CRUMB RUBBER MODIFIED BITUMEN

A PROJECT

Submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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MESSAGE

LEARNING IS NOT ATTAINED BY CHANCE, IT MUST BE SOUGHT FOR WITH ARDOR AND ATTENDED TO WITH DILIGENCE

CERTIFICATE

This is to certify that the work which is being presented in the project title **“CRUMB RUBBER MODIFIED BITUMEN”** in partial fulfillment of the requirements for the award of the degree of Bachelor of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Nakul (121642), Tejinder Khatri (121644) during a period from January 2016 to June 2016 under the supervision of **Mr. Abhilash Shukla** Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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Acknowledgement

This project report gives a detailed description of the study work done on the project topic **"CRUMB RUBBER MODIFIED BITUMEN"** for the partial fulfillment of the requirements for the degree of Bachelor of Technology in Civil Engineering, under the supervision of **Mr. Abhilash Shukla.**

We gratefully acknowledge the Management and Administration of Jaypee University of Information Technology, Waknaghat for providing us the opportunity and hence the environment to initiate and complete our project now.

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ABSTRACT

The abundance and increase of waste tyre disposal is a serious problem that leads to environmental pollution. Crumb rubber obtained from shredding of those scrap tires has been proven to enhance the properties of plain bitumen since the 1840s. It can be used as a cheap and environmentally friendly modification process to minimize the damage of pavement due to increase in service traffic density, axle loading and low maintenance services which has deteriorated and subjected road structures to failure more rapidly.

The rheology of CRMB depends on internal factors such as crumb rubber quantity, type, particle size, source and pure bitumen composition, and external factors such as the mixing time, temperature, and also the mixing process (dry process or wet process).

In the present study Marshall Stability method is adopted for mix design. Finally a comparative analysis is made among the modified bitumen samples using crumb rubber and traditional bitumen mix samples.

Chapter 1

Introduction

Introduction

India has a road network of over 4,689,842 kilometers in 2013 , the second largest road network in the world. It has primarily flexible pavement design which constitutes more than 98% of the total road network. India being a very vast country has widely varying climates, terrains, construction materials and mixed traffic conditions both in terms of loads and volumes. Increased traffic factors such as heavier loads, higher traffic volume and higher tyre pressure demand higher performance pavements. So to minimize the damage of pavement surface and increase durability of flexible pavement, the conventional bitumen needs to be improved.

There are many modification processes and additives that are currently used in bitumen modifications such as styrene butadiene styrene (SBS), styrene-butadiene rubber (SBR), ethylene vinyl acetate (EVA) and crumb rubber modifier (CRM). Crumb rubber is the term usually applied to recycled rubber from automotive and truck scrap tires. During the cycling process steel and fluff is removed leaving tire rubber with a granular consistency. Continued processing with a granulator and/or cracker mill, possibly with the aid of cryogenics or mechanical means, reduces the size of the particles. From physical and chemical interaction of crumb rubber with conventional bitumen Crumb Rubber Modified Bitumen (CRMB) is made.

Rubber is derived from tyre which is a complex and high-tech safety product representing a century of manufacturing innovation, which is still on-going. From the material point of view the tyre is made up of three main components materials: (i) elastomeric compound, (ii) fabric and (iii) steel. The fabric and steel form the structural skeleton of the tyre with the rubber forming the "flesh‷ of the tyre in the tread, side wall, apexes, liner and shoulder wedge. This engineering process is necessary to transform natural rubber in a product able to ensure performance, durability and safety. In fact, natural rubber is sticky in nature and can easily deform when heated up and it is brittle when cooled down. In this state it cannot be used to make products with a good level of elasticity. The reason for inelastic deformation of not-vulcanized rubber can be found in the chemical nature as rubber is made of long polymer chains. These polymer chains can move independently relative to each other, and this will result in a change of shape. By the process of vulcanization cross-links are formed between the polymer chains, so the chains cannot move independently anymore. As a result, when stress is applied the vulcanized rubber will deform, but upon release of the stress the rubber article will go back to its original shape. Compounding is finally used to improve the physical properties of rubber by incorporating the ingredients and ancillary substances necessary for vulcanization, but also to adjust the hardness and modulus of the vulcanized product to meet the end requirement. Different substances can be added according to the different tyre mixtures; these include mineral oil and reinforcing fillers as carbon black and silica. In general, truck TR contains larger percentages of natural rubber compared to that from car tyres. To summarizes the general tyre composition of tyres used in cars and trucks in the EU. From the structural point of view, the main components of tyre are the tread, the body, side walls and the beads. The tread is the raised pattern in contact with the road. The body supports the tread and gives the tyre its specific shape. Beads are metal-wire bundles covered with rubber, which holds the tyre on the wheel. The inherent characteristics of the tyre are the same worldwide. They include: the resistance to mould, mildew, heat and humidity, retardation of bacterial development, resistance to sunlight, ultraviolet rays, some oils, many solvents, acids and other chemicals.

1.1 Effect of Temperature on Natural Rubber

✓ At -10^{o}C	brittle and opaque
✓ At 20^{o}C	soft, resilient and translucent
✓ At 50^{o}C	plastic and sticky
✓ At 120^{o}C-160^{o}C	vulcanized when agents like sulphur are added
✓ At 180^{o}C	break down as in the masticator
✓ At 200^{o}C	decomposes

1.1.1 Vulcanization of Rubber

Raw dry rubber is heated with sulphur (5%-8% based on the requirement), zinc oxide (a filler, 5%) and accelerator (0.5% -1%) at 125^{o}C-165^{o}C for about half an hour. As the sulphur quantity increases, the rubber becomes tougher. 50% sulphur gives **ebonite (vulcanite)**. An accelerator containing nitrogen, sulphur or both is used to increase the reaction rate and for vulcanization to occur at room temperatures.

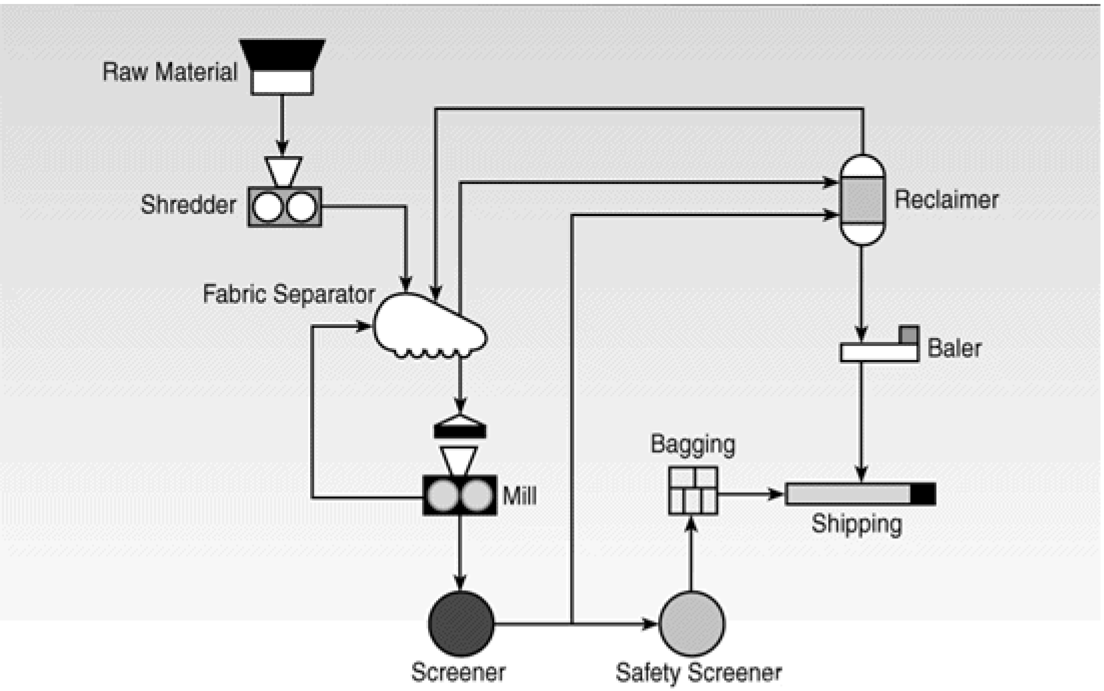
Serial No.	Raw Natural Rubber	Vulcanized Natural Rubber
1.	Soft and sticky	Comparatively hard and non-sticky
2.	Low tensile strength and not very strong	High tensile strength and very strong
3.	Low elasticity	High elasticity
4.	Can be used over a narrow range of temperature from 10 to 60 degrees centigrade	Can be used over a wide range of temperature from -40 to 100 degrees centigrade
5.	Low abrasion resistance	High abrasion resistance
6.	Absorbs a large amount of water	Absorbs a small amount of water
7.	Soluble in solvents like ether, carbon disulphide, carbon tetrachloride, petrol and turpentine	Insoluble in all the usual solvents

Table 1.1 Differences between Raw and Vulcanized Natural Rubber

-

1.2 Ambient Grinding

Ambient Grinding is a process used for deriving particles of rubber with a rough surface, giving it a greater surface area which helps in better binding with the bitumen. In ambient mechanical grinding process, the breaking up of a scrap tire happens at or above normal room temperature. Ambient grinding is a multi-step technology and uses whole or pre-treated car or truck tires in the form of shred or chips, or sidewalls or treads. The rubbers, metals and textiles are sequentially separated out. Tires are passed through a shredder, which breaks the tires into chips. The chips are fed into a granulator that breaks them into small pieces while removing steel and fiber in the process. Any remaining steel is removed magnetically and fiber through a combination of shaking screens and wind sifters. Finer rubber particles can be obtained through further grinding in secondary granulators and high-speed rotary mills.



NOTE: Magnets are used throughout the process

Figure 1.1 Ambient Grinding

1.3 Cryogenic Grinding

Particles derived from the cryogenic grinding have a smooth surface, akin to shattered glass. Cryogenic grinding refers to the grinding of scrap tires at temperatures near minus 80^{o}C using liquid nitrogen or commercial refrigerants. Cryogenic processing generally uses pre-treated car or truck tires as feedstock, most often in the form of chips or ambiently produced granulate. Processing takes place at very low temperature using liquid nitrogen or commercial refrigerants to embrittle the rubber. It can be a four-phase system which includes initial size reduction, cooling, separation, and milling. The material enters a freezing chamber where liquid nitrogen is used to cool it from –80 to –120 °C, below the point where rubber ceases to behave as a flexible material and can be easily crushed and broken. Because of its brittle state, fibres and metal are easily separated out in a hammer mill. The granulate then passes through a series of magnetic screens and sifting stations to remove the last vestiges of impurities. This process requires less energy than others and produces rubber crumb of much finer quality.

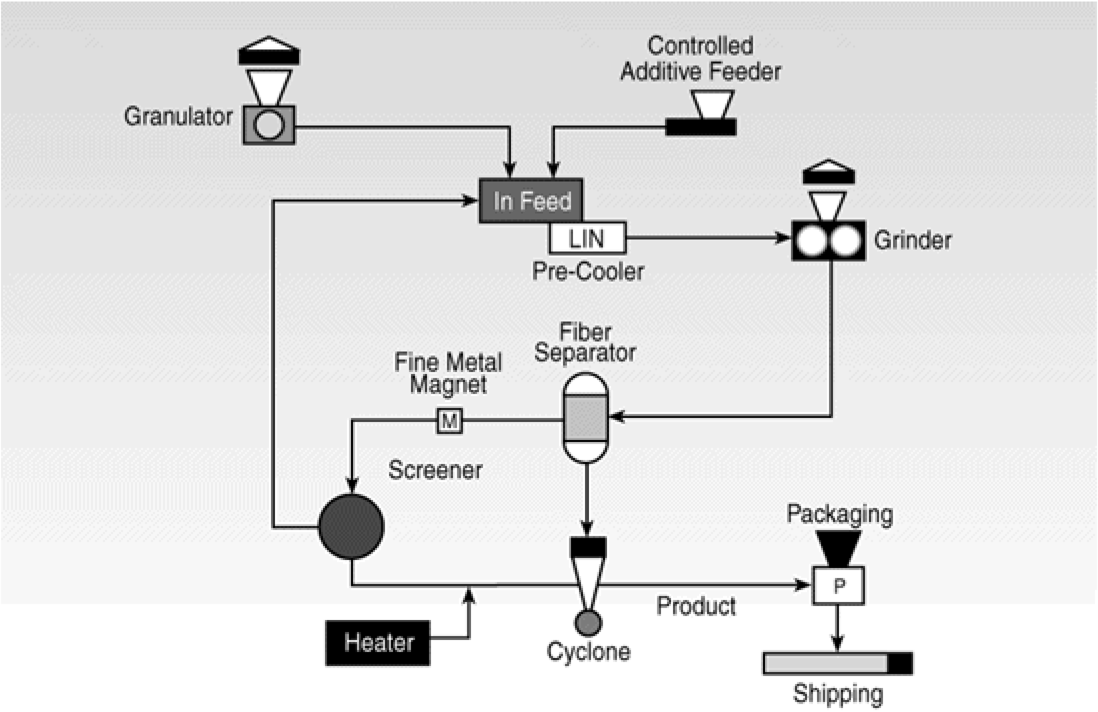


Figure 1.2 Cryogenic Grinding

1.4 Advantages of Crumb Rubber

- ✓ Lower susceptibility to daily & seasonal temperature variations
- ✓ Higher resistance to deformation at elevated pavement temperature
- ✓ Better age resistance properties
- ✓ Higher fatigue life of mixes
- ✓ Better adhesion between aggregate & binder
- ✓ Prevention of cracking & reflective cracking
- ✓ Overall improved performance in extreme climatic conditions & under heavy traffic condition.

1.5 Desirable Properties of Bituminous Mix

Adequate stability of the mix to withstand the stresses and deformation due to the repeated application of the wheel loads; this may be achieved by selecting suitable type and gradation of aggregates, appropriate binder and its proportion.

Adequate flexibility of the mix to withstand fatigue effects and development of cracks during service life of the pavement to be achieved by the selection of proper mix of aggregates and binder.

Adequate resistance to permanent deformation such as rutting due to movement of heavy wheel loads during hot weather; this may be achieved by selection of good quality of aggregates, ensuring its appropriate gradation and densification of the mix during compaction.

Possess adequate resistance to low-temperature cracking under traffic movement, this may be achieved by selection of suitable type and grade of bituminous binder.

Durability to sustain the combined effect of adverse weather and repeated traffic loads; this may be achieved by arriving at correct bitumen binder content during mix design to ensure adequate thickness of binder-film around aggregate particles.

Possess sufficient air voids to prevent ‘bleeding’ of the binder as a consequence of further densification of the bituminous mix under traffic movements and also reduction of skid resistance under wet condition; this may be achieved by selecting appropriate shape and gradation of aggregates and binder content and ensuring adequate air voids in the compacted mix at the stage of mix design.

The hot mix should have adequate workability of the mix at the mix at the mixing, laying and compacting temperatures.

Chapter 2

Literature Review

2.1 Introduction

A number of studies are available on topic of ―CRUMB RUBBER MODIFIED BITUMEN. Hence a detailed review of research works carried out related to the present study is described as below. Investigations in India and countries abroad have revealed that properties of bitumen and bituminous mixes can be improved to meet requirements of pavement with the incorporation of certain additives or blend of additives. These additives are called "Bitumen Modifiers" and the bitumen premixed with these modifiers is known as modified bitumen. Modified bitumen is expected to give higher life of surfacing (up to 100%) depending upon degree of modification and type of additives and modification process used. The additive used in our current study is Crumb Rubber. Use of crumb rubber as an additive to the conventional mixes leads to excellent pavement life, driving comfort and low maintenance. The rheology of CRMB depends on internal factors such as crumb rubber quantity, type, particle size, source and pure bitumen composition, and external factors such as the mixing time, temperature, and also the mixing process (dry process or wet process). Numerous Studies have been conducted to increase the stability of the pavement by altering the size and content of CRMB (Nabin Rana Magar 2014) and these studies provide positive results.

2.2 Reviews

A study by Rokade S (2012)[1] on the use of CRMB reveals that the Marshal Stability value, which is the strength parameter of SDBC has shown increasing trend and the maximum values have increased by about 55 % by addition of CRMB. The density of the mix has also increased in the case of CRMB when compared with 60/70 grade bitumen. This will provide more stable and durable mix for the flexible pavements. The serviceability and resistance to moisture will also be better when compared to the conventional method of construction.
The values of other parameters i.e. Vv, VMA and VFB in CRMB have found out to be within required specifications. This study not only constructively utilizes the waste tires in road construction industry but it has also effectively enhanced the important parameters which will ultimately have better and long living roads.

According to a study conducted by Sawant P.A and Kulkarni S.S.(2008)[2], use of Ethyl Vinyl Acetate and Crumb Rubber improves temperature susceptibility of binder as the softening point of bitumen increases with increase in the EVA and CR content. Also the penetration value of bitumen decreases with increase in EVA and CR content in bitumen. The decrease in penetration value is an indication of increased stiffness of binder.

Mohammed Sadeque and K APatil, (2014)[3] claimed that the use of crumb rubber as a modifier seems to have positive effects on physical and strength properties of the binders, including improved penetration, softening point. There is a significant improvement in the stability value of bituminous concrete. However the ductility of the binder reduces with increase in CR content. It is therefore recommended to use the 5% to 10% of CR to keep the ductility with in permissible limit. The use of crumb rubber as an additive in bitumen modification would reduce pollution problems and protect our environment as well.

B. Sudharshan Reddy , N. Venkata Hussain Reddy (2016)[4] claimed that the penetration values and softening points of plain bitumen can be improved significantly by modifying it with addition of crumb rubber which is a major environment pollutant and it's use leads to excellent pavement life, driving comfort and low maintenance. Also the rheology of CRMB depends on internal factors such as crumb rubber quantity, type, particle size, source and pure bitumen composition, and external factors such as the mixing time, temperature, and also the mixing process (dry process or wet process).

It was concluded by Dipak Rathva, Manish Jain, Ashish Talati (2015)[5] that the crumb rubber modified bitumen can impart beneficial properties of bitumen. In this study main emphasis was on determining the optimum blending time and blending temperature for preparing crumb rubber modified bitumen to get proper mix. Results shows that at less blending time homogenous mix is not prepared and hence penetration values comes higher for less blending time. The optimum temperature is found out 1750C and optimum blending time is 45 minutes for preparing the high-quality crumb rubber modified bitumen.

According to a study of Nuha S. Mashaan, Asim Hassan Ali, Mohamed Rehan Karim and Mahrez Abdelaziz, (2011)[6], the use of crumb rubber modified with bitumen binder seems to enhance the fatigue resistance. From the result of the study, it aspires to consider crumb rubber modifier in conventional mixes to improve resistance to rutting and produce pavements with better durability by minimising the distresses caused in pavement. Hence, road users would be ensured of safer and smoother roads.

Nabin Rana Magar(2014)[7], conducted a study investigating the experimental performance of the bitumen modified with 15% by weight of crumb rubber varying its sizes. Four different categories of size of crumb rubber will be used, which are coarse (1 mm - 600 μm); medium size (600 μm - 300 μm); fine (300 μm - 150 μm); and superfine (150 μm - 75 μm).It was found that the sample prepared using crumb rubber size (0.3-0.15mm) give the highest stability value of 1597.64 kg, minimum flow value, maximum unit weight, maximum air voids and minimum VMA and VFB % values. So the best size to be used for crumb rubber modification can be suggested as (0.3-0.15mm) size for commercial production of CRMB.

According to Harpal Singh Raol, Abhijit Singh Parmar, Dhaval Patel and Jitendra Jayswal[8], crumb rubber gives the satisfactory results by using it in 15% of proportion to replace the bitumen for various tests of bitumen & bitumen mix. Crumb rubber gives the Marshall Stability value of 1615.84 kg by using 15% of crumb rubber powder with bitumen mix, which is 1.6 times greater than the Marshall Stability value of conventional bitumen mix.

K. Rajesh Kumar, Dr. N. Mahendran (2014)[9] concluded that Dry Process (polymer coating of aggregates) is more useful as compared to Wet Process (adding polymer in the binder) for manufacturing modified mixtures, as it can accommodate higher amount of waste plastic as modifier and results more stable mixtures. Also the use of crumb rubber as asphalt mixture modifier ensures its safe, useful and environmental friendly disposal. It was also concluded that the Marshall Stability value increases with an increase in bitumen content from 5.5% to 6% then it decreases. The optimum binder content was found to be 6 %.

Patel Chirag B, Prof. S. M. Damodariya (2013)[10] concluded that the properties of bitumen such as penetration, softening point and ductility were improved with addition of the waste plastic and crumb rubber. There is significant decrease in penetration values for modified blends, indicating the improvement in their temperature susceptibility resistant characteristics. The ductility value decrease with increase in percentage of modifier, the ductility less than 50 cm should not use for road constructions, but may be used as crack and joint filler material.

2.3 Concluding Remarks

As we can see from the above studies, Bitumen showed an improvement in the performance of pavements over the base binders as a result of the interaction of crumb rubber with base binders. Significant increase in the stability values can be seen from the studies. There is better resistance to water and water stagnation, no stripping and have no potholes, increased binding and better bonding of the mix, increased load withstanding property, decrease in overall consumption of bitumen, reduction in pores in aggregate and hence less rutting and raveling, better soundness property and the maintenance cost of the road is almost nil plus the road life period is substantially increased. Thus it may be concluded that the bitumen modification by Crumb Rubber is beneficial, economic and environmental friendly.

Design Approach

3.1 Selection of aggregates

Aggregates which possess sufficient strength, hardness, toughness, soundness and polished stone value are chosen, keeping in view the availability. Crushed aggregates and sharp sand produce high stability of the mix when compared with gravel and rounded sands.

3.2 Selection of aggregate grading

The properties of a bituminous mix including the density and stability are very much dependent on the aggregates and their grain size distribution. Most of the engineering organizations have specified the use of dense graded mixes and not open graded mixes. As higher maximum size of aggregates gives higher stability, usually the larger size that can be adopted depends on the compacted thickness of the pavement layer. Maximum aggregate size of 25 to 50 mm are used in the bituminous mixes for base course and 12.5 to 18.7 mm are used for surface course.

3.3 Determination of Specific Gravity values of components

The specific gravity of aggregates is represented as either bulk specific gravity, or apparent specific gravity, or effective specific gravity. In apparent specific gravity the volume of capillaries which are filled by water on 24 hours soaking is excluded.

3.4 Proportioning of aggregates

Once the design grading is decided, then the available aggregates are proportioned by one of the methods:

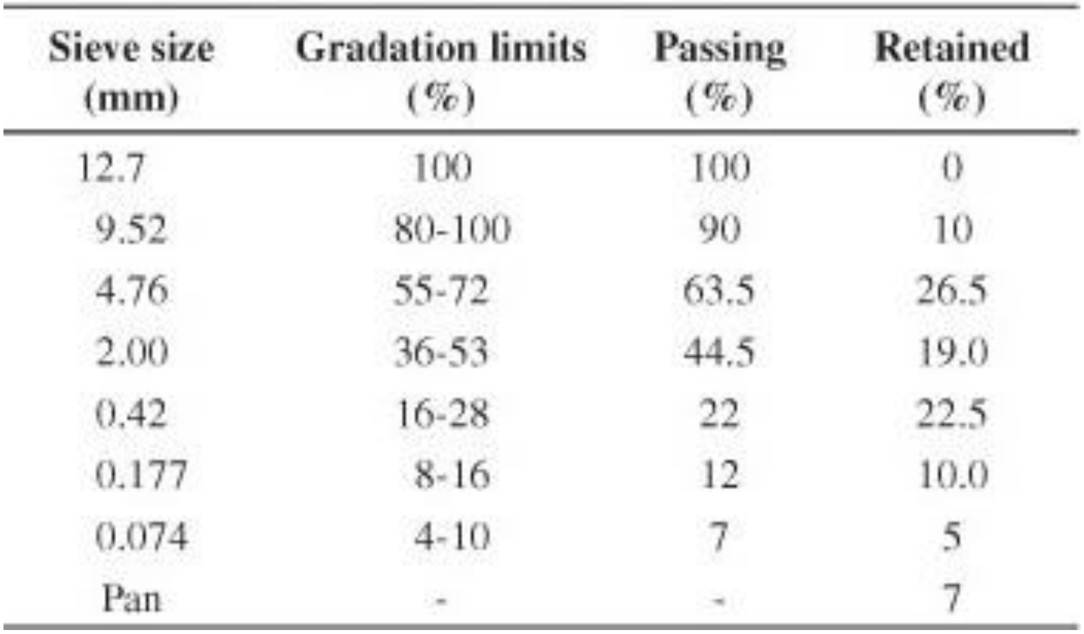
- ✓ Analytical Method
- ✓ Graphical Method
- ✓ Trial and Error Method

Generally it is attempted to obtain the mid-point of the different ranges specified for the respective aggregate sizes, vide IRC or MORTH specifications.

3.5 Preparation of test specimens

The preparation of specimen depends on the stability test method employed. Hence the size of the specimen, compaction and other specifications should be followed as specified in the selected stability test method. The test specimens are prepared in the following steps:

- ✓ Heating the required weight of the mixed aggregates to the desired temperature
- ✓ Heating the required weight of the bituminous binder to the specified temperature; different trial binder contents are selected so that at least two values are below and two values above the expected optimum bitumen content
- ✓ Mixing the aggregates and the binder in the laboratory mixer at the specified mixing temperature depending on the type and grade of the bitumen, such that aggregates are fully coated with bitumen
- ✓ Transferring the hot mix to the mould and compacting as specified in the test method
- ✓ Removing the test specimen from the mould and cooling to room temperature
- ✓ At least three test specimens are prepared at each trial bitumen content so that the mean of three consistent test values could be utilized for determining the mean value



Sieve size (mm)	Gradation limits (%)	Passing (%)	Retained (%)
12.7	100	100	0
9.52	80-100	90	10
4.76	55-72	63.5	26.5
2.00	36-53	44.5	19.0
0.42	16-28	22	22.5
0.177	8-16	12	10.0
0.074	4-10	7	5
Pan	-	-	7

Table 3.1 Specified Grading of Aggregates as per MoRTH Specifications

(Khanna S K, Justo C E G[18])

Chapter 4

Marshall Mix Design

4.1 Concept of Marshall Stability Test on bituminous mix

There are two major features of the Marshall method of designing mixes namely, density – voids analysis and stability – flow test.

Test is conducted on compacted cylindrical specimens of bituminous mixes (i) Normal Bituminous mix and (ii) Bituminous mix with 10% by weight of Crumb Rubber, of diameter 101.6 mm and thickness 63.5 mm. The load is applied perpendicular to the axis of the cylindrical specimen through a testing head consisting of a pair of cylindrical segments, at a constant rate of deformation of 51 mm per minute at the standard test temperature of 60°C.

The ‘Marshall Stability’ of the bituminous mix specimen is defined as a maximum load carried in kg at the standard test temperature of 60°C when load is applied under specified test condition. The ‘Flow Value’ is the total deformation that the Marshall test specimen under-goes at the maximum load, expressed in mm units.

The Marshall Stability value of a compacted specimen of bituminous mix indicates its resistance to deformation under applied incremental load and flow value indicates the extent of deformation it undergoes due to loading or its ‘flexibility’.

The flexibility is measured in terms of the ‘flow value’ which is measured by the change in diameter of the sample in the direction of load application between the start of loading and at the time of maximum load. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The associated plastic flow of specimen at material failure is called flow value.

4.2 Preparation of test specimens

4.2.1 Normal Bituminous Mix

Approximately 1200gm of aggregates and filler is heated to a temperature of 175-190^{o}C. Bitumen is heated to a temperature of 121-125^{o}C with the first trial percentage of bitumen (say 3.5 or 4% by weight of the mineral aggregates). The heated aggregates and bitumen are thoroughly mixed at a temperature of 154 - 160^{o}C. The mix is placed in a preheated mould and compacted by a rammer with 50 blows on either side at temperature of 138^{o}C to 149^{o}C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5+/-3 mm. Vary the bitumen content in the next trial by +0:5% and repeat the above procedure. Number of trials are predetermined.

Fig 4.1 Extraction of Sample from the Mould for Testing

The prepared mould is loaded in the Marshall test setup as shown in the figure.

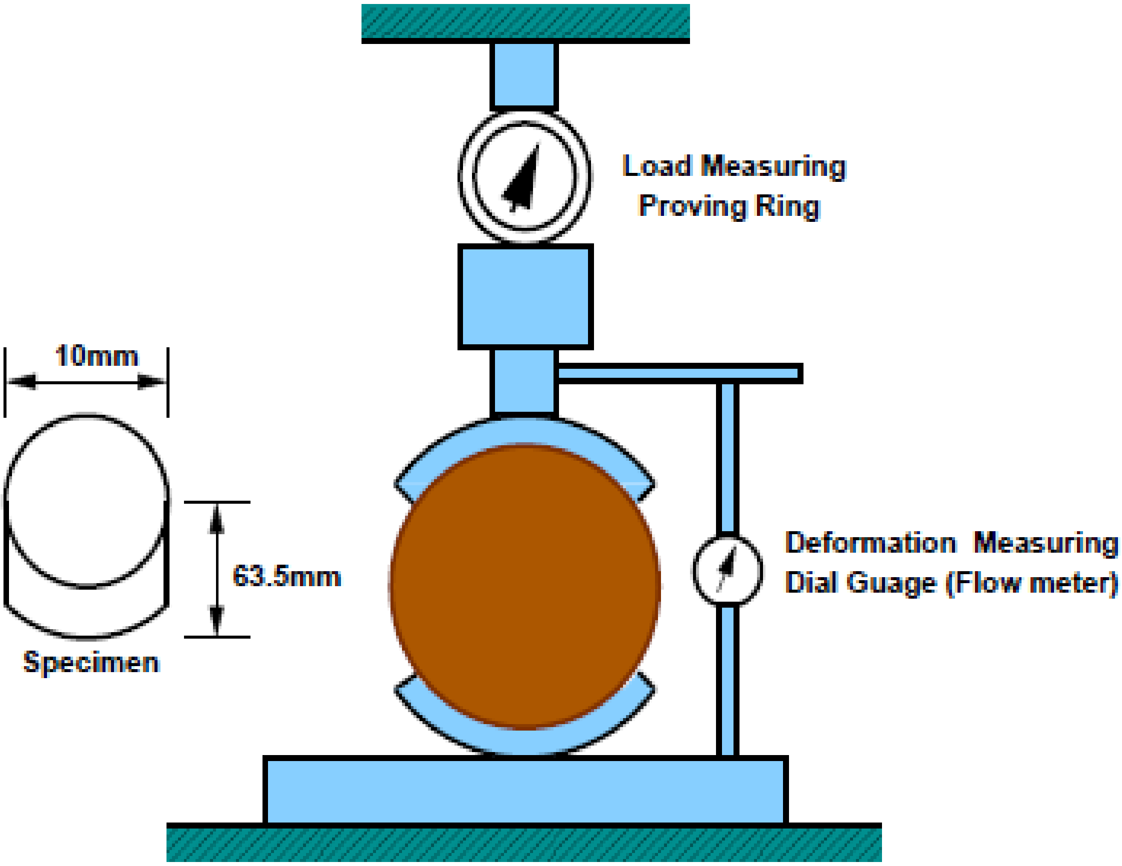


Fig 4.2 Marshall Stability Test Apparatus

Fig 4.3 Sample placed in Marshall Stability Test Apparatus

4.2.2 Crumb Rubber Modified Bitumen Mix

In preparing the modified binders, about 500 g of the bitumen was heated to fluid condition in a 1.5 litre capacity metal container. For blending of crumb rubber with bitumen, it was heated to a temperature of 160 °C and then crumb rubber was added. For each mixture sample 10% of crumb rubber by weight is used. The blend is mixed manually for about 3-4 minutes.

Approximately 1200gm of aggregates and filler is heated to a temperature of 175^{o}C-190^{o}C. The heated aggregates and CRMB are thoroughly mixed at a temperature of 154 - 160^{o}C. The mix is 75 placed in a preheated mould and compacted by a rammer with blows on either side at temperature of 138^{o}C to 149^{o}C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5+/-3 mm. Vary the bitumen content in the next trial by +0:5% and repeat the above procedure. Numbers of trials are predetermined. The prepared mould is loaded in the Marshall test setup.

4.3 Properties of Mix

The properties that are of interest include the theoretical specific gravity G_t, the bulk specific gravity of the mix G_m, percent air voids V_v, percent volume of bitumen V_b, percent void in mixed aggregate VMA and percent voids filled with bitumen VFB. To understand these calculations a phase diagram is given in figure.

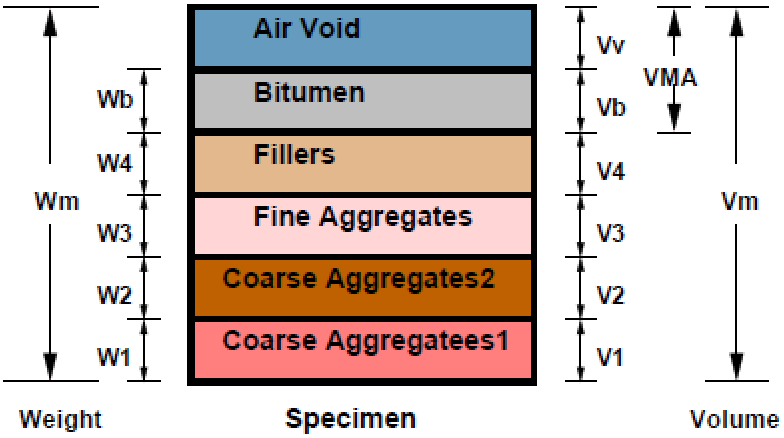


Fig 4.4 Phase Diagram of Bituminous Mix

4.3.1 *Theoretical specific gravity of the mix G_t*

Theoretical specific gravity $G_t$is the specific gravity without considering air voids, and is given by:

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}}$$

where, W_1 is the weight of coarse aggregate in the total mix, W_2 is the weight of fine aggregate in the total mix, W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_1 is the apparent specific gravity of coarse aggregate, G_2 is the apparent specific gravity of fine aggregate, G_3 is the apparent specific gravity of filler and G_b is the apparent specific gravity of bitumen.

4.3.2Bulk specific gravity of mix G_m

The bulk specific gravity or the actual specific gravity of the mix G_m is the specific gravity considering air voids and is found out by:

$$G_m = \frac{W_m}{W_m - W_w}$$

where, Wm is the weight of mix in air, W_w is the weight of mix in water, Note that W_m-W_w gives the volume of the mix. Sometimes to get accurate bulk specific gravity, the specimen is coated with thin film of paraffin wax, when weight is taken in the water. This, however requires to consider the weight and volume of wax in the calculations.

4.3.3Air voids percent Vv

Air voids Vv is the percent of air voids by volume in the specimen and is given by:

$$V_v = \frac{(G_t - G_m)100}{G_t}$$

Where G_t is the theoretical specific gravity of the mix, and G_m is the bulk or actual specific gravity of the mix given by equation

4.3.4 Percent volume of bitumen V_b

The volume of bitumen V_b is the percent of volume of bitumen to the total volume and given by:

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1+W_2+W_3+W_b}{G_m}}$$

where, W_1 is the weight of coarse aggregate in the total mix, $W_2$is the weight of fine aggregate in the total mix, $W_3$is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_b is the apparent specific gravity of bitumen, and G_m is the bulk specific gravity of mix given by equation

4.3.5 Voids in mineral aggregate VMA

Voids in mineral aggregate VMA is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen, and is calculated from

$$VMA = V_v + V_b$$

where, V_v is the percent air voids in the mix, and V_b is percent bitumen content in the mix

4.3.6 Voids filled with bitumen V FB

Voids filled with bitumen VFB is the voids in the mineral aggregate frame work filled with the bitumen, and is calculated as:

$$VFB = \frac{V_b \times 100}{VMA}$$

where, V_b is percent bitumen content in the mix, and VMA is the percent voids in the mineral aggregate

4.4 Determine Marshall stability and flow

Marshall stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain (5 cm per minute). While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25 mm is called the Marshall flow value of the specimen.

Fig 4.5 Performing Marshall Stability and Flow Value Test

Table 4.1 Marshall Stability and Flow Values for Normal Bituminous Mix

Bitumen Content (% Weight)	Stability (Kg)	Flow Value (units)
4.5	980	10.1
5	1120	12
5.5	1005.8	13.1
6	900	14.8
6.5	819	17.3

From Table 4.1 we can conclude that stability rises till the bitumen content is 5% and then it decreases. Thus the maximum stability is attained at a percentage of 5% bitumen content which will be used in the calculations to find the Optimum Bitumen Content.

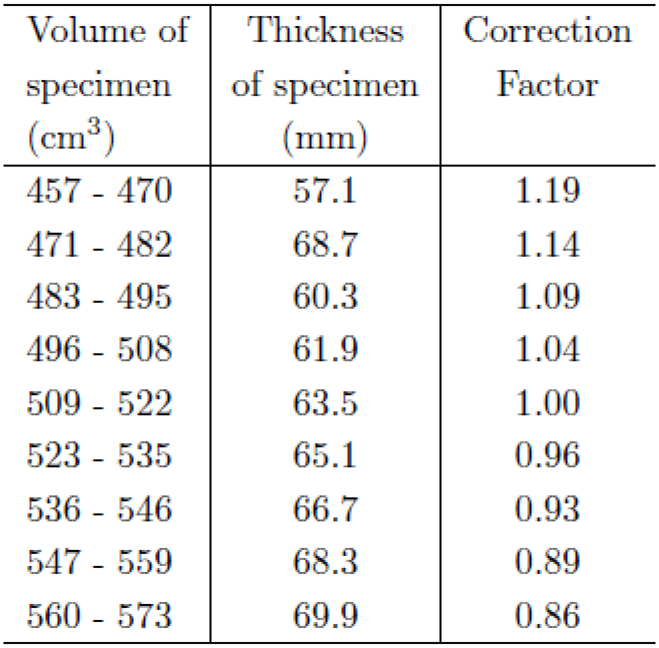
Fig 4.6 Removing the sample from the Apparatus after Load Test

Fig 4.7 Failed Sample with Lateral Elongation

4.5 Apply stability correction

It is possible while making the specimen the thickness slightly vary from the standard specification of 63.5mm. Therefore, measured stability values need to be corrected to those which would have been obtained if the specimens had been exactly 63.5 mm. This is done by multiplying each measured stability value by an appropriated correlation factors as given in Table.

Table 4.2 Correction Factors for Marshall Stability Values



Volume of specimen (cm^3)	Thickness of specimen (mm)	Correction Factor
457 - 470	57.1	1.19
471 - 482	68.7	1.14
483 - 495	60.3	1.09
496 - 508	61.9	1.04
509 - 522	63.5	1.00
523 - 535	65.1	0.96
536 - 546	66.7	0.93
547 - 559	68.3	0.89
560 - 573	69.9	0.86

(Khanna S K, Justo C E G[18])

Chapter 5

Analysis of Data and Discussion of Results

5.1 Introduction

The rheological properties of bituminous mix with and without crumb rubber are enlisted in this chapter and are compared along with a study published under “International Journal of Emerging Technology and Advanced Engineering.”

5.2 Analysis of Data

Particularly five specimens with varying bitumen content from 4.5-6.5% were prepared in the Highway Engineering Lab and Stability Test was performed by us in the Highway Engineering Lab of Civil Engineering Department of Jaypee University of Information Technology, Waknaghat (H.P). The results are analyzed and discussed as under.

In order to compare the effect of crumb rubber addition in bitumen, the results of K. Rajesh Kumar, Dr. N. Mahendran[9], (2014) and Nabin Rana Magar[7] (2014) on the same test are also complied. Table 5.3 and 5.4 depicts the data in these studies.

Table 5.1 Results for Marshall Stability Values for Normal Bituminous Mix

Bitumen Content (%)	Stability (Kg)	Flow (units)	V_v (%)	VFB (%)	G_m
4.5	980	10.1	9.38	65.7	2.3
5	1120	12	7.64	70.8	2.26
5.5	1005.8	13.1	5.05	76.3	2.26
6	900	14.8	3.8	78.5	2.23
6.5	819	17.3	3.95	79.2	2.18

From Table 5.1 it can be seen that maximum stability is achieved at 5% Bitumen content and the maximum percentage of air voids is achieved at 4.5% Bitumen content. Maximum value of Specific Gravity is noted at 5.5% Bitumen content. These three parameters help us in finding the Optimum Bitumen Content. Also it can be seen that the flow values increases gradually with the increase in Bitumen content. The air voids percentage keep on decreasing till the Bitumen content is 6% and then it rises at 6.5%.

Table 5.2 Results for Marshall Stability Values for Crumb Rubber Modified Bituminous Mix (CRMB)

Bitumen Content (%)	Stability (Kg)	Flow (units)	V_v (%)	VFB (%)	G_m
4.5	1405	9.2	4.8	82.7	2.27
5	1470	9.7	3.3	84.6	2.28
5.5	1590.4	10.2	2.1	89.8	2.27
6	2080.8	10.6	1.9	92.4	2.29
6.5	1430.7	11	2.1	85.9	2.26

From Table 5.2 it can be seen that maximum stability is achieved at 6% Bitumen content when the percentage of Crumb Rubber is kept at 10%. On comparing the data from table 5.1 and 5.2 it can be seen that maximum stability is now achieved at 6% bitumen content instead of 5% Bitumen content as in the case of Normal Bituminous mix but the maximum percentage of air voids is still achieved at 4.5% Bitumen content as was in the case of Normal Bituminous mix.

Maximum value of Specific Gravity is noted at 6% Bitumen content and it’s value has also risen from 2.26 to 2.29 meaning that the density of the mix has also increased. There is also a change in the values of VFB. Now more percentage of voids is filled with bitumen. The air voids percentage keep on decreasing till the Bitumen content is 6% and then it rises at 6.5%.

Table 5.3 Results for Marshall Stability Values for Normal Bituminous mix from Study

Bitumen Content (%)	Stability (Kg)	Flow (units)	V_v (%)	VFB (%)	G_m
4.5	1219.8	10.36	6.36	62.74	2.35
5	1290.53	12.6	5.52	67.21	2.41
5.5	1370.41	14.28	4.47	73.31	2.38
6	1211.33	16.64	3.87	78.38	2.35
6.5	993.6	20.84	3.95	79.03	2.35

From Table 5.3 it can be concluded that maximum stability is achieved at 5.5% Bitumen content and the maximum percentage of air voids is achieved at 4.5% Bitumen content. Maximum value of Specific Gravity is noted at 5% Bitumen content. Also it can be observed that the flow values increases gradually with the increase in Bitumen content. These values are taken from the study of Nabin Rana Magar (2014)[7].

Table 5.4 Results for Marshall Stability Values for Crumb Rubber Modified Bituminous mix from Study

Bitumen Content (%)	Stability (Kg)	Flow (units)	V_v (%)	VFB (%)	G_m
4.5	2218.5	8.8	3	85.8	2.29
5	2367.8	9.0	2.5	89.3	2.3
5.5	2518.3	9.2	2	94.3	2.28
6	3015.1	9.4	0.5	96.9	2.29
6.5	2403	9.6	0.8	87.9	2.25

From Table 5.4 it can be concluded that maximum stability is achieved at 6% Bitumen content instead of the 5.5% Bitumen content in case of Normal Bituminous mix and the maximum percentage of air voids is achieved at 4.5% Bitumen content. Maximum value of Specific Gravity is noted at 5% Bitumen content. Also it can be observed that the flow values increases gradually with the increase in Bitumen content. These values are taken from the study of K. Rajesh Kumar, Dr. N. Mahendran(2014)[9].

5.3 Graphical Analysis:

The graphs for Marshall stability and other rheological properties for the normal and crumb rubber bitumen mixes are plotted and discussions are made in the following section.

5.3.1 Normal Bituminous Mix vs. Crumb Rubber Modified Bituminous Mix

1. Binder content (%) versus corrected Marshall stability (kg)

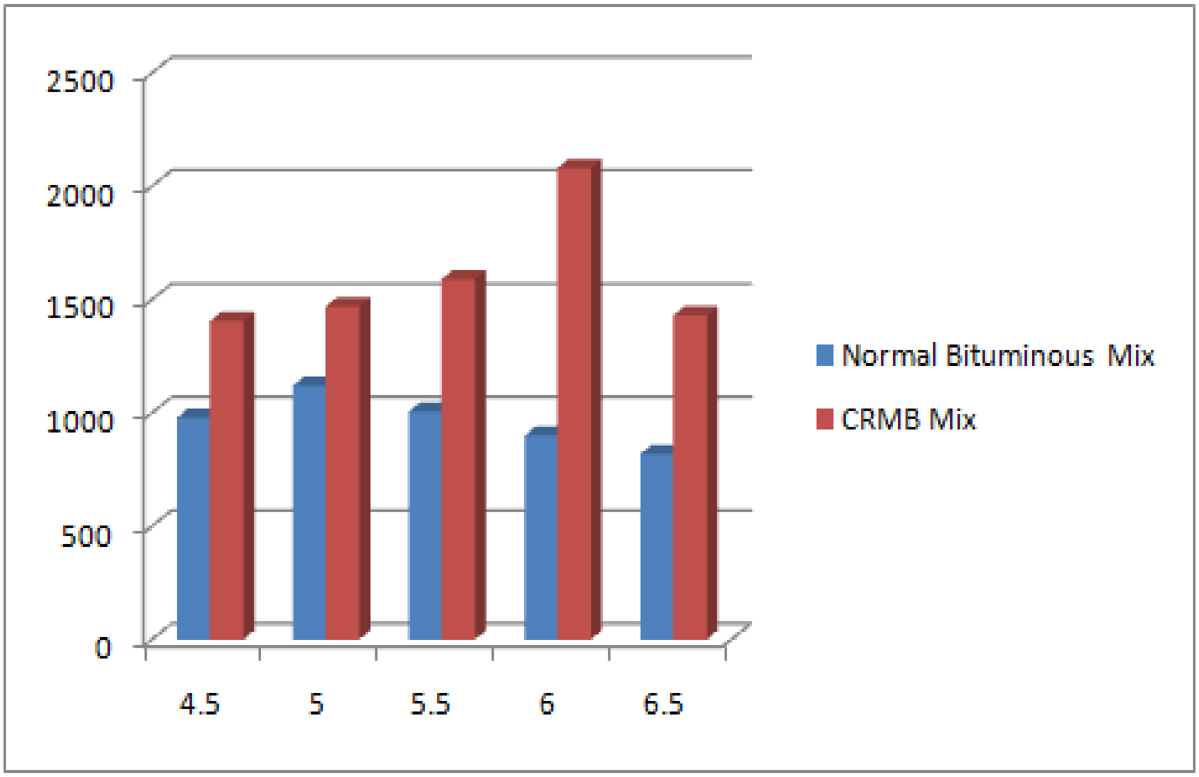


Fig 5.1 Bitumen Content vs. Marshall Stability

From Figure 5.1 it is clear that stability of CRMB is more than that of Normal Bituminous Mix through out the varying percentages of Bitumen content. The maximum stability as can be seen from the figure is 1120 kg in the case of Normal Bituminous Mix and 2080.8 kg in the case of CRMB. This means that addition of Crumb Rubber has led to an increase of 85.72 % in the maximum stability. The maximum stability is achieved at 5% Bitumen Content in the case of Normal Bituminous Mix and at 6% Bitumen Content in the case of CRMB. This is justified as addition of Crumb Rubber needs more amount of binder to bind all the aggregates efficiently.

2. Binder content (%) versus Marshall flow value (mm)

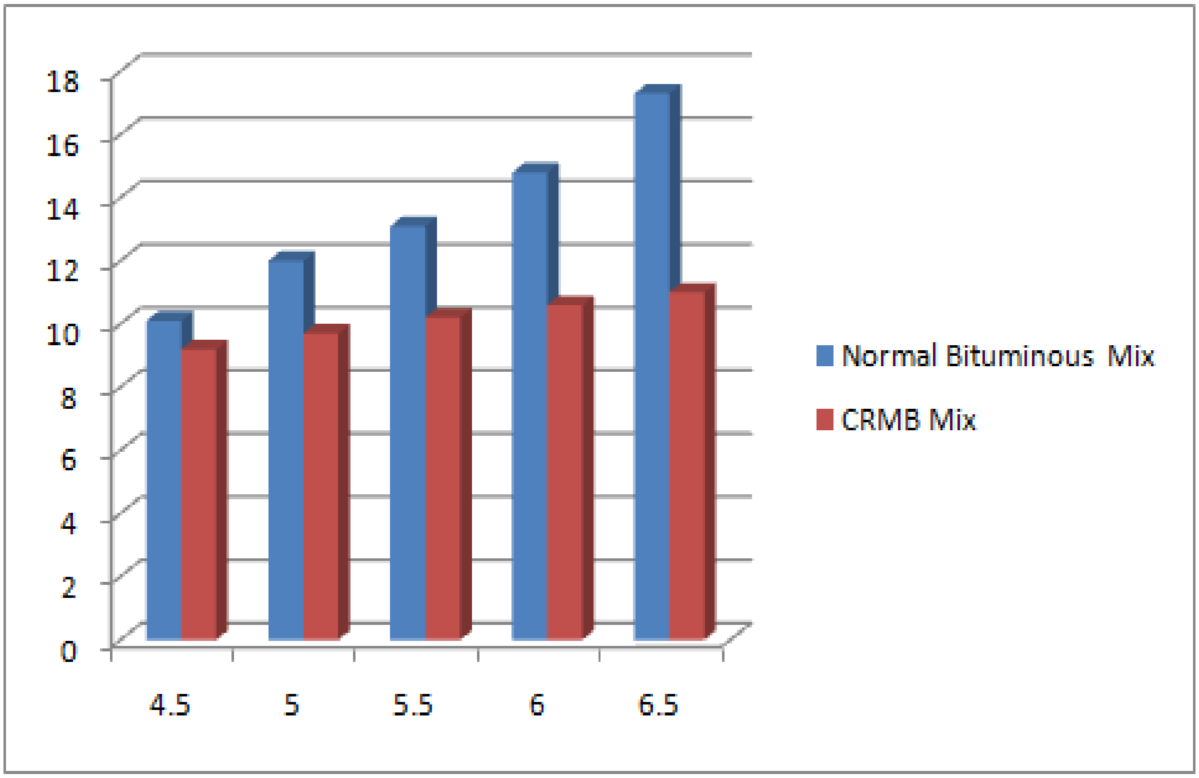


Fig 5.2 Bitumen Content vs. Flow Value

From Figure 5.2 it is clear that the flow values keep on increasing both in the cases of Normal Bituminous Mix and CRMB as the percentages of bitumen keeps on increasing. It can also be seen that the Flow values of CRMB is lesser than that of Normal Bituminous Mix throughout the varying percentages of Bitumen content. This is justified as addition of Crumb Rubber helps in the stiffening of the bituminous mix. Increased stiffness makes the pavement strong and avoids rutting of the pavement so it’s desirable to have required amount of stiffness in the bituminous mix.

3. Binder content (%) versus Percentage Air Voids- V_v (%) in the total mix

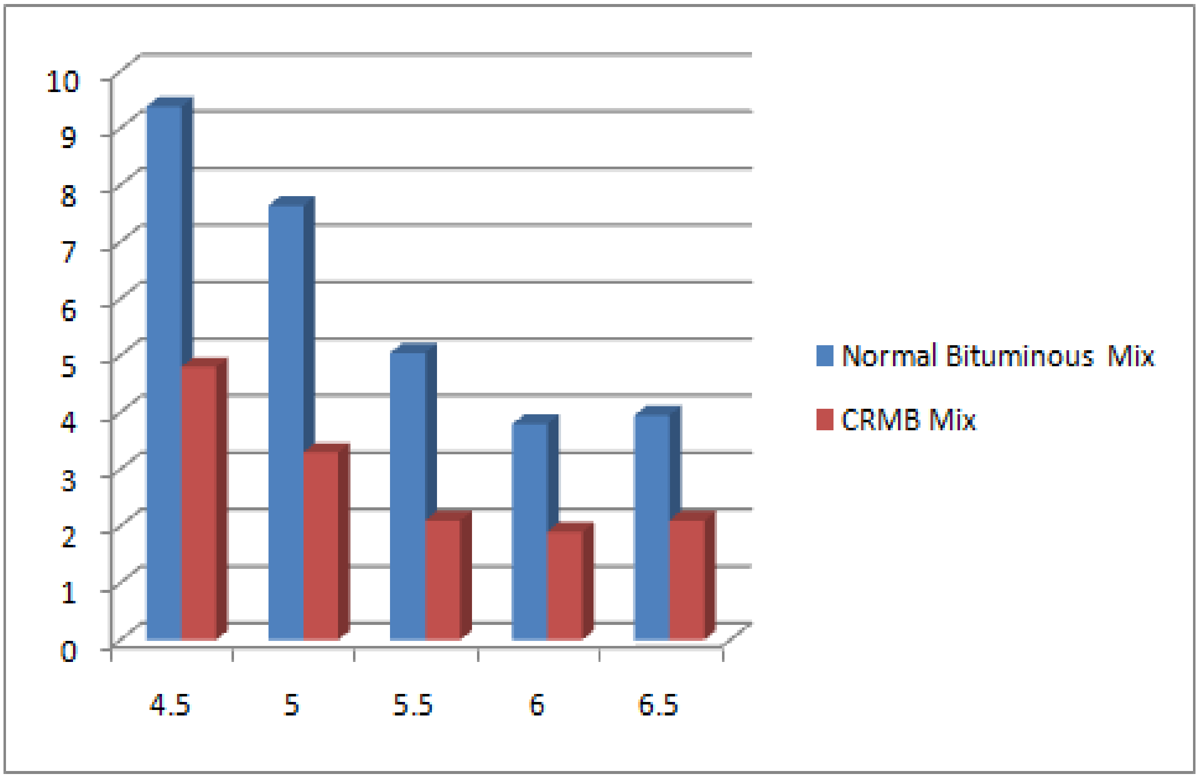


Fig 5.3 Bitumen Content vs. Percentage Air Voids (V_v)

From Figure 5.3 it is evident that the Percentage Air Voids keep on decreasing both in the cases of Normal Bituminous Mix and CRMB as the percentages of bitumen keeps on increasing and a slight increase is seen in both the cases at 6.5% Bitumen content. It can also be seen that the Percentage Air Voids of CRMB is lesser than that of Normal Bituminous Mix throughout the varying percentages of Bitumen content. This is due to the fact that the binding is more efficient in the case of CRMB than the Normal Bituminous Mixes. Hence the VFB percentage is more in case of CRMB and the Percentage Air Voids is less.

4. Binder content (%) versus Voids Filled with Bitumen –VFB (%)

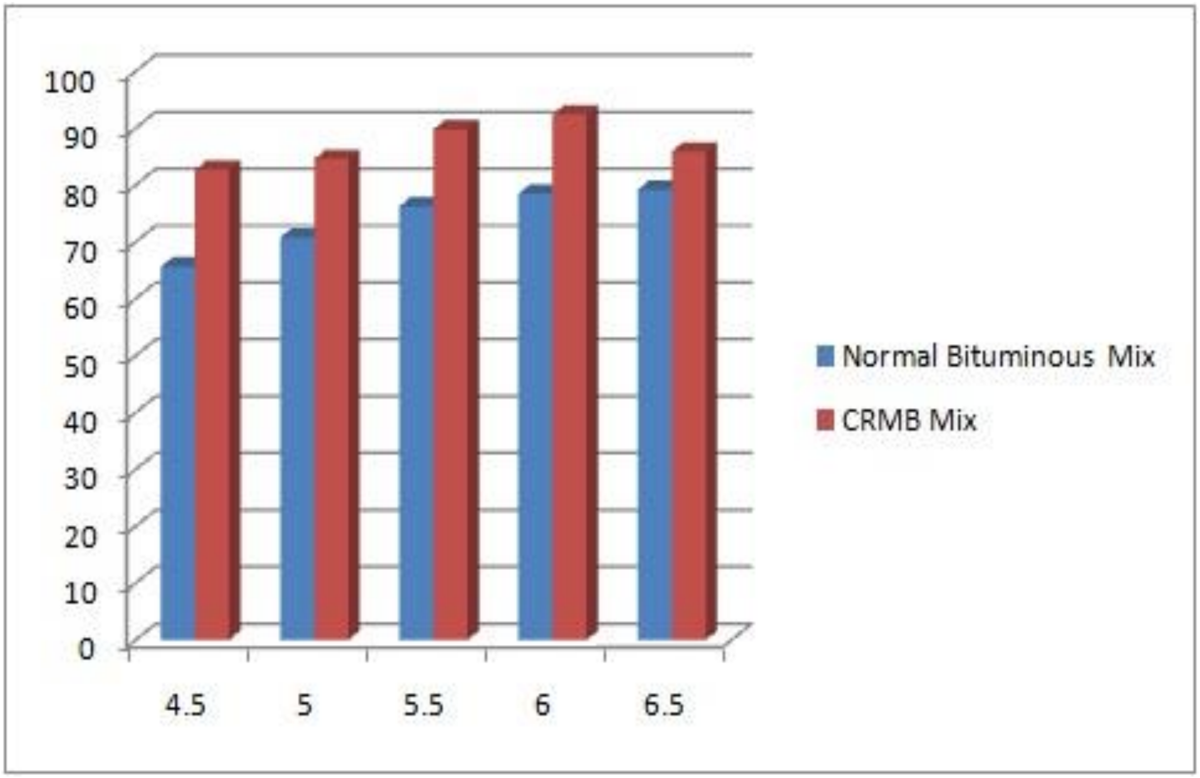


Fig 5.4 Bitumen Content vs. VFB

From Figure 5.4 it is evident that the VFB keeps on increasing both in the cases of Normal Bituminous Mix and CRMB as the percentages of bitumen keeps on increasing. It can also be seen that the VFB of CRMB is higher than that of Normal Bituminous Mix throughout the varying percentages of Bitumen content. This is due to the fact that the binding is more efficient in the case of CRMB than the Normal Bituminous Mixes. Hence the VFB percentage is more in case of CRMB and the Percentage Air Voids is less.

5. Binder content (%) versus unit weight or bulk specific gravity (G_m)

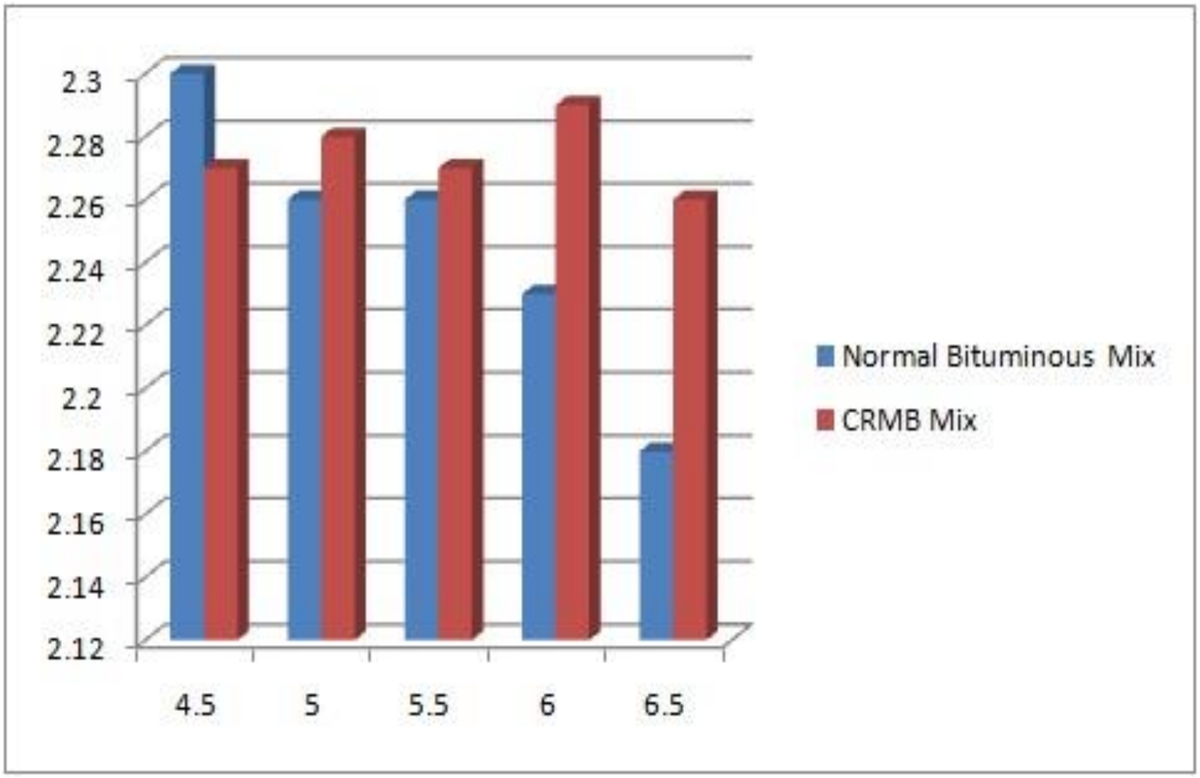


Fig 5.5 Bitumen Content vs. G_m

From Figure 5.5 it can be seen that the Specific Gravity keeps on decreasing in the case of Normal Bituminous Mix and in the case of CRMB the Specific Gravity increases till 5% Bitumen content then shows a slight decrease at 5.5% Bitumen content and then gives maximum value at 6% Bitumen content and then decreases at 6.5% Bitumen content. The Specific Gravity is higher in case of CRMB except at 4.5% Bitumen content.

5.3.2 Normal Bitumen Mix vs. Crumb Rubber Modified Bitumen Mix from Study

Here we showed the comparison of Normal Bituminous mix (NabinRanaMagar[7]) with CRMB (K. Rajesh Kumar, Dr. N. Mahendran[9]) by plotting graphs.

1. Binder content (%) versus corrected Marshall stability (kg)

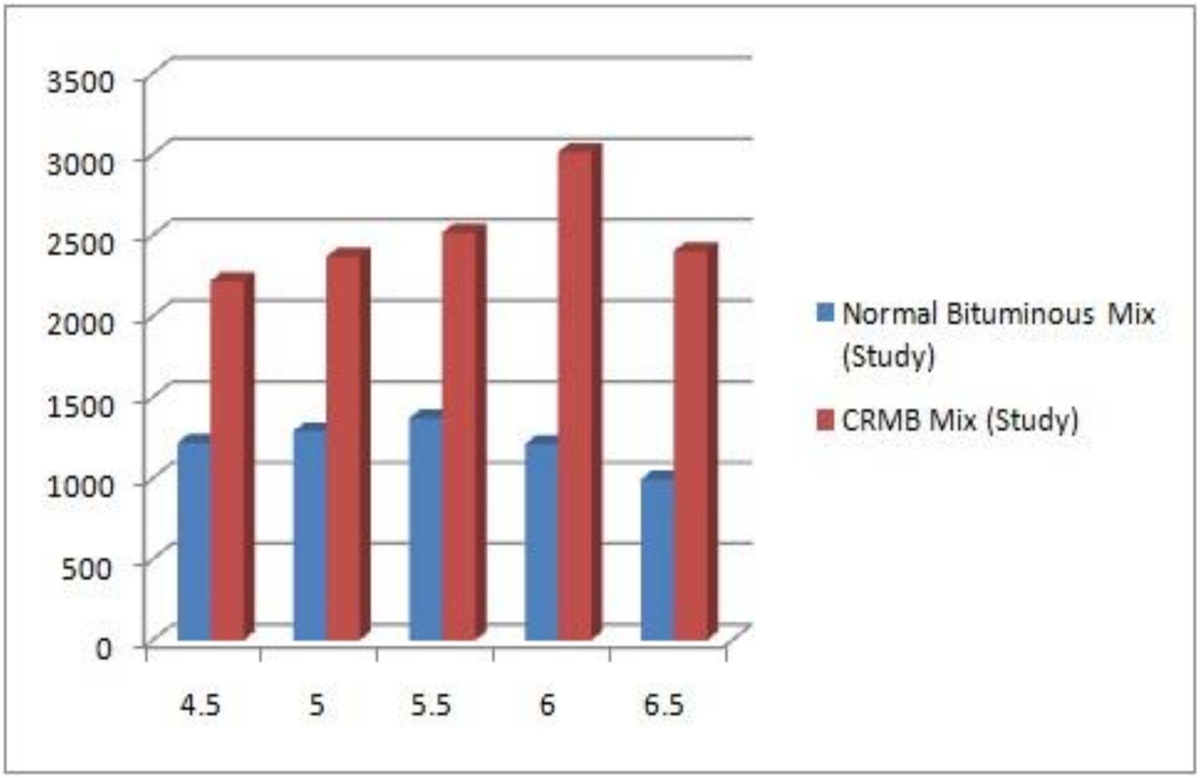


Fig 5.6 Bitumen Content vs. Marshall Stability

From Figure 5.6 it is clear that stability of CRMB is more than that of Normal Bituminous Mix through out the varying percentages of Bitumen content. The maximum stability as can be seen from the figure is 1370.41 kg in the case of Normal Bituminous Mix and 3015.1 kg in the case of CRMB. This means that addition of Crumb Rubber has led to an increase of 120 % in the maximum stability. The maximum stability is achieved at 5.5% Bitumen Content in the case of Normal Bituminous Mix and at 6% Bitumen Content in the case of CRMB. This is justified as addition of Crumb Rubber needs more amount of binder to bind all the aggregates efficiently.

2. Binder content (%) versus Marshall flow value (mm)

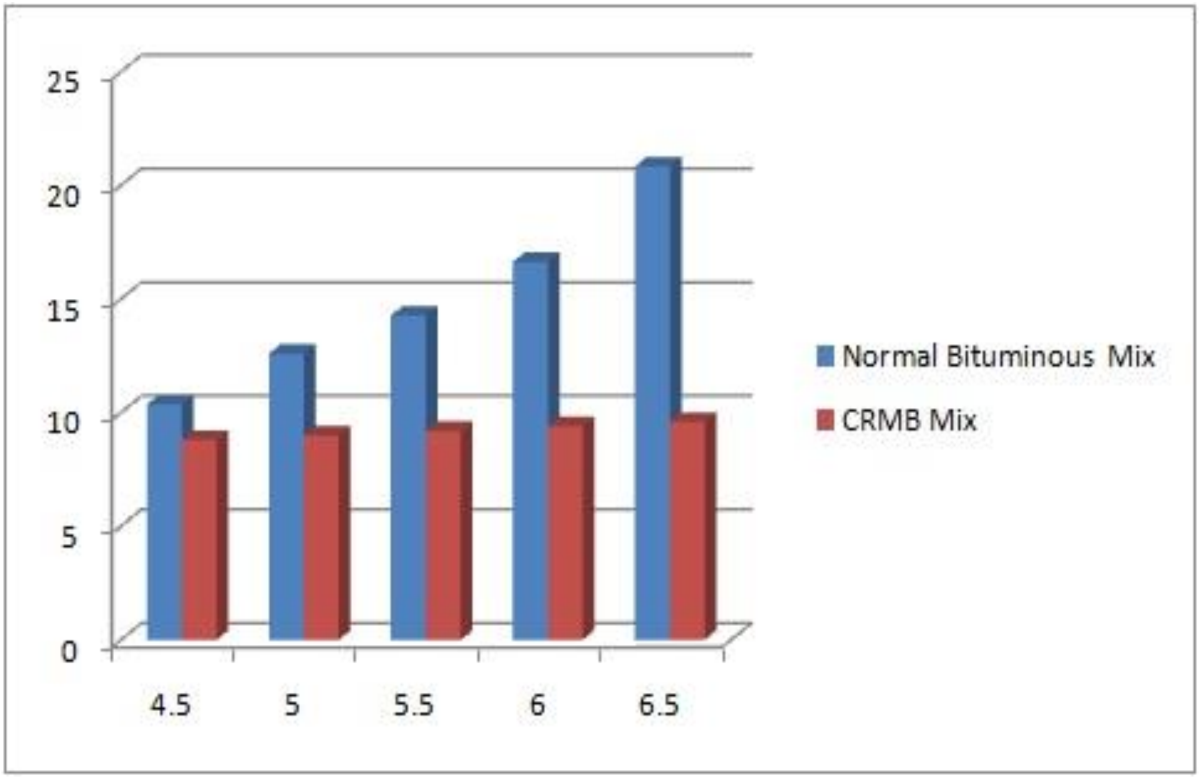


Fig 5.7 Bitumen Content vs. Marshall Flow Value

From Figure 5.7 it is clear that the flow values keep on increasing both in the cases of Normal Bituminous Mix and CRMB as the percentages of bitumen keeps on increasing. It can also be seen that the Flow values of CRMB is lesser than that of Normal Bituminous Mix throughout the varying percentages of Bitumen content. This is justified as addition of Crumb Rubber helps in the stiffening of the bituminous mix. Increased stiffness makes the pavement strong and avoids rutting of the pavement so it’s desirable to have required amount of stiffness in the bituminous mix.

3. Binder content (%) versus Percentage Air Voids-V_v (%) in the total mix

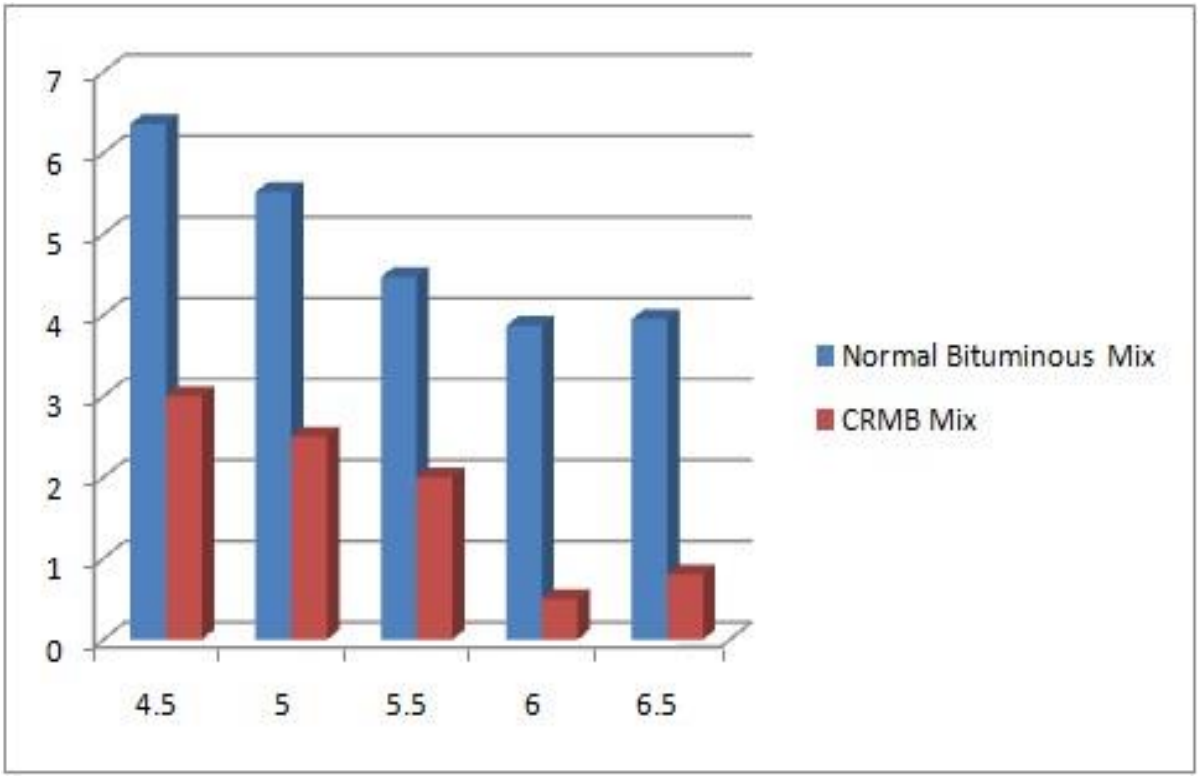


Fig 5.8 Bitumen Content vs. V_v

From Figure 5.8 it is evident that the Percentage Air Voids keep on decreasing both in the cases of Normal Bituminous Mix and CRMB as the percentages of bitumen keeps on increasing and a slight increase is seen in both the cases at 6.5% Bitumen content. It can also be seen that the Percentage Air Voids of CRMB is lesser than that of Normal Bituminous Mix throughout the varying percentages of Bitumen content. This is due to the fact that the binding is more efficient in the case of CRMB than the Normal Bituminous Mixes. Hence the VFB percentage is more in case of CRMB and the Percentage Air Voids is less.

4. Binder content (%) versus Voids Filled with Bitumen –VFB (%)

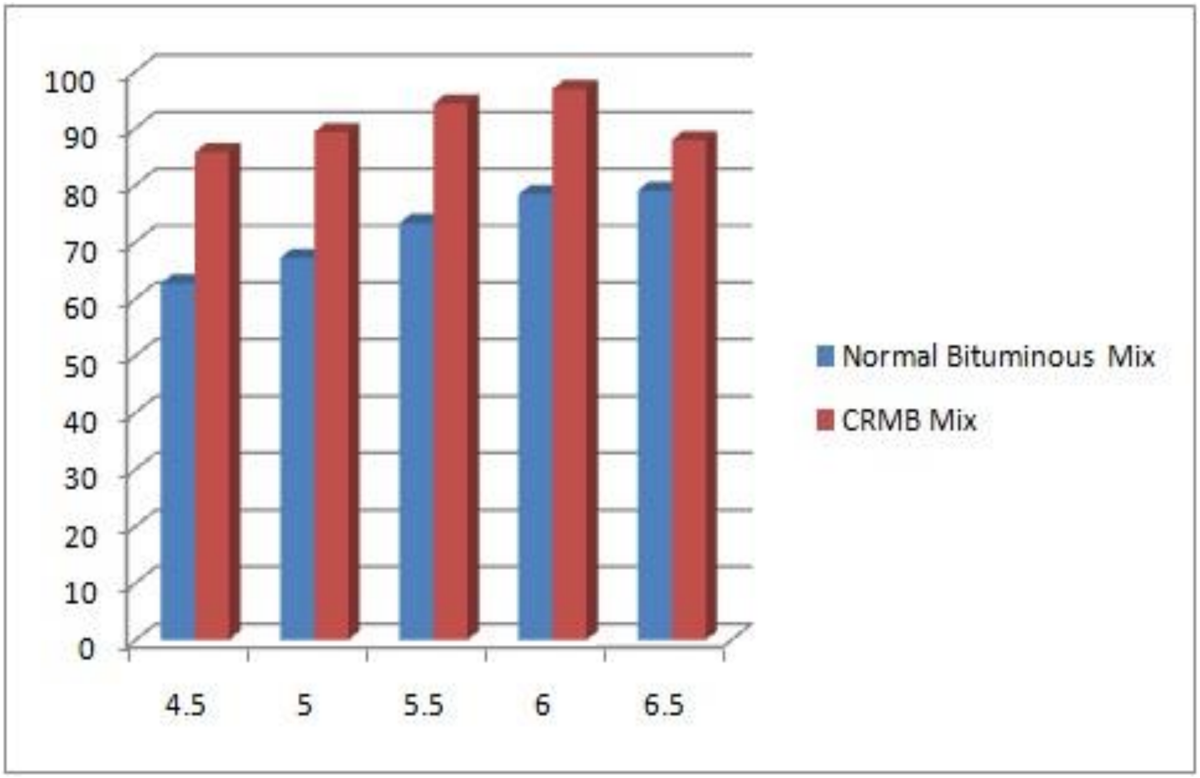


Fig 5.9 Bitumen Content vs. VFB

From Figure 5.9 it is evident that the VFB keeps on increasing both in the cases of Normal Bituminous Mix and CRMB as the percentages of bitumen keeps on increasing. It can also be seen that the VFB of CRMB is higher than that of Normal Bituminous Mix throughout the varying percentages of Bitumen content. This is due to the fact that the binding is more efficient in the case of CRMB than the Normal Bituminous Mixes. Hence the VFB percentage is more in case of CRMB and the Percentage Air Voids is less.

5. Binder content (%) versus unit weight or bulk specific gravity (G_m)

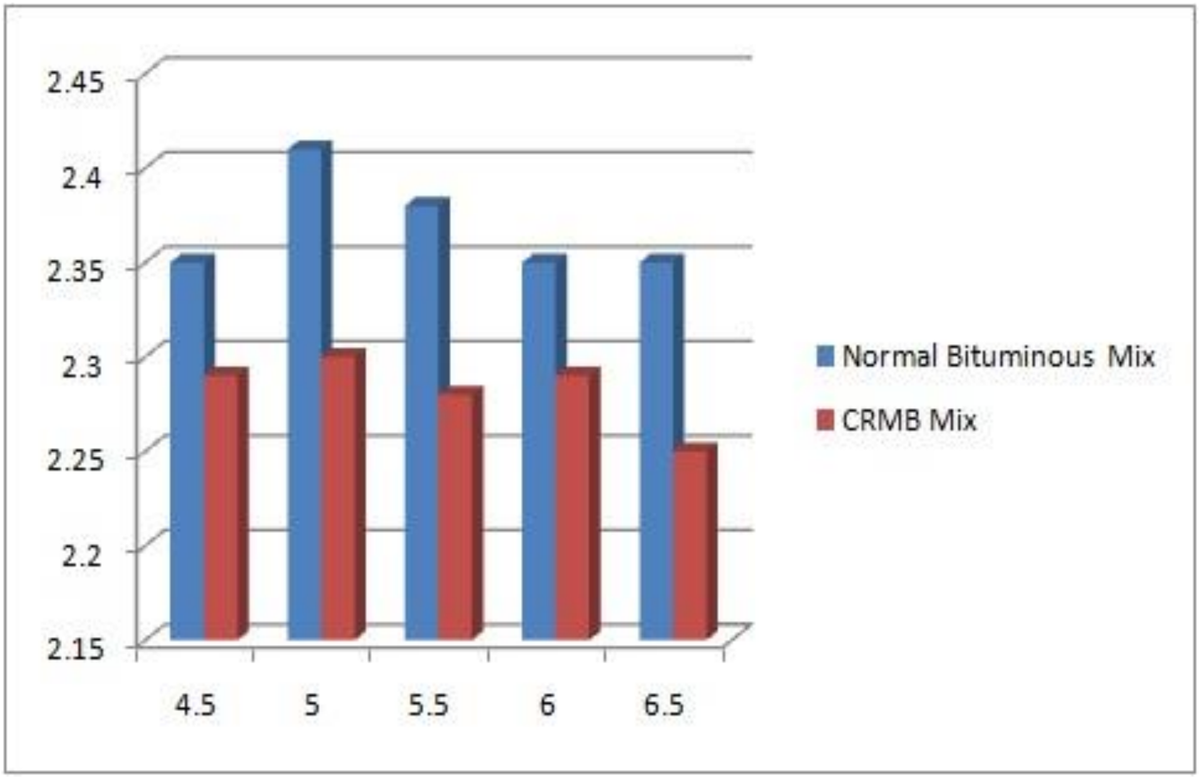


Fig 5.10 Bitumen Content vs. G_m

From Figure 5.10 it can be seen that the Specific Gravity gives maximum value at 5% Bitumen content in the case of Normal Bituminous Mix and in the case of CRMB the Specific Gravity is also maximum at 5% Bitumen content. The Specific Gravity is higher in case of Normal Bituminous mix.

5.5.3 Normal Bitumen Mix vs. CRMB Mix vs. Normal Bitumen Mix (Study) vs. CRMB Mix (Study)

Here graphs are plotted to show the variance between our present study and the studies of Nabin Rana Magar (2014)[7] and K. Rajesh Kumar, Dr. N. Mahendran (2014)[9].

1. Binder content (%) versus corrected Marshall stability (kg)

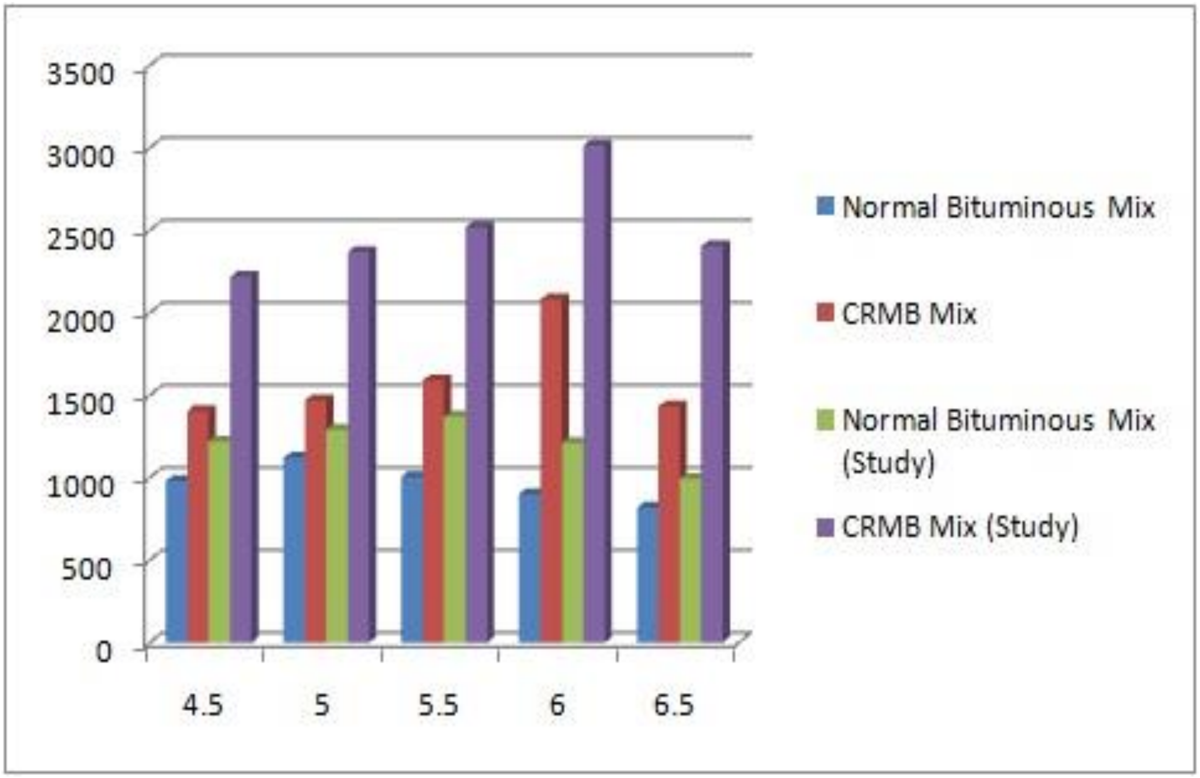


Fig 5.11 Bitumen Content vs. Marshall Stability

Fig 5.11 shows the similarity in the trends of our present study with the selected studies of Nabin Rana Magar (2014)[7] and K. Rajesh Kumar, Dr. N. Mahendran (2014)[9]. In our study the CRMB mix gives highest stability at 6% Bitumen content and it can also be seen that the CRMB mix from the selected study also gives highest stability value at 6% Bitumen content. We can observe that stability rises till 6% BC and then it decreases. Also the stability of CRMB is much higher than that of Normal Bituminous Mix. In our study the Normal Bituminous Mix attains Maximum Stability at 5% BC while in the study by Nabin Rana Magar it attains maximum stability at 5.5% BC and also the stability values in our study are less as compared to the selected studies.

2. Binder content (%) versus Marshall flow value (mm)

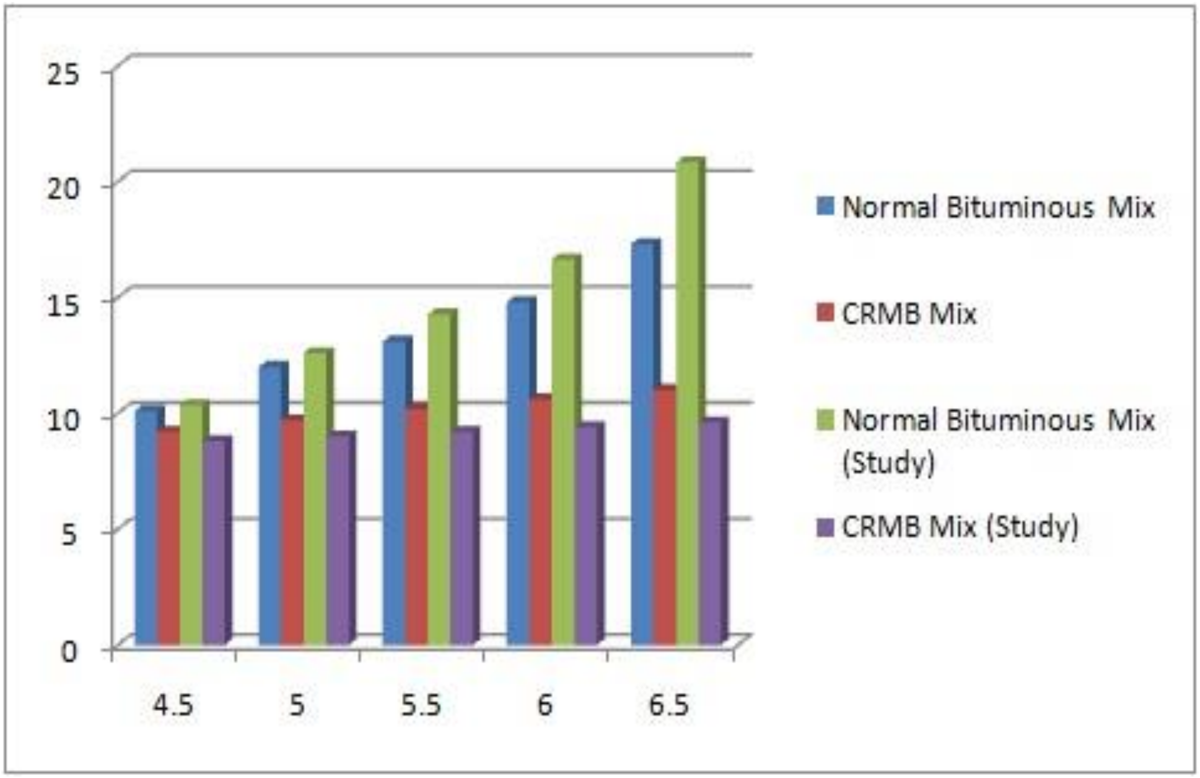


Fig 5.12 Bitumen Content vs. Flow Value

From Fig 5.12 the similarity in the trends of our present study can be seen with the selected studies of Nabin Rana Magar (2014)[7] and K. Rajesh Kumar, Dr. N. Mahendran (2014)[9]. It can be seen that the flow value increases with the increase in the bitumen content be it the Normal Bituminous Mix or the CRMB mix. The flow values of CRMB Mix are lower than that of the Normal Bituminous Mix both in our present study and the selected studies. This is due to the fact that CRMB Mix is stiffer than that of the Normal Bituminous Mix. This kind of stiffness helps in making the pavement strong and durable. The flow values of Normal Bituminous Mix in our study are less than those in the study which means our Normal Bituminous Mix was stiffer and the CRMB mix in our study has higher values than that in the selected study which means the CRMB mix of the selected study is stiffer than ours.

3. Binder content (%) versus Percentage Air Voids -V_v (%) in the total mix

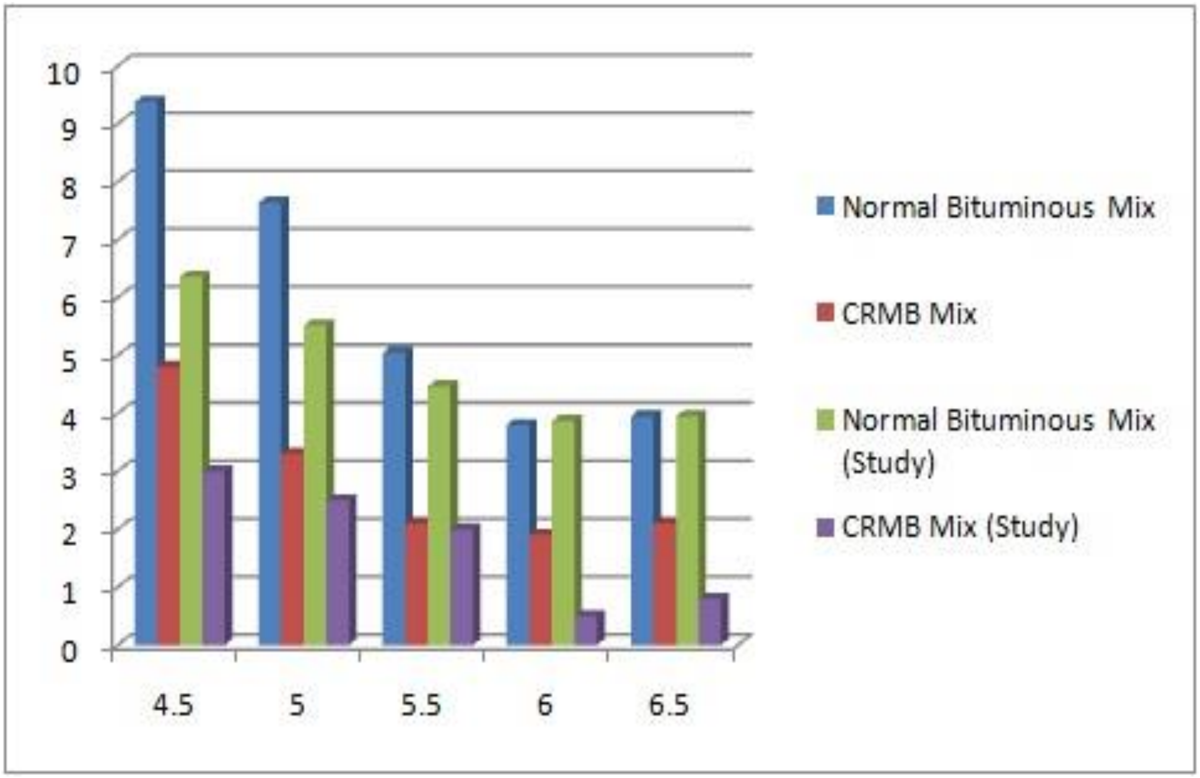


Fig 5.13 Bitumen Content vs. V_v

From Fig 5.13 the similarity in the trends of our present study can be seen with the selected studies of Nabin Rana Magar (2014)[7] and K. Rajesh Kumar, Dr. N. Mahendran (2014)[9]. It is evident that the Percentage Air Voids keep on decreasing both in the cases of Normal Bituminous Mix and CRMB as the percentages of bitumen keeps on increasing and a slight increase is seen in both the cases at 6.5% Bitumen content both in our study and the selected studies. It can also be seen that the Percentage Air Voids of CRMB is lesser than that of Normal Bituminous Mix throughout the varying percentages of Bitumen content. This is due to the fact that the binding is more efficient in the case of CRMB than the Normal Bituminous Mixes. Hence the VFB percentage is more in case of CRMB and the Percentage Air Voids is less. It can also be seen that the Percentage Air Voids in the CRMB mix and the Normal Bituminous Mix from the selected study are lower than that in our study.

4. Binder content (%) versus Voids Filled with Bitumen –VFB (%)

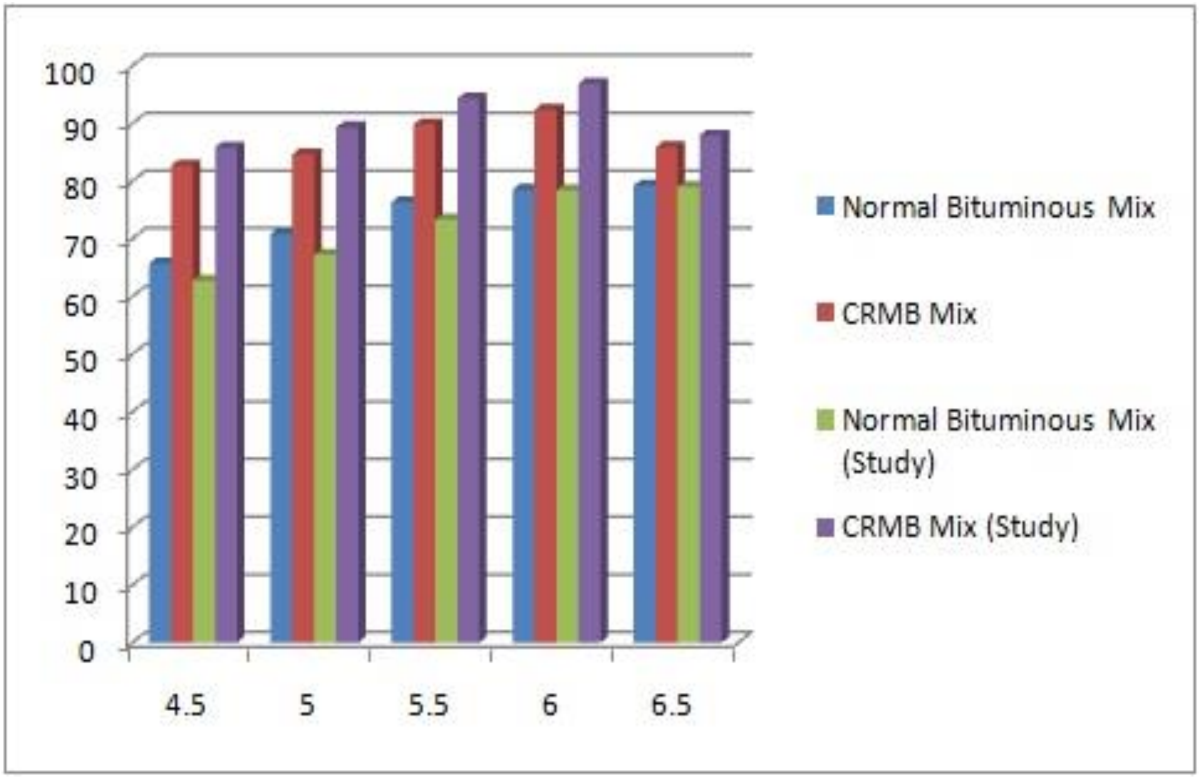


Fig 5.14 Bitumen Content vs. VFB

From Fig 5.14 the similarity in the trends of our present study can be seen with the selected studies of Nabin Rana Magar (2014)[7] and K. Rajesh Kumar, Dr. N. Mahendran (2014)[9]. It is evident that the VFB keeps on increasing both in the cases of Normal Bituminous Mix and CRMB as the percentages of bitumen keeps on increasing. It can also be seen that the VFB of CRMB is higher than that of Normal Bituminous Mix throughout the varying percentages of Bitumen content. This is due to the fact that the binding is more efficient in the case of CRMB than the Normal Bituminous Mixes. Hence the VFB percentage is more in case of CRMB and the Percentage Air Voids is less. It can also be seen that the VFB in the CRMB mix from the selected study are higher than that in our study and the VFB in the Normal Bituminous Mix is almost same in both the studies.

5. Binder content (%) versus unit weight or bulk specific gravity (G_m)

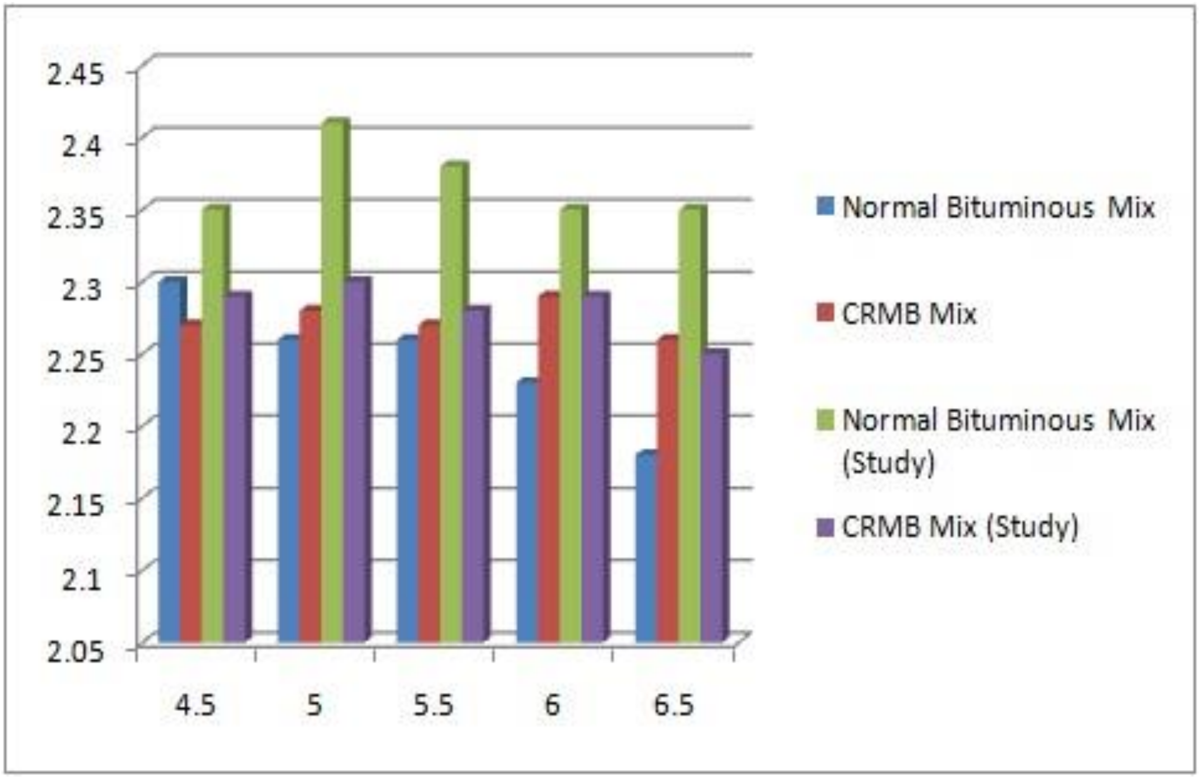


Fig 5.15 Bitumen Content vs. G_m

From Fig 5.15 the similarity in the trends of our present study can be seen with the selected studies of Nabin Rana Magar (2014)[7] and K. Rajesh Kumar, Dr. N. Mahendran (2014)[9]. It can be seen that the Specific Gravity gives maximum value at 5% Bitumen content in the case of Normal Bituminous Mix and in the case of CRMB the Specific Gravity is also maximum at 5% Bitumen content. The Specific Gravity is higher in case of Normal Bituminous mix.

Table 5.5 Optimum Bitumen Content For Various Specimens

Serial Number	Type of Mix	Max. Stability (Kg)	Max. Percentage Air Voids (%)	Max. Specific Gravity	Optimum Bitumen Content
1.	Normal Bituminous Mix	1120 @ 5% BC	9.38 @ 4.5% BC	2.26 @ 5.5% BC	5%
2.	CRMB Mix	2080.8 @ 6% BC	4.8 @ 4.5% BC	2.29 @ 6% BC	5.5%
3.	Normal Bituminous Mix (Study)	1370.41 @ 5.5% BC	6.36 @ 4.5% BC	2.41 @ 5% BC	5%
4.	CRMB Mix (Study)	3015.1 @ 6% BC	3 @ 4.5% BC	2.3 @ 5% BC	5.167%

5.4 Concluding Remarks

From the above graphs it can be concluded that:

- ✓ CRMB in our Present Study and CRMB (K. Rajesh Kumar, Dr. N. Mahendran (2014)[9]) showed variations in the stability and rheological properties due the fact that increasing natural rubber content increases the stiffness of the binder.
- ✓ After comparing the results of our study and the selected studies we can see that the Marshall Stability achieved was less than the targeted stability which could be the result of improper mixing and also due to varying temperature gradient.

By studying the test results of common laboratory tests on Normal Bituminous Mix and Crumb Rubber Modified Bitumen it is concluded that the stability of Normal Bituminous Mix can be improved significantly by modifying it with addition of Crumb Rubber which is a major environment pollutant.

Chapter 6

Conclusion and Discussions

6.1 Introduction

The main objective of the present study was to study the variation in properties of CRMB (K. Rajesh Kumar, Dr. N. Mahendran (2014)[9]) and CRMB (Present study) and compare them to the properties of Normal Bituminous Mixes through a systematically conducted series of laboratory experiments. The experimental data of Nabin Rana Magar (2014)[7] and K. Rajesh Kumar, Dr. N. Mahendran (2014)[9] were also used, combined with the data of present study, for the purpose of analysis. On the basis of experimental observations and analysis, the following main conclusions are drawn from the present study.

6.2 Conclusions and Discussions

From the experiments conducted with different percentages of bitumen on Marshal Stability Test using CRMB we arrive at:

- ✓ It showed maximum Marshal stability when percentage of Crumb rubber used was absolute 10% at a bitumen content of 6%.
- ✓ It showed an increase of 85.72% in the Marshall Stability value when compared to the traditional Bituminous Mixes.
- ✓ The Optimum Bitumen Content increased from 5% to 5.5% on addition of Crumb Rubber.
- ✓ Percentage Air Voids decreased considerably on addition of Crumb Rubber due to the fact that the binding is more efficient in the case of CRMB than the Normal Bituminous Mixes.
- ✓ A decrease was seen in Flow Values which is justified by the fact that addition of Crumb Rubber helps in the stiffening of the bituminous mix.
- ✓ Voids Filled with Bitumen increased considerably on addition of Crumb Rubber due to the fact that rubber binds more efficiently with the binder.
- ✓ Increasing content of natural rubber in crumb affects the properties of binder adversely making the binder stiffer and hence not suitable for highway construction.

From our conducted research it can be concluded that CRMB provides a lot of advantages over the traditional bituminous mixes. These advantages include increased stability, improved bitumen resistance to rutting due to high viscosity, high softening point and better resilience, improved bitumen resistance to surface initiated cracks, the reduction of fatigue/reflection cracking, the reduction of temperature susceptibility, improved durability as well as the reduction in road pavement maintenance costs. Plus it solves the problem of disposal of waste rubber tyres and thus takes care of environmental pollution.

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16. ISSN: 0975 – 6744| NOV 12 TO OCT 13 | Volume 2, Issue 2 1 DARSHNA B.JOSHI, 2 PROF. A. K. PATEL 1, 2 Department Of Civil Engineering ,Transportation Dept., L.D. College Of Engineering , Gujarat Technological University, Ahmedabad, Gujarat, India.

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