LABORATORY INVESTIGATIONS OF BITUMINOUS CONCRETE GRADE 1 WITH SAW DUST ASH AND HYDRATED LIME IN REPLACEMENT OF STONE DUST AS FILLERS

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DECLARATION

I hereby declare that this work which is being presented in the thesis entitled "**Laboratory investigations of Bituminous Concrete Grade 1 with saw dust ash and Hydrated Lime in replacement of Stone Dust as fillers** " in partial fulfilment of the requirement for the award of degree of **Master of Engineering** in the field of **Civil Engineering** with specialization in **Infrastructure Engineering** submitted at **Thapar Institute of Engineering & Technology (Patiala)** is an authentic record of my own work carried out during the period from 14.8.2018 to 15.7.2019 under the guidance of Dr. Tanuj Chopra.

The matter embodied in this thesis has not submitted by me for the award of any other degree or diploma.

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This is to certify that the above declaration made by the student concerned is correct according to the best of our knowledge and belief.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HMA	Hot Mix Asphalt
BC	Bituminous Concrete
DBM	Dense Bituminous Macadam
SD	Stone Dust
SDA	Saw Dust Ash
HL	Hydrated Lime
S.G.	Specific Gravity
CaO	Calcium Oxide
OPC	Ordinary Portland Cement
PC	Portland Cement
LS	Limestone
CPC	Portland Cement in cold state
RHA	Rice Husk Ash
DSA	Date Seed Ash
SBS	Styrene Butadiene Styrene
AG	American Gilsonite
IG	Iranian Gilsonite
PET	Polyethylene tetraphthalate
CD	Concrete Dust
BD	Brick dust

ABSTRACT

Hot Mix Asphalt pavements (HMA) are one of the fastest growing pavements in all over the world which requires the proper selection of the aggregates and the bitumen (binder) for its preparation . The type of aggregates used in the its preparation are coarse aggregates , fine aggregates and fillers as fines . Fillers play a significant role in the stiffness of the HMA mixes as they fill up the voids in the mixtures due to which stiffness of the mixes changes .There are large number of fillers like stone dust , lime , saw dust ash , glass powder etc . which can be used in the preparation of mixes but proper selection of fillers is needed which will be helpful in enhancing the properties of the HMA mixes .

This present study deals with use of Saw Dust Ash with 1 % Hydrated Lime (by weight of mix) as a filler replacement of Stone Dust used in the preparation of the conventional mixes . Optimum binder content was obtained as 5.37 % by weight of aggregates by the help of stone dust (conventional) fillers and this obtained optimum binder content was then used same in all the modified mixes with saw dust ash and hydrated lime fillers . The modified specimens were prepared by replacing stone dust with saw dust ash 10 % , 20% , 30 % , 40 % , 50 % , 60 % , 70 % and 80 % and 1 % hydrated lime (by weight of aggregates) .Marshall tests , Static modulus tests , Indirect tensile strength tests were performed to study out results and make comparisons between the values . Resilient modulus was also found out by empirical relations so as to design the pavements using IIT pave software .

The results concluded that Marshall stability , Resilient modulus , Static Modulus and Indirect tensile Strength were increased in 64.08 % , 39.72 % , 45.83 % and 33.33 % respectively correspond to usage of fillers at 60 % of Saw Dust ash and 1 % Hydrated Lime by weight of aggregates and with respect to conventional filler (Stone dust) in the HMA mixes .

The optimum value of with 60 % of Saw Dust ash and 1 % Hydrated Lime by weight of aggregates is suggested as the optimum value which can be used in the design of flexible pavements .

CHAPTER - 1

INTRODUCTION

1.1 GENERAL

Road development relates to the most vital key for the development of infrastructure and hence plays a fundamental task in the growth of the country which can be in the form of economy, aesthetics, gross domestic product and efficiency. The coverage of the road network in India which includes all road categories such as National Highways, State highways, District Roads, Rural Roads, Urban Roads and Project Roads has reached to 5903293 km in length as of January 2019 which has also been stated as second largest road network as compared to other countries in the world. For the better road development of roads, quality of roads should be better because as the time passes and traffic moves on roads it starts deteriorating. So to maintain the quality of roads for not getting deteriorating better mix design should be prepared for the roads to prevent pavement distresses.

1.2 TYPES OF PAVEMENT

There are two types of pavement which are being constructed namely Flexible pavements and Rigid pavements. Between the two pavements discussed Flexible Pavements are constructed the most. These pavements are discussed in detail below:

(i) Flexible Pavement : It mainly consists of four main layers namely Subgrade , Sub-base , Base and the topmost wearing courser layer called Bituminous Surface or Hot Mix Asphalt (HMA) . Load will be transferred by layer to layer from top wearing bituminous course to bottom sub - grade and each of the layer will behave elastically during the load transfer mechanism. Figure 1.1 shows a typical flexible pavement and depicts how the pavement behaves during load movement .

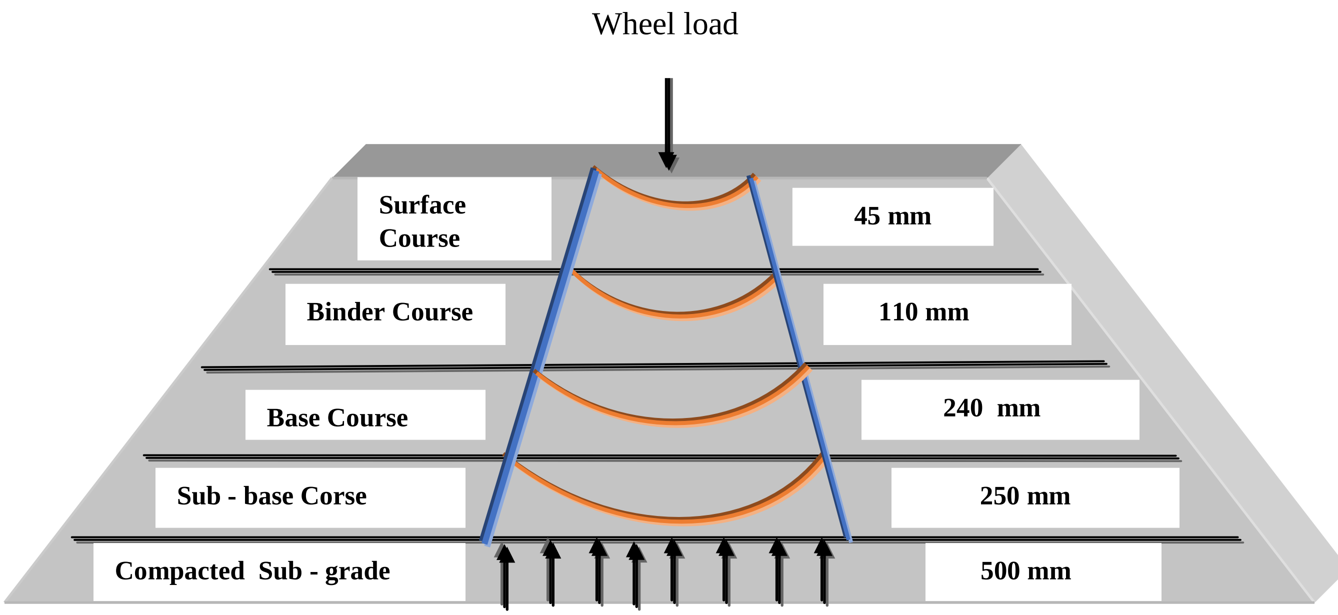

Figure 1.1 : Typical Flexible Pavement

(ii) Rigid Pavement : The layers present in the rigid pavement are Pavement Quality Concrete (PQC - Top Most layer) and then below it has Plastic Sheathing Membrane (125 micron) , (Dry Lean Concrete (DLC) , Sub - Base and then lastly Sub - grade . Load in Rigid Pavement is dispersed through slab action and due to good modulus of elasticity and stiffness of concrete slab the load is taken mostly by PQC or Cement Concrete (CC) slab. A typical cross section of Rigid Pavement and its load distribution is shown below in Figure 1.2.

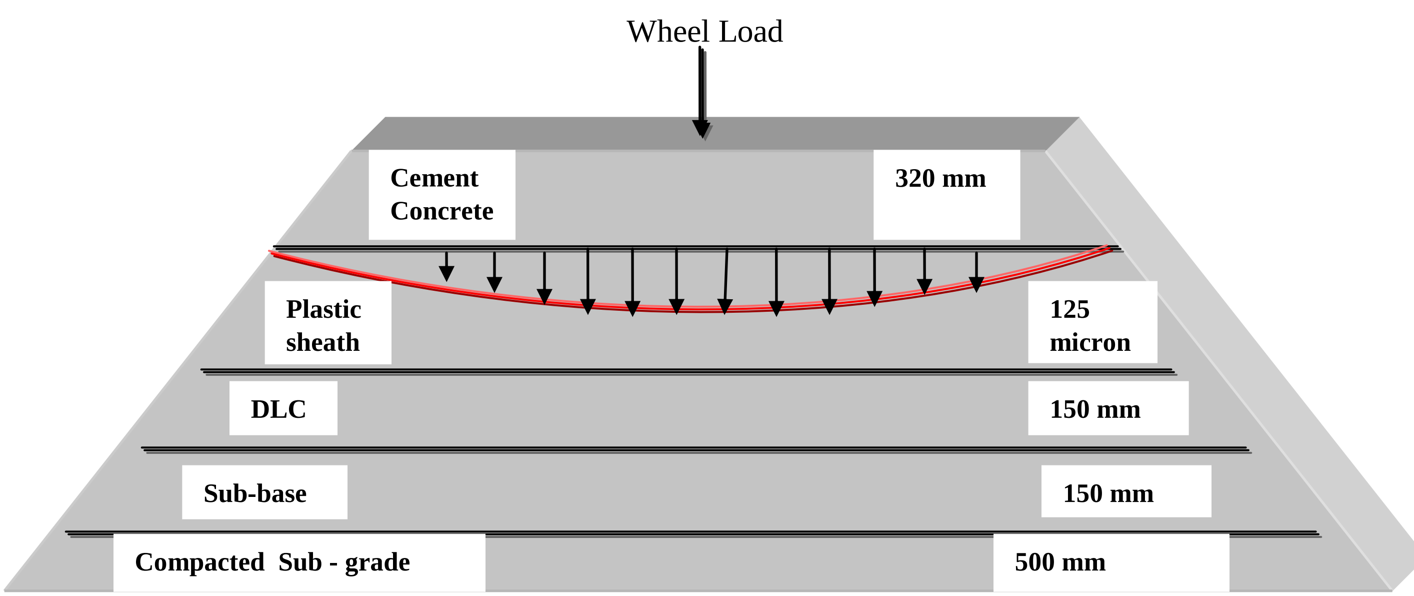

Figure 1.2 : Typical Rigid Pavement

1.3 BITUMINOUS CONCRETE

Bituminous Concrete (sometimes also called Asphalt Concrete) is the topmost black surface of the Flexible Pavement used up on the roads. It consists of aggregates and asphalt (Bitumen) where they are mixed together and bitumen act as a binding agent in the mix. There are different types of mix by which bituminous concrete is prepared namely Hot mix and Cold mix. This thesis is based on hot mix asphalt design so it is discussed in detail.

1.4 HOT MIX ASPHALT

Hot Mix Asphalt pavements (HMA) are being constructed in India from so many years and is continuously increasing its growth now also as it has become the integrated part of the infrastructure development of the country. But we all know as the traffic starts moving on the roads it starts deteriorating and distresses like fatigue cracking and rutting deformations comes on the roads. Subsequently, it leads maintenance of roads in the form of quality and proper mix designs. Researches are conducted every year by researchers and scientists on Hot Mix asphalt design processes and design proportions by alternating its ingredients and additives so as to produce best mixes. Thus proper care, accuracy and precision needs to be taken so as to obtain best HMA mix.

Hot Mix Asphalt mix design contains approximately 94% - 95 % of aggregates (Fine Aggregate ,Coarse Aggregate and Filler) and 5% - 6% bitumen and air voids. The aggregates and bitumen are allowed to heat and mix together so as to form a bond between them and to obtain a good quality mix. Following are the properties that a good Hot Mix Asphalt should posses when it used in paved roads:

i) Fatigue Resistant: As the traffic load is allowed to move on the roads it starts developing tensile strains at bottom of bituminous layer which ultimately leads to micro cracks and then bigger cracks. These cracks tries to reach to top surface as repetitions of load starts increasing and takes the form of alligator cracks. To ensure a fatigue resistant mix optimum asphalt binder content should be chosen, amount of filler used should be optimum to provide good stiffness to mix \, modified binders should be used to reduce the fatigue phenomenon.

ii) Rut Resistant: Rut means non recoverable plastic deformations which happens gradually as soon as traffic loads starts moving on roads. The main reason for rutting is vertical strains coming over the subgrade layer which in turn leads to large deformations also as number of load repetitions increases. Due to these deformations layers above (Granular and Bituminous) takes the deformed shape of subgrade deformation. Other than the subgrade failure bituminous mixes suffer secondary compaction and shear deformations directly coming from heavy loads moving on topmost bituminous layer. To ensure rut resistant mix proper compaction of bituminous layer should be done, higher grade or modified bitumen should be used , Subgrade of higher modulus should be used and should be properly compacted.

iii) Durability : Durability in pavements means should be such that it should be long lasting throughout its service life. This can be achieved only if no extreme aging and hardening of surface occurs. To ensure proper durability of HMA. proper coating of binder bitumen should be there around the aggregates of mix otherwise if there will be holes left in the coating then it can lead to moisture induced into it and bond between the binder and aggregates will be lost.

iv) Stability : It is the maximum vertical load in kg or kN taken up by the pavement under overcoming loads. In laboratory it is found out by Marshall stability test where loading is applied to cylindrical Marshall specimen and failure load is noted. For stability to be good optimum bitumen content should be chosen , aggregate gradation should be chosen carefully and proper mixing and compaction should be done .

v) Skid Resistance : Skid Resistance is another crucial factor in HMA pavements which is maintained by properties of aggregates like its shape, angularity, texture and size. Other than this care for binder content should also be checked i.e. optimum binder content should be chosen otherwise unnecessary bitumen will bleed out and will lead to more slip.

v) Workability : Workability means with how much ease you can work with the mix without facing problems . HMA should be such that it should be easy to compact after the mix is prepared and it should also not fail in performance during its serviceability .

vi) Air Void Content : Air void content in HMA also plays up important role where according to specifications in MORTH should not be less than 4% and more than 8% . A less air void content than minimum will lead to flushing where all bitumen will flush out of surface as it will not get space to flow and other than this if air voids will be more than maximum then more air and water will get entrapped which can also lead to problems. To ensure proper air voids then it should be between 4 % - 8% for some compaction of overcoming traffic loads.

1.5 STATEMENT OF THE RESEARCH PROBLEM

HMA is the pavement where conventional fillers like Stone Dust and Ordinary Portland Cement (OPC) are being used up by mostly every contractor in the pavement construction. If we talk about their cost and economy when they are used in laying on stretches of roads then they are not cheaper so we need to look for the fillers which are cheaper enough when laid on the roads. The main role of fillers in HMA is to make mix more stiffer, stronger and more dense graded material. To obtain the above discussed property of fillers we need to look for the fillers which are rich in binding like Calcium Oxide (CaO) also .

On considering the above properties in mind this thesis aims to evaluate the aptness of Saw Dust Ash with 1 % Hydrated Lime as filler in Hot Mix Asphalt pavements construction. The reason behind considering Saw Dust Ash as a filler is it is approximately free of cost and contains good amount of CaO in its chemical composition. Other than this using Hydrated Lime is also helpful because it also contains good amount of CaO hence when together they will be used then it might increase binding in the mix also increase stability and stiffness of the mix.

1.6 OBJECTIVES OF THE STUDY

- Evaluation and feasibility of Saw Dust Ash and Hydrated Lime as filler material in HMA and comparison with Stone Dust filler.
- To increase the Marshall stability value of the HMA by using Saw dust Ash and Hydrated Lime as a filler as compared to stone Dust filler.
- To increase the stiffness value or resilient modulus value of the mix by using Saw Dust Ash and Hydrated Lime as fillers so that we can reduce strains coming on the bituminous mixes.

- To check all the other tests like Indirect tensile strength (ITS) and Static modulus of the HMA by using Saw dust Ash and Hydrated Lime as a filler as comparing it with Stone Dust filler.
- To design the pavement by using the resilient modulus value of the mix with Saw dust Ash and Hydrated Lime as a filler and comparing the design with Stone dust filler.

1.7 OUTLINE OF THESIS

- Chapter 1 contains Introduction to road pavements, classification of pavements, overview on Hot Mix Asphalt and research objectives.
- Chapter 2 contains description of materials and specifications used in the HMA design for the current study work.
- Chapter 3 contains literature review of the past studies done on the current study area.
- Chapter 4 contains the mix design and material testing of HMA.
- Chapter 5 includes the results of the tests performed.
- Chapter 6 discusses about design of pavement through IIT pave by the help of modulus of conventional and modified mix.
- Chapter 7 discusses about conclusion of the study work.

CHAPTER - 2

LITERATURE REVIEW

2.1 GENERAL

This literature review deals with the past researches which had already been conducted related to current thesis work " Laboratory Investigations of Hot Mix Asphalt (Grade 1) Using Replacement of Stone Dust with Saw Dust Ash and 1 % Hydrated Lime as a Filler " which are discussed below :

Dr. Hasan et al . (2011) tried to check out the feasibility of using the glass powder as a filler in replacement of Ordinary Portland Cement (OPC) and traditional limestone powder fillers used in the Hot Mix asphalt . Three filler contents as 4% , 7% and 10 % (weight of aggregates in mix specimens) ,three specimens for particular filler and its particular investigation filler content so nine specimens as a whole were chosen to investigate the Marshall properties and volumetric analysis . Optimum binder content through results came out as 5% and was taken in the preparation of modified mixes . Before conducting the Marshall tests so as to check stability of the mixes , they performed the basic tests of aggregates and asphalt to check them under the specification limits.

Results showed that there was increment in stability in the range of 6 % to 36 % depending the type of percentage of filler used . The optimum content of the glass powder obtained was 7 % where up to 13 % increase in stability , 39 % decrease in flow value and 10 % decrease in density were observed as a whole .

Tayh et al . (2011) conducted study on various types of fillers like conventional dust , Portland Cement (PC) , Limestone (LS), Portland Cement in cold state (CPC) , Hydrated Lime (HL) and 1% Hydrated Lime as an additive that can be used in preparation of HMA mixes and then tried to find out that out of above three fillers which one shows improved Marshall tests results .

Total 90 samples as a whole with binder content starting from 4 % to 6 % in a gap of 0.5% were prepared so as to determine optimum binder content for each mix . It was observed that the highest stability was observed as 13.55 kN as compared to all other fillers and at 5.5 % optimum binder content which is also shown in Figure 2.1 . There was no tests done with increasing filler content in this study .

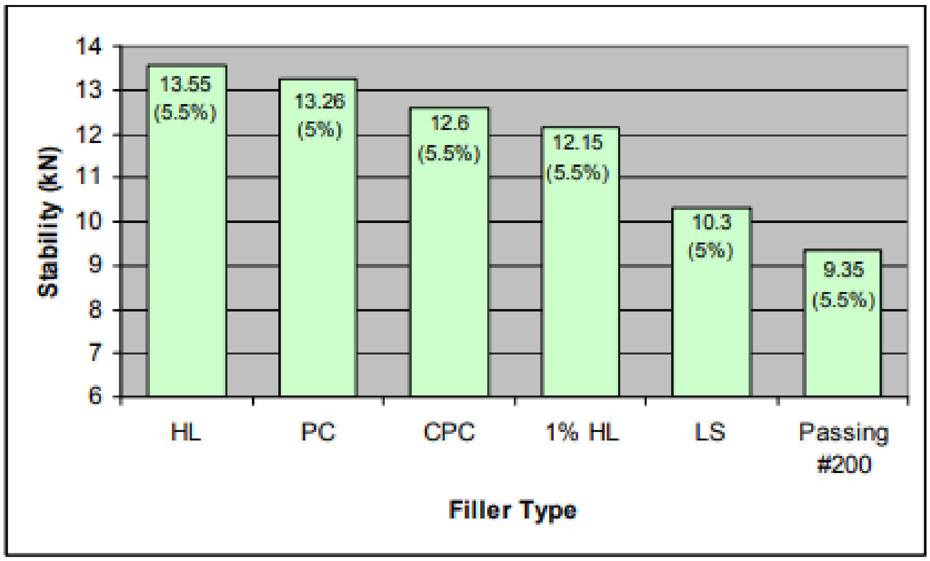

Figure 2.1 : Stability charts vs different fillers

Nathem et al . (2013) tried to study the effect of different fillers like Portland Cement, Limestone powder and Glass powder (Waste) by varying their content from 4% , 6% and 8% by total weight of aggregates . Optimum binder content as 4.9 % by weight of aggregates was used in preparation of modified mixes which came out by varying bitumen percentages from 4 % to 6 % in a gap of 0.5% . Stability observed at the optimum binder content was 10.4 kN through conventional mixes and by Marshall test . Nine specimens were made for every filler and its each content so as to study out the Marshall properties and volumetric analysis . Results depicted that at 8 % of glass powder has the higher stability increase by 11.7 % and 14.3% with Portland Cement and Limestone respectively . Results of Marshall are shown in Figure 2.2 .

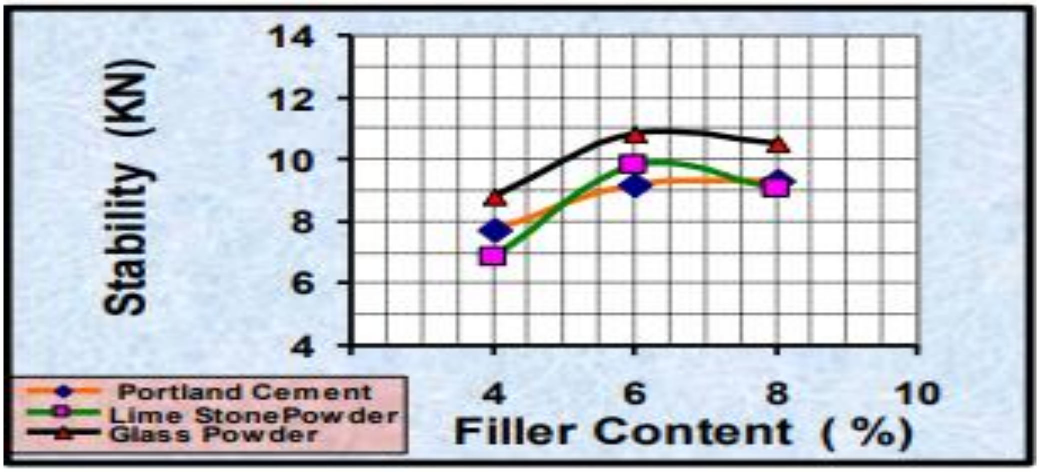

Figure 2.2 : Stability values vs different fillers content of different fillers

Kar et al . (2014) tested out the aptness of fly ash as a filler in the preparation of HMA specimens . Control mixtures were prepared by the cement and the stone dust fillers and tests like Marshall , indirect tensile strength and retained stability were done to make comparison between the control and modified mixtures .

Results predicted the increase of stability up to 5 % bitumen content and then got decreased for every filler but it was also seen that fly ash has least stability values , least indirect strength and lowest retained stability as compared to other fillers .

Murana et al . (2014) analyzed the Marshall properties for partially replacing Rice Husk Ash with the cement as filler in the preparation of HMA specimens . Filler content was taken from 0 % , 5 % , 7.5 % to 25 % (in a gap of 2.5 %) . Twelve specimens of conventional cement filler were made to determine OBC by varying bitumen content from 4.5 % to 7.5 % .Results predicted out the OBC value of 5.5 % and 10 % of RHA at this OBC as they were under the specifications of Marshall properties .

Erfen et al . (2015) checked out the usefulness of Egg Shell as a filler type for the increment of the properties of the flexible pavements .The Egg Shell content in the preparation of the modified mixes were taken as 0 % , 1% , 3% and 5 % . Total 15 samples for control mixture with 3 samples at single binder content starting from 4.5 % to 6.5% in a gap of 0.5% by weight of mix were taken so as to determine the optimum bitumen content by Marshall stability tests which will further be used in the modified mixes with egg shell filler .

Results predicted that optimum binder content came out at 5.38 % with 980 kg Marshall stability from the conventional mixes and optimum egg shell content came out at 3.38 % with 1110 kg marshall stability from modified mixes which finally meant that stability was increased . Results also predicted that percentage of egg shell filler from 3 % to 5 % will only give good and satisfactory results .

Yilmaz et al . (2015) conducted study on using different bitumen modifiers like Styrene-Butadiene- Styrene (SBS) , American Gilsonite (AG) and Iranian Gilsonite (IG) and Hydrated Lime (HL) together as a whole for the prediction of Marshall tests , moisture induced damage tests , Indirect tensile stiffness modulus tests and Wheel track tests . The contents taken for the additives of bitumen Dynamic shear rheometer (DSR) tests were 3 % , 4 % and 5 % for SBS , 10 % , 11 % and 12 % for AG , 9 % , 10 % and 11 % for IG and out of them 4 % , 11 % and 10 % of SBS , AG and IG were chosen respectively for the preparation of modified mixes with 2 % HL as they showed almost same results .

Results showed that for conditioned and having HL mixtures SBS samples had best results and for rest AG modified showed good results in Marshall stability tests . For retained Marshall stability and indirect tensile strength test SBS with 4 % bitumen showed good results . For stiffness modulus test and wheel track tests mixtures with 11 % AG (by bitumen weight) had best results .

Murana et al . (2015) conducted a study on partial replacement of Cement with the Bagasse ash as fillers in the HMA mixes . The content of filler replacement which was taken for the were starting from 0 % (control) to 50 % in a gap of 10 % for the unmodified and modified specimens . A total of seventy two specimens were made to study out the marsahl properties for all type of specimens . Tests were carried out for every type of filler with increasing bitumen content from 4.5 % to 7.5 % . Results predicted that usage of 10 % bagasse and 90 % cement at different bitumen content has only met the specifications and hence was suggested for future .

Ogundipe et al . (2016) conducted the Marshall stability tests with conventional crushed stone dust (CSD) filler and hydrated lime (HL) modified filler so as to check whether hydrated lime would be able to enhance the properties of modified mixes or not . The filler CSD content was taken as 10 % in weight for control CSD mixtures and same was replaced with HL in the lime modified mixes .Both type of mixes were prepared by varying bitumen content from 5 % to 7.5 % and optimum binder content of 6.5 % was obtained for both type of modified and unmodified mixes . Marshall tests results predicted stability values of 8.2 kN and 7.9 kN for HL and CSD mixes respectively and hence this incremental value of stability suggested to use hydrated lime as a filler in mixes .

Yasanthi et al . (2016) studied the effect of using the waste materials like saw dust ash (SDA) as a filler replacement , additive Polyethylene Terephthalate (PET) fibres of 3 cm in length and asphalt waste in the preparation of HMA specimens .The weight taken of the saw dust ash for the modified mixes were 30 g and 50 g in same amount of replacement of the stone dust for conventional mixes and weight and length taken for the PET fibres as an additive were 24 g, 36 g , 48 g and 1 cm , 3 cm respectively . Weight of asphalt waste taken was 20 % in the mixed gradation of samples for the its mix preparation .Bitumen taken for the determination of optimum bitumen content was taken in the range of 4 % to 6 % with gap of 0.5 % and came out as 5.28 % from conventional samples . OBC obtained for SDA 30 g , SDA 50 g , PET 2 % 1 cm , PET 3 % 1 cm , PET 4 % 1 cm , PET 2 % 3 cm , PET 4 % 3 cm and Asphalt waste were 5.5 % , 5.2 % , 4.87 % , 4.7 % , 5.0 % , 5.03 % and 4.67 % respectively and variation is shown in Figure 2.3 .

Results suggested that use of 2.74 % SDA by weight of total aggregate , PET fibres of 3 cm and 2 % by weight of aggregate will give satisfactory results . Other than this by using asphalt waste stability increased at every content other than 5 % binder content .

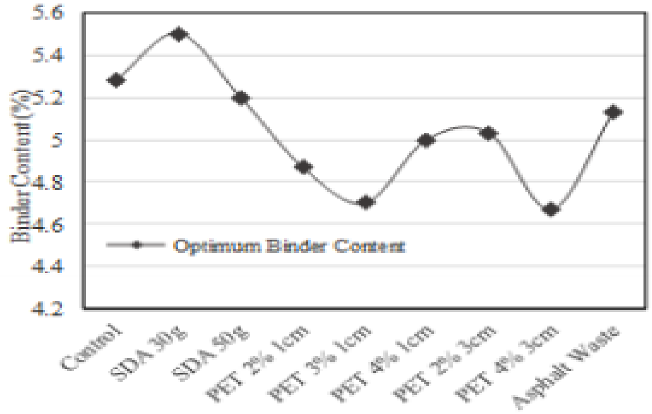

Figure 2.3 : Binder content vs different waste materials

Mahmood et al . (2016) checked out the aptness of White Cement Kiln Dust (WCKD) as a filler in replacement of Limestone as a filler used in the HMA mixes . The ratios of filler content for the investigation were partial to full replacement by WCKD filler starting from 0 % to 100 % (by weight of limestone) and in a variation gap of 25 % and hence five type of mixtures were prepared (one control with 0 % WCKD and other with 25 % ,50 % , 75 % , 100 %) . The tests conducted for the investigation of the HMA specimens for modified and unmodified were Marshall Test and Indirect Tensile Test .

According to the results it was seen that all stability , Indirect tensile strength got their maximum value at 50 % WCKD and 50 % Limestone . The optimum values as of stability (kN) and indirect retained strength (%) for conventional and optimum mixture were (15.4 kN , 12.3 kN) and (91 % , 79.73 %) respectively .

Lekhaz et al . (2016) studied the effect of using fillers like Cement , Ground Granulated Blast Furnace Slag (GGBS) and Brick Dust in the preparation of HMA specimens . Content of fillers stipulated in the study for above specified fillers was 5 % by weight of mix . Test specimens were made according to Marshall procedure so as to study marshall properties and to find optimum binder content for all the mixtures prepared by these three fillers . The range of bitumen content taken was from 4.5 % to 6 % in a gap of 0.5 % so as to determine optimum binder content (OBC) .

According to the results stipulated it was seen that highest stability value was achieved 15 kN at 5.64 % OBC and in cement filler whereas GGBS , brick dust achieved stability (kg) and OBC value (%) at 1347.01 , 1198.59 in kg and 5.9 , 5.85 in % respectively . Cement was suggested as a good filler to used in the mixes of HMA .

Bhat et al . (2016) studied the effect of using Concrete dust (CD) and Brick dust (BD) as fillers in the preparation of bituminous mixes . Marshall tests and volumetric analysis was done to determine the optimum binder content and the Marshall stability value of specimens made by the help of these two types of fillers . Bitumen content was taken starting from 4.5 % to 6 5 in a gap of 0.5 % to determine in OBC value for both the specimens .

Results predicted that both CD and BD specimens had their maximum stability at 6 % bitumen and values obtained at this content were 13.2 kN and 18.12 kN respectively . Brick dust filler was suggested for the future study .

Hussein et al . (2017) checked out the effect of additives like High-density polyethylene and Crumb rubber powder (CRP) on bitumen and studied the properties like Marshall properties , Moisture sensitivity ,wheel track tests for the HMA specimens prepared by these modified bitumen . Content of HDPE (4 % , 5 % and 6 % by weight of bitumen) and CRP (5 % , 10 % and 15 % by weight of bitumen) were taken for modification . Optimum content of 6.4 % of bitumen was taken for the preparation of specimens .

Results predicted the increase in stability of 32.92 % when 5 % HDPE and 10 % CRP was used in the unmodified HMA specimens. Tensile strength ratio was increased and rut depth was also decreases when HDPE and CRP were used .

Osuya et al . (2017) checked out the suitability of considering saw dust ash as a filler in partial replacement of the granite filler . The content of saw dust ash used in the partial replacement of granite dust was 0 % to 25 % in a gap of 5 % between them . Optimum binder content of 5.9 % obtained from control sample was taken further in the preparation of modified mixes with saw dust ash fillers . Marshall tests were carried out for the stability results and volumetric analysis . Results predicted the stability of 18.2 kN at optimum value of 15 % saw dust ash and hence was seen that saw dust ash enhanced the properties of mix . The reason behind increment was suggested that saw dust ash contains high amount of Calcium oxide (CaO) .

Affrin et al . (2017) tried to improve the Moisture damage in HMA specimens by the help of using agent like Hydrated Lime which was finally used to reduce stripping in specimens .

Hydrated Lime (HL) was added in the control specimens in the varying content of 0 % to 2.5 % (by weight of aggregate) in a gap of 0.5 % between them . Optimum binder content was obtained as 5.5 % through control samples and was then used in the HL modified samples . Indirect tensile strength , Marshall test and retained stability were found for the conventional an HL modified samples and it was seen that 2 % addition of HL produced higher an satisfactory results .

Tahami et al . (2018) studied the effect of using biomass ashes namely Rice Husk Ash (RHA) and Date Seed Ash (DSA) as a fillers in preparation of HMA specimens . Replacement of DSA and RHA taken for testing were partial to full starting from range of 0% to 100 % with a gap of 25 % . Marshall tests , Stiffness modulus , Four point bending and wheel track tests were done to investigate the properties of control and modified mixtures . Optimum binder content was taken as 5.6 % by weight of specimen obtained from the control mixtures and was taken constant throughout for all modified samples . Filler content was taken as 0.9 times the bitumen content taken for the mixes .

According to the results it was seen that Marshall stability and stiffness modulus increased with both of the fillers (DSA and RHA) and with their every increasing replacement .Wheel track test observed that rut depth decreases with increasing replacement of fillers . Bending test predicted that fatigue life or cycles of failure also increased with increasing content of both fillers .

Suvarna et al . (2019) has conducted the study on different fillers like Stone dust , Ceramic dust and Brick dust as fillers in the preparation of Bituminous Grade 2 specimens and checked out which of them was useful in enhancing the properties of specimens . They conducted Marshall , Indirect tensile strength (ITS) and Fatigue tests for the comparison of the results obtained by using these fillers . Content of filler was taken as 2% for all fillers in the HMA specimens . Test specimens were made to find the maximum stability and optimum binder content and it came out to be maximum for ceramic dust at 1310 kg and at 5.5 % OBC . It was also seen that ceramic dust specimens has the highest ITS values and modulus as compared to other fillers .

Kumain et al . (2019) checked out the feasibility of Saw Dust Ash (SDA) as a filler replacement with Ordinary Portland cement (OPC) by varying percentages of SDA starting from 0 % to 100 % with a gap of 10 % between them to be used in the preparation of HMA specimens . Marshall tests and volumetric analysis was done to investigate the properties of the compacted specimens . Optimum binder content was determined first by varying bitumen content from 5 % to 7 % in a gap of 0.5 % and it came out as 5.5 % through the conventional cement samples .

Results predicted stability value of 11.2 kN with no SDA mixture (control) and 7.5 kN with 10 % SDA . It was also seen that stability value got decreased after the use of 10 % SDA .

CHAPTER - 3

MATERIAL AND SPECIFICATIONS FOR HMA

3.1 HOT MIX ASPHALT COMPOSITION AND ITS MATERIAL SPECFICATIONS

Hot Mix asphalt is a mixture of following components namely fine aggregates, coarse aggregates , filler material and binding agent bitumen .

The materials used for this thesis work as listed and discussed in detail below:

- Bitumen of Viscosity Grade (VG) 30
- Coarse aggregates (20 mm and 10 mm)
- Fine aggregates (< 4.75 mm)
- Filler (75 micron size) - Stone Dust (Control)
- Filler (75 micron size) - Saw Dust Ash (Investigation) and Hydrated Lime (Investigation)

3.1.1 Bitumen

Bitumen is obtained as the last leftover residue from fractional distillation of the crude petroleum oil . It is basically a viscous liquid or solid material which composes of hydrocarbons and their subordinates soluble in trichloroethylene and gets softens when subjected to heating . Look wise it is black in color and has binding adhesive properties . There are various viscosity grades (VG) bitumen available in the market namely VG 10 , VG 20 , VG 30 and VG 40 and out them VG 40 is most viscous in nature and is hardest of all.

The bitumen used up in current thesis work is unmodified VG 30 grade and was bought from a distributor in Meerut , Uttar Pradesh as shown in Figure 3.1 . Paving bitumen when used for the HMA preparation should satisfy the specifications required as per " Paving Bitumen " IS 73 : 2013 and MORTH (Ministry of Road Transport and Highways) specifications for Road and Bridges Works (Fifth Revision) April 2013 . Specifications table is shown below in Table 3.1 :

Figure 3.1 : Bitumen

Table 3.1 : Bitumen tests and their specifications (Source : IS 73 2013 , Clause 6.2)

Property	Specifications for VG 30 Grade	Codes Referred
Penetration at 25^0 C ,100 g, 5 s, 0.1 mm, Minimum	45	IS 1203 : 1978
Softening Point , ^{0}C , Minimum	47	IS 1205 : 1978
Specific Gravity , at 27^0 C	0.97 to 1.02	IS 1202 : 1978

3.1.2 Coarse aggregates

These are the aggregates obtained from hard rock and hard gravels when they are crushed into pieces. Their size is given by the those aggregates which gets retained on 2.36 mm sieve size. To use them in the preparation of mixes they should possess properties like cleanliness, hardness, durability and should be free from dust and organic matter. The coarse aggregates used herein the thesis were taken from the Civil Engineering Department of Thapar Institute of Engineering and Technology and sizes used were 20 mm and 10 mm and as shown in Figure 3.2 below . According to MORTH (Ministry of Road Transport and Highways) and IS specifications these coarse aggregates to be used in the preparation of mix should firstly assure the physical requirements as shown in Table 3.2 below after the Figure 2.2 .

Figure 3.2 : Coarse Aggregates

Table 3.2 : Coarse Aggregates tests and their specifications (Source : MORTH , Clause 507.2.2)

Tests	Specifications	IS Codes Referred
Aggregate Impact Value	24 % (Maximum)	IS 2386 Part 1V : 1963
Los Angeles Abrasion value	30 % (Maximum)	IS 2386 Part 1V : 1963
Combined Flakiness and Elongation Indices	35 % (Maximum)	IS 2386 Part I : 1963
Water Absorption	2 % (Maximum)	IS 2386 Part III : 1963
Specific Gravity		IS 2386 Part III : 1963

3.1.3 Fine aggregates

They are the crushed stone aggregates which pass through 2.36 mm sieve and retains on 75 micron sieve. Before using them in the preparation of mixes they should possess properties like cleanliness, hardness, durability and should be free from dust and organic matter. The fine aggregates used herein the thesis were taken from the Civil Engineering Department of Thapar Institute of Engineering and Technology and used were smaller than 4.75 mm .as shown in Figure 3.3 below :

Figure 3.3 : Fine Aggregates

3.1.4 Filler

Fillers are those which are used to provide stiffness , resistance and stability to the mixes by filling up voids left in the mixes. These are finest matter obtained from the rocks like rock dust or other matter like hydrated lime and cement. Generally the size of these fillers is given by the particles which pass through 75 micron sieve. Other than the conventional fillers like stone dust various fillers like Egg shell dust, Coconut ash , Rice husk ash , Saw dust ash , Slag dust , Date seed ash etc are used to modify the conventional mixes with these fillers in the form of stability , stiffness and modulus of mixes. The fillers used here in this current thesis to modify the mixes are Saw Dust Ash and 1 % of Hydrated Lime (By weight of mix) in replacement of Stone Dust conventional filler so they will be discussed in detail. According to MORTH to use any material as filler in HMA mix it should satisfy the grading requirements as listed in Table 3.3 below .

Table 3.3 : Specifications for fillers (Source : MORTH , Clause 507.2.4)

IS Sieve (mm)	Cumulative Percent Passing by Weight of Total Aggregate
0.6	100
0.3	95 - 100
0.075	85 - 100

3.1.4.1 *Stone Dust Filler (Conventional)*

It is the conventional filler which is being used up in mostly every HMA mixes being constructed in India or the World . This Stone dust is obtained by crushing quarry stones through crushing machines where machine consist of screens that traps larger material and allow to pass the smaller ones through it . Though we know that Stone dust provides good properties to the mixes but still researches are being carried out by the researchers to modify or increase the conventional properties provided by the Stone Dust fillers by replacing it with other fillers .The Stone Dust filler used herein the current thesis work for the preparation of conventional mixes is taken from the Civil Engineering Department of Thapar Institute of Engineering and technology as shown in Figure 3.4 below .

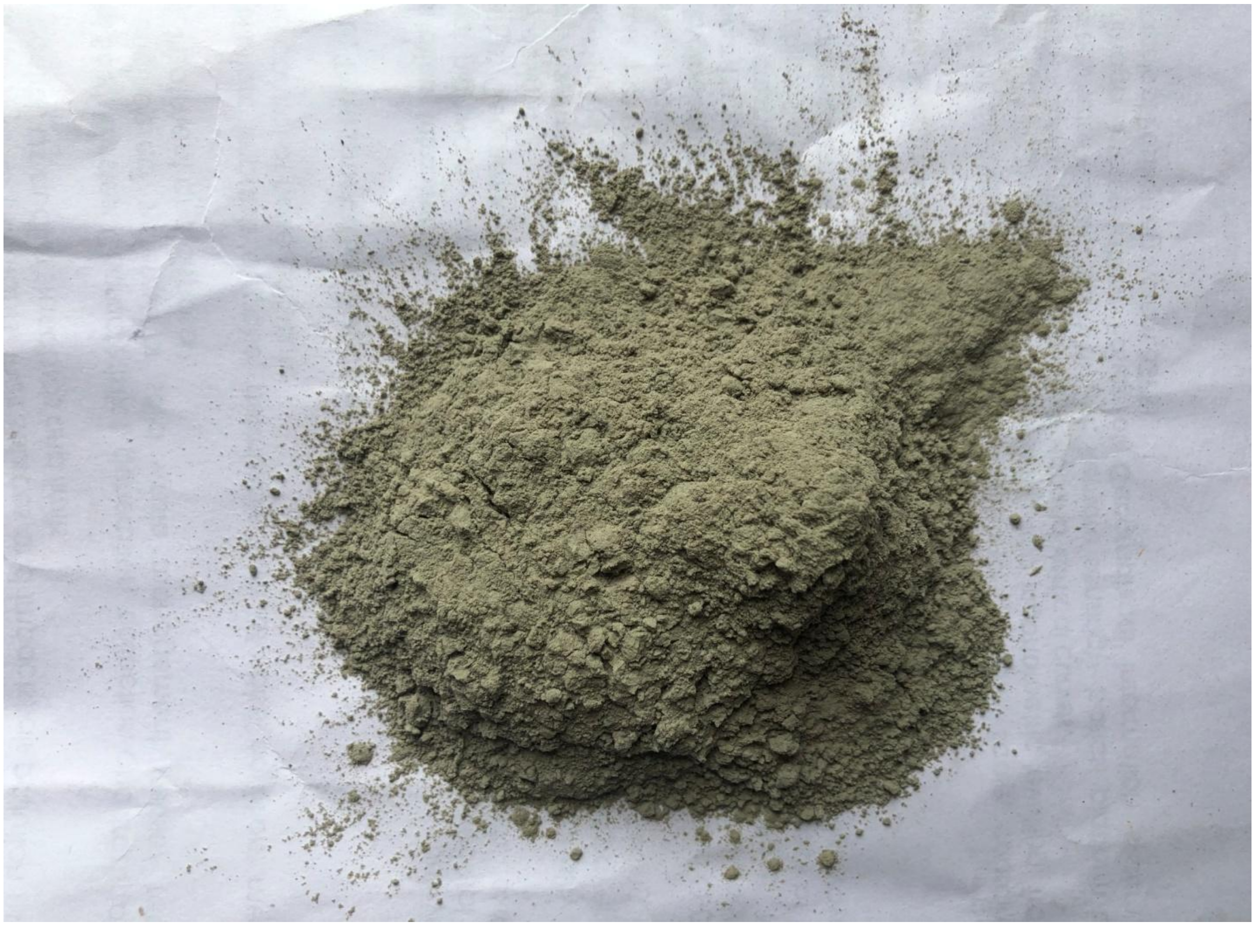

Figure 3.4 : Stone Dust

3.1.4.2 *Saw Dust Ash Filler (Investigation)*

Saw Dust ash is a material which is obtained from the burning of wood or you can say it is the residue leftover after the burning of wood . It is seen that saw dust ash is more is more cheaper or rather free than stone dust which you need to buy up from the stone crusher suppliers . As saw dust ash is cheaper than stone dust so it becomes the interest for the researchers and scientists to use it as a filler material and investigate its feasibility and effectiveness in the HMA mixes . Other than the cheapness factor of saw dust ash it was also seen that saw dust ash contains good amount of Calcium Oxide (Cao) as shown in the chemical composition given by **Osuya and Mohammed (2017)** and is depicted in Figure 3.5 .Use of Saw Dust Ash containing high amount of Cao might increase properties (Stability , Stiffness etc) of mixes so was taken in investigation . Saw Dust Ash is preferred over the saw dust as a filler material because saw dust is biodegradable in nature and is not good with water as if it comes in contact with the water then it swells up and destroy the properties like stability , resistance and stiffness of HMA mixes . Saw Dust Ash used herein the current thesis work was obtained from the waste wood dust of woodworks being carried out in Mechanical department Civil of Thapar Institute of Engineering and technology as shown in Figures 3.6 .

Chemical composition	Percentage (%)
SiO_2	5.30
Al_2O_3	1.90
Fe_2O_3	1.65
CaO	49.70
MgO	4.06
SO_3	9.04
WO_2	2.04
K_2O	21.72
P_2O_3	1.38
LOI	7.30

Figure 3.5 : Chemical composition Saw Dust Ash

(Source : Osuya and Mohammed (2017))

Figure 3.6 : Saw Dust Ash

3.1.4.3 *Hydrated Lime Filler (Investigation)*

Hydrated Lime is an inorganic compound whose chemical formula is given by $Ca(OH)_2$. It is also a good material to be used as a filler in replacement of stone dust filler as it also contains good amount of calcium oxide (CaO) which serves the purpose of binding . The chemical composition of Hydrated Lime given by **Halit Ozen (2017)** is shown in Figure 3.7 . According to the past studies it has been seen that hydrated lime interacts with some polar molecules of bitumen and makes a strong bond which helps in reducing stripping , age hardening and rutting of the HMA pavements . There are generally three methods of introducing hydrated lime to the HMA mixes namely - addition of dry hydrated lime to dry aggregates , addition of dry hydrated lime to wet aggregates and addition of hydrated lime in the form of slurry of lime and water . This current thesis has investigated addition of 1 % dry hydrated lime (by weight of mix) as a replacement for conventional filler to dry aggregates. The hydrated lime used herein the current thesis work was bought from the Scientific Junction chemical shop, Patiala and is shown in Figure 3.8 below.

Chemical properties	Method	Value
Total CaO (%)	EN 459-2	85.78
Active $Ca(OH)_2$ (%)	TS 32	82.04
MgO (%)	EN 459-2	3.52
Total CaO + MgO (%)	TS	89.3
Loss of ignition (%)	EN 459	22.51
Insoluble in acid (%)	TS 32	1.41
R_2O_3 (%)	TS 32	0.47
SO_3 (%)	EN 459	1.47
CO_2 (%)	EN 459	3.89
Physical properties		
Sandy-over 90 micron	EN 459	6
Density (kg/m^3)	EN 459	472

Figure 3.7 : Chemical composition of Hydrated Lime

Figure 3.8 : Hydrated Lime

3.2 HOT MIX ASPHALT MIX REQUIREMENTS AND SPECIFICATIONS

Hot Mix asphalt is prepared by mixing 94 % - 95 % of aggregates and 5 % - 6 % of binder (bitumen) content . For the convention and control mixes these aggregates and bitumen are unmodified without any additives or replacements and for the modified mixes scientists or researchers try to improve properties of mixes by partially replacing aggregates with RAP, Waste material or any other materials , try to replace conventional stone dust fillers (fines) with other equivalent fines like egg shell dust , coconut ash , saw dust ash and date seed ash etc . For the HMA mixes interaction of aggregates and bitumen is one of the important key factor for which you need to choose them very carefully and wisely. HMA mix preparation as per MORTH requires the following procedure and specifications which need to be satisfied and are listed below :

- Aggregate gradation
- Job mix formula
- Optimum binder content and mix design requirements

3.2.1 Aggregate Gradation

It is one of the basic starting step for the preparation of HMA mixes as gradation will only decide what size of nominal aggregates will be used for the preparation of mixes. Using different gradations of aggregates will give you different results so you need to take care what type of gradation you are using for the preparation of mix . Like for different course layers there will be different gradations so you need to choose wisely and carefully . Like as suggested in MORTH if we talk about surface course i.e. Bituminous concrete , there are two different types of combined gradations (Fine and Coarse aggregate both) specification limits for two different nominal size aggregates which need to be satisfied before preparation of mixes and are shown in Table 3.4 on next page . Gradation curve is shown in Figure 3.9 below . This current thesis has a concern on Bituminous concrete grade 1 so will be used further.

Table 3.4: Grading requirements for Bituminous Concrete layers (Source: MORTH, Clause 507.2.5)

Grading	**1**	**2**
Nominal Aggregate Size (mm)	**19**	**13.2**
Layer Thickness (mm)	**50**	**30 - 40**
IS Sieve (mm)	**Cumulative % by weight of total aggregate passing**	
45		
37.5		
26.5	100	
19	90 - 100	100
13.2	59 - 79	90 - 100
9.5	52 - 72	70 - 88
4.75	35 - 55	53 - 71
2.36	28 - 44	42 - 58
1.18	20 - 34	34- 48
0.6	15 - 27	26 - 38
0.3	10 - 20	18- 28
0.15	5 - 13	12 - 20
0.075	2 - 8	4 - 10
Bitumen content % by mass of total mix	Minimum 5.2	Minimum 5.4

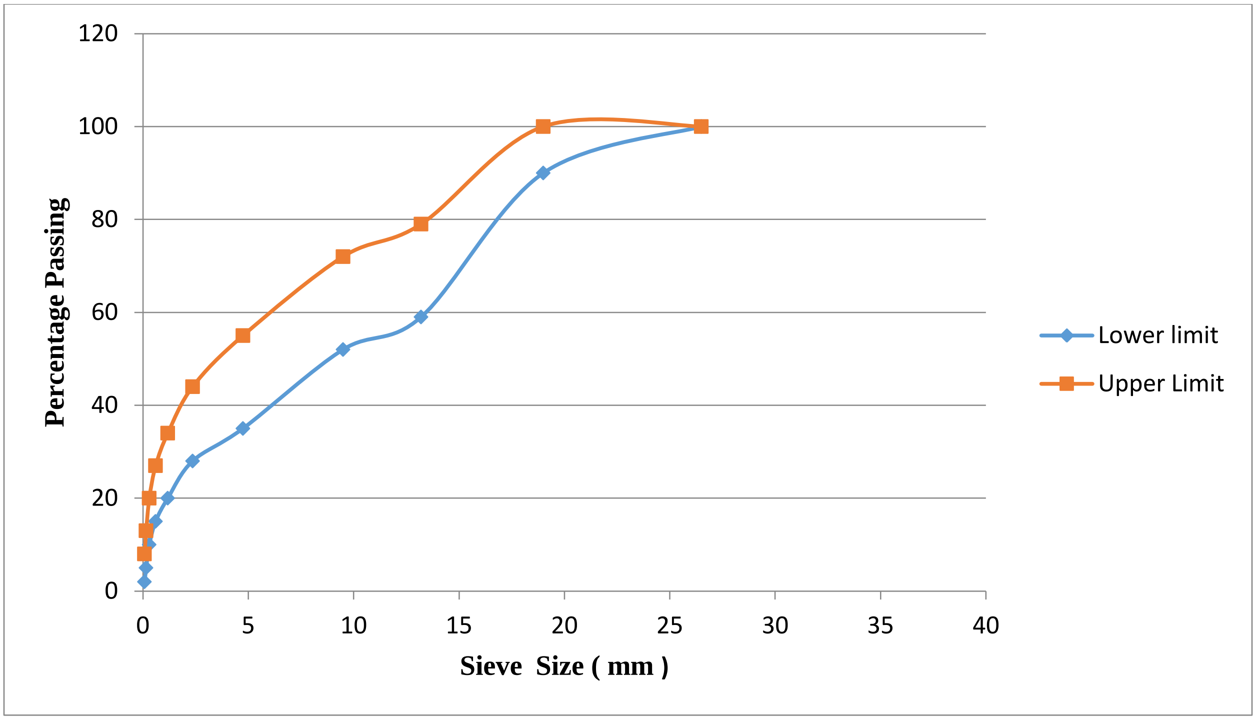

Figure 3.9 : Aggregate Gradation

3.2.2 Job Mix Formula

This Job mix formula is used when blending of aggregates is done for the preparation of mixes and is more accurate than mid - point gradation of combined aggregates from the specification limits . This Job mix formula will help in following points discussed below :

- Percentage of each aggregates (Coarse , Fine and Filler) by weight of total aggregate required in preparation of mix
- Single percentage of each aggregates passing each sieve used in the preferred combined blending gradation .
- The Job Mix Formula (JMF) used herein for the blending of aggregates is given by formula below :

  P = A x a + B x b + C x c + D x d

  where ,

  P = blended percentage passing for a given sieve

  A , B , C and D = percentage passing a sieve for individual bin a , b , c and d = proportion of bin to be added in the blending , where total = 1

3.2.3 Binder Content

It means the optimum bitumen content required in the mix to obtain minimum 4 % air voids and to satisfy mix design requirements as per MORTH listed below in Table 3.5 . This optimum binder content is obtained by performing the Marshall test on the mix as per MS - 2 Asphalt Institute Manual .

Table 3.5: Mix Requirements for Bituminous Concrete (Source: MORTH , Clause 507.3.1)

Minimum Marshall Stability (kN at 60^0 C)	9
Marshall Flow value (mm)	2 - 4
Number of Blow on each face of specimen	75
Percentage of air Voids (V_a)	3 - 5
Percent voids filled with Bitumen (VFB)	65 - 75
Minimum Percent voids in Mineral Aggregate (VMA) at 4 % air voids and 19 mm nominal aggregate	13

CHAPTER - 4

MIX DESIGN PROCEDURE AND TESTS FOR INGREDIENTS AND MIX

4.1 GENERAL

This section will cover the following tests and procedures for preparation and testing of Hot Mix Asphalt mixes as discussed below :

- Preparation of mixes by the help of Marshall Apparatus as per MS - 2 Asphalt Institute Manual and ASTM 6926 .
- Testing of Marshall Specimens for stability and flow value as per D 6927.
- Volumetric analysis of mixes.
- Testing of HMA mixes for its static modulus by Universal Testing Machine
- Testing Indirect tensile strength (ITS) of HMA mixes .
- Predicting Resilient Modulus of mixes through empirical relations .

4.2 MARSHALL TEST FOR BC GRADE 1

It is one of the basic method which is being used up by mostly every designer and contractor for the preparation of HMA mixes. By the help of Marshall mix design method properties like Stability , Flow value , Air voids , unit weight and most important factor optimum binder content of the mix (OBC) can be found out ." Stability "here means the maximum peak diametrical load taken by the compacted mix for constant rate of deformation . " Flow Value " means the maximum deformation (elastic and plastic) occurred at the peak Marshall stability load . " Optimum Binder Content " means the maximum binder content allowed in the mix preparation as after it bleeding of bitumen starts occurring in the mix or in terms of Marshall stability test it is the value which is obtained after which load (Stability) starts decreasing in the dial gauges of the Marshall assembly .

4.2.1 Apparatus required for Marshall mix preparation

- Flat metal pans and round metal bowls for heating and mixing of asphalt and aggregate.
- Hot oven or heating equipments for heating asphalt and aggregate and their mixture .
- Spoons , spatulas and trowels for proper mixing of aggregates and asphalt .
- Thermometers which can measure temperatures up to 300^0 C .
- Weighing balance of up to 5 kg capacity and sensitive to 0.1 g .
- Cylindrical compaction mould of diameter 101.6 mm and 75 mm in height , collar extension and the base plate . Other than this both end sides of compaction mould should be interchangeable so that base plate can be used both sides .
- Compaction hammer of 98.4 mm diameter , 4.5 kg in weight and should be able to lift and drop from 457 mm height .
- Compaction pedestal of 200 x 200 x 460 mm and wooden post capped with 305 x 305 x 25 mm steel plate .
- Specimen extractor consisting jack and disk of diameter not less than 100 mm .
- Lastly , welding gloves for holding hot specimens , face masks for preventing dust particles to go inside the body and marking crayons to specify specimens .

4.2.2 Procedure for mix preparation (Modified and Unmodified both)

- All aggregates including fine aggregate , coarse aggregate and fillers are taken are taken on such a way that their weight is approximately 1200 grams , falls under the gradation specified limits as per MORTH and their percentage used should be according to Job Mix Formula .
- These 1200 gm aggregates are mixed properly by trowels and spatulas and then allowed to heat at temperature of 175^0 C - 190^0 C as shown in Figure 4.1 and 4.2 .
- Bitumen content to be chosen for optimum binder content should be started from minimum content as specified in MORTH and at least 3 specimens should be prepared for each binder content .

Figure 4.1 : Unmodified mix with Stone Dust

Figure 4.2 : Modified mix while heating with Saw Dust Ash and Hydrated Lime

- The bitumen is allowed to heat to temperature of 120^0 C - 165^0 C depending upon type of grade used like here VG 30 was used so its temperature specified is approximately 160^0 C.
- The mixing temperature for the aggregates and the binder bitumen should also lie between 154^0 C - 160^0 C .
- Compaction assembly and rammer should be allowed to preheat to 95^0 C - 150^0 C before pouring mix into moulds .
- After all these things are heated up then base plate , mould and collar extension are put in series one after the other and mix is allowed to pour into assembly by the help of spatulas and trowels .
- These poured mix are then allowed to compact at temperature of 149^0 C with 75 number on blows on both sides of specimen by placing white paper on opposite side . The compacted specimens should attain a thickness of about 63.5 $\pm$ 1.27 mm as shown in Figure 4.3 and 4.4 .
- This whole compacted mix with mould is kept to cool for 24 hours at room temperature of 25^0 C and after 1 day they are allowed to extract from the mould through extractor as shown in Figure 4.5 .

Figure 4.3 : Unmodified conventional mixes

Figure 4.4 : Modified compacted mixes with Saw Dust Ash and Hydrated Lime filler

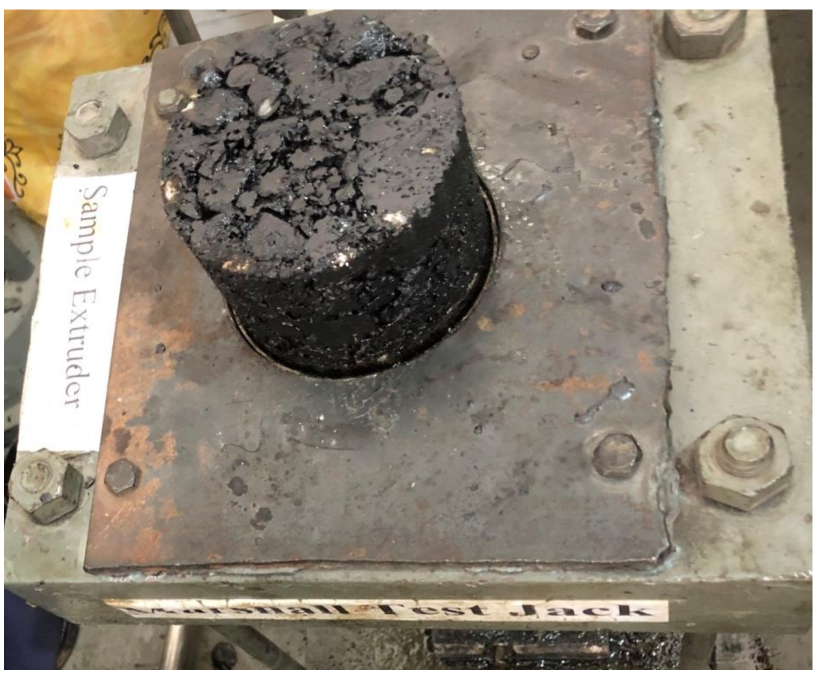

Figure 4.5 : Sample extraction from extractor

4.2.3 HMA mix testing (Modified and unmodified both)

- After the mix are extracted from the extractor their height are measured which should come between 63.5 ± 1.27 mm and if it does not comes in range then correction factors for stability are applied as per specifications in MS - 2 Asphalt Institute Manual .
- Determine the average bulk specific gravity (G_{mb}) of all the specimens as per ASTM D2726 code and bulk density of specimens by multiplying bulk specific gravity with density of water as shown in Figure 4.6 below .

Figure 4.6 : Saturated surface dry weight for Bulk specific gravity

- After determining the average bulk gravity and density of all the specimens , these specimens are then set to immerse in water bath at 60^0 C $\pm$ 1^0 C and for 30 - 40 minutes so as to determine the stability and flow value of the specimens at this weakest condition as shown in Figure 4.7 below .
- Specimens are taken out after 40 minutes and then allowed to adjust between the lubricated lower and the upper heads of the Marshall test assembly .
- Load is applied to the specimens by the Marshall assembly at the rate of 51 mm per minute until the failure load comes or load value starts decreasing on the dial gauges as shown in Figure 4.8 on next page .

Figure 4.7 : Specimens at 60^0 C water bath

Figure 4.8 : Marshall testing for specimens

- The failure load obtained from the gauge reading is termed as the Marshall stability value of the mix and the deformation corresponding to that failure load is termed as the flow value of that mix .
- Average value for stability of three specimens should be taken at each binder content to determine optimum binder content or to determine stability values for different replacement of filler content for modified mixes .

- At last theoretical maximum specific gravity (G_{mm}) for the unmodified and modified mixes are determined as per ASTM D2041 code so as to perform volumetric analysis on them. Figure 2.9 below shows G_{mm} test being performed on the mix .

Figure 4.9 : Theoretical Maximum Specific Gravity test for specimen

4.2.4 Volumetric analysis

It is the analysis by the help of which we will find the following properties of mixes as for listed below :

- Bulk specific gravity of specimens (G_{mb})
- Theoretical maximum specific gravity of specimens (G_{mm})
- Voids filled with bitumen (VFB)
- Voids in mineral aggregate (VMA)
- Percentage of air voids (V_a)

1) Bulk Specific Gravity (G_{mb}) : It is the ratio of oven dry mass of a unit volume of HMA mixture (including volume of aggregate , bitumen and air) to mass of same volume of water and is given by :

$$G_{mb} = \frac{A}{B-C}$$

where,

A = Dry mass of specimen in air

B = Saturated surface dry mass of specimen in air

C = Mass of specimen in water at 25^0 C

2) Theoretical Maximum Specific Gravity (G_{mm}) : It is the ratio of oven dry mass of a unit volume of HMA mixture (including volume of aggregate and bitumen only) to mass of same volume of water and is calculated as step wise procedure below :

- Weight of Flasks + Corks as (A)
- Weight of Flasks + Corks + Water as (B)
- Weight of Sample in Air as (C)
- Weight of Flasks + Corks + Water (25^0 C) + loose Sample as (D)
- Weight of Replaced Water as (C - (D - B)) and is equal to E
- Maximum Theoretical Specific Gravity is given by :

$$G_{mm} = \frac{C}{E}$$

3) Voids in Mineral aggregate (VMA)

These are those percentages of voids in the compacted HMA which are the intergranular spaces between aggregate particles filled by air voids and bitumen content only. It is given by the formula below:

$$\text{VMA} = 100 - \left(\frac{P_s G_{mb}}{G_{sb}}\right)$$

where ,

P_s = Percentage of aggregate by total mix weight

G_{mb} = Bulk specific gravity of paving mixture

G_{sb} = Bulk (dry) specific gravity of aggregate

4) Voids Filled with Bitumen (VFB)

These are those voids in the compacted HMA which are filled with the bitumen used in the mix . It increases with increase in bitumen content in the mix and also increases when mix becomes more finer . It is given by the formula below :

$$\text{VFB} = 100\,X \left(\frac{\boldsymbol{VMA - Pa}}{\boldsymbol{VMA}} \right)$$

where ,

P_a = Percentage of air voids in compacted HMA mix

4) Percentage of air voids (P_a)

These are the smaller air spaces between bitumen coated aggregate particles and is given by the formula below :

$$P_a = 100 - \left(\frac{\boldsymbol{100\,X\;G_{mb}}}{\boldsymbol{G_{mm}}} \right)$$

4.3 STATIC MODULUS OF HMA SPECIMENS

Static modulus is defined as the ratio of the stress coming on the specimens due to static loads divided by the strain obtained on those corresponding stress .

Static modulus of the mixes will only help you to predict the failure pattern under static loads when they comes over the pavement corresponding to those failure patterns study of stresses can also be done .

Failure pattern under the linear elastic and beyond elastic (non linear) can be observed by the help of this test . The static modulus in the current thesis work was found out by the help of Universal Testing Machine (UTM) under static compression load and procedure is discussed on next page :

a) Temperature for the test was noted down which was 25^{0} C and corresponding to temperature static modulus was predicted.

b) Specimen was allowed to set under the Universal Testing Machine (UTM) between the metal plate of UTM as shown in Figure 4.10 below .

Figure 4.10 : Specimen setting under UTM

c) Loading rate was set to 0.01 kN / seconds so that precisely stress (load per unit cross sectional area) can be found out by dividing load coming on the UTM monitor screen .

d) A arrangement was made as shown in figure 4.10 above to measure strains like on left side one LVDT (Linear Variable Differential Transformer) was attached and on right side one digital dial gauge was attached to measure displacement so that strain can be found out from that displacement by dividing displacement to Whole length of specimen .

d) Failure load was noted down from the screen so as to plot stress - strain curve of all the compacted HMA specimens .

e) Modulus of the specimens were obtained by dividing stress values to their corresponding strains .

f) Failed specimen is shown in Figure 4.11 below .

Figure 4.11 : Failed specimen under UTM test

4.4 INDIRECT TENSILE STRENGTH (ITS) OF HMA SPECIMENS

This Indirect Tensile Strength test will help you to determine the tensile characteristics of the compacted HMA mixes which will then help you to predict the cracking failure and cracking resistance of the pavements. This Indirect tensile strength test helps you to determine peak tensile stress (strength) that particular modified or unmodified specimen can take. A higher tensile strength of the specimen justifies the higher cracking resistance of the specimen under testing .

One of the most important property due to which mostly HMA pavements fails is the fatigue failure which occurs when the tensile cracks increases due to increasing tensile strains at the bottom of bituminous layers and ultimately is related to the stiffness of the pavement layers. So to reduce these tensile strains a check need to be made for the tensile strength of the compacted HMA mixes and hence Indirect Tensile Strength test is done to determine peak tensile stresses .

In this Indirect tensile tests same Marshall compacted specimen are prepared and allowed to set under compressive loading rate of 51 mm / minute through 13 mm wide loading strips in Marshall assembly along the vertical diametric plane of specimen as shown in Figure 4.12 below taken from ASTM D6931 . The reason behind using loading strips is to provide uniform stress distribution over the specimen which will ultimately create tensile load in horizontal direction and your specimen will get tear apart into two halves as shown in Figure 4.13 on next page .

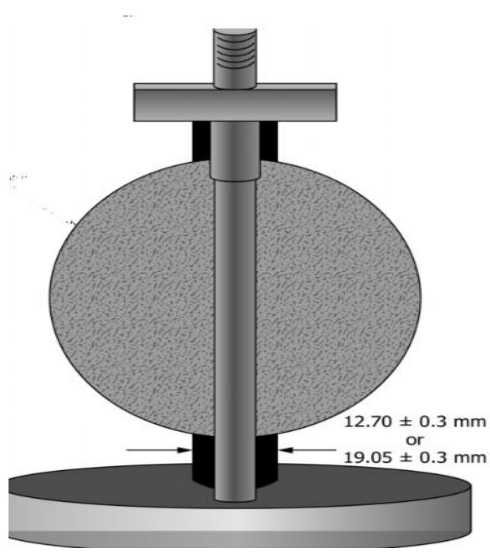

Figure 4.12 : **ITS testing**

The formula used here in this current thesis to calculate indirect tensile strength of the specimen is taken from ASTM D6931 code as shown below :

$$S_t = \frac{2000 \, X \, P}{\Pi \, X \, t \, X \, D}$$

where ,

S_t = ITS value , kPa

P = maximum peak load , N

t = specimen height immediately before test , mm and

D = specimen diameter , mm

Figure 4.13 : Failed specimen under ITS testing

4.5 RESILIENT MODULUS OF HMA SPECIMENS

It is one another most important laboratory test of the HMA mixes which need to be find out so as to determine the stiffness of the pavement under actual traffic loading conditions coming on them . In terms of mathematical relationship this stiffness is the ratio of stresses generated due to repeated loads divided by the recoverable elastic strain obtained from the test and formula is shown below :

$$M_r = \frac{\sigma}{\varepsilon_r}$$

where ,

M_r = Resilient modulus , MPa

σ = Stress due to repeated loads , MPa

$\varepsilon_{r} =$ Recoverable strain , no units

The stiffness value obtained will further can be used in the design and analysis of the flexible pavement like by the help of the stiffness value , actual and failure strains can be find out for HMA mixes .

In this current thesis work Resilient modulus value at 25^0 C for the compacted HMA mixes was predicted by the help of empirical relation predicted in ASTM STP 1265, Page 138 and temperature correction factor for prediction of resilient modulus at 35^0 C in Journals of materials in civil engineering by Hamad I. Al- Abdul Wahaab , Ibrahim M. Asi and Rezqallah H. Ramadhan , Page 304 as shown below respectively :

Log (y) = 3.198 + 1.162 Log (x) , $r^2 = 0.88$

where ,

y = Total resilient modulus at 25^0 C , psi

x = Indirect tensile strength at 25^0 C , psi

$$\frac{M_r(25\,^0C)}{M_r(T\,^0C)} = 0.1732\, e^{(0.0699\ \text{Test temperature})}$$

where ,

$M_r(25^0\,C)$ = Resilient modulus at $25^0\,C$

$M_r(T\,^0C)$ = Resilient modulus at test temperature , ^0C

After calculating the resilient modulus values of all the compacted modified and unmodified HMA specimens they were used in the failure strains equations and IIT pave for the design of flexible pavements and values were compared between both type of specimens as discussed in Chapter 6.

CHAPTER - 5

RESULTS AND DISCUSSIONS OF TESTS

5.1 GENERAL

This chapter includes the testing of the of 1 unmodified type of specimen with Stone Dust Filler and 8 type of modified specimen with Saw Dust Ash and Hydrated Lime filler . The testing results includes the testing of the aggregates , fillers , bitumen and the mix specimens .

The procedure followed for the testing of the mix specimens was firstly at least 3 conventional Stone Dust filler specimens were prepared for the Marshall tests at each binder content so as to determine the optimum binder content to be used in the preparation of modified mixes with Stone Dust Ash and Hydrated Lime fillers by keeping the binder content same and varying the percentages of Stone dust ash and 1% Hydrated lime by weight of mix with equal amount of Stone Dust required in the conventional mixes as per gradation

At last when Marshall tests were performed on the modified and unmodified specimens then these 2 type of specimens were prepared again for the Indirect Tensile Strength tests and Static Modulus tests and their results were compared . For Resilient Modulus values , they were found out through empirical relations for both type of specimens and results were compared .

5.2 BITUMEN TESTS

Various tests like softening point , penetration and specific gravity tests were performed on the bitumen (binder) so as to justify that whether bitumen which is being used is falling under the specifications limits or not because if they will not be under the specifications then it need to be discarded and other bitumen need to be used .

Softening point test was done so as to check under what temperature bitumen melts and can be used in the mix preparation . Penetration test was done so as to check whether grade you are using is that grade only or out of the grade specified by the distributor .

Specific gravity test was done because sometimes in calculations of volumetric analysis or when they are being used up with aggregates they need to be used in the form of volume which can ultimately be calculated by the help of specific gravity of bitumen only . Given below are the results of tests performed in Table 5.1

Table 5.1 : Bitumen tests results

Property	Specifications	Test results
Penetration at 25^0 C ,100 g, 5 s, 0.1 mm, Minimum	45	62
Softening Point , ^{0} C , Minimum	47	52
Specific Gravity , at 27^0 C	0.97 to 1.02	1.00

5.3 AGGREGATE TESTS

This section includes tests results of aggregates including fine aggregates , coarse aggregates and fillers as discussed in next topics .

5.3.1 Coarse aggregate tests results

Various Tests were performed on these aggregates as discussed in the Table 5.2 so as to check whether aggregates you are using in the mixes are of good quality , durable , not much more prone to wear and tear etc and are under the specification limits .

Table 5.2 : Coarse Aggregates tests

Tests	Specifications	Test results
Aggregate Impact Value	24 % (Maximum)	18 %
Los Angeles Abrasion value	30 % (Maximum)	26 %
Water Absorption	2 % (Maximum)	1.5 %
S.G for 20 mm and 10 mm		2.61 and 2.63 respectively

5.3.2 Fine aggregate tests results

Specific gravity test was done for the fine aggregates by the help of pycnometer method so that it can be used in the calculation of bulk specific gravity of total aggregate . The value of the specific gravity came out to be 2.65

5.3.3 Filler tests results

Sieve analysis for fillers and specific gravity tests by pycnometer method was performed on Stone Dust , Saw Dust Ash and Hydrated and results obtained are showed in Table 5.3 , 5.4 ,5.5 and 5.6 below .

Table 5.3 : Sieve analysis results for Stone Dust

Sieve Size (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)	Specification Limits
0.6	0	0	100	100
0.3	4	4	96	95 - 100
0.075	13	13	87	85 - 100
Pan	83	83	0	
TOTAL	100	100		

Table 5.4 : Sieve analysis results for Saw Dust Ash

Sieve Size (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)	Specification Limits
0.6	0	0	100	100
0.3	3.5	3.5	96.5	95 - 100
0.075	14	14	86	85 - 100
Pan	82.5	82.5	0	
TOTAL	100	100		

Table 5.5 : Sieve analysis results for Hydrated Lime

Sieve Size (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)	Specification Limits
0.6	0	0	100	100
0.3	3.8	3.8	96.2	95 - 100
0.075	11.8	11.8	88.2	85 - 100
Pan	84.4	84.4	0	
TOTAL	100	100		

Table 5.6 : Sieve analysis results for Hydrated Lime

Type of Filler Material	Specific Gravity
Stone Dust	2.42
Saw Dust Ash	2.25
Hydrated lime	2.35

5.4 SIEVE ANALYSIS

Sieve analysis was done so as to decide what types of aggregates sizes and in what proportions whether coarse , fine or fillers will be required in the preparation of the mixes as shown in Table 5.7 . Job Mix formula will further be used and will decide in what blending percentages each aggregates will be taken on each sieves so as to prepare accurate good mixture as shown in Table 5.8 . After the sieve analysis and use of Job mix Formula the final combined gradation need to be checked whether it is under the specified gradation given in MORTH for Bituminous Concrete (BC) Grade 1 as shown in Table 5.9 . Gradation curve is shown in Figure 5.1 .

Table 5.7 : Sieve analysis tests results

Sieve Size (mm)	Percentage Passing 20 mm	Percentage Passing 10 mm	Percentage Passing 6 mm	Percentage Stone Dust
26.5	100	100	100	100
19	87	100	100	100
13.2	13	83	100	100
9.5	3	30.27	100	100
4.75	0.78	2.5	100	100
2.36	0.42	0.83	71	100
1.18	0.29	0.79	43	100
0.6	0	0	38	95
0.3	0	0	23	88
0.015	0	0	13	74
0.075	0	0	5	54

Table 5.8 : Blending Percentage of aggregate size taken as per JMF

Combined total blending percentage for aggregates size taken				
20 mm	**10 mm**	**6 mm**	**Stone Dust**	**Sum Total**
22	31	43	4	100

Table 5.9 : Total combined gradation for the aggregates

Sieve size (mm)	Percentage Passing 20 mm	Percentage Passing 10 mm	Percentage Passing 6 mm	Percentage Passing stone dust	Combined gradation passing	limits as per MORTH	
						Lower Limit	Upper Limit
26.5	22	31	43	4	100	100	100
19	19.14	31	43	4	97.14	90	100
13.2	2.86	25.73	43	4	75.59	59	79
9.5	0.66	9.3837	43	4	57.0437	52	72
4.75	0.1716	0.775	43	4	47.9466	35	55
2.36	0.0924	0.2573	30.53	4	34.8797	28	44
1.18	0.0638	0.2449	18.49	4	22.7987	20	34
0.6	0	0	16.34	3.8	20.14	15	27
0.3	0	0	9.89	3.52	13.41	10	20
0.15	0	0	5.59	2.96	8.55	5	13
0.075	0	0	2.15	2.16	4.31	2	8

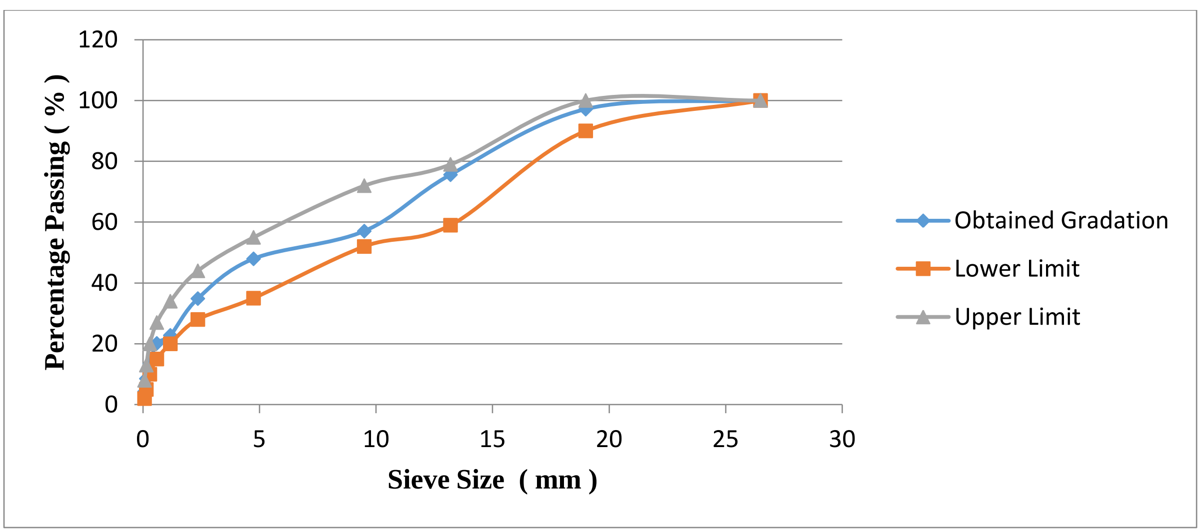

Figure 5.1 : Gradation curve showing lower , used and upper limit percentages

5.5 RESULTS OF HOT MIX ASPHALT SPECIMENS

5.5.1 General

Approximately 1200 g mixture compacted specimens (modified filler and unmodified filler) as per the gradation specified below in Table 5.10 and results of Marshall tests , Indirect Tensile Strength , Static Modulus and Resilient Modulus are discussed in next sections.

Table 5.10 : Gradation showing percentage and weight retained in sieves

Sieve size (mm)	Cumulative percentage used gradation	Cumulative weight passing	Cumulative weight retained (g)	Weight retained on particular sieve (g)
26.5	100	1200	0	0
19	97.14	1166	34	34
13.2	75.59	907	293	259
9.5	57.04	684	516	222
4.75	47.94	576	624	108
2.36	34.87	418	782	158
1.18	22.79	273	927	145
0.6	20.14	242	958	31
0.3	13.41	161	1039	81
0.15	8.55	100	1098	59
0.075	4.31	52	1148	50
Pan (Filler weight)				53
TOTAL				**1200**

For the preparation of stone dust filler specimens, 53 grams weight was taken as per gradation calculated above and for the modified specimens with replacement of stone dust with saw dust ash and 1 % hydrated lime (by weight of mix) weight is taken as shown in Table 5.11 .

Table 5.11 : Weight in grams taken for mix specimens

Varying percentages for fillers								
	10 % SDA + 1 % HL + SD	**20 % SDA + 1 % HL + SD**	**30 % SDA + 1 % HL + SD**	**40 % SDA + 1 % HL + SD**	**50 % SDA + 1 % HL + SD**	**60 % SDA + 1 % HL + SD**	**70 % SDA + 1 % HL + SD**	**80 % SDA + 1 % HL + SD**
Saw Dust Ash weight (g)	5.3	10.6	15.9	21.2	26.5	31.8	37.1	42.4
1 % Hydrated Lime by weight of mix (g)	12	12	12	12	12	12	12	12
Stone Dust weight (g)	35.7	30.4	25.1	19.8	14.5	9.2	3.9	
TOTAL (g)	53	53	53	53	53	53	53	53~54.4 (approximated)

5.5.2 Marshall test results

5.5.2.1 For conventional filler (Stone dust)

Mixes were prepared by taking varying bitumen content starting from 4.5 % to 6 % (by weight of aggregates) having Stone Dust as a filler to determine the optimum binder content which can further be used in the modified mixes by keeping this optimum binder content same and varying filler content . The test results for the Marshall Stability , Flow Value and Volumetric Analysis are shown in Table 5.12 and Figure 5.2 to 5.6 . Volumetric Analysis needs values of G_{mm} (Theoretical maximum specific gravity of mix) for different binder contents if it is calculated for particular binder content , G_{sb} (Bulk dry specific gravity of aggregates) which are calculated by formulas (Source : MS -2 Asphalt Institute Manual) given below :

- $G_{sb} = \dfrac{P_1 + P_2 + \ldots\ldots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \ldots + \frac{P_n}{G_n}}$

  where ,

P_1 , P_2 , P_n = Percentages of aggregates of 1, 2 ... n

G_1 , G_2 , G_n = Bulk specific (dry) of corresponding aggregates of 1, 2 ... n

- $G_{mm} = \dfrac{100}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}}$ (used for calculating at other binder content)

  where ,

P_s = Percentage of aggregate by total mix

P_b = Percentage of binder by total mix weight at which G_{mm} test was performed

G_b = Specific gravity of binder

Table 5.12 : Marshall tests results for conventional specimens

Specimen No.	% Bitumen By Total Wt. of Mix	% Aggregate By Total Wt. of Mix	Max theoretical Sp. Gr. Of Mix (Gmm)	Thickness of Specimen (mm)		Specimen properties				Bulk Sp. Gr. Of Compacted Mix= (A)/(B -C)	% Air Void (Va) (4-7)x 100/4	% VMA 100-(7x3)/Gsb	% VFB 100x (9- 8) /9	Stability(KN)		Flow (mm)
				Measured (mm)	Stability Correlation Ratio	Wt . In Air (g)	Wt . in Water (g)	SSD weig-ht in air (g)	Vol-ume (cc)					Measured	Corrected (11a×5b)	
						A	B	C								
1.	**2.**	**3.**	**4.**	**5.a**	**5.b**	**6.**				**7**	**8.**	**9.**	**10**	**11a.**	**11.b**	**12.**
	4.5	95.5	2.447	63.4	1	1196	682	1197	513	2.322	5.10	15.55	67.20	9.1	9.1	2.13
	4.5	95.5	2.447	63.9	1	1198.5	680.5	1200	520	2.307	5.72	16.10	64.47	9	9	2.16
	4.5	95.5	2.447	64.2	1	1193	678	1195	518	2.307	5.72	16.10	64.47	9.2	9.2	2.14
Avg	**4.5**	**95.5**	**2.447**	**63.8**	**1**	**1195.8**	**680.1**	**1197.3**	**517**	**2.312**	**5.51**	**15.9**	**65.38**	9.1	**9.1**	**2.14**
	5.0	95.0	2.429	63.3	1	1191.5	681	1193	512	2.327	4.19	15.81	73.49	9.8	9.8	2.43
	5.0	95.0	2.429	63	1	1189.5	680.5	1191	511	2.330	4.07	15.7	74.07	9.7	9.7	2.46
	5.0	95.0	2.429	63.3	1	1190	678	1191	512	2.325	4.28	15.88	73.04	9.7	9.7	2.45
Avg	**5.0**	**95.0**	**2.429**	**63.2**	1	**1190.3**	**679.8**	**1191.6**	**511**	**2.327**	**4.18**	**15.79**	**73.53**	9.73	**9.73**	**2.44**
	5.5	94.5	2.416	62.3	1.04	1180	678	1183	505	2.336	3.31	15.93	79.22	11.5	11.96	3.11
	5.5	94.5	2.416	63.3	1	1191.5	685.5	1197.5	512	2.327	3.68	16.25	77.35	11.9	11.9	3.14
	5.5	94.5	2.416	63.3	1	1195	686	1198	512	2.333	3.43	16.04	78.61	11.7	11.7	3.13
Avg	**5.5**	**94.5**	**2.416**	**62.9**	**1.01**	**1188.83**	**683.1**	**1192.8**	**509**	**2.332**	**3.47**	**16.07**	**78.39**	11.7	**11.81**	**3.12**
	6.0	94.0	2.389	63.6	1	1195.5	683	1198	515	2.321	2.85	16.91	83.14	10.3	10.3	3.51
	6.0	94.0	2.389	62.3	1.04	1172	670	1175.5	505	2.318	2.98	17.02	82.49	10.4	10.81	3.6
	6.0	94.0	2.389	62.2	1.04	1165	665	1169	504	2.311	3.26	17.27	81.12	10.1	10.50	3.55
Avg	**6.0**	**94.0**	**2.389**	62.7	1.02	**1177.5**	**672.6**	**1180.8**	**508**	**2.316**	**3.03**	**17.05**	**82.25**	**10.2**	**10.40**	**3.55**

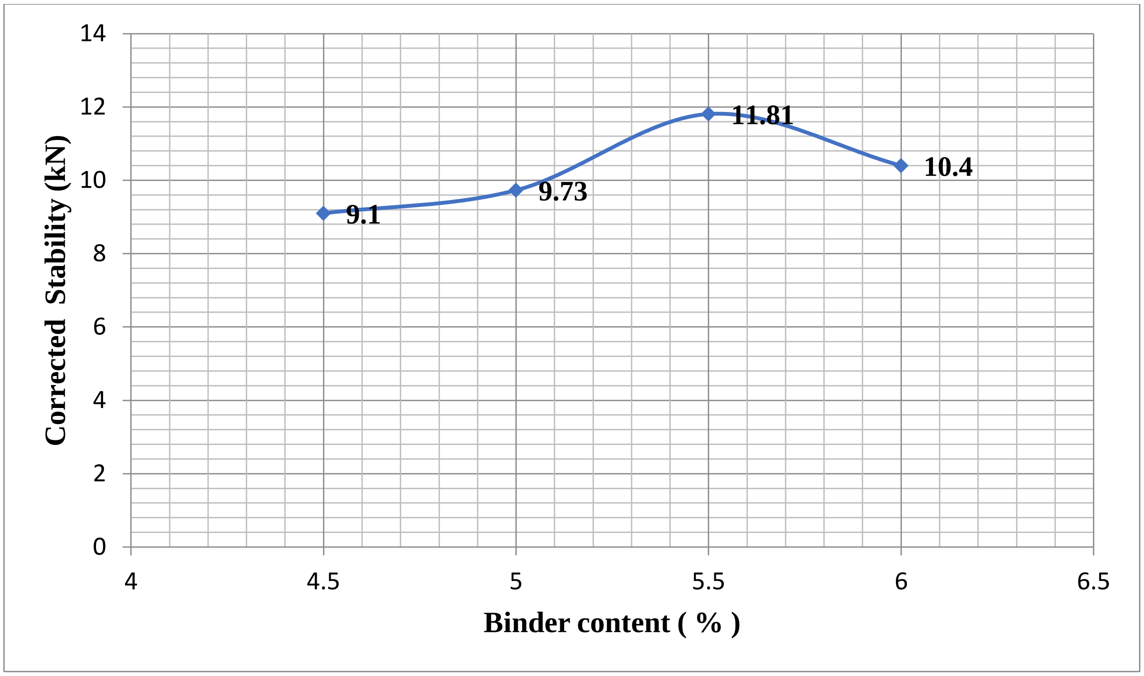

Figure 5.2 : Stability vs Binder content curve

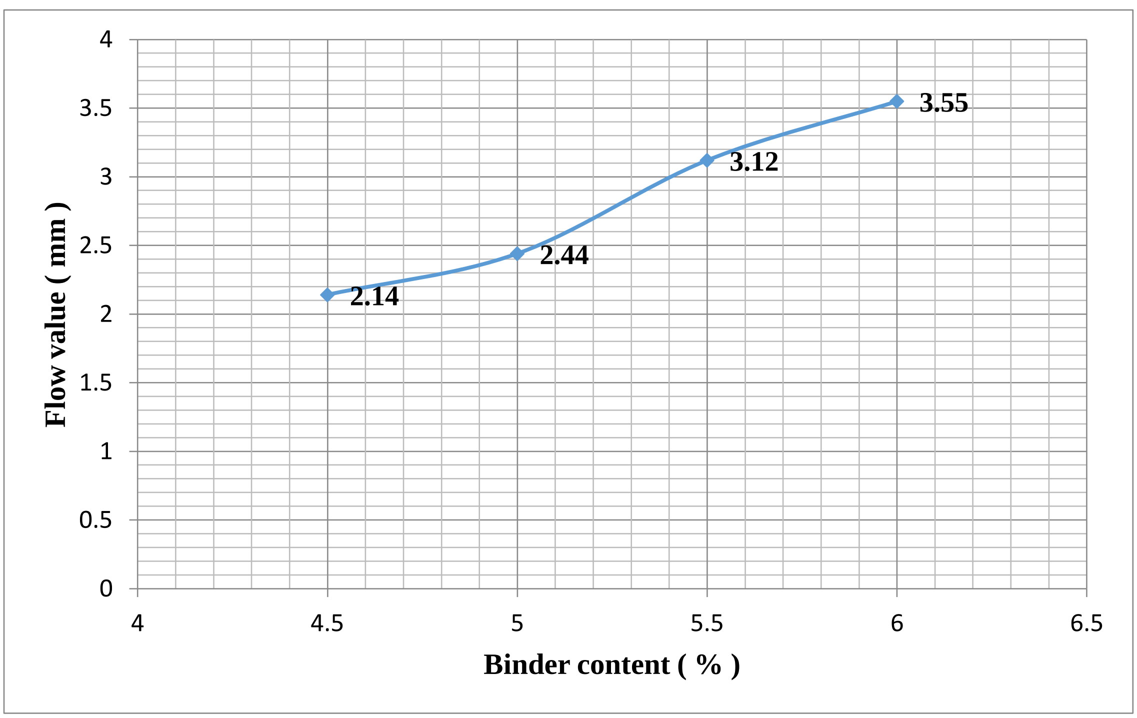

Figure 5.3 : Flow vs Binder content curve

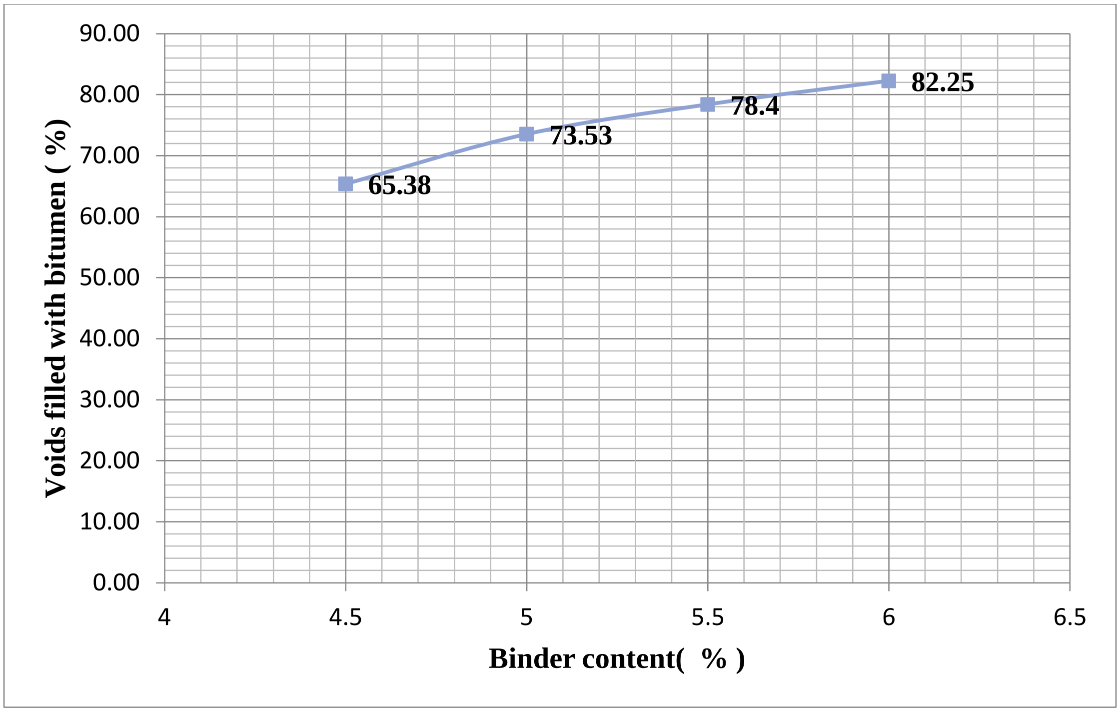

Figure 5.4 : VFB vs Binder content curve

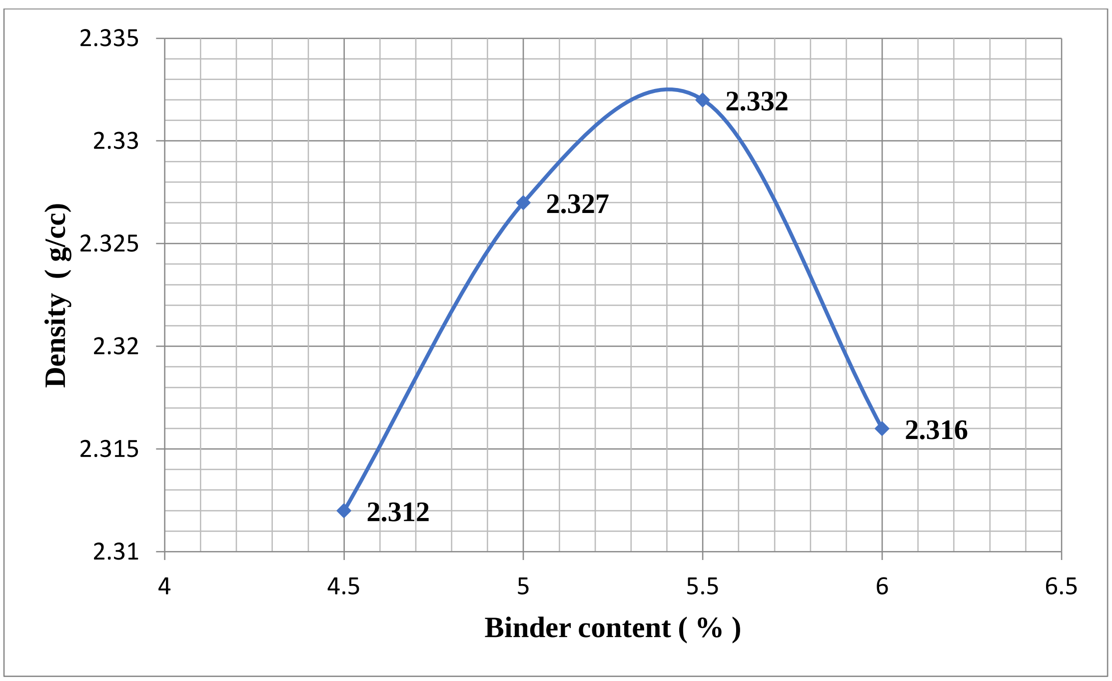

Figure 5.5 : Density vs Binder content curve

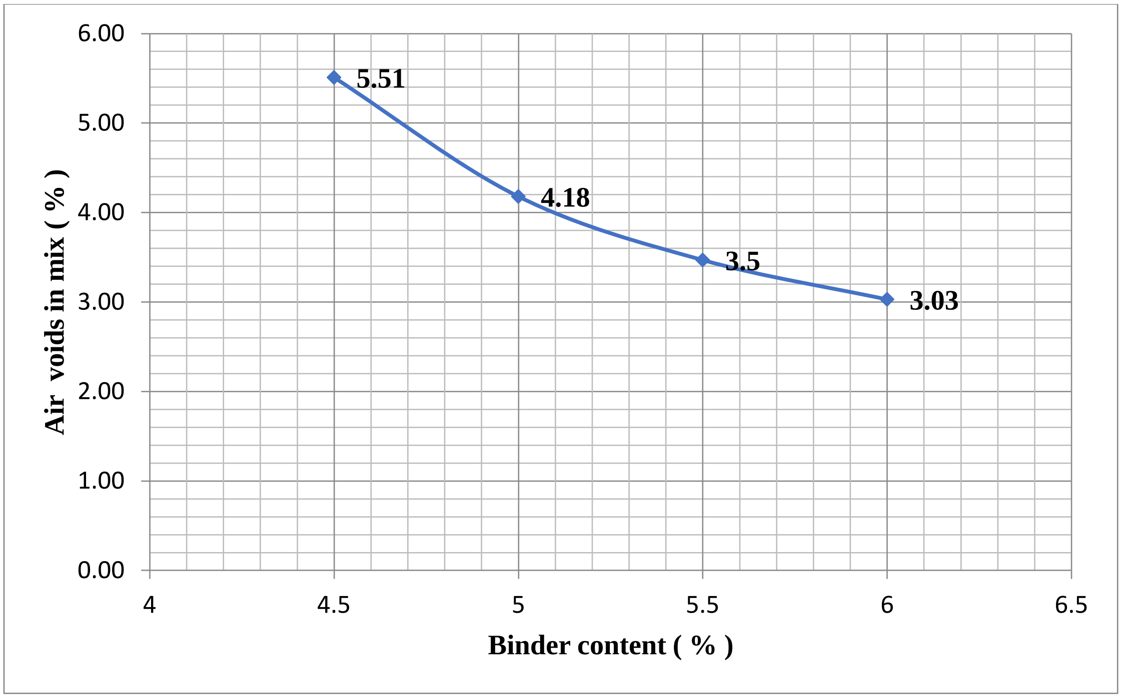

Figure 5.6 : Air voids vs Binder content curve

From the above graphs binder optimum binder content was found out by taking average values of that binder content at which maximum stability , maximum unit weight and 4 % air voids occur . It was seen that maximum stability occurred at 5.5 % bitumen , maximum unit weight occurred at 5.5 % bitumen and 4 % air voids are corresponding to 5.1 % bitumen content . hence average value of bitumen content is obtained as 5.37 % . This optimum bitumen content was taken constant throughout for the preparation of the modified mixes with Saw dust ash and Hydrated lime .Corrected Marshall stability at OBC with 4 % air voids came out as 13.31 kN by testing .

5.5.2.2 For modified fillers (Saw dust ash and Hydrated lime)

These fillers were prepared at the OBC of 5.37 % by weight of mix and only content of fillers were varied .Figure 5.7 to 5.12 shows all the graphs of test results obtained and Table 5.13 shows all the Marshall results values obtained from the Marshall stabilty tests performed .

Table 5.13 : Marshall results for modified specimens

Specimen No.	Specimen type	Max theoretical Sp. Gr. Of Mix (Gmm)	Thickness of Specimen (mm)			Bulk specific gravity of mix (G_{mb})	% Air Voids (V_a)	% Voids in mineral aggregate (VMA)	% Voids filed with bitumen (VFB)	Stability (kN)			Flow value (mm)
			Measured (mm)	Volume (cc)	Stability correction ratio					Measured	Corrected	At 4 % air voids	
1.	10 % SDA + 1 % HL + SD	2.440	63.4	514	1	2.350	3..68	14.4	74	15.34	15.34	16.68	4
2.	20 % SDA + 1 % HL + SD	2.440	63.5	515	1	2.346	3.85	14.8	73.9	15.64	15.64	16.25	3.8
3.	30 % SDA + 1 % HL + SD	2.440	63.4	514	1	2.341	4.05	15	73	16	16	15.81	3.3
4	40 % SDA + 1 % HL + SD	2.440	62.7	508	1.02	2.330	4.50	15.1	70.19	16.85	17.187	15.28	2.7
5.	50 % SDA + 1 % HL + SD	2.440	62.2	504	1.04	2.325	4.71	15.2	69.01	19.5	20.28	17.23	2.5
6.	60 % SDA + 1 % HL + SD	2.440	62.3	505	1.04	2.323	4.8	15.25	68.52	21	21.84	18.20	3
7.	70 % SDA + 1 % HL + SD	2.440	63.5	515	1	2.322	4.84	15.3	68.36	18.10	18.10	14.96	3.2
8.	80 % SDA + 1 % HL + SD	2.440	62.7	508	1.02	2.320	4.92	15.35	67.94	16	16.32	13.27	3.5

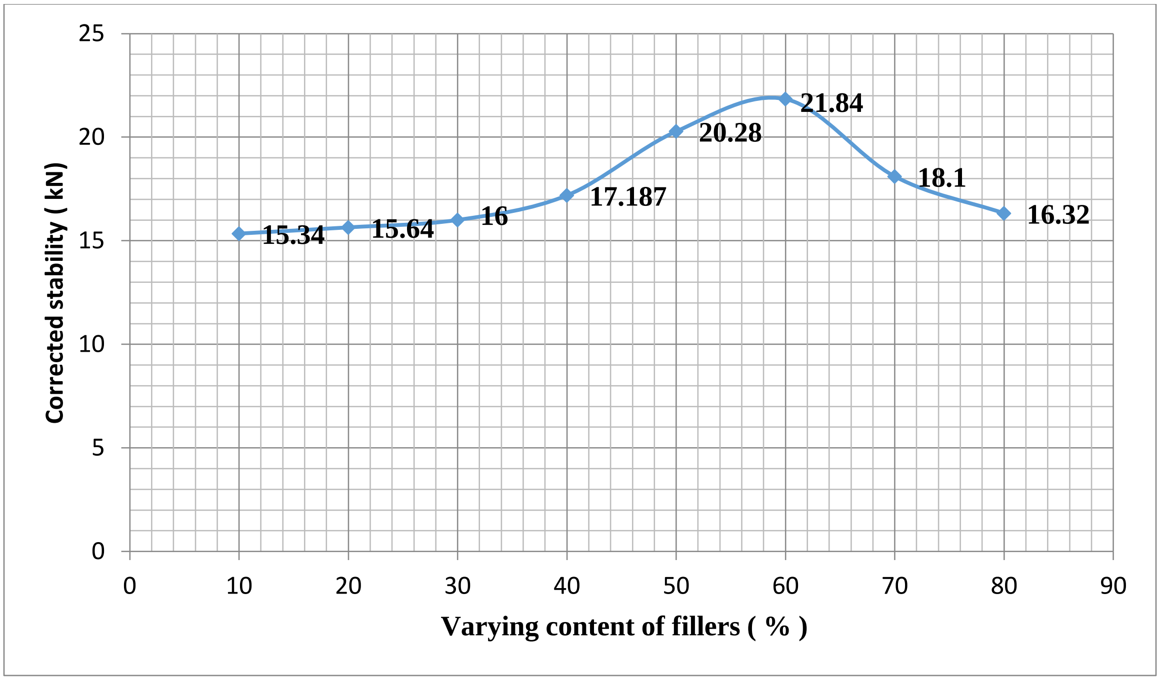

Figure 5.7 : Stability vs varying filler content with modified fillers

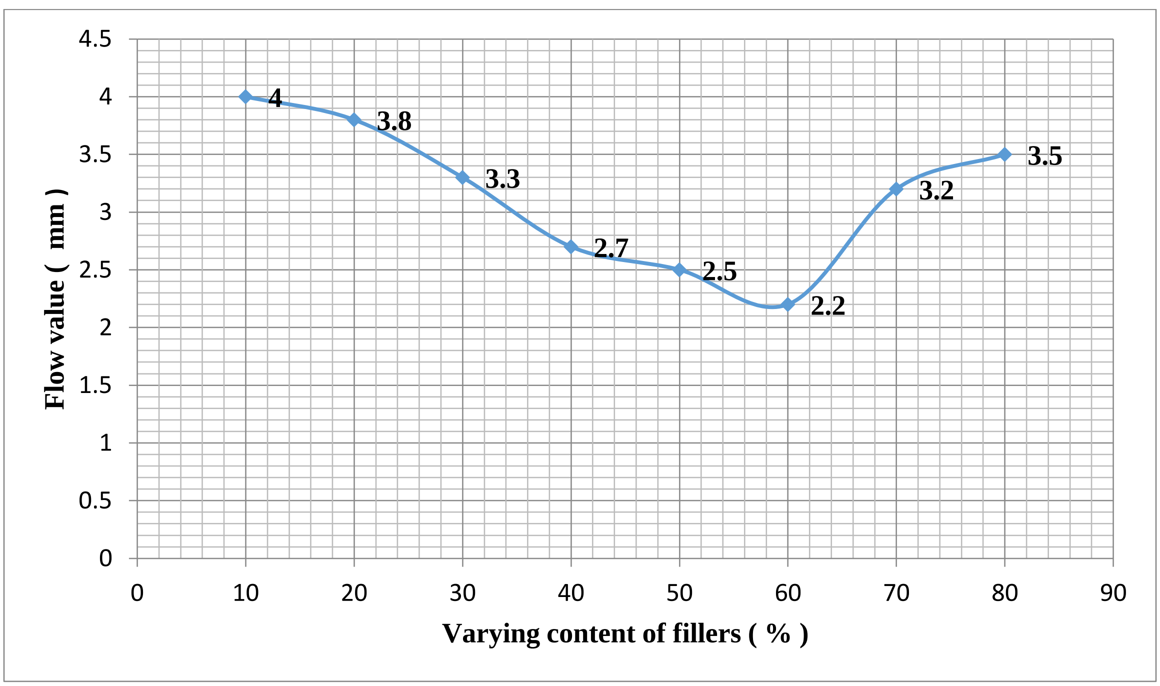

Figure 5.8 : Flow vs varying filler content with modified fillers

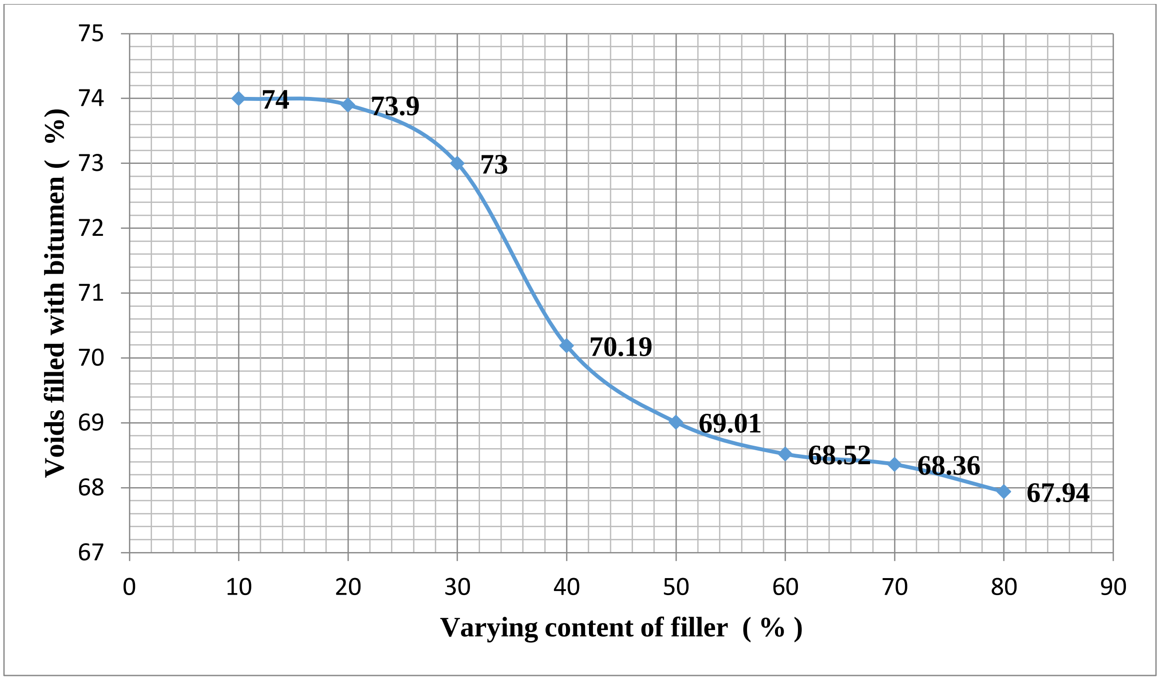

Figure 5.9 : Voids filled with bitumen vs varying filler content with modified fillers

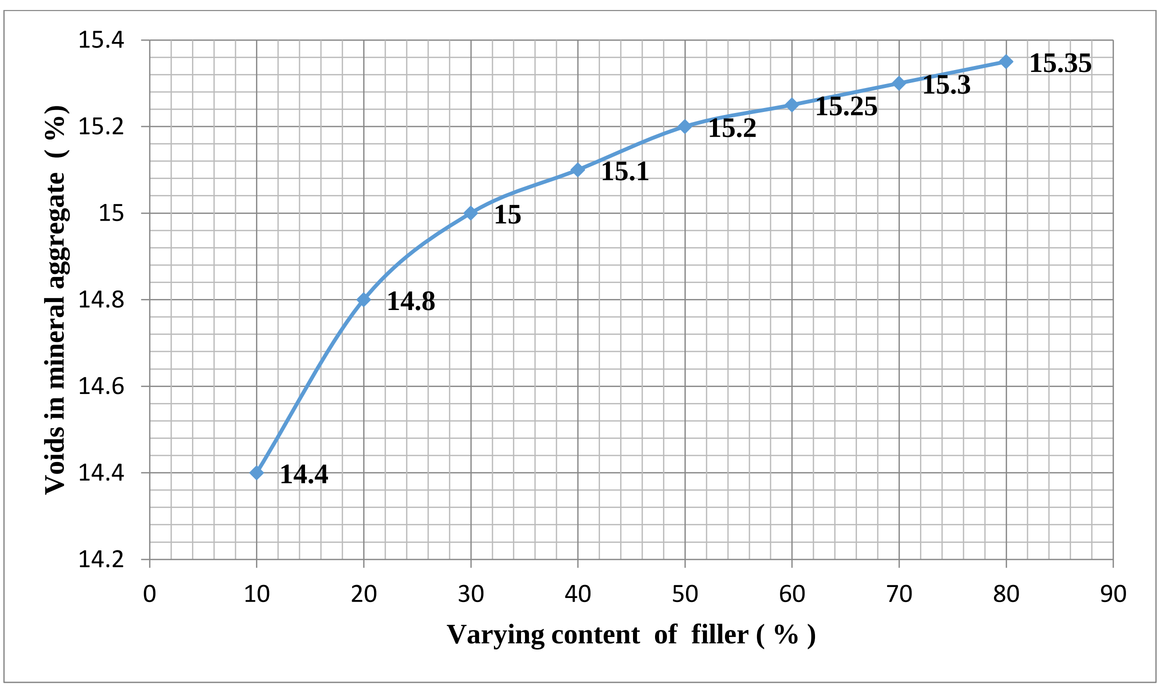

Figure 5.10 : Voids in mineral aggregate vs varying filler content with modified fillers

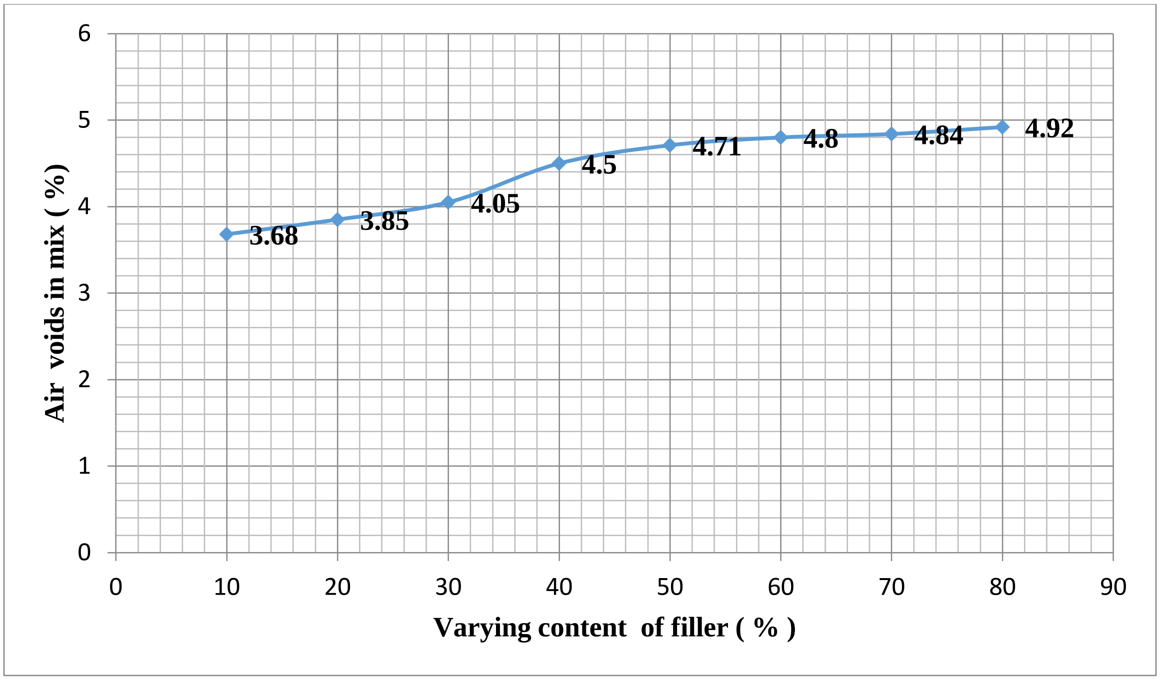

Figure 5.11 : Air voids in mix vs varying filler content with modified fillers

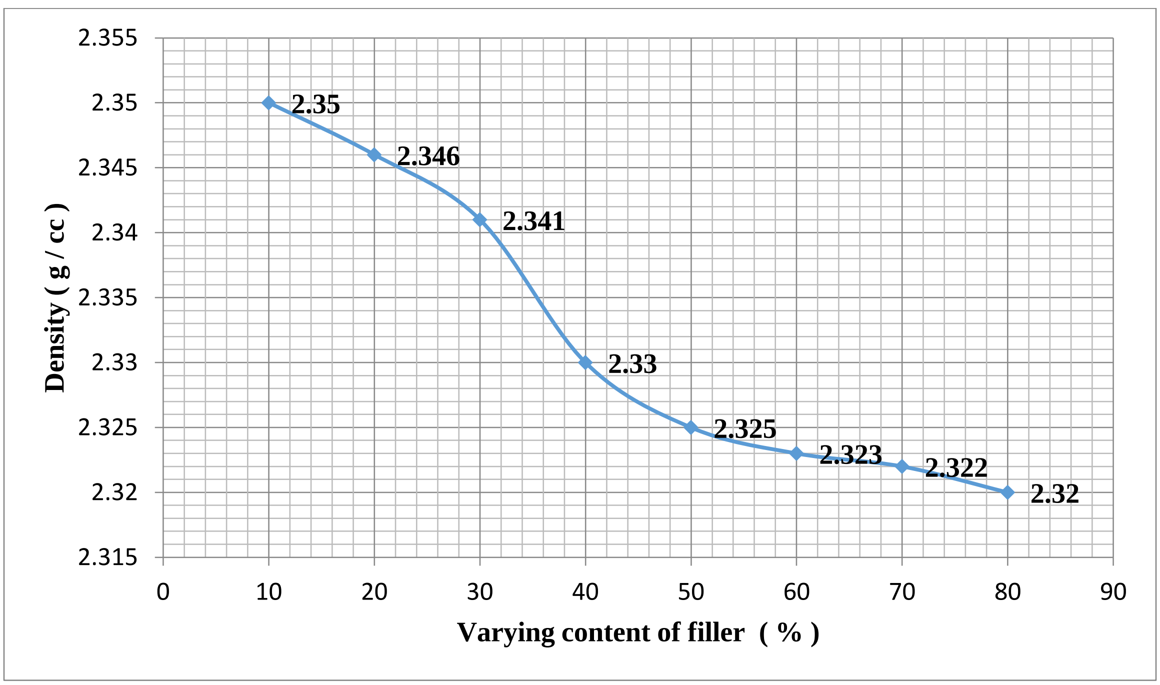

Figure 5.12 : Density of mix vs varying filler content with modified fillers

From the above results following things were observed which are discussed below in points to make final conclusions :

- There is an increase in Marshall stability value up to 60 % SDA and 1 % HL filler which might be due to presence of good amount of calcium oxide (CaO) in both the fillers as seen in their chemical compositions discussed earlier which acts as binder and also stability decreased after 60 % SDA and 1 % HL filler content .
- There is decrease in flow observed in flow value up to same 60 % SDA and 1 % HL filler content and after that it got increased . The reason behind decrease in flow could be due to more stiffening with increase in content of Cao with increase in 60 % SDA and 1 % HL filler .
- There is decrease in voids filled with bitumen observed in modified mixes with increase in content of SDA and 1 % HL which may be due to high porosity of calcium particles which in turn absorbs bitumen when heated .
- There is increase in voids in mineral aggregate observed in modified mixes with increase in content of SDA and 1 % HL which may be due to high porosity of calcium particles which in turn absorbs bitumen when heated and correspondingly voids in mineral aggregate increase .
- There is increase in air voids in mix observed in modified mixes with increase in content of SDA and 1 % HL which may be due to high porosity of calcium particles which in turn absorbs bitumen when heated and correspondingly voids in mix increase .

5.5.3 Indirect tensile strength results

Indirect Tensile Strength test was performed on the modified and the unmodified specimens and average value of two specimens for control and under investigation mixtures was found out by the help of formula as discussed in chapter 4 and is shown in the Table 5.14 .A chart showing ITS values is shown in Figure 5.13 .These indirect tensile strength values obtained from the experiment will be further helpful in calculating the resilient modulus values of the mixes from the empirical relations discussed in the before chapters .

Table 5.14 : ITS values for varying fillers percentages

Varying percentages for fillers									
	0 % SDA & 0 % HL or Control mixture	**10 % SDA + 1 % HL + SD**	**20 % SDA + 1 % HL + SD**	**30 % SDA + 1 % HL + SD**	**40 % SDA + 1 % HL + SD**	**50 % SDA + 1 % HL + SD**	**60 % SDA + 1 % HL + SD**	**70 % SDA + 1 % HL + SD**	**80 % SDA + 1 % HL + SD**
ITS values (MPa)	1.2	0.98	1.1	1.2	1.35	1.5	1.6	1.3	1.1

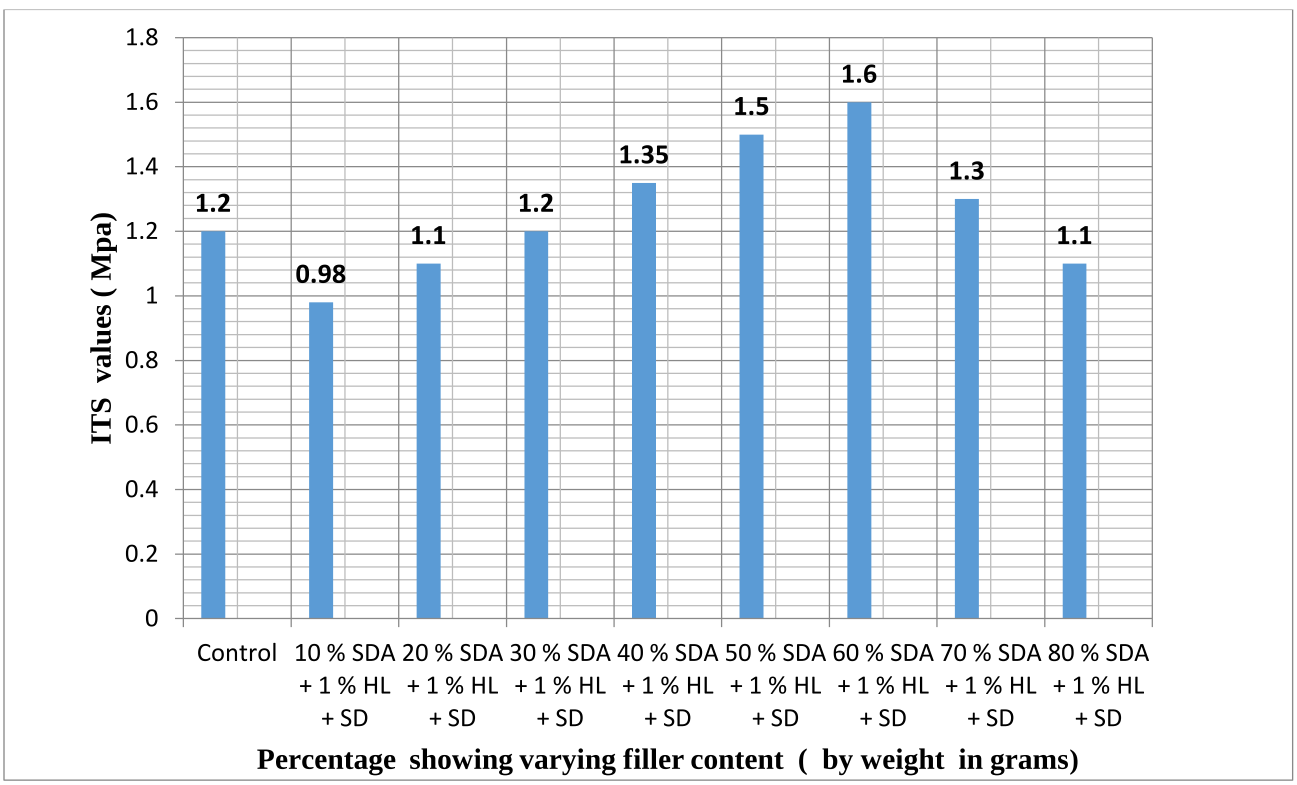

Figure 5.13 : Charts for ITS values

5.5.4 Static modulus tests results

Static Modulus test through Universal Testing Machine under compression was performed on the modified and the unmodified specimens and average value of two specimens for control and under investigation mixtures is shown in the Table 5.15 . A chart showing Static modulus values is shown in Figure 5.14 . Though static modulus of the HMA specimens has no use in the design of pavements but still it was found out just to predict the nature of cracks and behavior of the HMA compacted specimens when it will be under static loading .

Table 5.15 : Static Modulus values for varying fillers percentages

Varying percentages for fillers									
	0 % SDA & 0 % HL or Control mixture	**10 % SDA + 1 % HL + SD**	**20 % SDA + 1 % HL + SD**	**30 % SDA + 1 % HL + SD**	**40 % SDA + 1 % HL + SD**	**50 % SDA + 1 % HL + SD**	**60 % SDA + 1 % HL + SD**	**70 % SDA + 1 % HL + SD**	**80 % SDA + 1 % HL + SD**
Static Modulus values (MPa)	1200	1100	1180	1350	1400	1600	1750	1400	1250

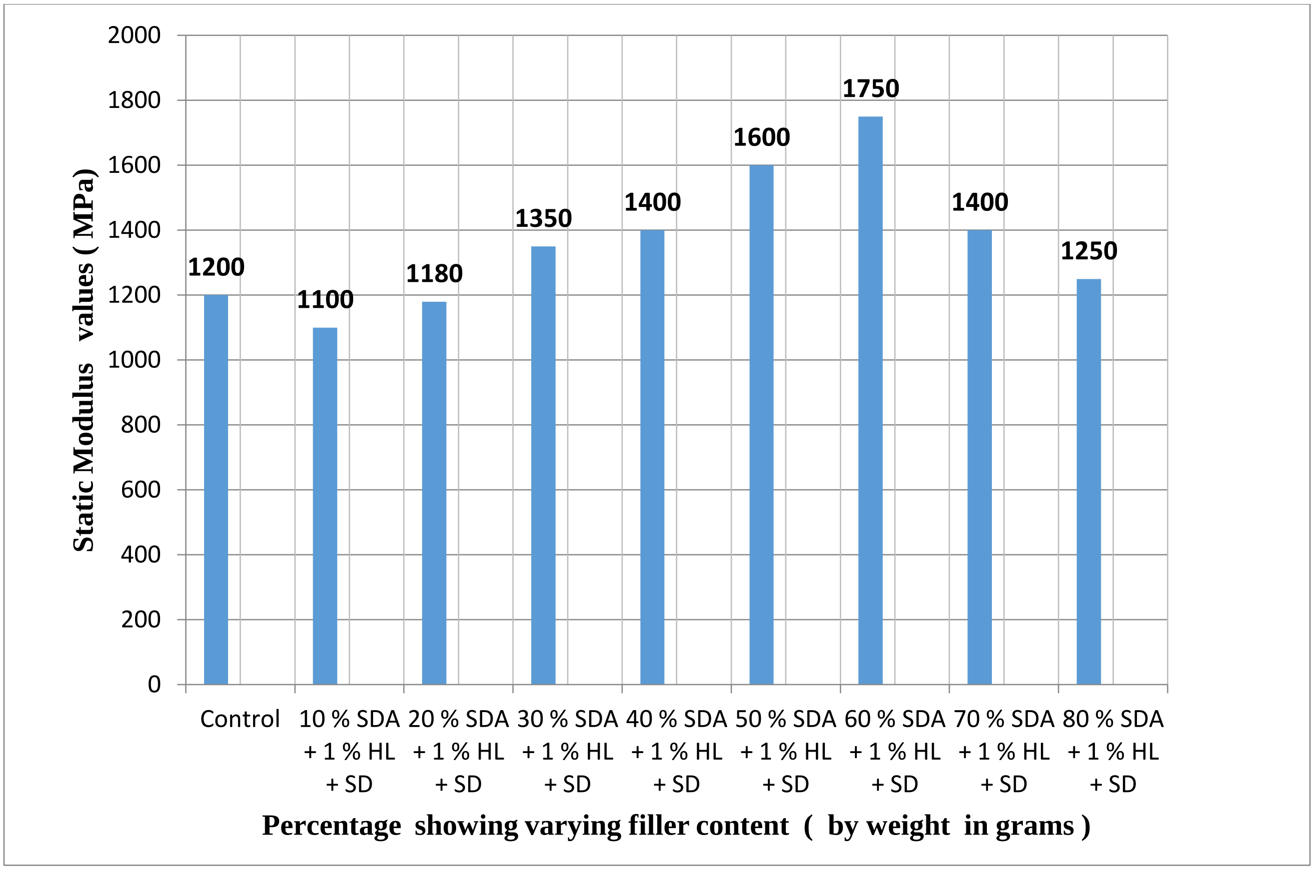

Figure 5.14 : Charts for Static Modulus values

5.5.5 Resilient modulus tests results

Resilient Modulus was found out for the modified and the unmodified specimens by the help of formulas discussed in chapter 4 relating ITS and correction factor for temperature . The average value of two specimens for control and under investigation mixtures is shown in the Table 5.16. According to the formulas values were in " psi " so they were converted in " MPa " so that they can further be used in the next Chapter 6 for the design and analysis of Flexible Pavements by the help of IIT Pave . A chart showing the plot of Resilient Modulus values of all the unmodified and modified specimens is shown in the Figure 5.15.

Table 5.16 : Resilient modulus values for varying fillers percentages

Varying percentages for fillers									
	0 % SDA & 0 % HL or Control mixture	10 % SDA + 1 % HL + SD	20 % SDA + 1 % HL + SD	30 % SDA + 1 % HL + SD	40 % SDA + 1 % HL + SD	50 % SDA + 1 % HL + SD	60 % SDA + 1 % HL + SD	70 % SDA + 1 % HL + SD	80 % SDA + 1 % HL + SD
Resilient Modulus values (MPa)	2200	1740	1990	2200	2523	2852	3074	2415	1990

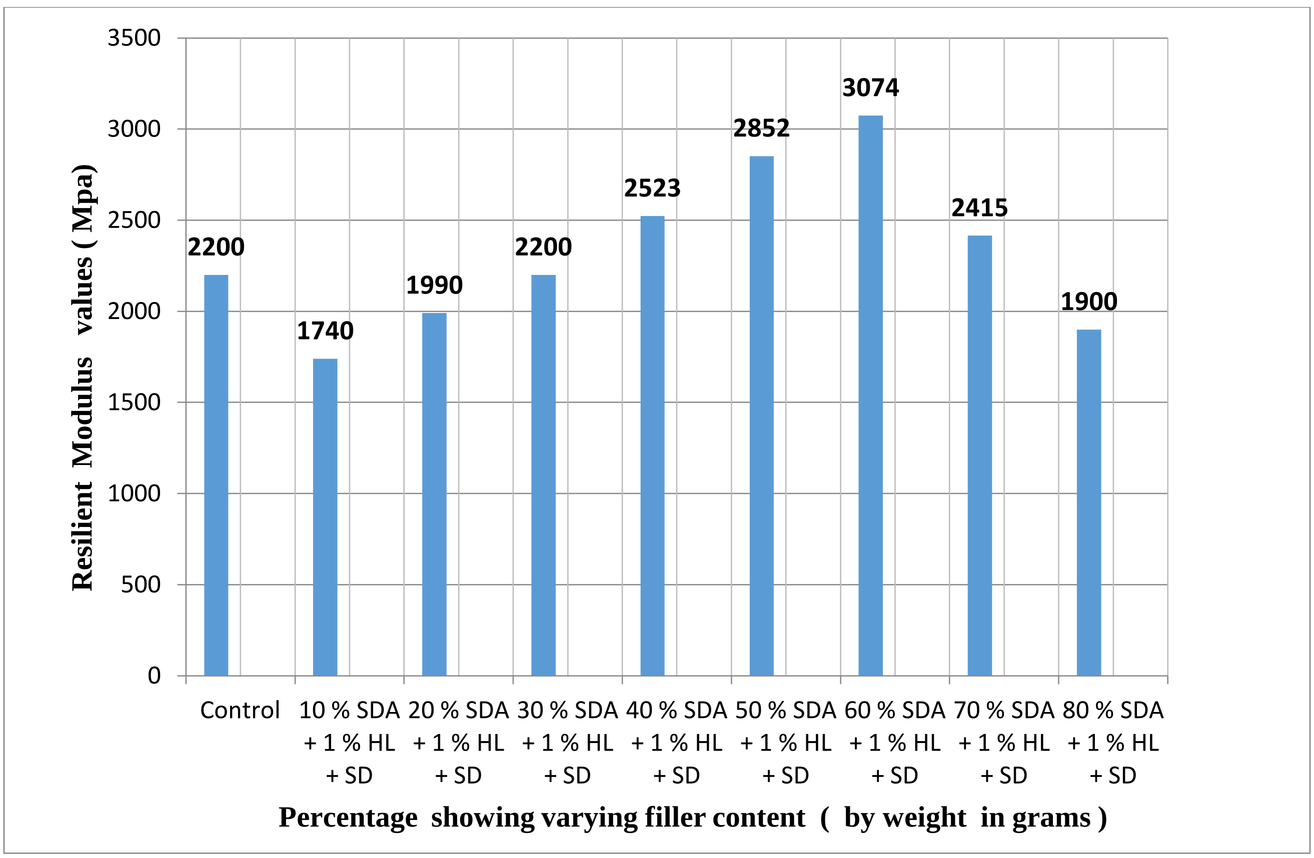

Figure 5.15 : Charts for Resilient Modulus values

CHAPTER - 6

FLEXIBLE PAVEMENT DESIGN

6.1 GENERAL

Flexible pavement design means thickness of the crust need to be decided and strains need to be calculated including failure and actual for all the critical pavement layers which are considered in the design as per IRC-37 -2018 for the design of flexible pavements . For the design of pavements software named IITPAVE will be used for calculating the actual strains coming over the pavements and IRC- 37- 2018 " Guidelines for the design of flexible pavements " will be used for the calculating the failure strains of pavement .

6.2 DESIGN CONSIDERATIONS

It includes the following parameters which will be used in the design of flexible pavements and analysis .

- Annual average pavement temperature = 35^0 C
- Design traffic = 150 msa
- CBR of the subgrade = 10 %
- Granular subbase thickness = 200 mm
- Granular base thickness = 250 mm
- Tyre pressure = 0.56 MPa
- Standard axle load = 80 kN
- c/c spacing of wheel = 155 mm
- Poisson ratio considered for all layers = 0.35
- Thickness of Dense bituminous macadam (DBM) will be varied from 100 mm to 160 mm
- Thickness of Bituminous concrete layer = 50 mm (constant)

6.2.1 Calculation of Resilient Modulus

6.2.1.1 Resilient Modulus of subgrade (IRC- 37 -2018 , Equation 6.2)

It was computed from the equation shown below for the CBR value more than 5 % .

$M_{RS} = 17.6 * (\text{CBR})^{0.64}$

where ,

M_{RS} = Resilient Modulus of subgrade soil (in Mpa)

CBR = California Bearing ratio of subgrade soil (%)

M_{RS} = 76.82 MPa

6.2.1.2 Resilient Modulus of GSB layer (IRC- 37 -2018 , Equation 7.1)

$M_{RGRAN} = 0.2 * (h)^{0.45} * M_{RSUPPORT}$

where ,

M_{RGRAN} = Resilient Modulus of granular layer (in Mpa)

$M_{RSUPPORT}$ = Resilient Modulus of supporting layer (in Mpa)

h = Thickness of granular layer (mm)

$M_{RGRAN} = 0.2 * (200 + 250)^{0.45} * 76.82$

M_{RGRAN} = 240.13 MPa

6.2.1.3 Resilient Modulus of bituminous mixes

These have already been calculated in the chapter 5 by the help of the empirical relations discussed earlier and these will be used in the calculation of failure and actual strains .

6.2.2 Calculation of failure strains

This involves the calculation of strains by the help of equations given in IRC-37 2018 for the design of pavements .According to the specifications there are two type failure strains considered namely and their critical locations are shown in Figure 6.1 :

- Horizontal tensile strain at the bottom of the bituminous layer or fatigue failure .
- Vertical compressive strain at the top of the subgrade or rutting failure .

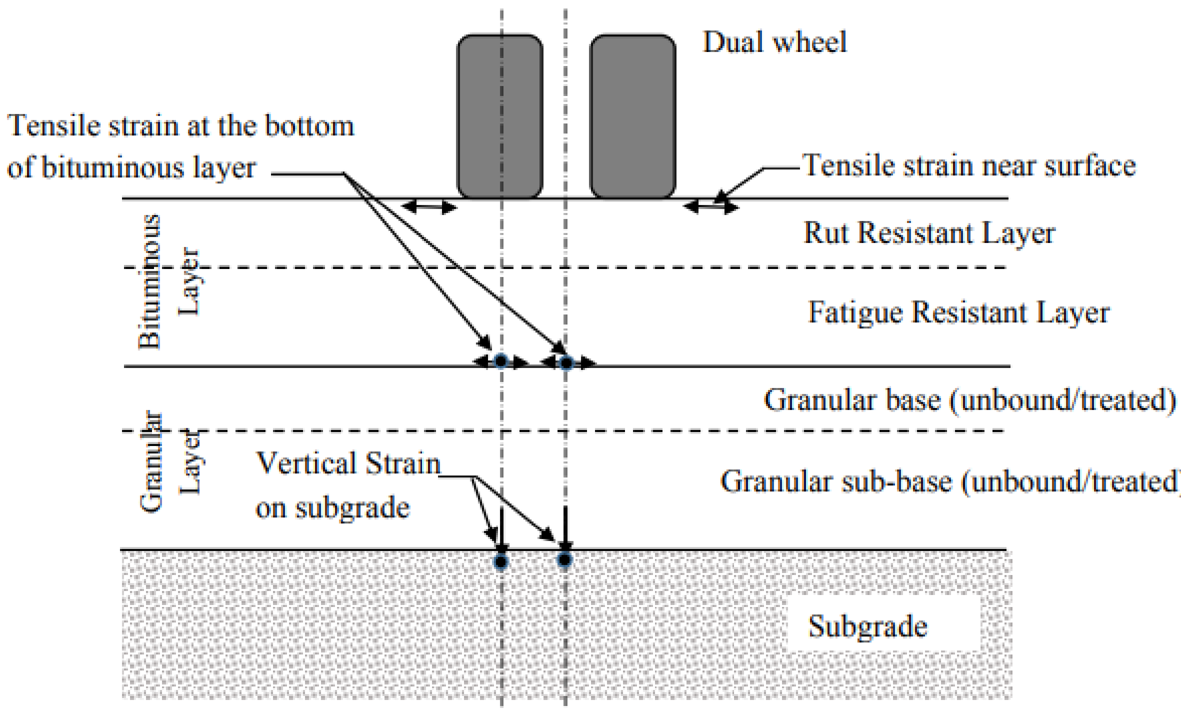

Figure 6.1 : Critical locations for both strains

6.2.2.1 Maximum horizontal tensile strain

$$N_f = 0.5161 * C * 10^{-4} * \left(\frac{1}{\varepsilon_t}\right)^{3.89} * \left(\frac{1}{M_R}\right)^{0.854} \qquad \text{(for 90 \% reliability)}$$

where ,

$C = 10^M$, and $M = 4.84\left(\frac{V_{be}}{V_a+V_{be}} - 0.69\right)$

V_a = Percent volume of air void in the mix used in bituminous layer considered as 4 % for all specimens including modified and unmodified in the current study

V_{be} = Percent volume of effective bitumen in the mix used in bottom bituminous layer

N_f = Fatigue life (standard axles) for bituminous mixes

M_R = Resilient modulus of bituminous layer (Mpa)

ε_t = Maximum tensile strain at the bottom of bituminous layer

Here V_{be} (Effective bitumen) is calculated from the formula given by S.K Khanna , C.E.G Justo and A.Veearagavan as shown below :

$$V_{be} = G_b \times \left(\frac{W_{bitumen}}{G_{bitimen}} \right)$$

where ,

G_b = Bulk density of specimen

$W_{bitumen}$ = Percentage of bituminous binder by weight in mix taken as 5.37 % OBC for all the mixes

$G_{bitumen}$ = Specific gravity of bitumen

The values of V_{be} , M and C for the different type of modified and unmodified specimens obtained are shown in Table 6.1 which will further be helpful in calculating the strains and fatigue life .

Table 6.1 : Values of V_{be} , M and C

Specimen type	V_{be}	M	C
Control	12.45	0.32	2.11
10 % SDA + 1 % HL + SD	12.61	0.33	2.16
20 % SDA + 1 % HL + SD	12.59	0.33	2.16
30 % SDA + 1 % HL + SD	12.57	0.33	2.16
40 % SDA + 1 % HL + SD	12.51	0.32	2.11
50 % SDA + 1 % HL + SD	12.48	0.32	2.11
60 % SDA + 1 % HL + SD	12.47	0.32	2.11
70 % SDA + 1 % HL + SD	12.46	0.32	2.11
80 % SDA + 1 % HL + SD	12.45	0.32	2.11

6.2.2.2 Maximum compressive vertical strain

$$N_R = 1.4100 * 10^{-8} * \left(\frac{1}{\varepsilon_v}\right)^{4.5337} \qquad \text{(for 90 \% reliability)}$$

where ,

N_R = Rutting life (standard axles) for subgrade

ε_v = Maximum compressive vertical strain at the top of subgrade

6.3 PROCEDURE FOR DESIGN FOLLOWED IN CURRENT STUDY

- Design considerations discussed above will be used to calculate the actual vertical and horizontal strains by the help of IIT pave .
- Now the maximum vertical and horizontal strains obtained from the IITPAVE will be considered as the failure strains to calculate the corresponding maximum fatigue and rutting life from the equations discussed in previous section.
- After that check will be made that for which of the modified and unmodified mixtures and the DBM thickness rutting and fatigue lives are more than the considered 150 msa .
- Minimum DBM thickness will then be calculated for the corresponding satisfied results to make comparisons between the mixtures .

The values obtained from the calculations are shown in the Table 6.2 on the next page for the comparison of results .

Table 6.2 : Values of strains and their failure fatigue and rutting

DBM Thickness (mm)	Design parameters	Control mix	10 % SDA + 1 % HL + SD	20 % SDA + 1 % HL + SD	30 % SDA + 1 % HL + SD	40 % SDA + 1 % HL + SD	50 % SDA + 1 % HL + SD	60 % SDA + 1 % HL + SD	70 % SDA + 1 % HL + SD	80 % SDA + 1 % HL + SD
100 mm	ε_t	197.5	219.8	207	197.5	184.4	174.3	167.9	188.9	207
	ε_v	288.6	301.1	294	288.6	281	274.2	269.9	283.5	294
	Fatigue life	38.84	32.17	36.22	39.92	44.74	50.59	54.89	42.65	32.35
	Rutting life	157.46	129.92	144.77	157.46	177.71	198.59	213.34	170.72	144.77
110 mm	ε_t	186.4	206	195	186.4	174.8	164.5	158.4	178.5	195
	ε_v	275.4	288.2	280.9	275.4	267.7	260.8	256.5	270.2	280
	Fatigue life	48.64	41.40	45.69	49.99	55.55	63.36	68.85	53.15	40.81
	Rutting life	194.69	158.45	178	194.69	221.41	249.23	268.74	212.27	178
120 mm	ε_t	176.7	196.4	185.1	176.7	165.3	155.4	149.4	168.9	185.1
	ε_v	263	275.9	268.6	263	255.3	248.3	243.9	257.8	268.6
	Fatigue life	59.87	49.84	55.96	61.54	69.04	79.06	86.44	65.91	49.98
	Rutting life	239.92	193.1	218.06	239.32	274.52	311.40	337.69	262.66	218.06
130 mm	ε_t	167.4	186.7	175.6	167.4	156.4	146.8	141.1	159.9	175.6
	ε_v	251.4	264.4	257	251.4	243.6	236.6	232.2	246.1	257
	Fatigue life	73.89	60.69	68.69	75.94	85.63	98.66	107.96	81.55	61.35
	Rutting life	294.36	234.21	266.38	294.36	339.58	387.57	422	324.22	266.38
140 mm	ε_t	158.8	177.5	166.7	158.8	148.1	138.8	133.3	151.5	166.7
	ε_v	240.4	253.5	246.1	240.4	232.6	225.6	221.3	235.1	246.1
	Fatigue life	90.72	73.88	84.1	93.24	105.86	122.7	134.69	100.6	75.1

	Rutting life	360.56	283.47	324.22	360.56	418.72	480.93	524.78	398.91	324.22
150 mm	ε_t	150.6	168.7	158.3	150.6	140.3	131.4	126.1	143.6	158.3
	ε_v	230.1	243.3	235.8	230.1	222.3	215.3	211	224.8	235.8
	Fatigue life	111.5	90.04	102.83	114.59	130.66	151.84	167.16	123.90	91.84
	Rutting life	439.74	341.48	393.57	439.74	514.16	594.43	651.36	488.74	393.57
160 mm	ε_t	143	160.5	150.4	143	133.1	124.5	119.3	136.2	150.4
	ε_v	220.4	233.6	226.1	220.4	212.7	205.7	201.4	215.2	226.1
	Fatigue life	136.38	109.29	125.49	140.16	160.67	187.29	207.39	152.22	112.07
	Rutting life	534.57	410.65	476.13	534.57	628.09	730.99	804.46	595.68	476.13

Note. ** ε_t and ε_v are in microstrains , Fatigue and Rutting life are in msa

From the above values it is seen that only filler contents containing 40 % SDA + 1 % HL + SD , 50 % SDA + 1 % HL + SD and 60 % SDA + 1 % HL + SD and highlighted have satisfied both rutting and fatigue lives . For the fatigue lives interpolation will be performed for minimum DBM thickness required corresponding to 150 msa . Other contents did not satisfied the minimum 150 msa life required including control mixture also .

Allowable horizontal and vertical strains will be calculated by failure equations as shown in Table 6.3 below.

Table 6.3 : Results showing thickness and strains required for 150 msa

Type of mixture	Minimum DBM thickness required (mm)	Allowable maximum horizontal tensile strain (microstrains)	Allowable maximum vertical compressive strain (microstrains)
40 % SDA + 1 % HL + SD	156.5	135.6	291.7
50 % SDA + 1 % HL + SD	149.36	132	291.7
60 % SDA + 1 % HL + SD	144.71	129.8	291.7

The variation fatigue lives and rutting lives with the corresponding thickness of the DBM are shown through charts as shown in Figure 6.2 and 6.3 .

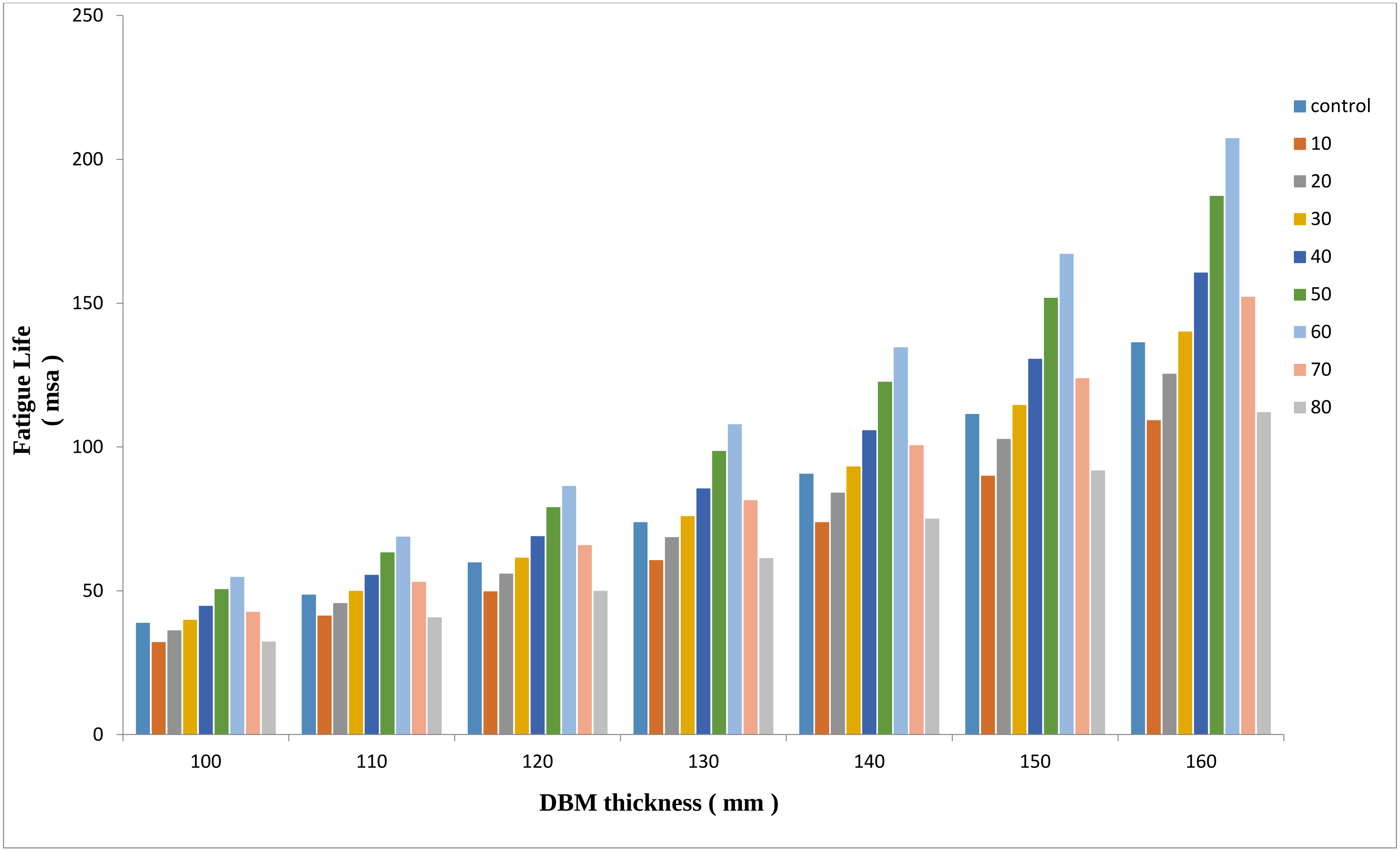

Figure 6.2 : Variation of Fatigue life with DBM thickness

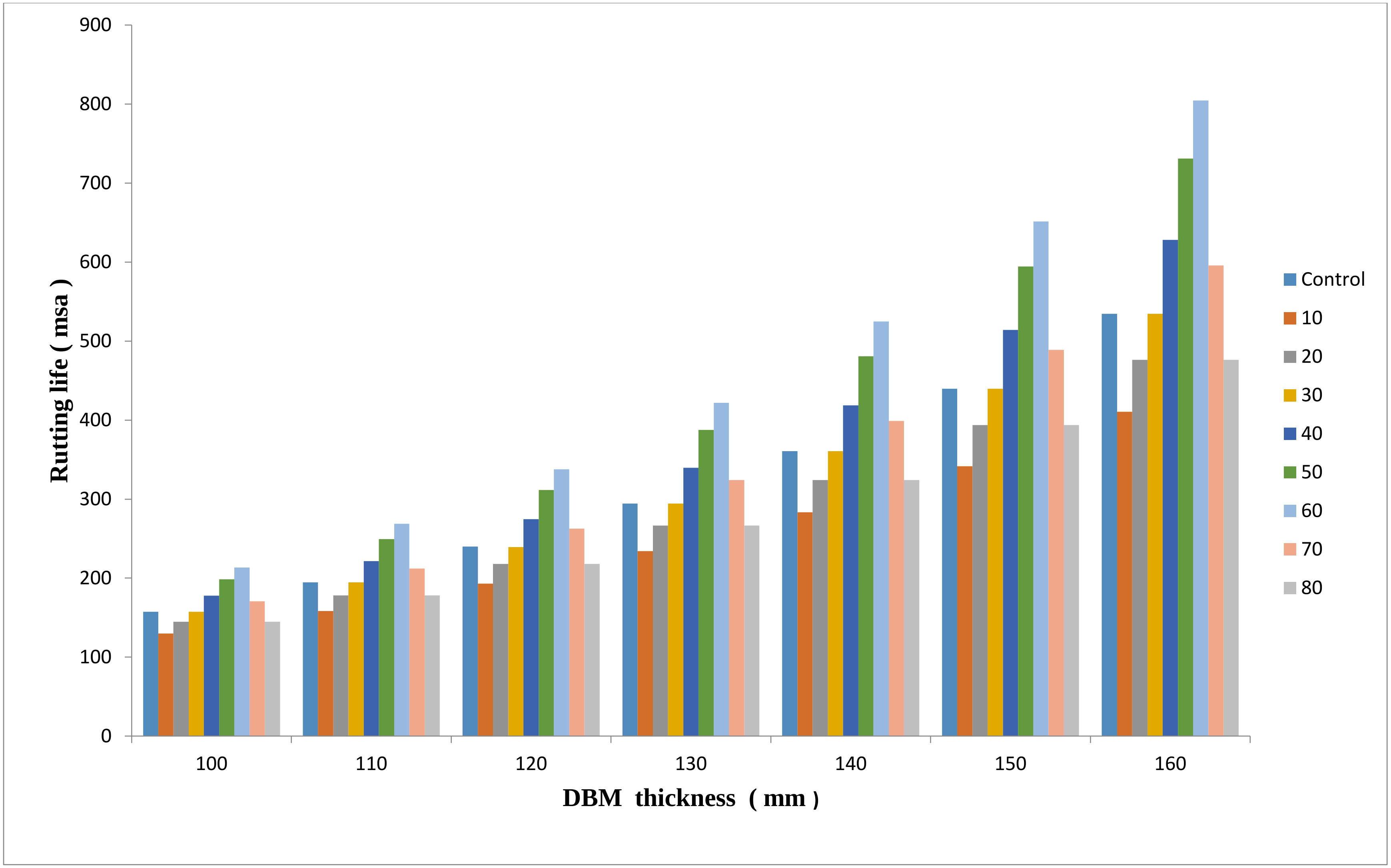

Figure 6.3 : Variation of Rutting life with DBM thickness

CHAPTER - 7

CONCLUSION

This thesis used up two type of fillers namely Saw Dust ash and Hydrated Lime in replacement of conventional stone dust for the preparation of the modified HMA specimens . A number of tests were conducted on these specimens (modified and unmodified both) so as to study out the comparisons and results. Various conclusions made from the tests are discussed below .

- It was observed that optimum binder content came at as 5.37 % by weight of aggregates from the conventional mixes and stability of 13.31 kN was observed at this binder cinder content and at 4 % of air voids in mix .
- Stability for modified mixes increased up to 60 % of Saw Dust ash and 1 % Hydrated Lime by weight of aggregates and then got decreased as compared to conventional mixes .The increase observed was due to increase in concentration of calcium oxide (Cao) .
- The percentage increase in stability with 60 % of Saw Dust ash and 1 % Hydrated Lime by weight of aggregates was observed as 64.08 % in respect to conventional mix at optimum binder content .
- The percentage increase in Static modulus with 60 % of Saw Dust ash and 1 % Hydrated Lime by weight of aggregates was observed as 45.83 % in respect to conventional mix at optimum binder content .
- The percentage increase in Indirect Tensile strength (ITS) with 60 % of Saw Dust ash and 1 % Hydrated Lime by weight of aggregates was observed as 33.33 % in respect to conventional mix at optimum binder content .
- The percentage increase in Resilient modulus with 60 % of Saw Dust ash and 1 % Hydrated Lime by weight of aggregates was observed as 39.72 % in respect to conventional mix at optimum binder content.
- The reason behind increasing Resilient modulus, Static modulus and Indirect tensile strength of the modified mixes are due to stiffening effect of Calcium Oxide (Cao) .

- From the design of pavements by IITPAVE it was observed that there was a increasing trend of fatigue and rutting lives with respect to increasing modified fillers content up to with 60 % of Saw Dust ash and 1 % Hydrated Lime by weight of aggregates at particular Dense Bituminous Macadam (DBM) thickness .
- There was a increase in fatigue and rutting lives with increasing thickness of DBM and at particular modified filler contents .
- It was seen that from the results of fatigue and rutting lives thickness required from control mix was going beyond 160 mm and from the modified mix with 60 % of Saw Dust ash and 1 % Hydrated Lime by weight of aggregates thickness of DBM required was least as 144.71 mm which means cost of construction was economized with modified mix .
- From the all above results it can be concluded that usage of with 60 % of Saw Dust ash and 1 % Hydrated Lime by weight of aggregates will be helpful in the construction of actual pavements .

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