Combined flakiness and elongation index is calculated by adding the above flakiness and elongation index values.

3.5.5 Specific Gravity and Water Absorption Test of Aggregates

Specific gravity of a stone aggregate is considered to be a measure of strength or quality of material. In general, stones with a low specific gravity are weaker than those with a high specific gravity. On the other hand, stones having high water absorption are more porous in nature and are generally considered unsuitable. In this test, about 2 kg of aggregate sample was taken and washed thoroughly to remove fines and then drained and placed in a wire basket and immersed in distilled water at a temperature between 22°C and 32°C and a cover of at least 5 cm of water above the top of the basket. After removing entrapped air bubbles the basket and the aggregate remained completely immersed in water for a period of 24 hours afterwards and then the weight was noted (W1). The basket and the aggregate were removed from water and allowed to drain for a few minutes. After that the aggregates were transferred to one of the dry absorbent clothes. Then the empty basket was then returned to water and the weight was noted (W2). When the aggregates placed on the dry cloth is completely surface dried, weight of the dried aggregates is noted (W3). The aggregates was placed in a shallow tray and kept in an oven maintained at temperature of 110°C for 24 hours. It was then removed from the oven, cooled and weigh was noted (W4). Specific gravity and water absorption of aggregates is calculated using the equations 3.8 and 3.9.

$$\text{Specific gravity} = \left(\frac{W4}{(W3 - (W1 - W2))} \right) * 100 \quad (3.8)$$

$$\text{Water absorption} = \left(\frac{W3 - W4}{W4} \right) * 100 \quad (3.9)$$

3.6 GRADATION OF AGGREGATES

Bituminous concrete (BC) grade 1 has been selected in this present study for bituminous mix. Gradation of aggregates is selected according to the requirements specified by Ministry of Road Transport and Highways (MORTH, 2013) and is shown in Table 3.1. Total weight of sample taken in this study is 1250 g. Individual weight of aggregates according to MORTH gradation is shown in Table 3.

Table 3.1 BC MORTH Requirements Grade 1

IS sieve (mm)	Cumulative % by weight of total aggregate passing	Mid-range of aggregate value selected
26.5	100	
19	90-100	95
13.2	59-79	69
9.5	52-72	62
4.75	35-55	45
2.36	28-44	36
1.18	20-34	27
0.6	15-27	21
0.3	10-20	15
0.15	5-13	9
0.075	2-8	5

Table 3.2 Individual weight calculations as per MORTH specifications

IS sieve (mm)	Cumulative % by weight of total aggregate passing	Mid-range of aggregate value selected	Individual % by weight of aggregate retained	Individual weights (g)
26.5	100			
19	90-100	95	5	59.125
13.2	59-79	69	26	307.45
9.5	52-72	62	7	82.775
4.75	35-55	45	17	201.025
2.36	28-44	36	9	106.425
1.18	20-34	27	9	106.425
0.6	15-27	21	6	70.95
0.3	10-20	15	6	70.95
0.15	5-13	9	6	70.95
0.075	2-8	5	4	47.3
PAN			5	59.125

3.7 MARSHALL MIX DESIGN

Marshall samples for normal mixes were prepared using the above aggregate gradation at 5.2%, 5.4%, 5.6% and 5.8% of bitumen. Total weight of sample is about 1250 g. Three samples were prepared at each bitumen content and Optimum Bitumen Content (OBC) is found out for bituminous mix. Coir fibre and crumb rubber modified bituminous mixes were prepared for 4%, 6%, 8% and 10% of coir fibre at 5.2%, 5.4%, 5.6% and 5.8% of bitumen. Size of crumb rubber used in this study is about 0.8mm and that of coir fibre is about 6mm. For the mix design, the aggregates are taken and heated to a temperature of 165 to 180°C. The bitumen is also heated to a temperature of 160°C. The binder and aggregate are then mixed together and the temperature is maintained at 145°C. The mix is then poured on to the mould assembly and is compacted with 75 blows on each side using Marshall compactor (Fig. 3.5). After compaction the specimen with the mould is allowed to cool down to the room temperature for 24 hours. After that, Marshall specimens (Fig. 3.6) is then extracted from the mould and it is then immersed in water bath for 30-40 minutes at 60°C (Fig. 3.7). Then the specimen was tested in automatic Marshall stability test apparatus (Fig. 3.8).



Fig. 3.5 Marshall compactor



Fig. 3.6 Marshall specimens



Fig. 3.7 Specimens in water bath

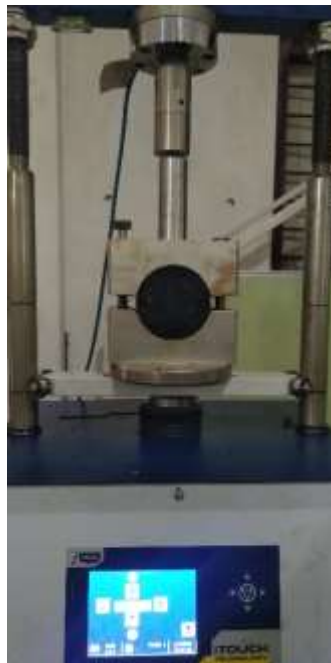


Fig. 3.8 Automatic Marshall stability testing machine

3.7.1 Density and Voids Analysis

The compacted specimen of bituminous mix consists of mineral aggregates, bituminous binder and some air voids. Volumetric properties of the bituminous mix include bulk specific gravity, theoretical specific gravity, air voids, voids filled with bitumen, voids in the mineral aggregates, stability and flow values.

3.7.1.1 Bulk specific gravity (G_{mb})

It is the specific gravity containing air voids and is found out by the equation 3.10.

$$G_{mb} = \left(\frac{A}{B - C} \right) \quad (3.10)$$

Where, A= dry mass of specimen in air

B= saturated surface dry mass of specimen in air

C= mass of specimen in water

3.7.1.2 Theoretical maximum specific gravity (G_t)

It is determined based on the known values of specific gravity of aggregate and bitumen and is found out by equation 3.11.

$$G_t = \frac{100}{\left(\frac{W_1}{G_1} \right) + \left(\frac{W_2}{G_2} \right) + \left(\frac{W_3}{G_3} \right)} \quad (3.11)$$

Where, W1= percentage by weight of coarse aggregate in total mix

W2= percentage by weight of fine aggregate

W3= percentage by weight of bituminous binder

G1= apparent specific gravity of coarse aggregates

G2= apparent specific gravity of fine aggregates

G3= specific gravity of bituminous binder

3.7.1.3 Volume of voids or Percentage air voids (V_v)

The volume of air voids in the compacted mix is expressed as percentage of the volume of the test specimen and is calculated using the equation 3.12.

$$V_v = \frac{100(G_t - G_b)}{G_t} \quad (3.12)$$

Where, G_t = theoretical maximum specific gravity

G_b = specific gravity of bitumen

3.7.1.4 Volume of bitumen (V_b)

The volume of bitumen in the compacted specimen is also expressed as a percentage of volume of the compacted specimen and is calculated using the equation 3.13.

$$V_b = G_b * \left(\frac{W_3}{G_3} \right) \quad (3.13)$$

3.7.1.5 Voids in mineral aggregates (VMA)

It is the total volume of air voids and the volume of bitumen in the compacted mix and it is found out by equation 3.14.

$$VMA = V_v + V_b \quad (3.14)$$

3.7.1.6 Voids filled with bitumen (VFB)

It is expressed as a percentage of volume of bitumen to the total voids in the mineral aggregates of the compacted mix and is found out by equation 3.15.

$$VFB = \frac{100V_b}{VMA} \quad (3.15)$$

3.7.1.7 Marshall Stability and Flow value

To determine the Marshall Stability and flow value, load is applied at a rate of 51mm/minute and the maximum load value expressed in KN is noted as 'Marshall Stability' value of the specimen. The vertical deformation of the test specimen corresponding to the maximum load expressed in mm units is noted as the 'Flow Value'. The measured value of maximum load is to be multiplied by the appropriate correction factor to obtain the corrected value of Marshall stability.

3.8 INDIRECT TENSILE STRENGTH TEST

This test was performed according to AASHTO T-283 with air voids content of 7%. This test method is used to determine if the materials may be subjected to stripping and also to measure the effect of additives. The mixes were prepared with a mixing temperature of 150-160°C and the specimens were compacted at a temperature of 140-150°C. The specimens (Fig. 3.9) were kept at room temperature for 24 hours after being taken from the moulds.

3.8.1 Indirect Tensile Dry Test

At the end of curing period, the specimens were placed in a leak proof plastic bag (Fig. 3.10). The specimens were then submerged in a water bath at 25°C for 2 hours with a minimum of 25 mm of water above the surface. Specimens were then removed from the water bath and placed on the testing machine. A load was applied at a constant rate of 51 mm per minute and the load at which the specimen fails were noted.

3.8.2 Indirect Tensile Wet Test

At the end of curing period, the specimens were put in a vacuum container for 5 to 10 minutes (Fig. 3.11). A vacuum of 13-67 Kpa absolute pressure is applied for approximately 5 to 10 minutes. After that vacuum is removed and the specimen is left submerged for 5 to 10 minutes. The conditioning by freezing may go on if the saturation level is between 70% and 80%. If the saturation level is less than 70%, the vacuum technique is repeated with increased vacuum and/or duration. The specimen is considered damaged and rejected if the saturation level is greater than 80%. After that the specimens were wrapped in a plastic bag and is placed in a freezer for 16 hours. The plastic bag and film were removed from the specimens and they were immediately immersed in a water bath at 60°C for 24 hours. Then the specimens were removed and placed in a water bath at 25°C for 2 hours. The specimens were then removed from the water bath and placed on the testing machine (Fig. 3.12). A load was applied at a constant rate of 51 mm per minute and the load at which specimen fails or cracks was noted.



Fig. 3.9 Specimens for ITS



Fig. 3.10 Specimens to be placed in water bath and freezer



Fig. 3.11 Specimens in vacuum container



Fig. 3.12 ITS testing machine

3.8.3 Tensile Strength Ratio

The tensile strength ratio of bituminous mixes reflects their resistance to moisture susceptibility. According to AASHTO, a TSR value of 0.8 or above is recommended for mixtures having resistance to moisture susceptibility. Tensile Strength Ratio was calculated using the equation 3.16.

$$\text{Tensile Strength Ratio (TSR)} = \frac{S_2}{S_1} \quad (3.16)$$

Where S1= average tensile strength from dry test

S2 = average tensile strength from wet test

3.9 RUTTING TEST OF MIXES

To determine the rut depth of normal and modified mixes, cylindrical specimens of diameter 100 mm and height 65 mm (Fig. 3.13) were prepared according to the optimum values with 7% air voids. The specimens were placed in rectangular shaped rut mould (Fig. 3.14) and it is then subjected to reciprocating load repetitions for 10000 passes and the depression formed on the surface of specimen is observed. Wheel rut testing machine

(Fig. 3.15) is used for studying the rutting characteristics of the mixes. To find the rut depth, 0.7 MPa tyre pressure is applied. Fig. 3.16 shows the specimen after rut testing.



Fig. 3.13 Specimen for rut test



Fig. 3.14 Specimen before rut test



Fig. 3.15 Wheel rut tester



Fig. 3.16 Specimen after rut test

4. RESULTS AND DISCUSSION

This section emphasis on the results obtained after conducting the laboratory tests to determine the physical properties of bitumen, aggregates, crumb rubber modified bitumen and coir fibre modified bitumen. Results on volumetric properties, moisture susceptibility and rutting characteristics of the mixes were also discussed here.

4.1 PHYSICAL PROPERTIES OF BITUMEN

Table 4.1 indicates the results obtained after conducting the physical tests of bitumen. Tests were conducted according to IS 73: 2013 specifications. Test results shows that the physical properties of the bitumen meets the requirements specified by BIS.

Table 4.1 Physical properties of bitumen

Property	Value	Required value
Penetration at 25°c	63	Min 45
Softening point (°c)	52	Min 47
Ductility (cm)	82	Min 75
Specific gravity	1.024	Min 0.99
Viscosity (cst)	526	Min 350
Loss on heating (%)	0.96	Less than 1

4.2 PHYSICAL PROPERTIES OF AGGREGATES

Table 4.2 indicates the results obtained after conducting the physical properties of aggregates. Tests were conducted according to IS: 2386 Part 1, Part 3 and Part 4 specifications. Tests results shows that the physical properties of aggregates meets the requirements specified by BIS.

Table 4.2 Physical properties of aggregates

Property	Value	Required value
Aggregate crushing value	28	Less than 30
Aggregate impact value (%)	26	Max 24
Los Angeles abrasion value (%)	22	Max 30
Combined flakiness and elongation index (%)	26	Max 35
Specific gravity	2.72	2.5 to 3
Water absorption (%)	0.82	Max 2

4.3 PROPERTIES OF CRUMB RUBBER MODIFIED BITUMEN

Table 4.3 indicates the results obtained after conducting the physical properties of crumb rubber modified bitumen. Tests were conducted according to IS 15462: 2004 and it meets the requirements specified by them.

Table 4.3 Physical properties of crumb rubber modified bitumen

Property	Value	Required value
Penetration at 25°C	57	Less than 60
Softening point (°C)	55	Min 50
Elastic recovery (%)	74	Min 50
Viscosity (cst)	388	Min 200
Specific gravity	1.032	Min 0.99
Loss on heating (%)	0.63	Max 1

4.4 PROPERTIES OF COIR FIBRE MODIFIED BITUMEN

Table 4.4 indicates the results obtained after conducting the physical properties of coir fibre modified bitumen. Tests were conducted according to IS 73: 2013 specifications and it meets the requirements satisfied by them.

Table 4.4 Physical properties of coir fibre modified bitumen

Property	Value	Required value
Penetration at 25c	53	Min 45
Softening point (°c)	62	Min 47
Viscosity (cst)	635	Min 350
Specific gravity	1.01	Min 0.99
Loss on heating (%)	0.58	Max 1

4.5 MARSHALL TEST RESULTS

For the determination of volumetric properties of normal and modified bituminous mixes, Marshall samples were prepared at 5.2%, 5.4%, 5.6% and 5.8% of bitumen with varying percentages of fibre and crumb rubber powder. Three samples were prepared for each bitumen content and optimum bitumen content, optimum fibre content and optimum crumb rubber powder content is determined. Table 4.5 shows the results of volumetric properties of normal mix. Volumetric properties of normal mix at OBC is shown in Table 4.6.

Table 4.5 Volumetric properties of normal mix

% of bitumen	Stability (KN)	Flow (mm)	Va (%)	VMA (%)	VFB (%)	Bulk density(g/cc)
5.2	14.24	2.82	6.73	13.72	68.4	2.33
5.4	14.86	3.24	5.66	13.43	72.6	2.35
5.6	15.30	3.37	4.84	13.31	74.43	2.42
5.8	14.66	3.86	3.96	13.85	78.67	2.38

Table 4.6 Volumetric properties of normal mix at OBC

OBC (%)	Stability (KN)	Flow (mm)	VMA (%)	VFB (%)	Bulk density (g/cc)
5.7	15.2	3.31	13.55	66.2	2.407

The relationship between Marshall stability, flow value, air voids in percentage, voids in mineral aggregate (VMA), voids filled with bitumen (VFB) and bulk density is shown in Fig. 4.1, Fig. 4.2, Fig. 4.3, Fig. 4.4, Fig. 4.5 and Fig. 4.6.

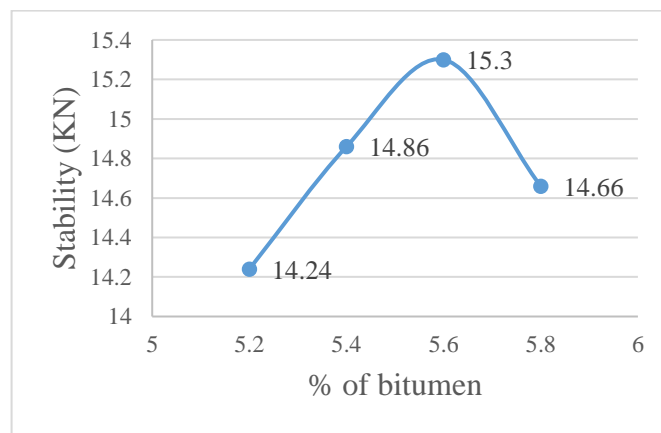


Fig. 4.1 Variation of stability value with bitumen content of normal mix

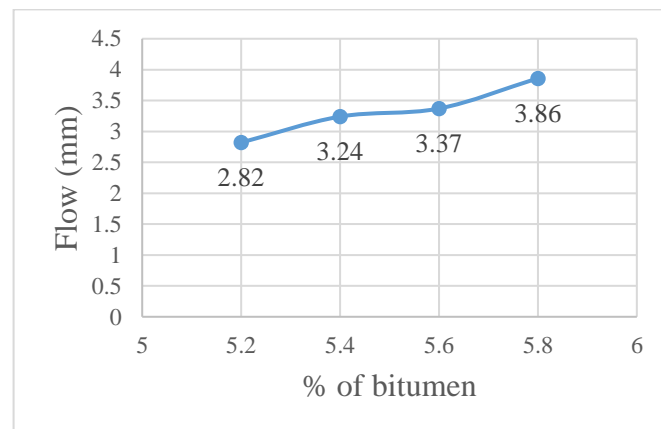


Fig. 4.2 Variation of flow value with bitumen content of normal mix

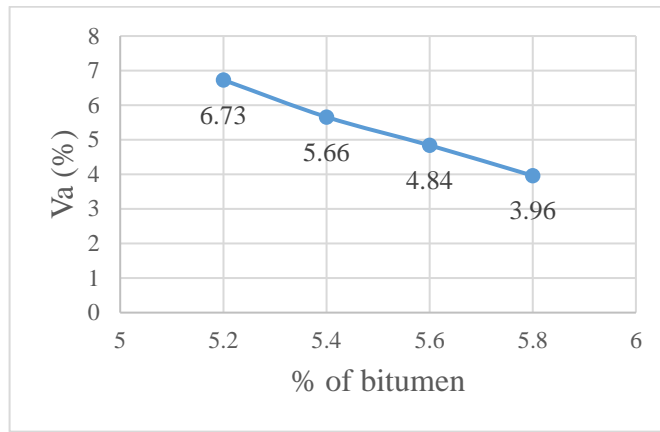


Fig. 4.3 Variation of air voids with bitumen content of normal mix

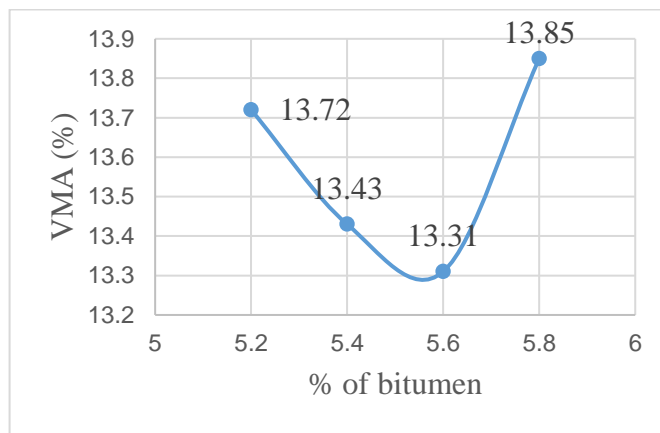


Fig. 4.4 Variation of VMA with bitumen content of normal mix

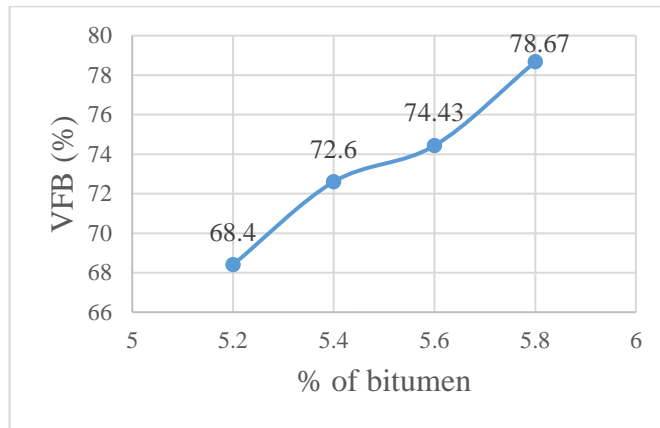


Fig. 4.5 Variation of VFB with bitumen content of normal mix

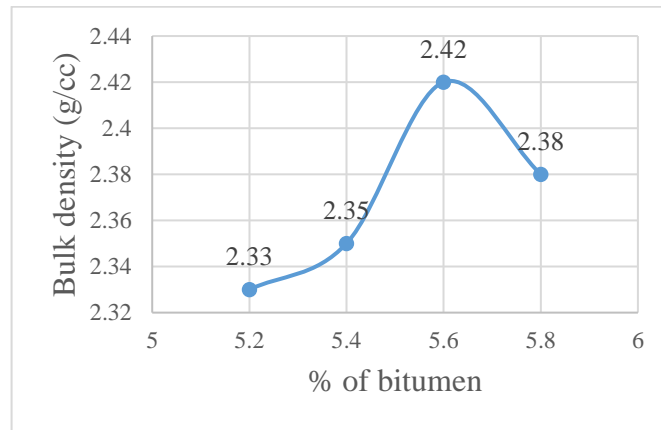


Fig. 4.6 Variation of bulk density with bitumen content of normal mix

From the test results, it was observed that stability of normal mixes increased by increasing the percentage of bitumen up to 5.6% and shown a decreasing trend after that. Test results shows that optimum bitumen content of the normal mix is 5.7%. Optimum bitumen content of the mix is calculated as the average of the bitumen content corresponding to maximum stability, minimum voids in mineral aggregates, maximum bulk density and air voids of 4%.

4.5.1 Marshall Properties of Coir Fibre Modified Bituminous Mixes

The volumetric properties of coir fibre modified bituminous mixes is shown in Table No. 4.6. The relationship between volumetric properties of coir fibre modified bituminous mixes with different bitumen content and coir fibre content were plotted. Fig. 4.7, Fig. 4.8, Fig. 4.9, Fig. 4.10, Fig. 4.11 and Fig. 4.12 shows the variation in volumetric properties of coir fibre modified bituminous mixes with coir fibre content of 4% and bitumen content of 5.2%, 5.4%, 5.6% and 5.8%.

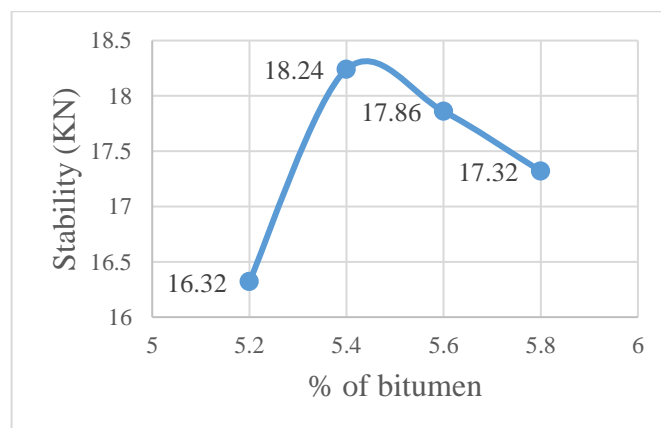


Fig. 4.7 Variation of stability value for 4% coir

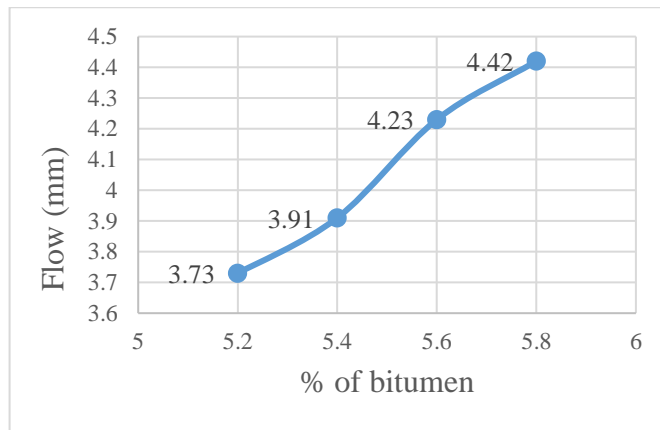


Fig. 4.8 Variation of flow value for 4% coir

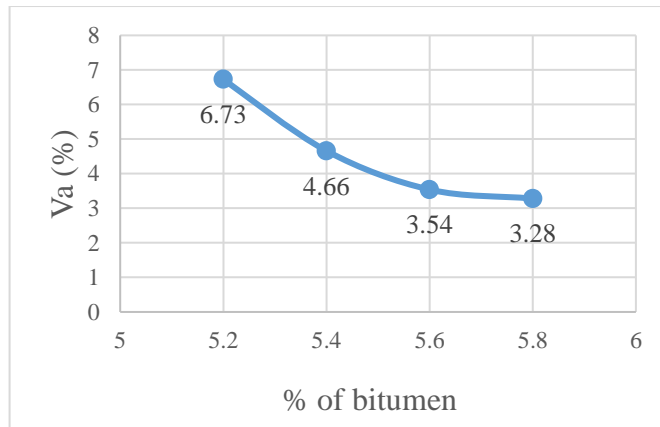


Fig. 4.9 Variation of air voids for 4% coir

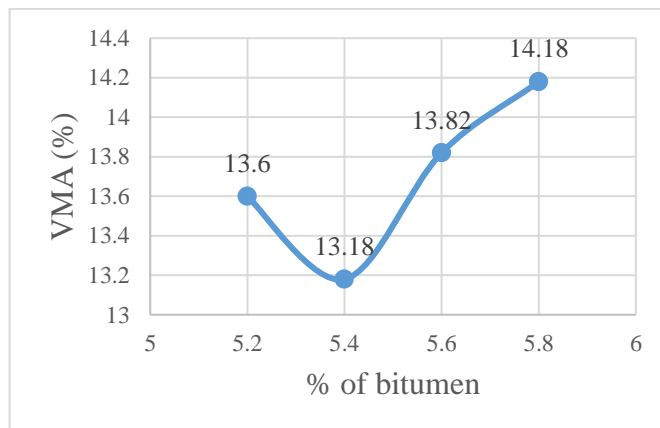


Fig. 4.10 Variation of VMA for 4% coir

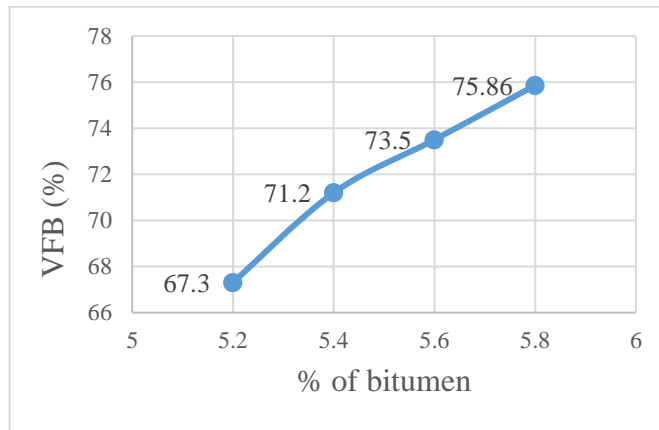


Fig. 4.11 Variation of VFB for 4% coir

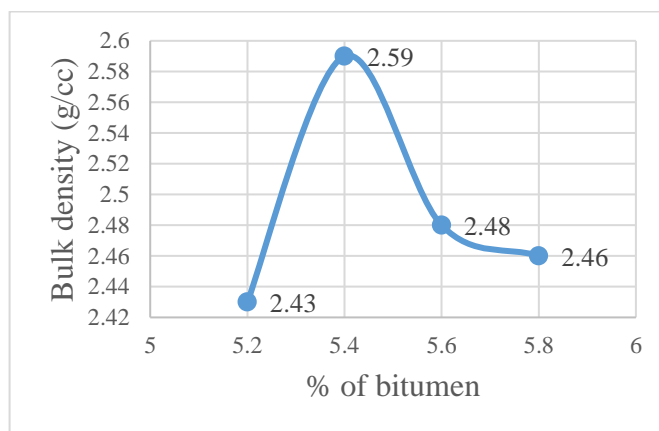


Fig. 4.12 Variation of bulk density for 4% coir

From the above test results, it is observed that by varying the bitumen and coir fibre content, stability and flow values goes on increasing up to a certain bitumen content. For 4% coir fibre content maximum stability is achieved at a bitumen content of 5.4%. Variation of volumetric properties of coir fibre modified bituminous mixes with coir fibre content of 6% is shown in Fig. 4.13, Fig. 4.14, Fig. 4.15, Fig. 4.16, Fig. 4.17 and Fig. 4.18.

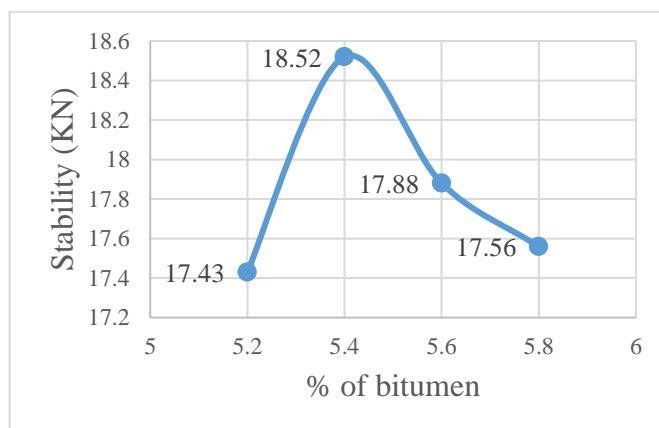


Fig. 4.13 Variation of stability value for 6% coir

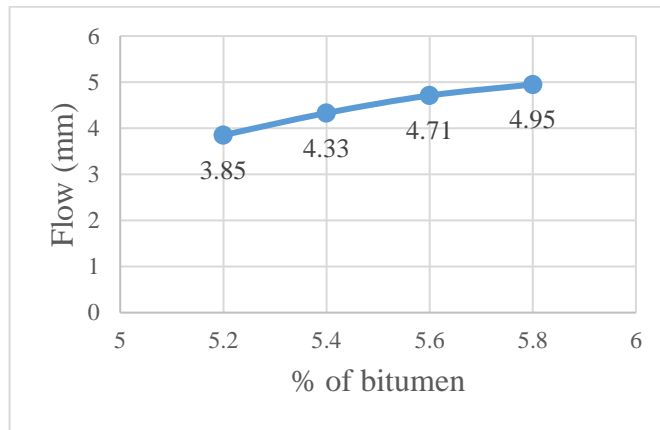


Fig. 4.14 Variation of flow value for 6% coir

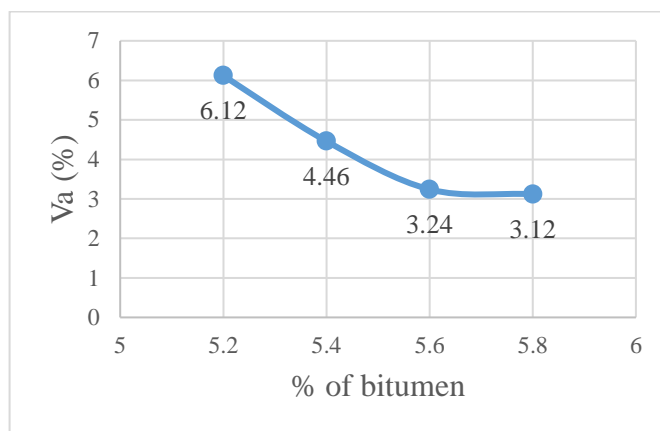


Fig. 4.15 Variation of air voids for 6% coir

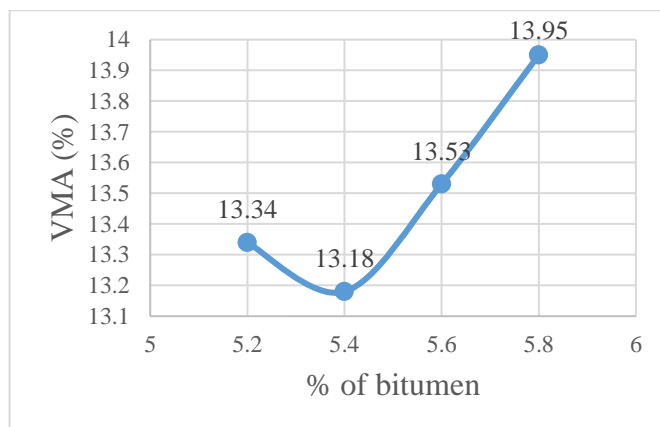


Fig. 4.16 Variation of VMA for 6% coir

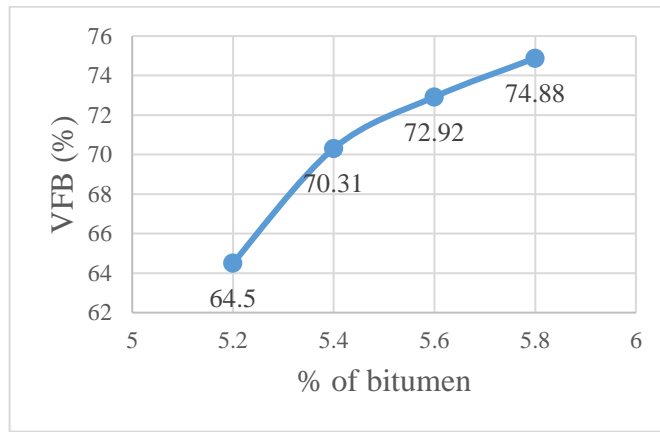


Fig. 4.17 Variation of VFB for 6% coir

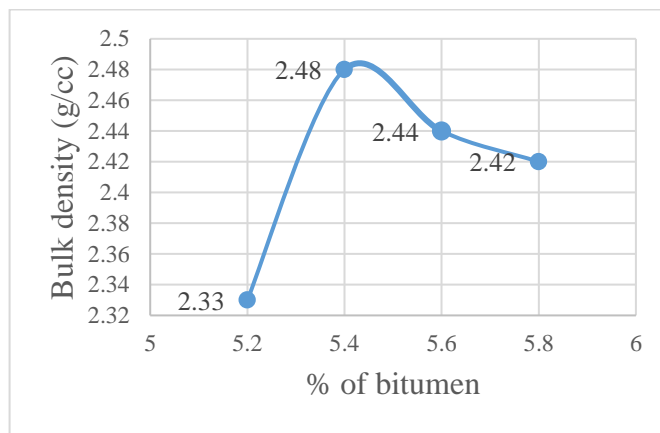


Fig. 4.18 Variation of bulk density for 6% coir

The above results shows that by varying the bitumen content and coir fibre content to 6% also shows an increasing trend in the stability and flow values. Voids in mineral aggregates goes on decreasing as the bitumen content is varied. For 6% coir fibre content maximum stability of 18.52 KN is achieved at 5.4% of bitumen. Variation of volumetric properties of coir fibre modified bituminous mixes with coir fibre content of 8% is shown in Fig. 4.19, Fig. 4.20, Fig. 4.21, Fig. 4.22, Fig. 4.23 and Fig. 4.24.

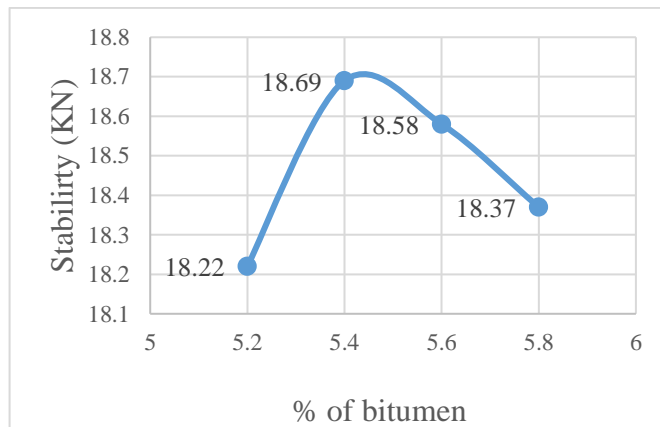


Fig. 4.19 Variation of stability value for 8% coir

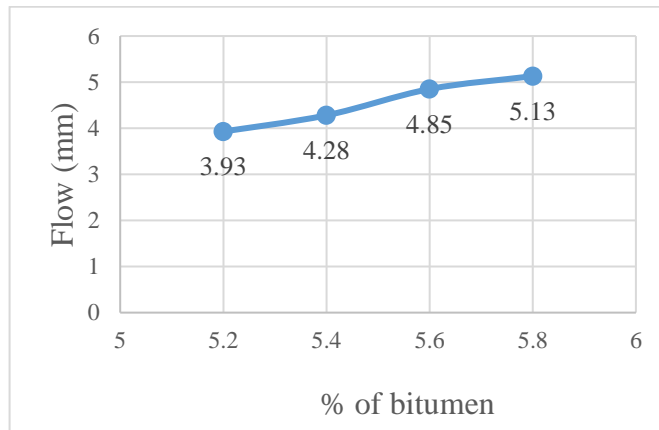


Fig. 4.20 Variation of flow value for 8% coir

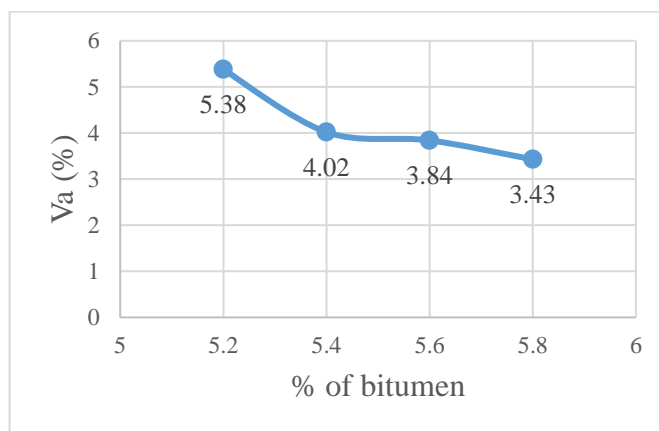


Fig. 4.21 Variation of air voids for 8% coir

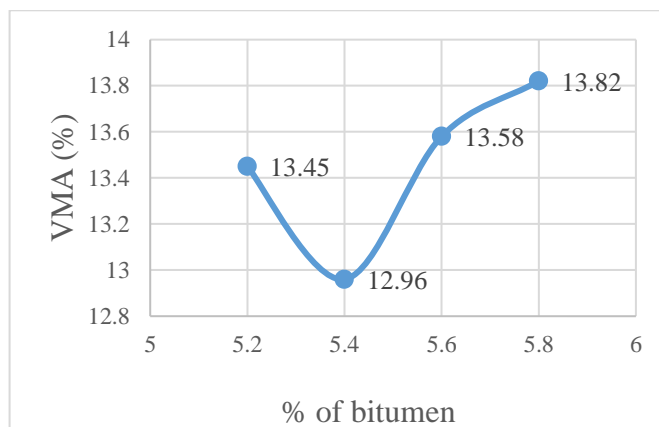


Fig. 4.22 Variation of VMA for 8% coir

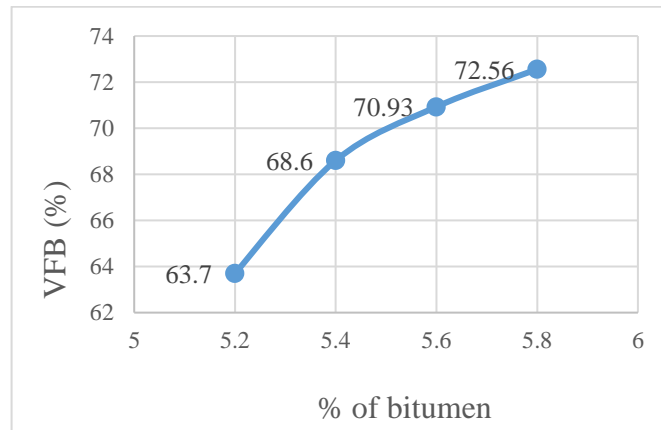


Fig. 4.23 Variation of VFB for 8% coir

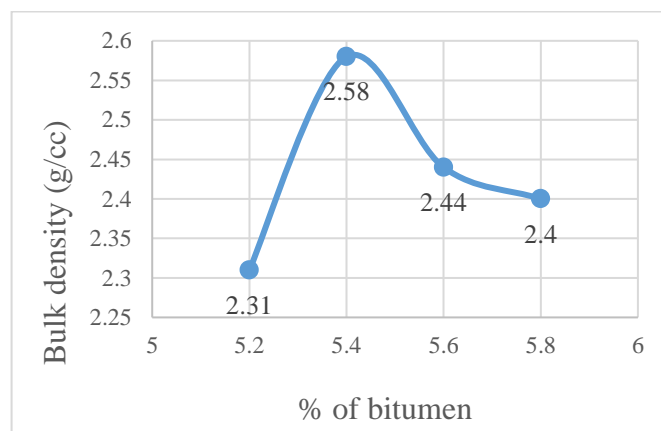


Fig. 4.24 Variation of bulk density for 8% coir

The percentage of bitumen and coir fibre content is again varied and the test results were observed. For 8% coir fibre content maximum stability is achieved at 5.4% of bitumen. Density of a mix is related to its compaction and the air voids in the mix. If the air voids is decreased it indicates that the suitable compaction is provided for the mix and the mix will be more durable. Variation of volumetric properties of coir fibre modified bituminous mixes for 10% coir fibre content is shown in Fig. 4.25, Fig. 4.26, Fig. 4.27, Fig. 4.28, Fig. 4.29 and Fig. 4.30.

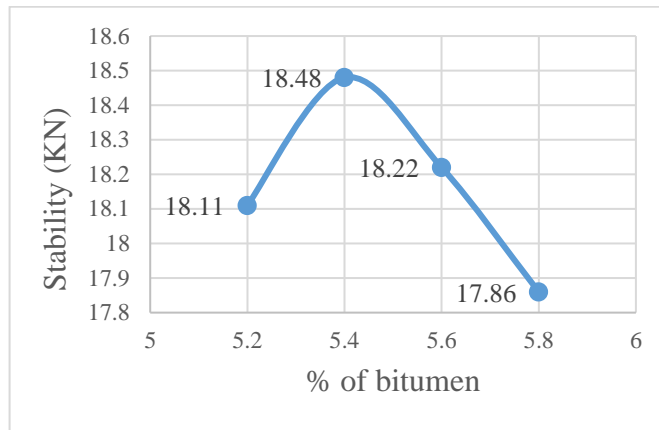


Fig. 4.25 Variation of stability value for 10% coir

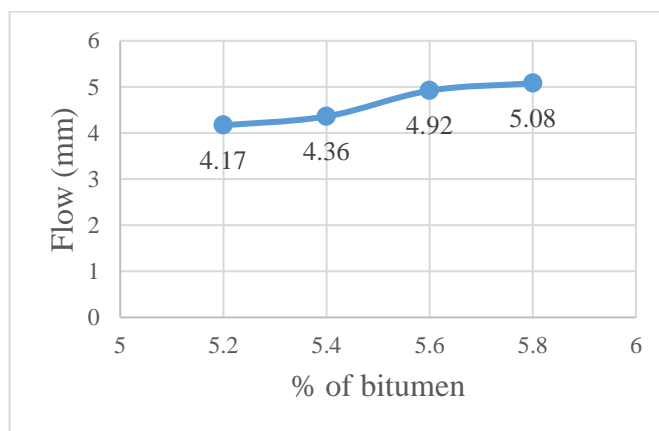


Fig. 4.26 Variation of flow value for 10% coir

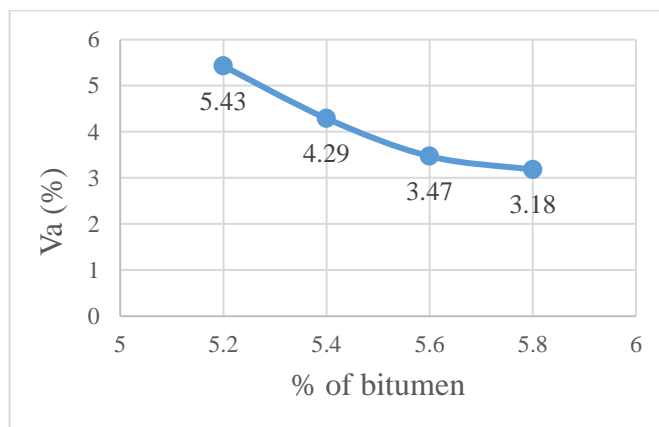


Fig. 4.27 Variation of air voids for 10% coir

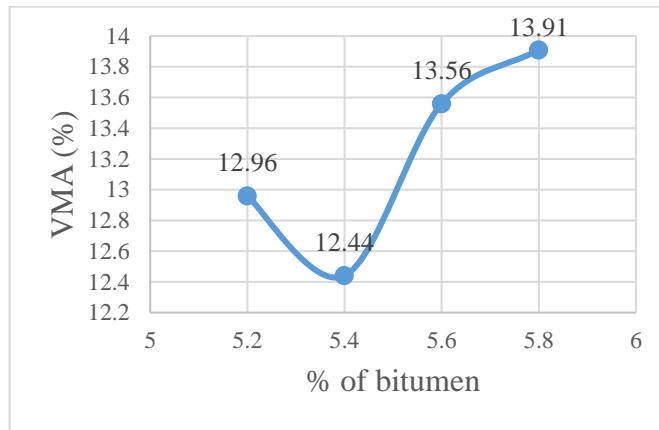


Fig. 4.28 Variation of VMA for 10% coir

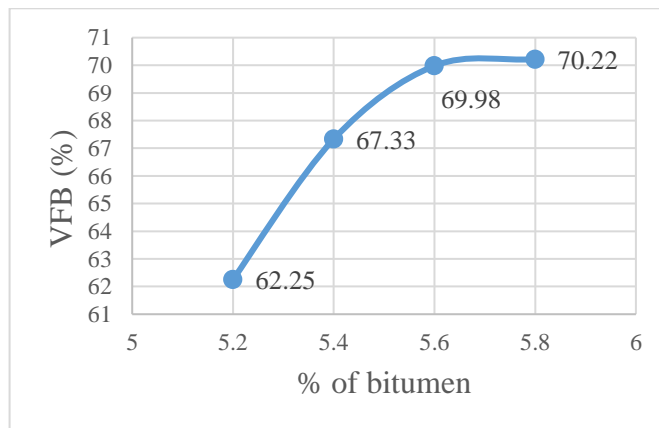


Fig. 4.29 Variation of VFB for 10% coir

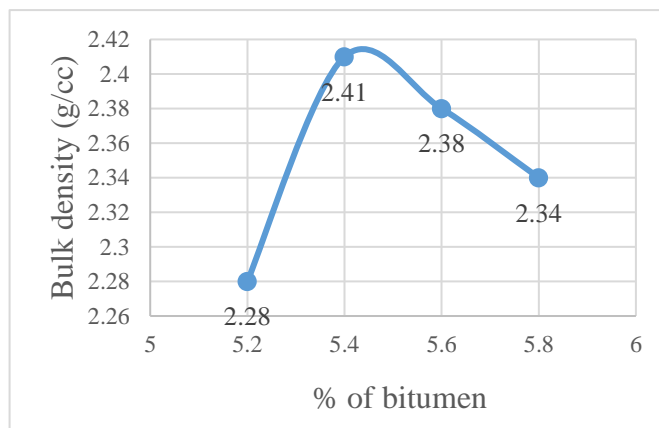


Fig. 4.30 Variation of bulk density for 10% coir

From the test results it is observed that by the addition of coir fibres, stability and flow values shown higher values than normal mixes. Air voids shows a decreasing trend with increasing coir fibre content. From the above results, Marshall properties corresponding to OBC of each modified mix is determined. Table 4.7 shows the volumetric properties corresponding to OBC of coir fibre modified bituminous mixes. Results shows that maximum stability of 18.7 KN is obtained at 8% fibre content. The stability value of coir

fibre modified bituminous mixes increases by 22.2% compared to normal mixes. Target air voids of 4% is also achieved at this stability value. So modified mix with 8% coir fibre having 5.45% OBC is considered as the optimum fibre and bitumen content.

Table 4.7 Volumetric properties of coir fibre modified bituminous mix at OBC

% of coir	OBC (%)	Stability (KN)	Flow (mm)	Va (%)	VMA (%)	VFB (%)	Bulk density (g/cc)
4	5.42	18.22	3.92	4.50	13.20	71.3	2.59
6	5.43	18.53	4.44	4.30	13.22	71.0	2.48
8	5.45	18.70	4.5	4.00	13.11	69.5	2.56
10	5.41	18.48	4.37	4.27	12.50	67.3	2.42

4.5.2 Marshall Properties of Crumb Rubber Modified Bituminous Mixes

The volumetric properties of crumb rubber modified bituminous mixes is shown in Table 4.8. The relationship between volumetric properties of crumb rubber modified bituminous mixes with different bitumen content and crumb rubber content were plotted. Variation in volumetric properties of crumb rubber modified bituminous mixes with crumb rubber powder content of 4% and bitumen content of 5.2%, 5.4%, 5.6% and 5.8% were shown in Figs. 4.31 to 4.36.

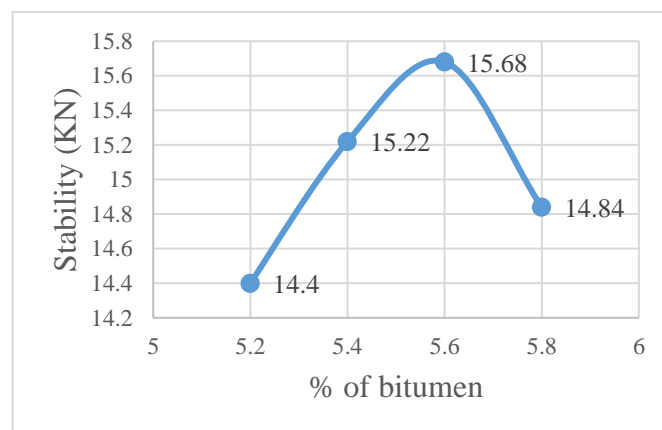


Fig. 4.31 Variation of stability value for 4% crumb rubber

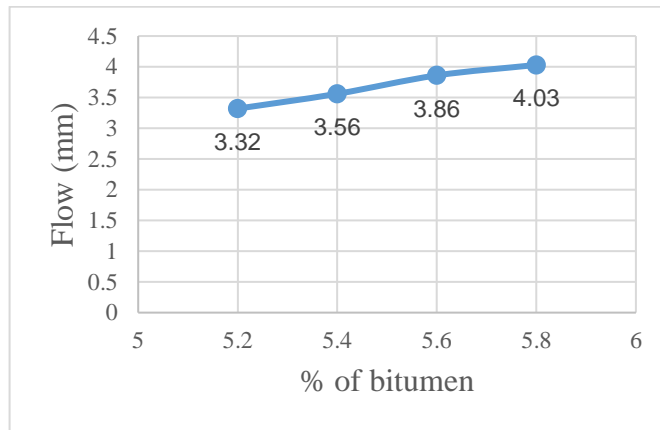


Fig. 4.32 Variation of flow value for 4% crumb rubber

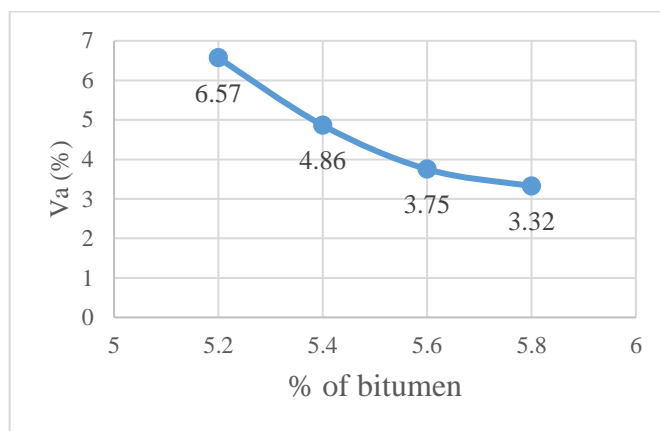


Fig. 4.33 Variation of air voids for 4% crumb rubber

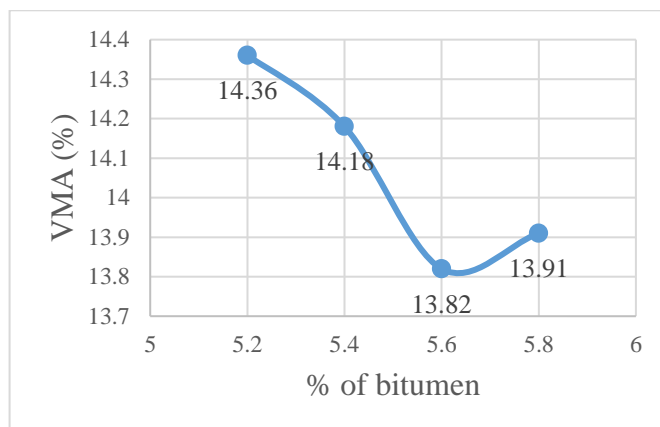


Fig. 4.34 Variation of VMA for 4% crumb rubber

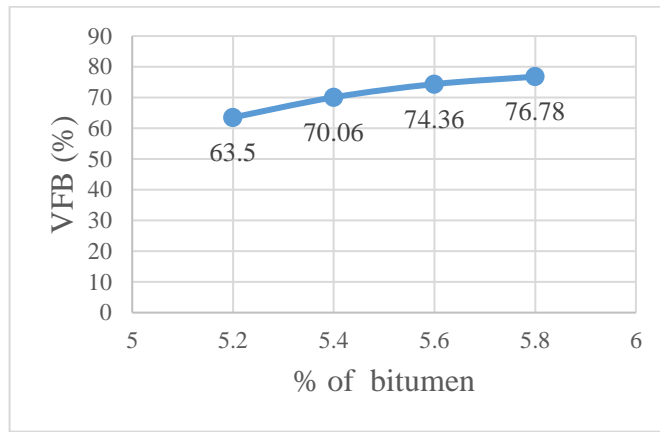


Fig. 4.35 Variation of VFB for 4% crumb rubber

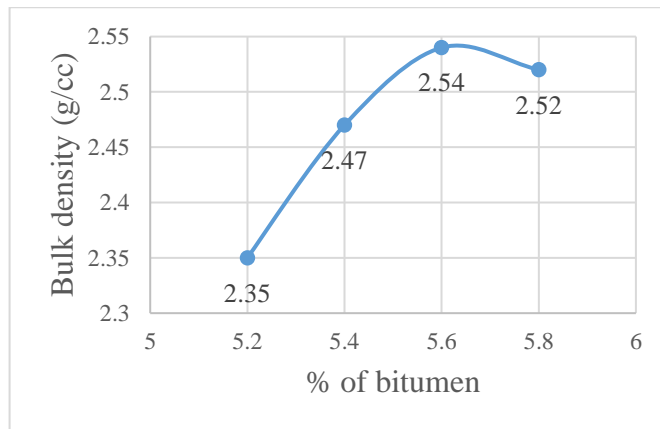


Fig. 4.36 Variation of bulk density for 4% crumb rubber

The above results shows that for 4% crumb rubber powder content maximum stability of 15.68 KN is achieved at 5.6% of bitumen. Further increasing of bitumen content shown a decreasing trend in stability values. Variation of volumetric properties of crumb rubber modified bituminous mixes with 6% crumb rubber powder content is shown in Figs. 4.37 to Figs. 4.42.

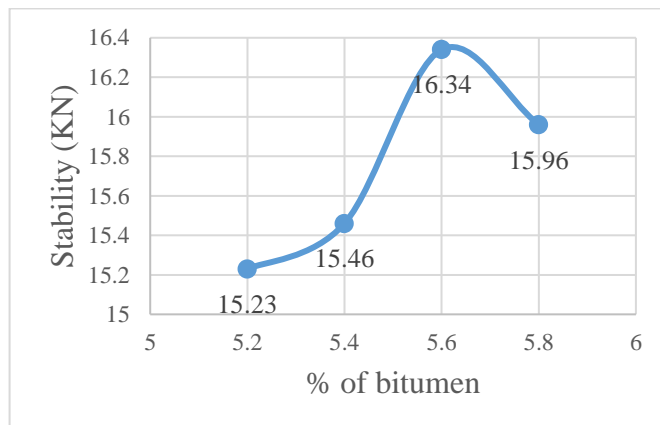


Fig. 4.37 Variation of stability value for 6% crumb rubber

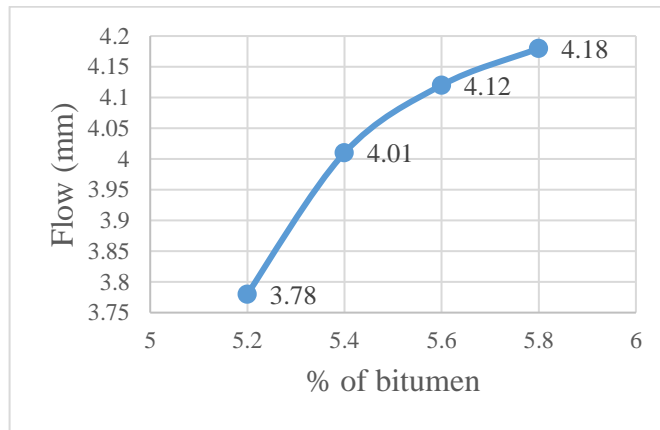


Fig. 4.38 Variation of flow value for 6% crumb rubber

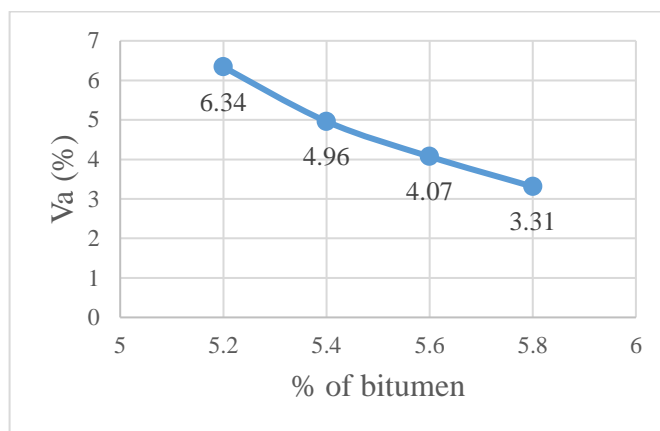


Fig. 4.39 Variation of air voids for 6% crumb rubber

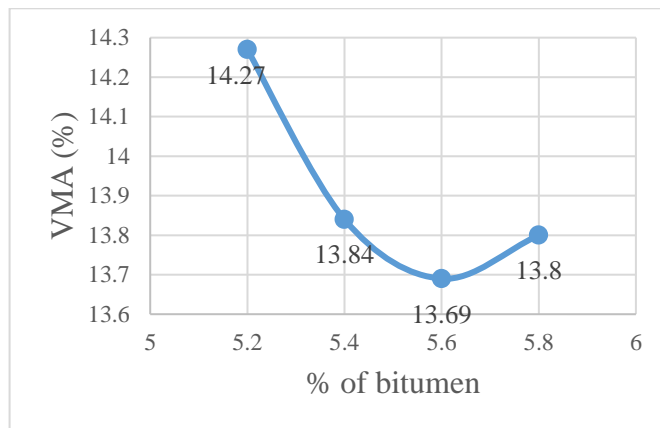


Fig. 4.40 Variation of VMA for 6% crumb rubber

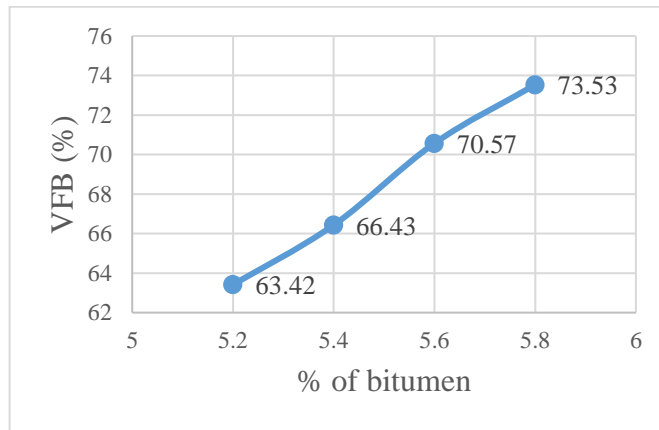


Fig. 4.41 Variation of VFB for 6% crumb rubber

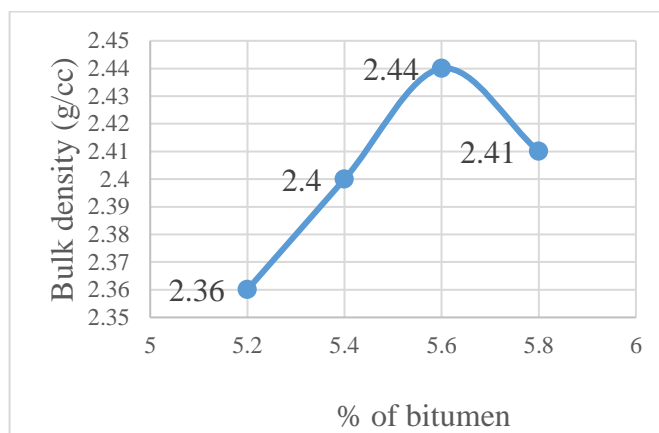


Fig. 4.42 Variation of bulk density for 6% crumb rubber

After using 4% crumb rubber powder content, tests were conducted on 6% crumb rubber powder content by varying the percentage of bitumen. Maximum stability is achieved at 5.6% of bitumen. Variation in volumetric properties of crumb rubber modified bituminous mixes with crumb rubber powder content of 8% and 10% is shown in Figs. 4.43 to 4.48 and Figs.4.49 to 4.54.

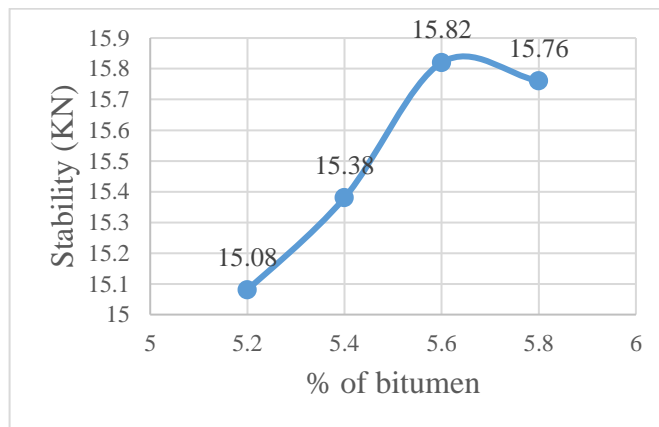


Fig. 4.43 Variation of stability value for 8% crumb rubber

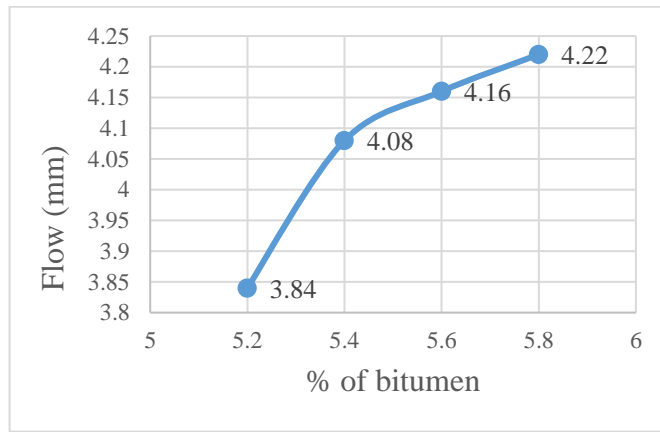


Fig. 4.44 Variation of flow value for 8% crumb rubber

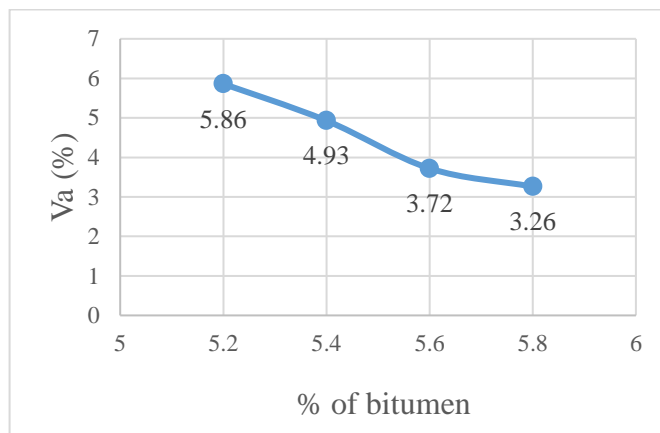


Fig. 4.45 Variation of air voids for 8% crumb rubber

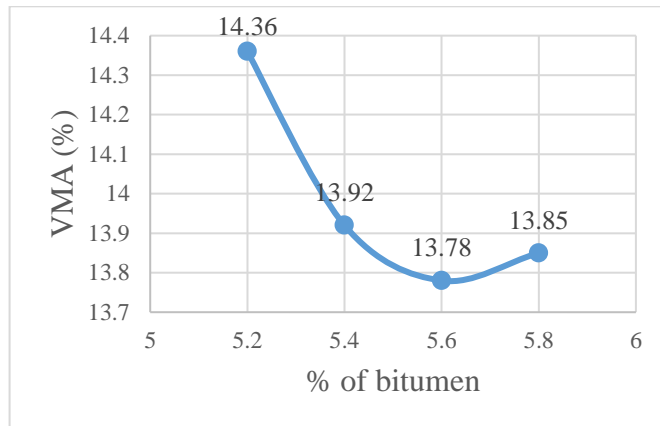


Fig. 4.46 Variation of VMA for 8% crumb rubber

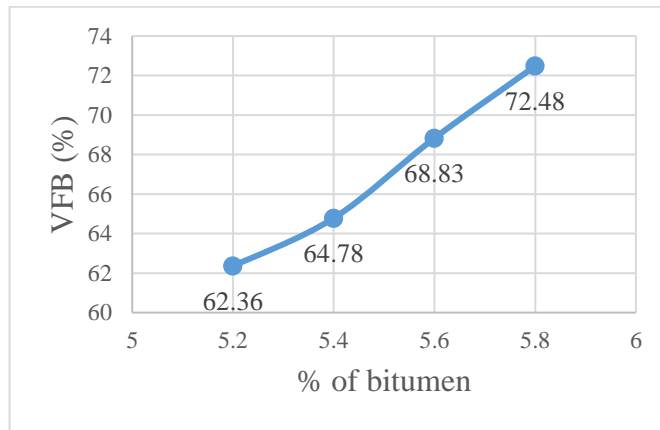


Fig. 4.47 Variation of VFB for 8% crumb rubber

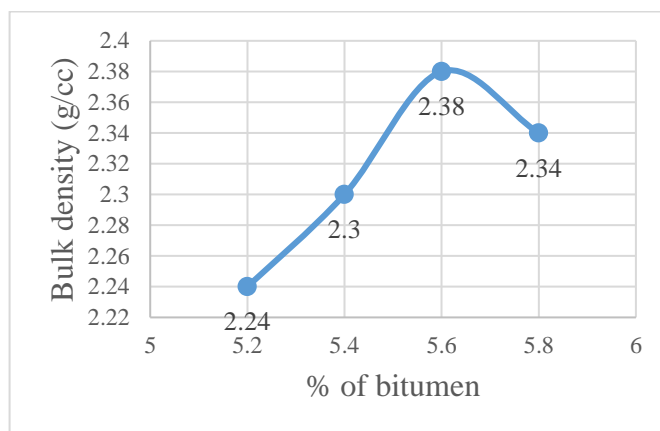


Fig. 4.48 Variation of bulk density for 8% crumb rubber

For 8% crumb rubber powder content, maximum stability is achieved at 5.6% of bitumen. Further increasing of bitumen content shown a decreasing trend in stability and flow values. The air voids shown a decreasing trend by increasing the bitumen content. The presence of air voids depends on the compaction effort that is provided during the making of the samples.

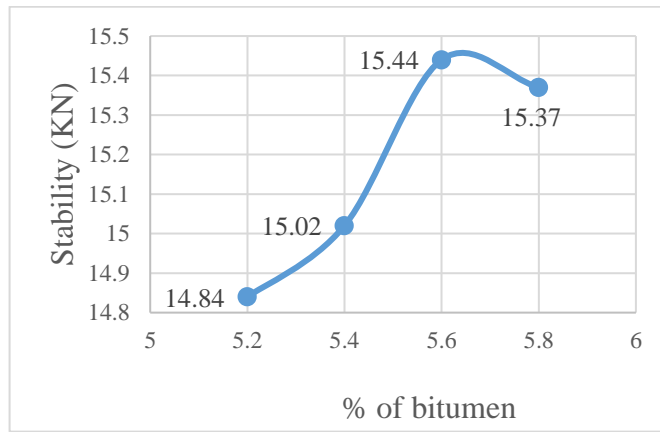


Fig. 4.49 Variation of stability value for 10% crumb rubber

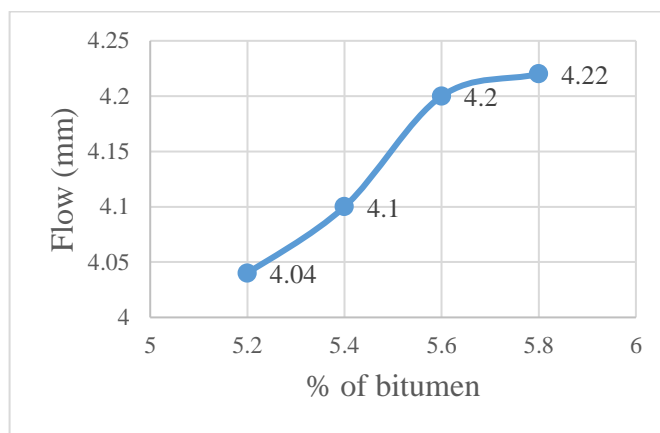


Fig. 4.50 Variation of flow value for 10% crumb rubber

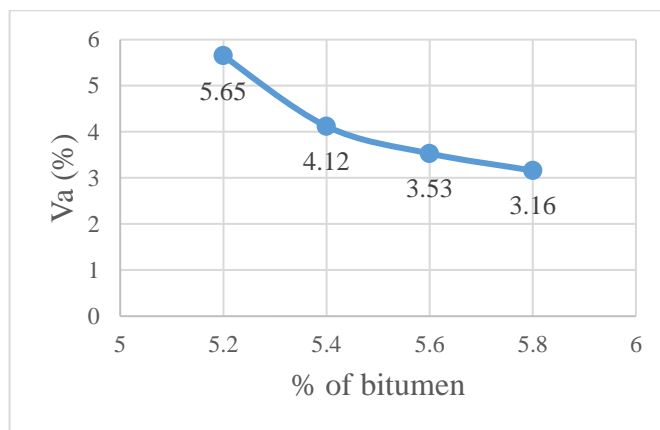


Fig. 4.51 Variation of air voids for 10% crumb rubber

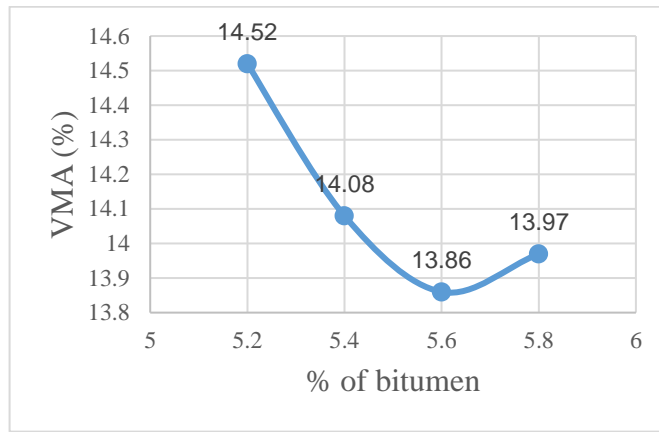


Fig. 4.52 Variation of VMA for 10% crumb rubber

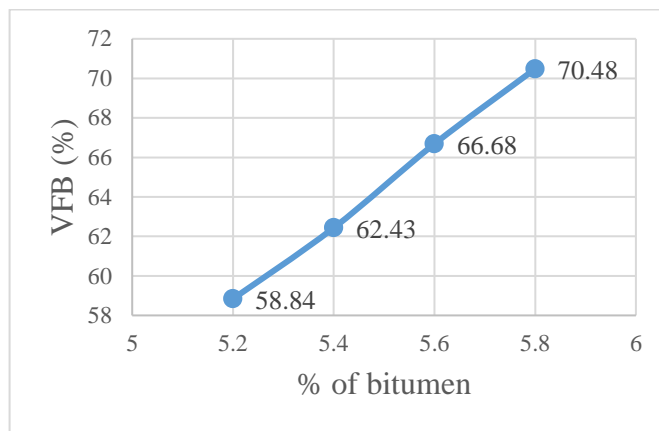


Fig. 4.53 Variation of VFB for 10% crumb rubber

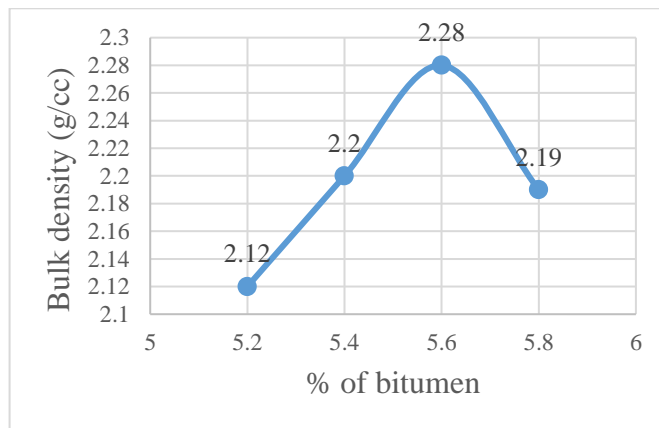


Fig. 4.54 Variation of bulk density for 10% crumb rubber

From the test results it is observed that by the addition of crumb rubber powder, stability and flow values shown higher values than normal mixes. Voids in mineral aggregates, air voids and voids filled with bitumen shown lower values compared to normal mixes. By the increasing crumb rubber content air voids also a decreasing trend. Marshall properties corresponding to OBC of each modified mix is determined from the above results. Table 4.8 shows the volumetric properties corresponding to OBC of crumb rubber modified

bituminous mixes. Results shows that maximum stability of 16.35KN is obtained at 6% crumb rubber powder content. The stability of crumb rubber modified bituminous mixes increases by 6.86% compared to normal mixes. Target air voids of 4% is achieved at this stability value. So modified mix with 6% crumb rubber powder having 5.64% OBC is considered as optimum crumb rubber powder and bitumen content.

Table 4.8 Volumetric properties of crumb rubber modified bituminous mix at OBC

% of CR	OBC (%)	Stability (KN)	Flow (mm)	Va (%)	VMA (%)	VFB (%)	Bulk density (g/cc)
4	5.620	15.65	3.93	3.62	13.80	75.00	2.542
6	5.640	16.35	4.13	4.00	13.67	71.10	2.435
8	5.632	15.83	4.17	3.60	13.77	69.98	2.380
10	5.610	15.45	4.20	3.43	13.85	66.80	2.280

4.6 INDIRECT TENSILE STRENGTH TEST RESULTS

Indirect tensile strength results were conducted for both conditioned and unconditioned samples. Three set of samples were prepared for each mixes for both conditions. Table 4.9 shows the results of indirect tensile strength for optimum mixes. Tensile strength ratio of the mixes were also calculated to determine the moisture susceptibility of the mixes.

Table 4.9 Indirect tensile strength results for optimum mixes

	Unconditioned (MPa)	Conditioned at 60° c for 24h (MPa)	Tensile strength ratio (%)
Normal mix	0.584	0.462	79.1
Coir fibre modified mix	0.659	0.550	83.4
Crumb rubber modified mix	0.675	0.592	87.7

From the above results, it is observed that modified mixes meets the minimum TSR threshold of 80%. Tensile strength ratio of coir fibre modified mix is 83.4 % and crumb rubber modified mix is 87.7%. It indicates that they have higher moisture resistance than normal mixes.

4.7 RUTTING TEST RESULTS

To determine the rut depth of normal and modified mixes, rutting test were conducted and the results were shown in Fig. 4.55. Three set of samples were prepared for each mixes. Higher rut depth indicates that the normal mix has lower strength and low aggregate bonding compared to modified mixes.

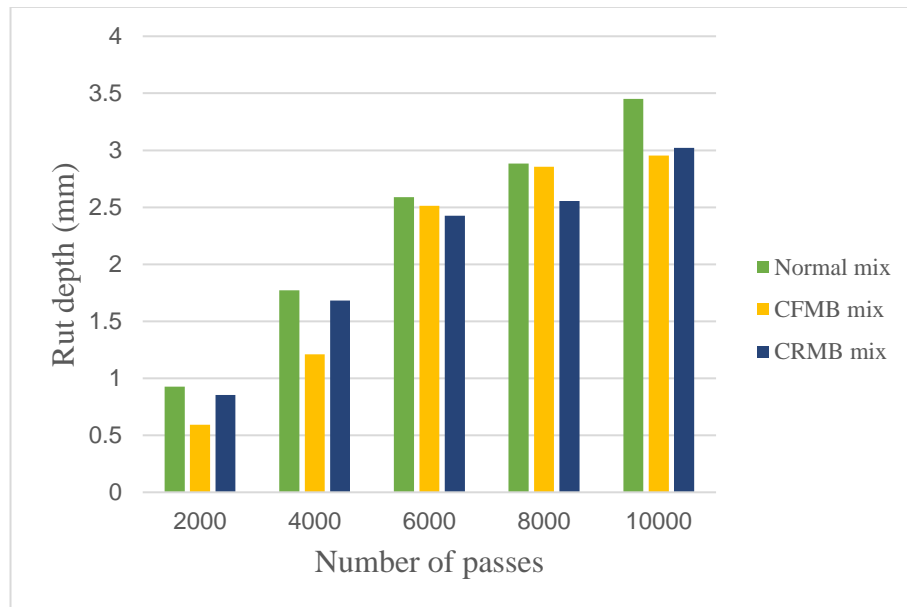


Fig. 4.55 Variation in rut depth of mixes

As the number of passes increased, rut depth also increased. At 10000 number of passes, rut depth for normal mix is 3.45 mm and for coir fibre modified bituminous mixes the rut depth is 2.954 mm which is 14.3% lesser than normal mix. For crumb rubber modified bituminous mix, the rut depth is 3.022 mm which is 12.4% lesser than normal mix.

5. CONCLUSION

The following conclusions were made after conducting the laboratory investigations:

- The physical properties of the bitumen (VG-30), aggregates and modified bitumen were determined and found to be suitable for road construction as per MORTH and IS specifications.
- Marshall stability test was conducted to determine the stability and flow value of normal and modified mixes. Volumetric properties of the mixes were evaluated and graphs were plotted.
- Optimum bitumen content of the normal mix was obtained at 5.7%. On the other hand, optimum bitumen content of coir and crumb rubber modified mixes were obtained at 5.45% and 5.64%. It indicates that by the addition of additives bitumen content of the mixes can be reduced.
- Maximum stability of normal mixes were found to be 15.2 KN while for coir and crumb rubber modified mixes it were found to be 18.7 KN and 16.35 KN. It indicates that stability increases by 22.2 % for coir fibre modified mixes and 6.86% for crumb rubber modified mixes. Thus the modified mixes were durable and long lasting compared to normal mixes.
- Target air voids of 4% is achieved at 8% coir fibre content and 6% crumb rubber content.
- Tensile strength ratio of optimum coir and crumb rubber modified mixes were higher compared to normal mixes and it indicates higher moisture resistance.
- Rut depth of the normal mixes were found to be 3.45mm and that of coir and crumb rubber modified mixes were found to be 2.954mm and 3.022 mm. It indicates that rut depth of the coir fibre and crumb rubber modified mixes were 14.3% and 12.4% lesser than normal mixes.
- Thus the usage of the coir fibre and crumb rubber has enhanced the stability of the mix, moisture resistance and rutting characteristics of the mixes.

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APPENDIX- A

Volumetric properties of coir fibre modified bituminous mixes

% of coir	% of bitumen	Number of samples	Stability (KN)	Flow (mm)	Va (%)	VMA (%)	VFB (%)	Bulk density (g/cc)
4	5.2	3	16.32	3.73	6.73	13.60	67.30	2.43
	5.4	3	18.24	3.91	5.66	13.18	71.20	2.59
	5.6	3	17.86	4.23	4.54	13.82	73.50	2.48
	5.8	3	17.32	4.42	3.98	14.18	75.86	2.46
6	5.2	3	17.43	3.85	6.12	13.34	64.50	2.33
	5.4	3	18.52	4.33	4.46	13.18	70.31	2.48
	5.6	3	17.88	4.71	3.24	13.53	72.92	2.44
	5.8	3	17.56	4.95	3.12	13.95	74.88	2.42
8	5.2	3	18.22	3.93	5.38	13.45	63.70	2.31
	5.4	3	18.69	4.28	4.02	12.96	68.60	2.58
	5.6	3	18.58	4.85	3.84	13.58	70.93	2.44
	5.8	3	18.37	5.13	3.43	13.82	72.56	2.40
10	5.2	3	18.11	4.17	5.43	12.96	62.25	2.28
	5.4	3	18.48	4.36	4.29	12.44	67.33	2.41
	5.6	3	18.22	4.92	3.47	13.56	69.98	2.38
	5.8	3	17.86	5.08	3.18	13.91	70.22	2.34

Volumetric properties of crumb rubber modified bituminous mixes

% of CR	% of bitumen	Number of samples	Stability (KN)	Flow (mm)	Va (%)	VMA (%)	VFB (%)	Bulk density (g/cc)
4	5.2	3	14.40	3.32	6.57	14.36	63.50	2.35
	5.4	3	15.22	3.56	4.86	14.18	70.06	2.47
	5.6	3	15.68	3.86	3.75	13.82	74.36	2.54
	5.8	3	14.84	4.03	3.32	13.91	76.78	2.52
6	5.2	3	15.23	3.78	6.34	14.27	63.42	2.36
	5.4	3	15.46	4.01	4.96	13.84	66.43	2.40
	5.6	3	16.34	4.12	3.85	13.69	70.57	2.44
	5.8	3	15.96	4.18	3.31	13.80	73.53	2.41
8	5.2	3	15.08	3.84	5.86	14.36	62.36	2.24
	5.4	3	15.38	4.08	4.93	13.92	64.78	2.30
	5.6	3	15.82	4.16	3.72	13.78	68.83	2.38
	5.8	3	15.76	4.22	3.26	13.85	72.48	2.34
10	5.2	3	14.84	4.04	5.65	14.52	58.84	2.12
	5.4	3	15.02	4.10	4.12	14.08	62.43	2.20
	5.6	3	15.44	4.20	3.53	13.86	66.68	2.28
	5.8	3	15.37	4.22	3.16	13.97	70.48	2.19

Rut depth value of normal mix

Sl no.	Rut depth value at each number of passes (mm)					
	0 (initial)	2000	4000	6000	8000	10000
1	19.51	18.75	17.80	17.92	17.39	16.14
2	19.52	18.87	18.07	16.80	17.31	17.12
3	19.56	18.66	17.99	16.48	16.14	16.12
4	19.46	18.45	17.95	17.44	17.11	16.00
5	19.66	18.72	17.60	16.88	16.45	16.32
6	19.58	18.62	17.52	17.20	17.00	15.85
7	19.38	18.82	17.53	16.38	16.22	15.96
8	19.61	18.43	17.70	17.25	16.23	15.92
9	19.54	18.21	17.42	16.64	16.38	15.98
10	19.58	18.60	18.10	16.52	16.32	16.12
Average	19.540	18.613	17.768	16.951	16.655	16.153
Final rut depth (initial – number of passes)		0.927	1.772	2.589	2.885	3.45

Rut depth of coir fibre modified mix

Sl no.	Rut depth value at each number of passes (mm)					
	0 (initial)	2000	4000	6000	8000	10000
1	19.57	18.81	18.72	17.73	17.06	16.61
2	19.61	18.36	18.14	17.35	17.26	16.52
3	19.88	19.48	18.93	17.49	16.98	16.96
4	19.80	19.24	18.36	17.67	17.19	16.68
5	19.72	19.46	18.14	17.81	17.50	16.05
6	19.75	19.34	18.74	17.12	16.84	16.53
7	19.51	18.96	18.42	17.27	17.18	16.14
8	19.82	19.44	18.56	16.38	15.25	16.23
9	19.62	19.26	18.73	16.21	16.91	16.42
10	19.93	18.92	18.38	17.06	16.48	16.33
Average	19.721	19.127	18.512	17.209	16.865	16.447
Final rut depth (initial – number of passes)		0.594	1.209	2.512	2.856	2.954

Rut depth of crumb rubber modified mix

Sl no.	Rut depth value at each number of passes (mm)					
	0 (initial)	2000	4000	6000	8000	10000
1	18.98	18.30	16.86	16.34	16.21	15.94
2	18.81	18.40	17.9	16.11	15.98	15.63
3	18.92	18.48	16.89	17.25	16.52	15.88
4	18.86	16.84	17.65	16.75	16.92	15.42
5	18.75	18.63	16.57	15.64	15.81	15.37
6	18.62	17.65	16.56	15.63	16.11	15.25
7	18.72	17.92	17.81	16.36	16.22	15.14
8	18.54	18.06	16.81	16.44	16.38	15.46
9	18.88	17.75	17.23	16.32	15.77	15.82
10	18.57	17.08	16.54	16.56	16.18	15.74
Average	18.765	17.911	17.082	16.340	16.210	15.565
Final rut depth (initial – number of passes)		0.854	1.683	2.425	2.555	3.022