PERFORMANCE EVALUATION OF STONE MASTIC ASPHALT (SMA)

FINAL YEAR PROJECT UG 2013

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This is to certify that the

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DEDICATION

We dedicate our work to our beloved parents and teachers who enabled us to achieve education and meet our objectives with such dignity and respect.

ACKNOWLEDMENT

We are deeply obliged to acknowledge and thank those people who put their ever best contribution into our thesis. First of all thanks to Almighty Allah for blessing us with everything that he has provided us.

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ABSTRACT

In Pakistan on National Highways with the flexible pavements the phenomena of rutting is a very common distress. This distress in roads is caused by many factors including but not limited to increase in temperature and the design techniques adopted.

Road problems are not only occurring because of the increase in the traffic on roads but it also may be due to reason of poor pavement designs and structures. Pre-mature rutting phenomena and the poor selection of the aggregate gradations may also be one of the reasons of the poor road pavements. All this ultimately leads towards the loss of capital investment and makes it very difficult and uncomfortable to travel on a road section.

Marshal Mix Design technique is one of the methods for finding the volumetric properties of asphalt mix. 60/70 ARL Bitumen and Marghalla crush are best suited for the making of Stone Mastic Asphalt (SMA). The addition of additive changes the behavior of asphalt and reduces the viscous nature of it.

Stone mastic asphalt (SMA) using Sasobit is considered effective solution in heavily trafficked areas because of the larger single size aggregate that can be used with the increased bitumen thus controlling rutting susceptibility. Comparison of 12.7mm NMA gradation and 9.5 mm NMA gradation shows that SMA gives better results using higher gradations and the addition of Sasobit will improve the results and properties of SMA and does not change the trends in the results of higher and lower gradations.

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CHAPTER 1

INTRODUCTION

1.1 General

The population of Pakistan is almost 189 million and is the 6th most populous country in the world. Pakistan comprises of the total area equals to 796096 km^2 and the most of the transportation is done by roads in Pakistan. Roads are the major source of inland movement of people and goods from one place to other in Pakistan. Studies reveal that the total road network of Pakistan is 259,000 km and about 60% of the road network in Pakistan consists of paved roads. And there is no doubt in saying that Roads like any other country are the major back bone of Pakistan.

For roads to serve the purpose it is needed that they are designed by considering the nature of the use of the road. A road will fall into its proper strength parameters if it has a proper gradation of aggregate, suitable bitumen content, desirable additive and it has been prepared by the use of proper mix designs. Stone Mastic Asphalt is the type of the pavement structures that are better in regard to less rutting and better riding qualities. The use of SMA is very common at the roads with heavy traffics especially in countries like Germany and Australia.

Marshall Mix Design method is one of the methods that have been used in the world. Different aggregates have different strengths and thus affect the road in different manners. In the line coming next the second part of Marshal Mix Design is the compaction phenomena. Optimum Bitumen Content (OBC) is another part of Marshal Mix design which is very important in achieving the desired strength parameters of any road.

1.2 Study Background

Countries like Pakistan, Australia, New Zealand where roads are used by heavy traffic the phenomena of rutting is very common. Rutting is caused with variation in Loads and temperature. The texture of Stone Mastic Asphalt (SMA) is such that it provides better riding qualities, low noise production and less skidding. SMA is also very useable in roads where the phenomenon of rutting is relatively higher in percentage. The arrangement of stone aggregate in SMA is very delicate and this enables a stone to stone contact for the transformation of loads. It is also note able that cost of SMA is generally 20-30% more than the other conventional asphalt mixes. The reason for this is the higher content of asphalt used in the preparation of SMA and the addition of the filler. But despite of the fact that it costlier than others it also guarantees longer life and enhanced performance of the road structure.

Fig 1-1 Stone Mastic Asphalt (SMA), Skeletal Structure

Marshal Mix Design procedure was adopted for this research to check the properties and performance of Stone Mastic Asphalt. This method is most commonly used by road authorities and it has great significance as this expose the details about the pavement performance in an indirect fashion.

In 1939 Bruce Marshall developed the concept of Marshall Mix design. Bruce Marshall was working in Mississippi Highway Department. Further this concept was modified by the U.S. Army. The purpose of this method is to select the Optimum Bitumen content at a desired density which satisfies the criteria of stability, flow, Air Voids, Voids in mineral aggregate, Voids filled with asphalt and Unit weight of specimen ranges. **(White, 1985)**

1.3 Problem Statement

Studies and researches state that there are three main reasons for the failure of roads:

- Geographical environmental condition including the variations in temperature
- Overloaded vehicular use on the roads and compromise over quality
- The Negligence in the construction.

All these factors results in the following problems:

- Premature rutting.
- The improper selection of the aggregate gradations against the nature of use of the road.
- Huge loss of capital in the rehabilitation or maintenance is causing problems in road travelling and results in the wastage of capital investment all over the country.

1.4 Objectives

In countries like Pakistan where the variations in temperature in different parts of the country are very high and axle load of the vehicles is strongly recommended to be evaluated while designing a pavement structure.

The Objectives of our Research project are given below.

- To investigate the properties of the materials used for making stone mastic asphalt (SMA).
- To study and evaluate the properties and the performance of stone mastic asphalt (SMA) with the variation in the gradation of aggregate used.
- To study the difference in the behavior of Stone Mastic Asphalt (SMA) with and without the addition of additive.

1.5 Scope

Extensive literature review and research studies enable us to develop the following scope for our project:

- Identifying and classifying the materials to be used and conducting specific tests to judge if they fall within limits.
- Preparation of samples using two different gradations of maximum nominal size of aggregates 12.7mm & 9.5mm, (60/70) penetration grade bitumen and an additive.
- Calculations and Comparison of the properties of SMA samples prepared using two different gradations.
- Analysis and comparison Stone Mastic Asphalt within the two different gradations with the addition of an Additive.

1.6 Organization of Thesis

- Chapter 1: Introduction of the project.
- Chapter 2: Literature Review.
- Chapter 3: Research Methodology.
- Chapter 4: Comparison and Detailed Analysis.
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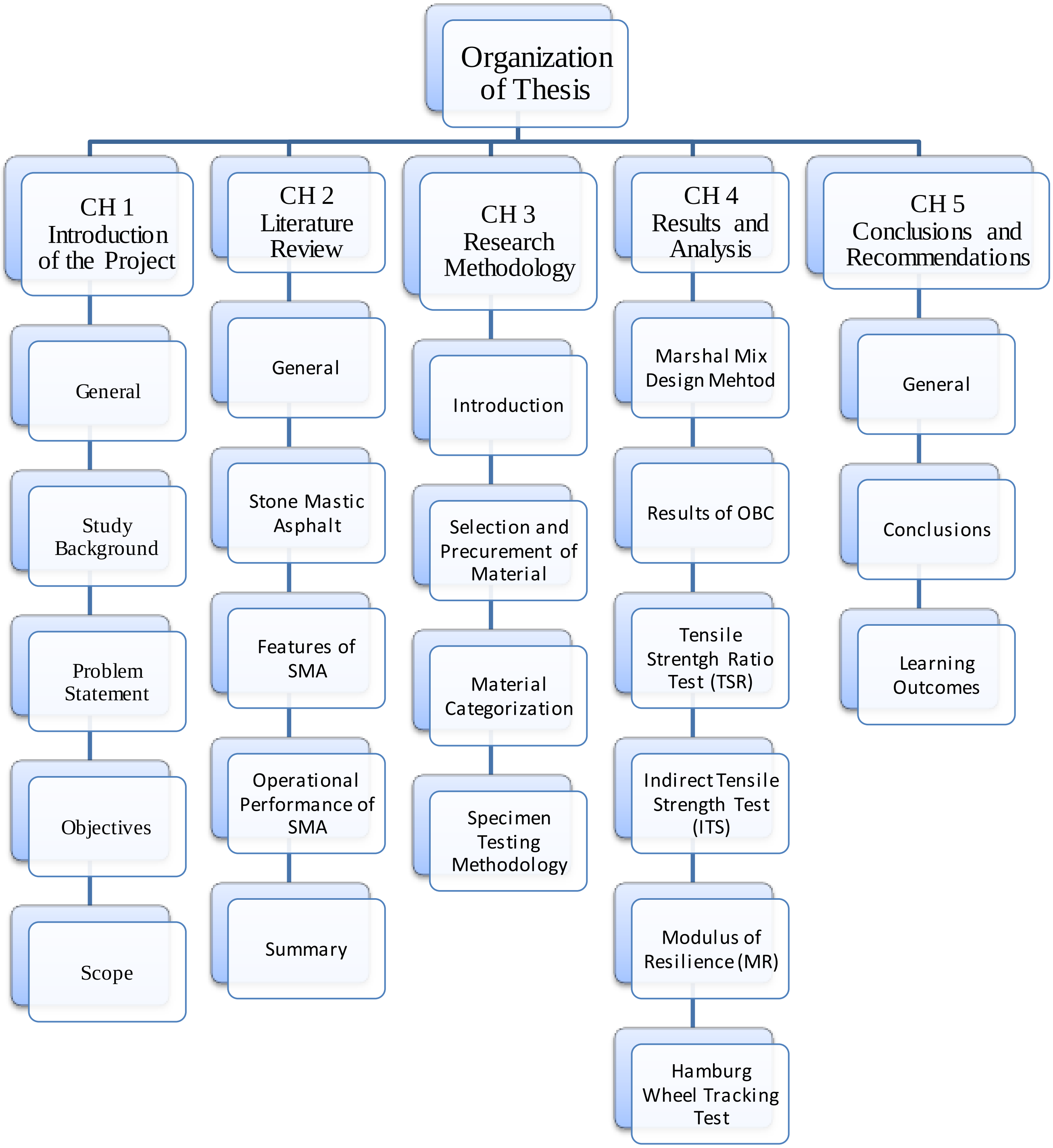
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CHAPTER 2

LITERATURE REVIEW

2.1 General

Asphalt pavements can be defined as a combination of Aggregate and Bitumen and aggregate may be stone aggregate. There are three major types of asphalt surfacing namely,

- Open graded asphalt (OGA)
- Gap graded asphalt (SMA)
- Dense graded asphalt (DGA)

Asphalt surfacing differs by proportion of different size aggregates (coarse and fine aggregate), bitumen content and additive. We primarily focus on stone mastic asphalt which belongs to gap graded asphalt pavements. Gap graded asphalt consist of larger proportion of coarse aggregate and fine aggregates and lack intermediate size aggregates. Initially, it is considered that well grade aggregate which means presence of all standard sizes of aggregates in mix work more efficiently in fatigue and rut resistance. In well graded aggregate proportion, it is generally considered that the voids which are produced by the larger aggregate gradation will be filled up by the next upcoming nominal aggregate size and again if some smaller voids will be left out which will again be filled up by next smaller aggregate size. But practically it is observed that size of voids created by particular size of aggregate can be efficiently filled by second or third lower size aggregate i-e: if the voids are produced by the 1.5inch aggregate size will be filled by the #4 or #10 sieve passes aggregate size not by 1inch aggregate size because the smaller aggregate commonly filled the void spaces. This concept is about Gap Graded aggregate.

2.2 Stone Mastic Asphalt (SMA)

Stone Mastic Asphalt (SMA) is also called as Stone Matrix Asphalt based on its structure like formation. It was actually developed in Germany in 60's for the preparation of durable road surfacing and to resist wear from the studded tires. The design of SMA generally contains the large percentage of coarse aggregate. Due to the reason that large percentage of coarse aggregate presence makes the SMA good in strength and also enables it to have a stone-on-stone contact. This stone-on-stone contact allows the SMA to bear more axle load of the vehicles without being subjected to wear and rutting.

In the period of 60's the Stone Mastic asphalt was invented and its origin was Germany. The purpose of this invention was to provide maximum resistance against the rutting which is commonly caused by the studded tyres on the roads of different countries. After its invention a well-known and big German company starts the development of SMA. The studded tyres were no longer allowed, and it was good against rutting on heavy and high traffic roads. The durability of SMA was much better than the other surface pavements and proved to be tremendously effective in opposing wear. The wear and tear properties of SMA are also much better than other surfacing types. In credit of its great performance against rutting, wear and tear a national standard was set in Germany in 1984. Since then SMA has spread throughout Europe, North America and Asia Pacific. Now many countries in Europe and in other continents have their own National Standards for SMA. The European standards body is in the process of developing a European product standard. The popularity of SMA is increasing day by day due to its extraordinary performances against the problems which are commonly faced by other road surfaces. Now in United States, Australia, New Zealand, and in Asia its demand is increasing day by day amongst road authorities and asphalt industries. One of the main advantages is that the road safety is also increased in case of stone mastic asphalt, safety in case of accident brakes because the causes of sliding are reduced in case of this surfacing.

Until 1994 there was no official mix design procedure available for SMA in United States and other Europe countries. Federal Highway Administration authority took a task of development of mix design procedure for stone mastic asphalt (SMA). Than the technical working team of FHWA developed mix design for SMA, since this was the method used to design SMA in Europe and United States. In the same year the National Center for Asphalt Technology (NCAT) also developed mix design procedure for SMA using the concepts of Super-pave mix design system. This research was based on 4 year study period of team of NCAT. **(ASPHALT,2016).**

In Pakistan the researcher have also probed SMA for its local applicability and reported that at high temperatures SMA have low rutting potential despite of higher binder content and the SMA composition with size of 19 mm is recommended for binder course and 12.5 mm is suitable for wearing course. Moreover, SMA requires less compaction effort due to its low compressibility and are less susceptible to change in air voids, thus SMA retains sufficient strength even at low air voids. **(Waliuddin, 2000)**

Hafeez et al. 2012 this man from UET Taxila published his research paper in which he described that, with increase in size of aggregate i.e. if the nominal maximum size of aggregate increases the rut depth going to decrease or sample performance going to increase. He also stated that temperature has significant effect on rutting phenomena of SMA, especially when the aggregate gradation or size is smaller.

2.3 Features of SMA

Stone Mastic Asphalt (SMA) in comparison with dense graded asphalt has the following features:

- Enhanced shear resistance
- Enhanced durability
- Enhanced crack resistance

- Enhanced skid resistance
- Enhanced light reflection
- Noise reduction equal/better

Author	Year	Findings
Hemant Manglorkar	1993	In this report there is a comparison of SMA projects carried out in USA and Europe. The study shows how aggregate and asphalt binder effects SMA and how an additive acts in SMA.
Alvarado & I. Abdallah	2007	This study is conducted as a research for TEXAS state university. In this the effect and the relation 0f coarse aggregate in SMA was studied and reveal that stone on stone contact is the main strength of SMA.
Samuel B. Cooper	2009	This study provided a laboratory and field comparative evaluation of PG 76-22 hot mix asphalt (HMA) mixture and a mixture containing the additive Sasobit. They observed the 0.4 Percent increase in Asphalt content when they use Sasobit with PG 76-22 HMA binder.
Imran Hafeez	2013	This study was all about the rutting phenomena where it has been observed that with the change in aggregate size the rutting phenomena also differs.

Table 2-1, Published Papers about SMA and their Summary

2.4 Operational performance of SMA

Many road surfacing are commonly used in different countries and everyone has its own benefits and dis benefits. Technical reports of AAPA on SMA listed the following advantages and disadvantages of SMA.

2.4.1 Advantages of SMA

- The Surface texture of SMA is very similar to OGA so that the noise produced by traffic in case of SMA is lower than DGA but slightly higher than OGA.
- The wearing course of SMA is very good against rutting phenomena and also durable i.e. SMA surfacing life is greater than other surfacing types.
- One of the main advantages of SMA is that it can be produced at HMA plant and the compaction procedure is also same.
- SMA is commonly used in the location where there is a heavy and high traffic e.g. on intersections etc. and where other surfacing types are not suitable.
- Due to flexible mastic in SMA type roads the reflection cracking is reduced from underlying cracked pavements.
- If the comparison is between DGA, SMA and OGA the durability of SMA should be greater than OGA and equal to DGA.

2.4.2 Disadvantages of SMA

- Due to higher asphalt content, filler content and addition of additive results into higher material cost for SMA.
- The productivity of SMA is lower than other mix types due to increased mixing time and time taken to add extra filler.
- To avoid the flushing of asphalt binder to surface, maybe there is a possible delay in opening to traffic till that mix cooled to 40°C.
- Initial skid resistance may be low until the thick binder film is worn off the top of the surface by traffic. In critical situations, a small, clean grit may need to be applied before opening to traffic.

2.5 Summary of Chapter

This chapter includes the history and origin of SMA and also explains about the utility and usability of SMA in comparison with other pavement structures. This chapter explains a lot about the features of SMA and also included the advantages and disadvantages of SMA.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter will contain the facts about the test methods and techniques adopted for making and testing of SMA to achieve the desire objectives as mentioned in Chapter 1 of this research. Materials used in the making of SMA are characterized and tested to gain the results which are listed in this research. Marshal Mix design method is opted for this research. For finding the facts about the strength parameters about SMA there is a need to know about the three main constituents of SMA first. These constituents are aggregates, asphalt and the additives itself.

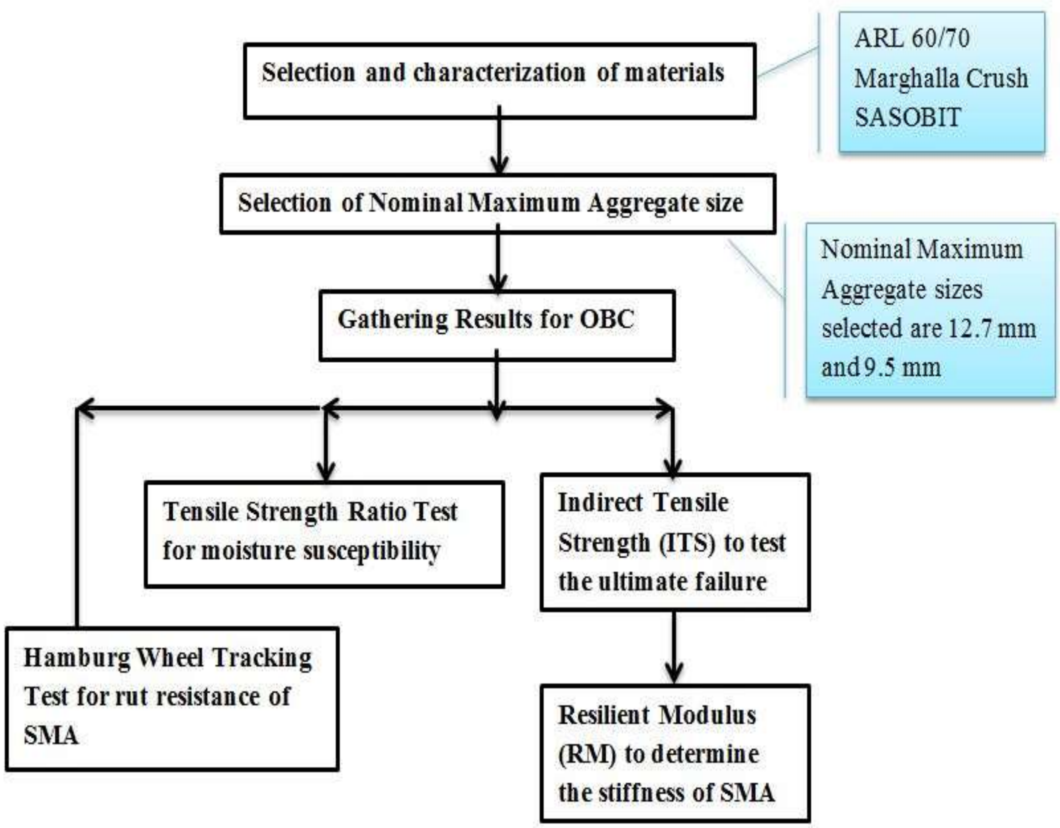


Fig 3-1 Steps for Research Methodology

3.2 Selection and Procurement of Material

Aggregate used in Stone Mastic Asphalt (SMA) must be of high quality, well-shaped, resistant to crushing and of suitable polish resistance. Gap-graded aggregate (usually from coarse aggregate, manufactured sands and mineral filler all combined into a final gradation), asphalt binder (typically with a modifier).

3.2.1 Aggregate Gradation and Sieve Analysis

With the change in aggregate gradation the parameters of SMA change. Primarily the aggregate used in the pavement is responsible for the strength. There are two different aggregate gradations are used in this research with two different nominal maximum aggregate sizes.

- **12.7mm NMA**
- **9.5mm NMA**

The sieve analysis of these two gradations subdivides the aggregate into 3/8 in, #4, #10, #40, #100, #200 and pan sized aggregate.

Fig 3-2 Stone Aggregate

Gradation 12.7mm NMA

Gradation with the aggregate having NMAS equals to 12.7 mm has the following passing and retained aggregate sizes.

Sieves Sizes (in)	Sieves Sizes (mm)	Cumulative Passing %	Cumulative Retained %	Each Sieve Retained %
1/2"	12.7	100	0	0
3/8"	9.5	80	20	20
#4	4.75	31	69	49
#10	2.36	23	77	8
#40	0.6	16	84	7
#80	0.31	13	87	3
#200	0.127	10	90	3
Pan	Pan	0	100	10

Table 3-1, 12.7 mm NMA Aggregate Gradation

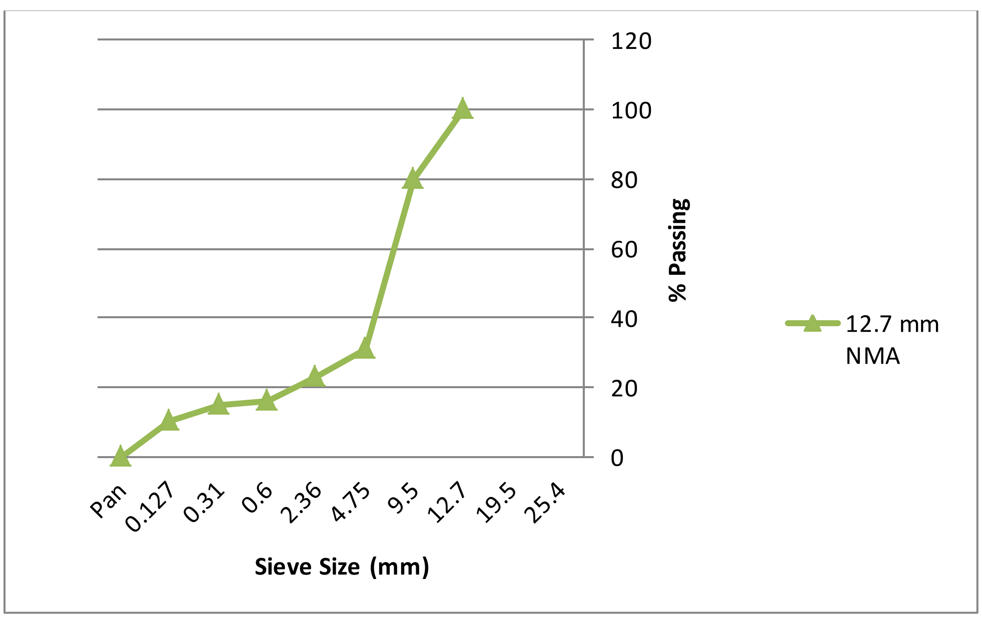


Fig 3-3, 12.7 mm NMA Aggregate Gradation

Gradation 9.5mm NMA

Gradation with the aggregate having NMAS equals to 9.5mm has the following passing and retained aggregate sizes.

Sieves Sizes	Sieves Sizes (mm)	Cumulative Passing %	Cumulative Retained %	Each Sieve Retained %
1/2"	12.7	100	0	0
3/8"	9.5	100	0	0
#4	4.75	46	54	54
#10	2.36	27	73	19
#40	0.6	19	81	8
#80	0.31	17	83	2
#200	0.127	10	90	7
Pan	Pan	0	100	10

Table 3-2 9.5 mm NMA Aggregate Gradation

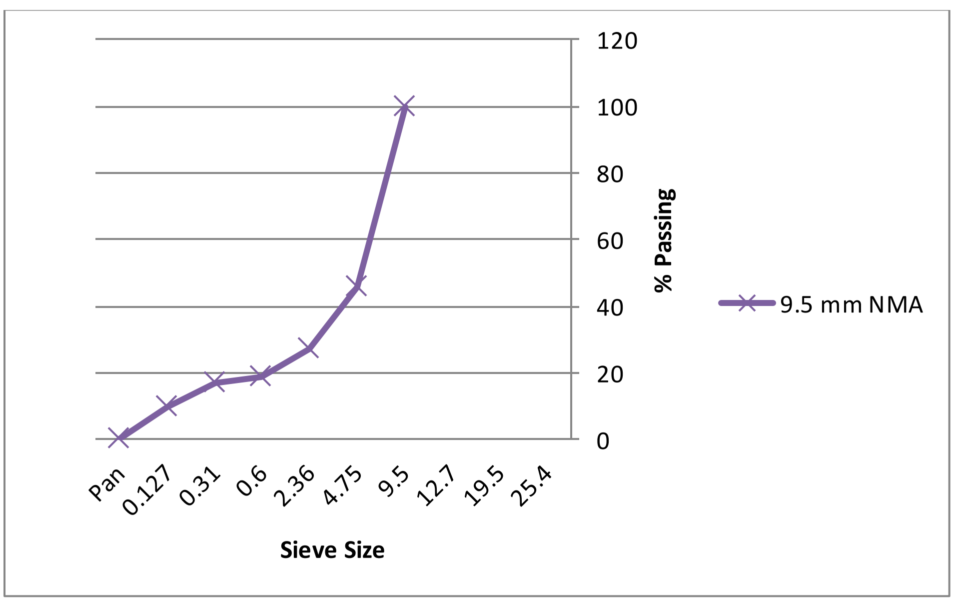


Fig 3-4, 9.5 mm NMA Aggregate Gradation

3.2.2 Bitumen/Asphalt

There are different grades of asphalts available i.e. 30/40, 40/50, 50/60, 60/70 and 80/100. With the increase in Bitumen grade it becomes soft and thus can be used readily in snow bound areas of the country. On contrary in the areas with high temperatures the low bitumen grades are used because of their hard nature. Despite of the facts the Bitumen Content used in this research is of grade **60/70** because this is used in the most parts of Pakistan and give better result in the areas with moderate climatic conditions. This 60/70 grade bitumen has been acquired from Attock Oil Refinery which is one of the finest oil refineries in Pakistan. Then for each sample measuring the OBC bitumen of percentage 5%, 5.5%, 6%, 6.5% and 7% has been used. So it proves with change in aggregate size the Optimum bitumen content varies.

Fig 3-5, 60/70 ARL Bitumen

3.3 Material Categorization

American Society for Testing Materials (ASTM) has set some standards that allows one individual to check whether the aggregates used for making SMA fall within the specified limits or not. Similarly there are standards set for the testing Asphalt using for the making of SMA. Both aggregate and asphalt are tested and there results are provided in the Table 3.3 and 3.4.

3.3.1 Aggregate Evaluation

For Marshal Mix Design method it is necessary that aggregate must fall within the acceptable limits defined by **ASTM.** The tests performed on aggregate for this purpose are Impact Test, Shape Test, LOS Angles abrasion test and the test to find the specific gravity of the aggregate. There are standard given by ASTM which asks for the test values to lie within those ranges.

Test Description		Specifications	Results
Specific Gravity	Coarse Aggregate	ASTM C127	2.60
	Fine Aggregate	ASTM C128	2.57
Aggregate Absorption	(10-20)mm	ASTM C127	0.73%
	(5-10)mm		2.45%
LA Abrasion		ASTM C131	22%
Impact Value		BS 812	24%
Elongation Index		ASTM D4791	3.578%
Flakiness Index		ASTM D4791	12.9%

Table 3-3, Test Results of Aggregate

3.3.2 Bitumen Evaluation

Bitumen in roads acts as binder which binds the coarse and fine aggregate material. Therefore like aggregate it is also necessary to evaluate the bitumen and check whether it falls within the acceptable limits or not. Various tests are conducted before the preparation of the bituminous material.

Tests	Specifications	Test Results
Penetration	ASTM D5	64 mm
Ductility	ASTM D113	104 cm
Softening	ASTM D36	48.2 ^{o}C
Flash Point	ASTM D92	232 ^{o}C
Fire point	ASTM D92	241 ^{o}C
Specific Gravity	ASTM D70	1.03

Table 3-4, Test results for 60/70 Bitumen

3.3.3 Sasobit (Additive)

Sasobit is the additive used in this research. It is a product of **SASOL WAX**. It is produced from coal gasification and it acts as asphalt improver which makes asphalt less viscous and more workable. Sasobit melts at **99^{0} C** and at the temperature of **115^{0} C** it is completely soluble in the asphalt. According to researches the recommended useable range of Sasobit is between **0.8 – 3.0%**. The quantity of Sasobit used in this research is **1.5%**. The use of 1.5% Sasobit in this project results in the decrease in the temperature of the mix by **18 – 54 ^{0} C**.

Fig 3-6, Sasobit (Additive)

3.4 Specimen Testing Methodology

Specimens prepared are tested to find the results. Each Specimen has been prepared under the specifications of the standard testing methodologies.

3.4.1 Finding Optimum Bitumen Content

For OBC tests has been conducted on bitumen content of 5.0%, 5.5%, 6.0%, 6.5% and 7.0% and for each percentage of the Bitumen 3 + 3 samples have been prepared for each gradation. Here 3 samples are virgin samples without the addition of the additive and three samples are the sample after the addition of the Sasobit as an additive.

Tests	Apparatus	
Marshal test	Marshal stability and flow apparatus(ASTM D6927-15)	
%Bitumen (60/70)	No. Samples 12mm	No. Samples 9.5mm
5.0%	3 + 3	3 + 3
5.5%	3 + 3	3 + 3
6.0%	3 + 3	3 + 3
6.5%	3 + 3	3 + 3
7%	3 + 3	3 + 3
Sub-Total	30	30
TOTAL	60	

Table 3-5, Testing Methodology for finding OBC

3.4.2 Performance Evaluation of SMA

For the performance evaluation of SMA following tests has been performed:

- Moisture Susceptibility Test (Tensile Strength Ratio)
- Indirect Tensile Strength (ITS)
- Modulus of Resilience (RM Value)
- Wheel Tracking Test (Rutting)

Test	**Apparatus**	**Gradation of Aggregate.**		
		12.7 mm	9.5 mm	
		No. of Samples	No. of Samples	Test Standard
Moisture Susceptibility	Universal Testing Machine (UTM)	6+6 (Dry, Wet)	6+6(Dry, Wet)	ALDOT 361-88
Indirect Tensile Strength(ITS)	UTM	3+3	3+3	ASTM D6931-12
Resilient Modulus	UTM	3+3	3+3	ASTM D7369-11
Wheel tracking test	Hamburg Wheel Tracker	2+2	2+2	AASHTO T324
Sub-Total		28	28	
Total		56		

Table 3-6, Testing Methodology for Performance Evaluation of SMA

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Marshal Mix Design Method

In 1939 Bruce Marshall developed the concept of Marshall Mix design. Bruce Marshall was working in Mississippi Highway Department. Further this concept was modified by the U.S. Army. The purpose of this method is to select the Optimum Bitumen content at a desired density which satisfies the criteria of stability, flow, Air Voids, Voids in mineral aggregate, Voids filled with asphalt and Unit weight of specimen ranges. This design consists of six basics Steps:

- Aggregate Selection
- Selection of Asphalt Binder
- Sample Preparation
- Determination of Stability and Flow using Stabilometer Apparatus
- Calculation of Air Voids, VMA and VFA
- Calculation of Optimum Bitumen content Using Graphs.

4.1.1 Selection of Aggregate

The suitability of Aggregate was checked i.e. either it is suitable for Stone Mastic Asphalt. For Our Project we use Margalla Crush Aggregate and the test Performed on this Aggregate was:

- Specific Gravity
- Aggregate Absorption
- LA Abrasion
- Impact Value
- Elongation Index
- Flakiness Index

And the results of all these values fall within the limits it means the aggregate is suitable for Stone Mastic Asphalt (SMA).

Fig 4-1, Marghalla Crush Stone Aggregate

4.1.2 Selection of Asphalt Binder

The 60/70 Penetration Grade Attock Refinery Asphalt Bitumen was selected for this Project. This is commonly used Asphalt in the areas of Rawalpindi and Islamabad. We check the following Properties of Asphalt Binder:

- Penetration
- Ductility
- Softening
- Flash Point
- Fire Point
- Specific Gravity

The results of all these Properties within the limits and satisfying the criteria of their usage.

4.1.3 Sample Preparation

For the preparation of Samples first the aggregate placed in oven for 1 hour to minimize the moisture of aggregate than we select the asphalt percentage for sample preparation and in mixer we mix the both Asphalt and aggregate. The mix temperature was about 160C after that the compaction of specimen takes place at 150C.

While in case of Sasobit sample the temperature ranges were different. The Sample Preparation temperature was 130C and Compaction temperature was 120C. The Compaction of Samples was done by Automatic Compactor. In case of rutting test we prepared the Gyratory samples and compaction was also done by Gyratory Compactor.

Fig 4-2, Preparation of SMA sample

4.1.4 Determination of Stability and Flow

For this Purpose we use the Marshall stability and flow apparatus and this was performed according to ASTM D6927-15 Standard. Before this we placed the sample in water bath for 35-40 min at 60C. Than the sample tested at Marshall Stability and flow apparatus and this gives us the value of Stability in KN and Deflection in millimeter. The Loading rate was 50.8mm/min. LVDT was attached with the mold of specimen which automatically noted the readings of Stability and displacement of samples. The values of all these samples were noted and further used in the preparation of graphs.

Fig 4-3, Stabilometer

4.1.5 Calculation of Air Voids, VMA and VFA

Air Voids

The small Pockets of air that occurred between the coated aggregate particles in the final compacted mix are known as Air voids. A Specific Percentage of mix is required in the all samples because this is further use in determination of Optimum bitumen content. We commonly used 4% air voids in our Project. Durability of Pavement is depend s upon the air voids content. If the air void content is too high than it provide passageway through the mix for the entrance of damaging air and water. If the air voids content is too low the mixture will lead to flushing and it will also less permeable. Density also directly related to air voids content. Higher the air voids content lower will be the density and vice versa.

The formula used to determine the air voids content is:

$$\textbf{Air Voids} = \frac{Gmm - Gmb}{Gmm} * 100$$

For this Purpose first we determine the **Gmb** (Bulk specific Gravity) and **Gmm** (Maximum Specific Gravity).

Bulk Specific Gravity (AASHTO T166-07)

The Ratio of SMA sample weight to the Weight of equal volume of water is known as Bulk specific Gravity. Commonly represented by Gmb.

$$Gmb = \frac{A}{B - C}$$

- A= Mass of Sample in air (g)
- B= Mass of SSD Sample in air (g)
- C= Mass of Sample in Water (g)

Fig 4-4, Buoyancy Balance for finding Gmb

Maximum Specific Gravity (AASHTO T209-05)

It is also known as theoretical maximum specific gravity. If the all air voids removed from samples the collective specific gravity of remaining aggregate and asphalt binder would be the theoretical maximum specific gravity. This is very important parameter because it is used in calculation of Air voids. The formula for air voids is

$$Gmm = \frac{a}{(a + d - e)}$$

- a= Mass of sample in air (g)
- d= Mass of flask filled with water (g)
- e= Mass of flask and sample filled with water (g)

Fig 4-5, Pyconometer for finding Gmm

Voids in Mineral Aggregate (VMA)

Air voids spaces that exist between the aggregate particles in a compacted mixture including spaces filled with asphalt is known as voids in mineral aggregate. It represents the space available to accommodate the binder and air voids. It is the property of Aggregate. If the voids in mineral aggregate are more it means more space is available to accommodate the air voids and binder content. It also affects the durability of roads. If Voids in mineral Aggregate s are lower than the durability will be low. To ensure the Proper filling of voids with asphalt content the Optimum VMA is needed. The formula which is commonly used for VMA is:

$$\boldsymbol{VMA = 1 - \frac{Gmm(1 - Pb)}{Gsb} * 100}$$

Voids Filled with Asphalt (VFA)

The Percent of air voids in the compacted sample that are coated with asphalt is commonly known as voids filled with asphalt (VFA). It is very important design parameter and also affects the durability of pavements. For Stone mastic Asphalt the range of Voids filled with asphalt should be between 65-75. VFA ranges helps to avoid those mixes that are vulnerable towards rutting in heavy traffic loading. The formula used for calculation of Voids filled with bitumen is:

$$\boldsymbol{VFA = \frac{VMA - VA}{VMA}}$$

4.1.6 Calculation of OBC

After the Calculation of Volumetric Properties of mix which are explained above the Graphs made between:

- Air Voids and Bitumen contents
- VMA and Bitumen contents
- VFA and Bitumen contents
- Stability and Bitumen contents

- Displacement and Bitumen contents

From these graphs against 4% air voids first we calculate OBC. After finding OBC we use other graphs for the Calculation of VMA, VFA, Stability and displacement against the calculated OBC. And all the value should pass the criteria of SMA ranges.

4.2 Results Optimum Bitumen Content (OBC)

In this research two Gradations were selected first is 12.7mm Nominal maximum aggregate size and second is 9.5mm Nominal maximum aggregate size. From these two gradations total four OBC's were obtained. Two samples prepared using Sasobit as an additive and other two are prepared without additive.

4.2.1 OBC for 12.7mm NMA Gradation Virgin Samples

Volumetric Properties of 12.7mm Gradation Virgin Samples are as follows

Asphalt %	Gmb (avg)	Gmm (avg)	Va % (avg)	VMA % (avg)	VFA % (avg)	Stability (KN) (avg)	Flow (mm) (avg)
5	2.331	2.533	7.96	14.83	46.3	14.28	3.33
5.5	2.349	2.47	4.9	14.24	65.63	15.41	3.78
6.0	2.361	2.435	3.11	14.63	78.73	13.62	4.13
6.5	2.362	2.414	2.15	15.05	85.71	10.58	4.71
7.0	2.363	2.394	1.5	15.47	90.6	9.78	4.88

Table 4-1, Volumetric Properties of 12.7mm NMA Gradation

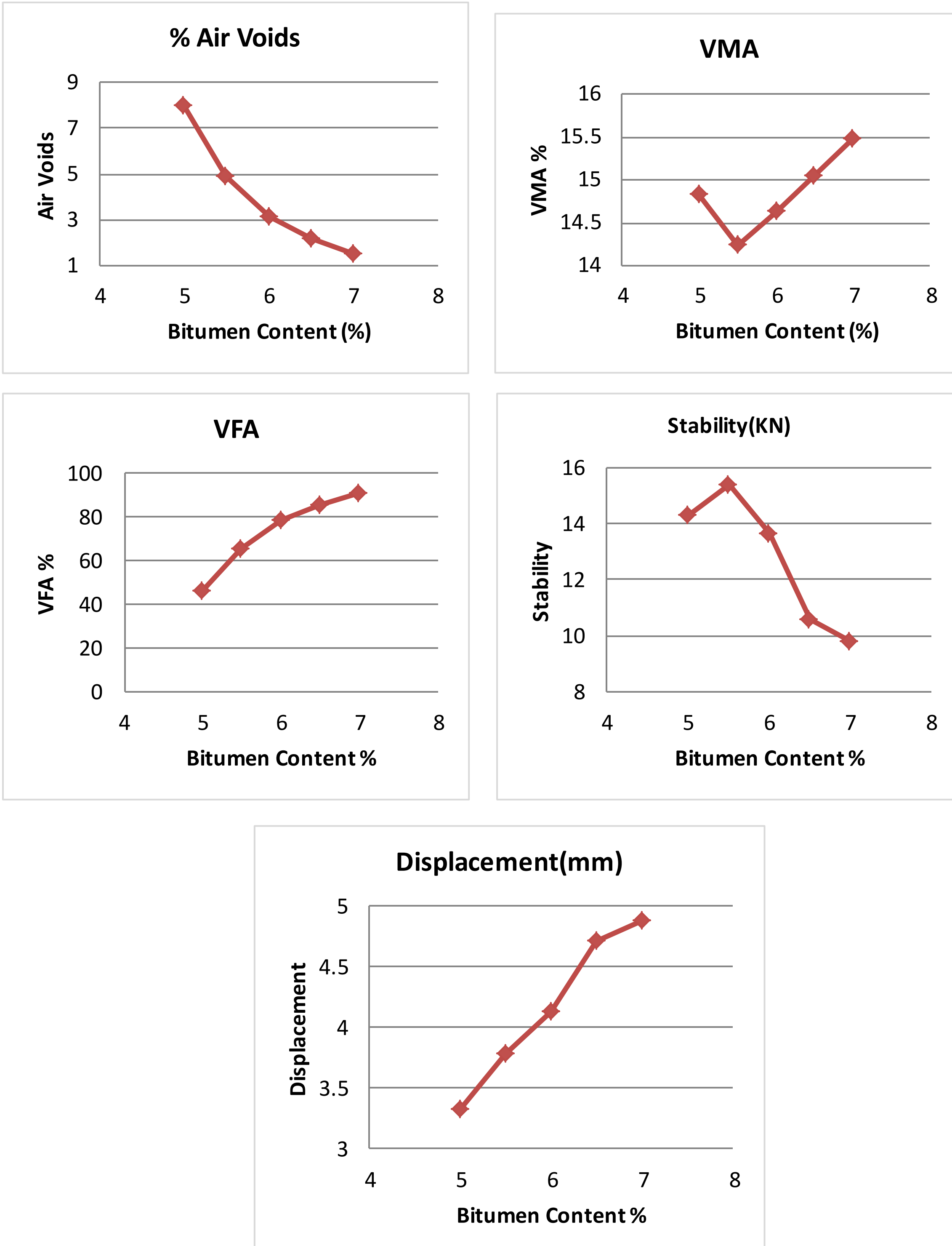


Fig 4-6, Graphical Representation of OBC Calculations for 12.7mm NMA Gradation

Marshall Test Results			
Properties	**Values**	**Specifications**	**Remarks**
Air Voids	4.0%	3 – 5%	Ok
OBC	5.73%	-	Ok
VMA	14.38%	14 – 16%	Ok
VFA	71%	65 – 75%	Ok
Stability	14.9 KN	>8 KN	Ok
Flow	3.90 mm	2 – 4mm	Ok

Table 4-2, Volumetric Properties of 12.7mm NMA Gradation against 4% Air Voids

4.2.2 OBC for 9.5mm NMA Gradation Virgin Samples

Volumetric Properties of 12.7mm Gradation Virgin Samples are as follows

Asphalt %	Gmb (avg)	Gmm (avg)	Va % (avg)	VMA % (avg)	VFA % (avg)	Stability (KN) (avg)	Flow (mm) (avg)
5	2.321	2.613	11.17	15.175	26.405	14.088	3.005
5.5	2.348	2.511	6.53	14.75	54.97	15.116	3.622
6.0	2.3605	2.449	3.695	14.65	74.77	15.806	4.212
6.5	2.345	2.391	1.92	15.675	87.75	10.806	4.550

Table 4-3, Volumetric Properties of 9.5mm NMA Gradation

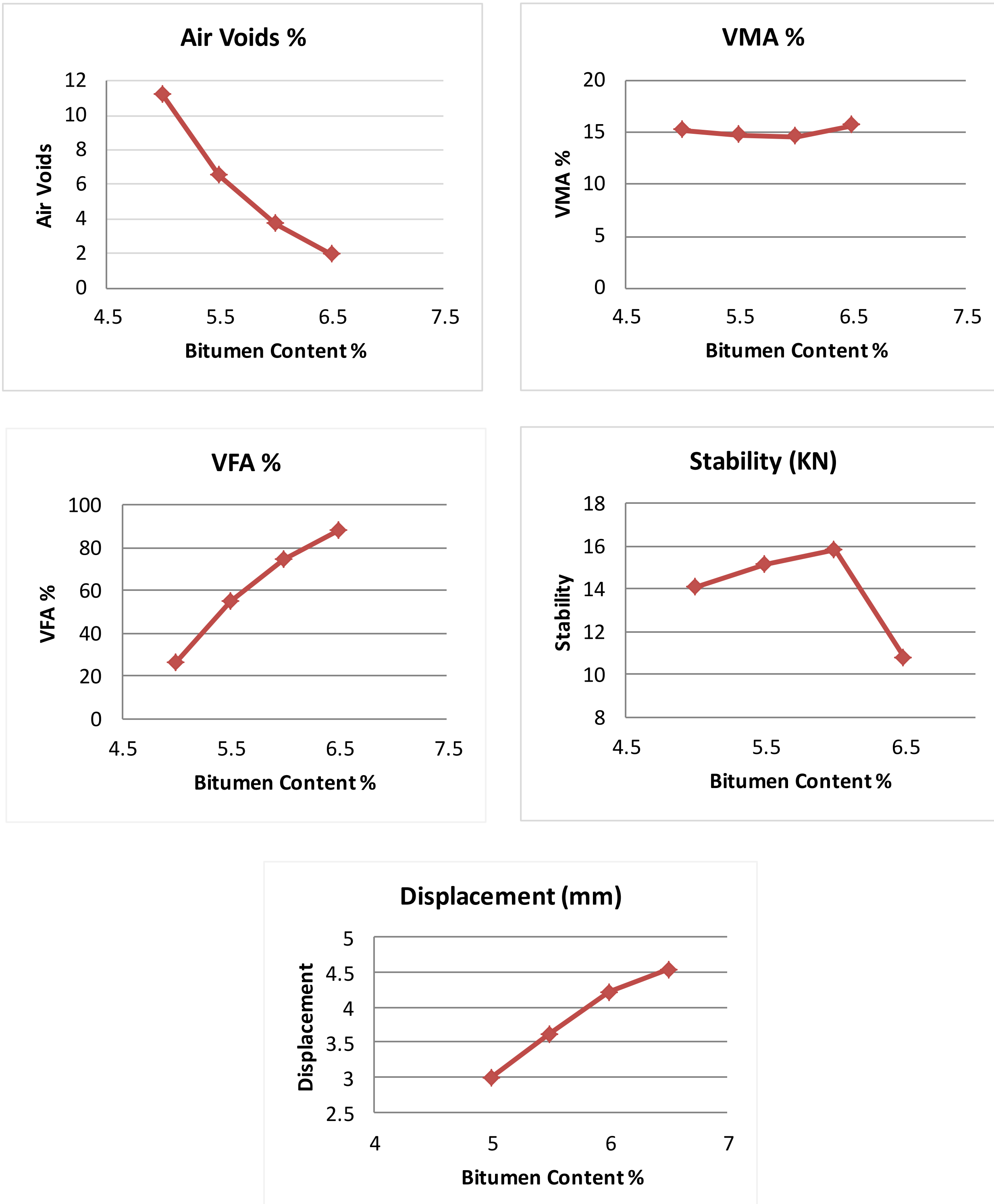


Fig 4-7, Graphical Representation of OBC Calculations for 9.5mm NMA Gradation

Marshall Test Results			
Properties	**Values**	**Specifications**	**Remarks**
Air Voids	4.0%	3 – 5%	Ok
OBC	5.94%	-	Ok
VMA	14.70%	14 – 16%	Ok
VFA	74%	65 – 75%	Ok
Stability	15.9 KN	>8 KN	Ok
Flow	4.00 mm	2 – 4mm	Ok

Table 4-4, Volumetric Properties for 9.5mm NMA Gradation against 4% Air Voids

4.2.3 OBC for 12.7mm NMA Gradation Sasobit Samples

Volumetric Properties of 12.7mm Gradation Sasobit Samples are as follows

Asphalt %	Gmb (avg)	Gmm (avg)	Va % (avg)	VMA % (avg)	VFA % (avg)	Stability (KN) (avg)	Flow (mm) (avg)
5	2.316	2.566	9.73	15.375	39.08	11.86	2.891
5.5	2.342	2.479	5.495	14.85	63.03	12.43	3.16
6.0	2.349	2.45	4.115	15.05	72.66	13.06	3.521
6.5	2.32	2.40	3.305	16.54	79.84	11.52	4.321
7.0	2.319	2.375	2.35	16.98	86.16	9.96	5.150

Table 4-5, Volumetric Properties for 12.7mm NMA Gradation with SASOBIT

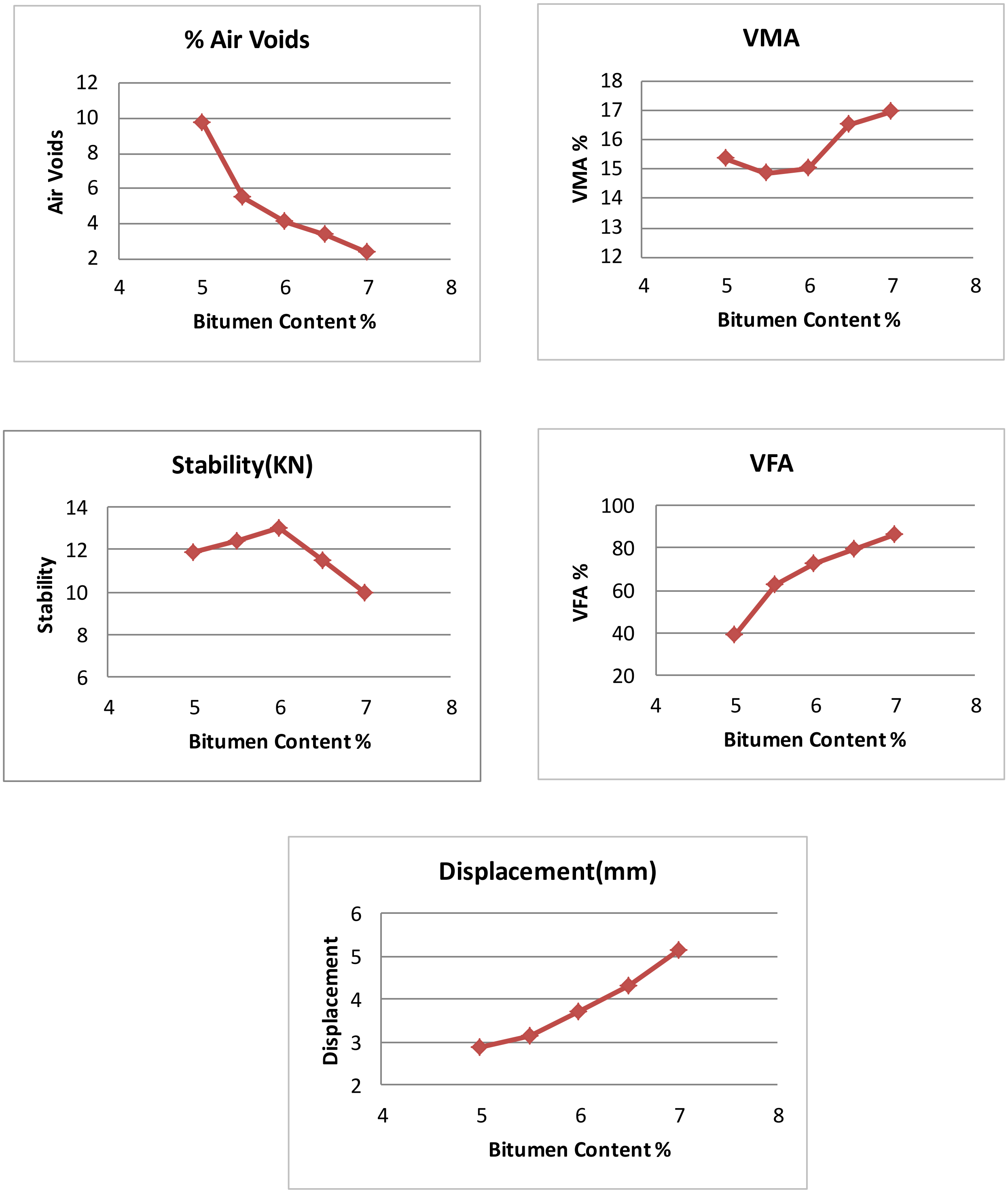


Fig 4-8, Graphical Representation of OBC Calculations for 12.7mm NMA Gradation with SASOBIT

Marshall Test Results			
Properties	**Values**	**Specifications**	**Remarks**
Air Voids	4.0%	3 – 5%	Ok
OBC	6.05%	-	Ok
VMA	14.7%	14 – 16%	Ok
VFA	72%	65 – 75%	Ok
Stability	13 KN	>8 KN	Ok
Flow	3.70 mm	2 – 4mm	Ok

Table 4-6, Volumetric Properties for 12.7mm NMA Gradation with SASOBIT against 4% Air Voids

4.2.4 OBC for 9.5mm NMA Gradation Sasobit Samples

Volumetric Properties of 9.5mm Gradation Sasobit Samples are as follows

Asphalt %	Gmb (avg)	Gmm (avg)	Va % (avg)	VMA % (avg)	VFA % (avg)	Stability (KN) (avg)	Flow (mm) (avg)
5	2.3375	2.72	13.1	13.98	6.13	11.328	2.611
5.5	2.3495	2.6835	12.34	13.38	9.26	12.943	2.991
6.0	2.337	2.469	5.35	14.44	63.18	12.48	3.424
6.5	2.303	2.401	3.70	15.59	76.67	12.785	3.86
7.0	2.31	2.394	3.5	16.19	78.59	10.075	4.20

Table 4-7, Volumetric Properties for 9.5mm NMA Gradation with SASOBIT

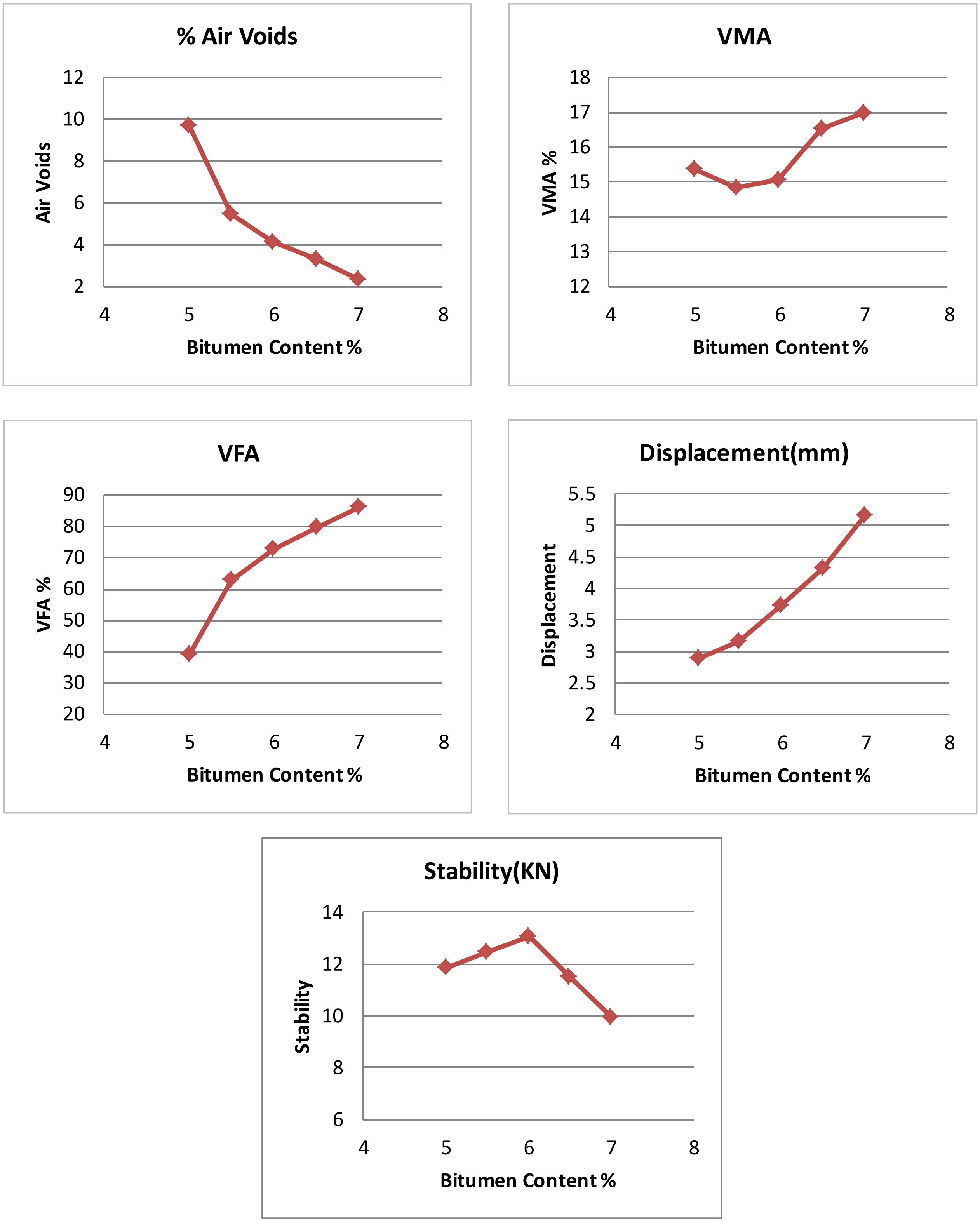


Fig 4-9, Graphical Representation of OBC Calculations for 9.5mm NMA Gradation with SASOBIT

Marshall Test Results			
Properties	**Values**	**Specifications**	**Remarks**
Air Voids	4.0%	3 – 5%	Ok
OBC	6.05%	-	Ok
VMA	14.7%	14 – 16%	Ok
VFA	72%	65 – 75%	Ok
Stability	13 KN	>8 KN	Ok
Flow	3.70 mm	2 – 4mm	Ok

Table 4-8, Volumetric Properties for 9.5mm NMA Gradation with SASOBIT against 4% Air Voids

After the calculation of four Optimum Bitumen content, two using Additive and two without additive the next target was to check the performance of Stone mastic asphalt using following test.

- Tensile strength Ratio test (TSR)
- Indirect tensile strength test (ITS)
- Resilient Modulus test (RM)
- Wheel Tracking test

To check the performance the same samples were prepared as we prepared in Marshall Mix design. The samples were prepared at each Optimum bitumen content to check the performance of SMA.

4.3 Tensile Strength Ratio (TSR)

In this test we determine the Moisture susceptibility of Stone mastic Asphalt samples i.e. how much they are susceptible towards the water. Susceptibility is determined by taking ratio of conditioned and unconditioned samples. Six samples were prepared for this purpose they were tested as a conditioned and three as an unconditioned. Conditioned samples are those which are held in water so that water effect that samples and then we take ratio of this sample to that unconditioned which is tested according to simple conditioning and their ratio must be greater than 80% to pass the criteria of this test. The results may be used to predict long term .stripping susceptibility of the asphalt, and evaluating liquid anti-stripping additives that are added to the asphalt cement such as .hydrated lime, which are added to the mineral aggregate.

Apparatus for this test is same as mentioned in the indirect tensile strength test i.e. Equipment for preparing and to compact the specimens.

Balance and water bath and Water bath capable of maintaining a temperature. .Loading jack and ring .dynamometer to determine the ultimate load and the deformation, and steel loading strip is also used in this test and the length of the loading strips shall .exceed the diameter of the specimens. The edges of the loading strips shall be rounded by grinding. The specimen are same size which aretested in ITS.

The procedure we adopt for the testing of specimen was according to standards in which we test the conditioned and unconditioned samples separately. The dry i.e. unconditioned samples were tested under room temperature. We held the specimen at **25^0 C** for one hour in water bath and then tested in Universal testing machine (UTM). With the help of **US002 software** we applied the load over the sample and note the ultimate failure load. For the conditioned sample first place the specimens into a (60 ºC) water bath filled with distilled water for 24 hours. _Than After 24 hours in the (60ºC) water bath, remove the specimens and place them in a water bath already at (25 ºC) for one hour. That is called conditioning after that we place the sample in the UTM and repeat the procedure and obtain the ultimate failure loads.

After obtaining loads we calculate the tensile strength of three conditioned and unconditioned samples by the following formula.

$$\boldsymbol{St} = \frac{\boldsymbol{2P}}{\boldsymbol{3.14Dt}}$$

Where:

- St = tensile strength psi (Pascal's)
- P = maximum load pounds (Newton)
- t = specimen thickness inches (mm)
- D = specimen diameter inches (mm)

Represent the Strength of conditioned samples by S2 and unconditioned by S1. Remember we take the average of three samples tensile strength in both conditioned and unconditioned cases. After that we take the ratio of conditioned over unconditioned samples i.e.

$$\boldsymbol{Tensile\ Strength\ Ratio} = \frac{\boldsymbol{S2}}{\boldsymbol{S1}}$$

Where:

- S1 = average tensile strength of .dry subset (unconditioned) and
- S2 = average tensile strength of .conditioned subset.

TSR must be greater than **80%** to qualify the criteria of test.

4.3.1 Test Results for Tensile Strength Ratio (TSR)

Stress(MPa)	Sample 1	Sample 2	Avg.(MPa)	Remarks
Unconditioned Samples (S1)	0.872	0.770	0.821	
Conditioned Samples (S2)	0.798	0.745	0.771	
S2/S1 (Ratio)			**93.9%**	**>80% OK.**

Table 4-9, Virgin Samples of 12.7mm Gradation

Stress(MPa)	Sample 1	Sample 2	Sample 3	Avg.(MPa)	Remarks
Unconditioned Samples (S1)	0.795	0.811	0.805	0.803	
Conditioned Samples (S2)	0.758	0.767	0.739	0.754	
S2/S1 (Ratio)				93.8%	>80% OK.

Table 4-10, Virgin Samples of 9.5mm Gradation

Stress(MPa)	Sample 1	Sample 2	Avg.(MPa)	Remarks
Unconditioned Samples (S1)	0.812	0.828	0.820	
Conditioned Samples (S2)	0.775	0.743	0.759	
S2/S1 (Ratio)			**92.56%**	**>80% OK.**

Table 4-11, SASOBIT Samples of 12.7mm Gradation

Stress(MPa)	Sample 1	Sample 2	Avg.(MPa)	Remarks
Unconditioned Samples (S1)	0.756	0.751	0.753	
Conditioned Samples (S2)	0.706	0.687	0.696	
S2/S1 (Ratio)			92.43%	>80% OK.

Table 4-12, SASOBIT Samples of 9.5mm Gradation

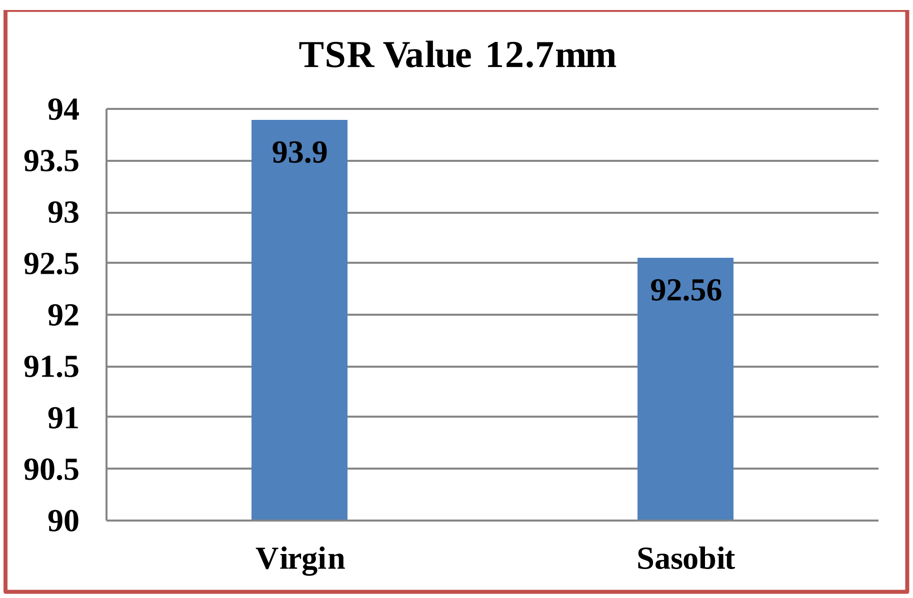
4.3.2 Comparison of TSR Results

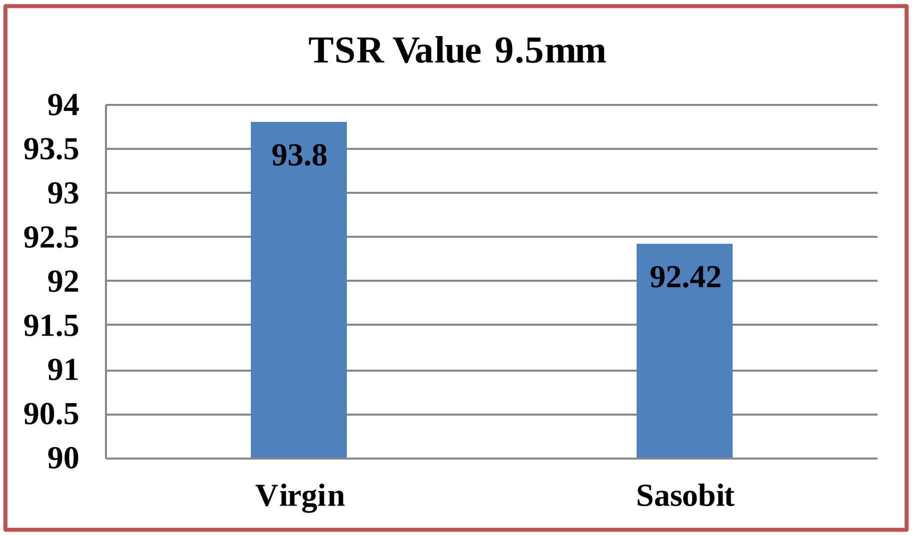
The table given below is the comparison between the values obtained from the test of Moisture Susceptibility.

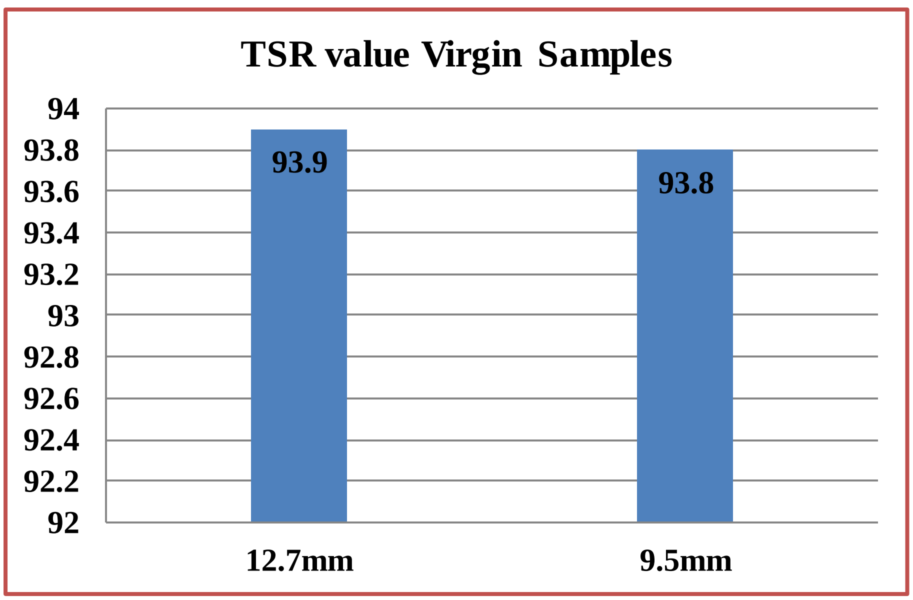
Gradation	9.5mm	12.7mm
Virgin Samples TSR	**93.8%**	**93.9%**
Sasobit Samples TSR	92.43%	92.56%

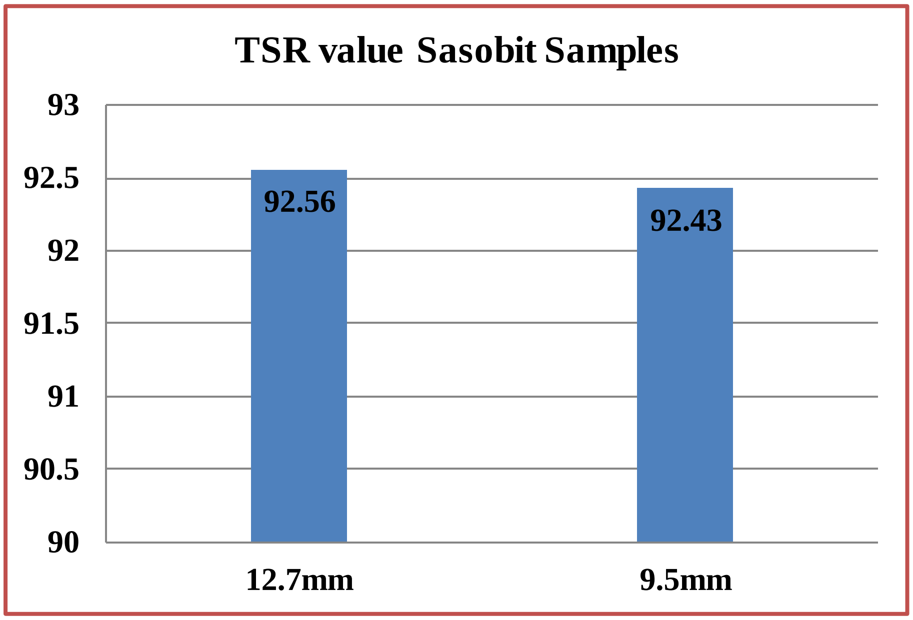
Table 4-13, Comparison of TSR Results

4.3.3 Graphical Representation




TSR Value 9.5mm
94
93.5
93
92.5
92
91.5
91
90.5
90
93.8
92.42
Virgin
Sasobit


TSR value Virgin Samples
94
93.8
93.6
93.4
93.2
93
92.8
92.6
92.4
92.2
92
93.9
93.8
12.7mm
9.5mm



From 12.7mm and 9.5mm Nominal maximum Aggregate size graphs the value of virgin samples are more than as compared to Sasobit samples it means the 12.7mm gradation is less susceptible towards water or less prone towards water. If we compare two gradation i.e. 12.7mm and 9.5mm gradations from virgin and Sasobit samples graphs the 12.7mm samples are performing better than 9.5mm Nominal maximum aggregate size which states that 12.7mm samples are less susceptible towards water.

4.4 Indirect tensile strength test (ITS)

The Purpose of Indirect tensile strength is to determine the Strength of Asphalt Mix i.e. the load of failure of mix at which it gives ultimate strength. This test can also be used to determine the potential for field pavement moisture damage when results are obtained on both moisture conditioned and unconditioned specimens We Prepared Marshall Samples of 63.5mm thickness and 100mm diameter for testing of their Strength. These samples are tested under

Universal testing Machine (UTM). We prepared three samples on each gradation for testing. The recommended rate of loading of was 50.8mm/min and test temperature was 25ºC on which we conduct tests. Other apparatus which is used in UTM for this test is **Loading Devices** which measured load and deformation. **Loading Strips** Steel loading strips with a concave surface having a radius of curvature equal to the nominal radius of the test specimen the outer edges of the loading strips shall be beveled slightly to remove sharp edges. **Temperature Control System** an air or water bath capable of maintaining the specimens at the specified test temperature within 60ºC. Balance and water bath must be there. Water bath should be capable of maintaining a temperature around about 60ºC.

The test was conducted according to following **Procedure.** As part of this procedure, the maximum specific gravity, bulk specific gravity, and percent air voids must be determined for each mix. First of all determine the specimen height in accordance with the standard. The second step is Bring the specimen to test temperature by any of the following three alternative procedures. The recommended test temperature is 25ºC.

In the very next step when the temp of whole core become constant bring the sample into the UTM machine and start the test with the Software US002. Save the setting so that at end it will be easy to find the graphs and run the test. UTM will apply load till the failure of Specimen and at the failure the specimen will give the ultimate load at which he'll fail. Note the readings and repeat the procedure on three specimens.

For the Calculation of tensile strength following formula will be used

$$\boldsymbol{St} = \frac{\boldsymbol{2P}}{\boldsymbol{3.14Dt}}$$

Where:

- St = tensile strength, psi (Pascal's)
- P = maximum load, pounds (Newton)
- t = specimen thickness, inches (mm)
- D = specimen diameter, inches, (mm)

4.4.1 Test Results for ITS

Gradations	Ultimate Failure Load (KN)
12.7mm Virgin Samples	**8.509**
12.7mm Sasobit Samples	**8.277**
9.5mm Virgin Samples	**7.872**
9.5mm Sasobit Samples	7.413

Table 4-14, Test Results for Indirect tensile Strength (ITS)

The above table shows the results of two gradations with and without additive. If we compare 12.7mm Nominal maximum aggregate size virgin samples with the Sasobit samples the ultimate failure load is greater in case of Virgin samples and trend is same in case of smaller gradation. If we compare 12.7mm Nominal maximum aggregate size virgin samples with 9.5mm Nominal maximum aggregate size virgin samples the value is greater in case of 12.7mm gradation and trend remains same if we compare Sasobit Samples. So this confirms that the virgin samples with 12.7mm gradation are performing better.

4.5 Modulus of Resilience (MR)

Resilient Modulus test is used to determine the stress and strain relation of Asphalt Mix i.e. when the stress is applied then how much strain is produced by the sample. Poisons ratio is also determined by this test and purpose of all these are same i.e. determination of Modulus. The .repeated load indirect tension resilient modulus test of bituminous mixtures is conducted through .repetitive applications of .compressive loads in a .haversine .waveform. The .compressive load is .applied along a vertical .diametric plane of a .cylindrical specimen of asphalt concrete. The resulting .horizontal and .vertical deformations of the specimen are measured. Values of .resilient .Poisson's ratio are calculated using .recoverable vertical and horizontal .deformations. The resilient modulus values are .subsequently calculated using the calculated .Poisson's ratio.

The apparatus used for this test includes, testing machine i.e. we used UTM in this case it provides graph in the haversine shaped form. Loading devices which include loading strips etc. Temperature control System which includes water bath and oven and water bath should be capable of maintaining the temperature according to requirement. Measurement and recording system it includes the sensors which measure the horizontal and vertical deformation simultaneously and it is capable to record readings in micro of inches. Deformation measurements both horizontal and vertical deformation is measured with the LVDT's, LVDT's should be on each face of specimen i.e. two LVDT's are required for this test. Load Measurement the repetitive load is measured with the electronic load cell for the maximum required loading.

For this test we prepared three samples for each gradation. The .procedure involves .resilient modulus testing at .defined load, loading .frequency and load .duration at a temperature of 25°C. Specimen is conditioned to 25°C for 6hour before the testing. One important thing to remember that indirect tensile strength

(ITS) test is a pre-requisite of this test. Because the ultimate failure loads which is obtained in this test is further used in resilient modulus test. We take 20% of ultimate failure load and apply over the sample. The UTM chamber in which we held the samples for testing should be temperature control and temperature according to standards. When we applied the load over the specimen it gave us the value of resilient modulus in MPa it means US002 software done all the background calculations of horizontal and vertical deformations and gives us only one value and this value represents the fluctuations in the Mix. If the applied load is more the sample will give more fluctuations i.e. the resilient modulus value will be greater. Same procedure is followed for other two samples and at end we will use average value of these samples.

4.5.1 Test Results for Modulus of Resilience (MR)

Applied Load	1662 N
Avg. MR Value	6857 MPa

Table 4-15, Virgin Sample 12.7mm NMA Gradation

Applied Load	1618 N
Avg. MR Value	6482 MPa

Table 4-16, Virgin Sample 9.5mm NMA Gradation

Applied Load	**1538 N**
Avg. MR Value	7681 MPa

Table 4-17, Sasobit sample 12.7mm NMA Gradation

Applied Load	**1523 N**
Avg. MR Value	**6658 MPa**

Table 4-18, Sasobit sample 9.5mm NMA Gradation

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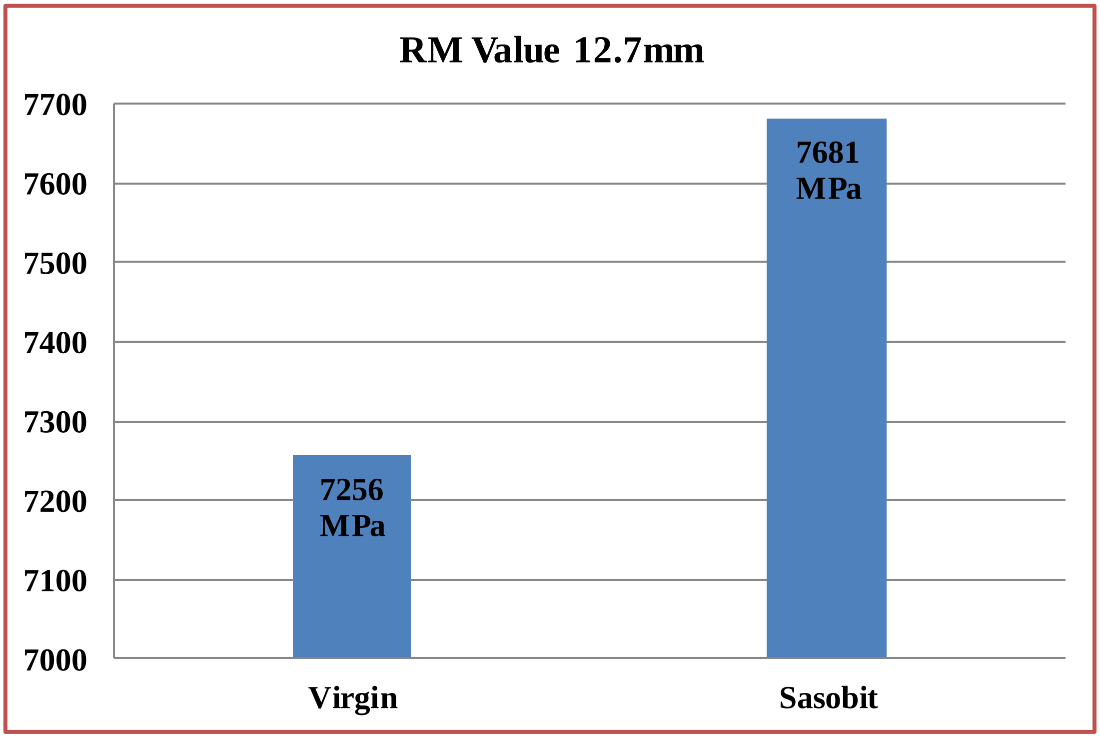
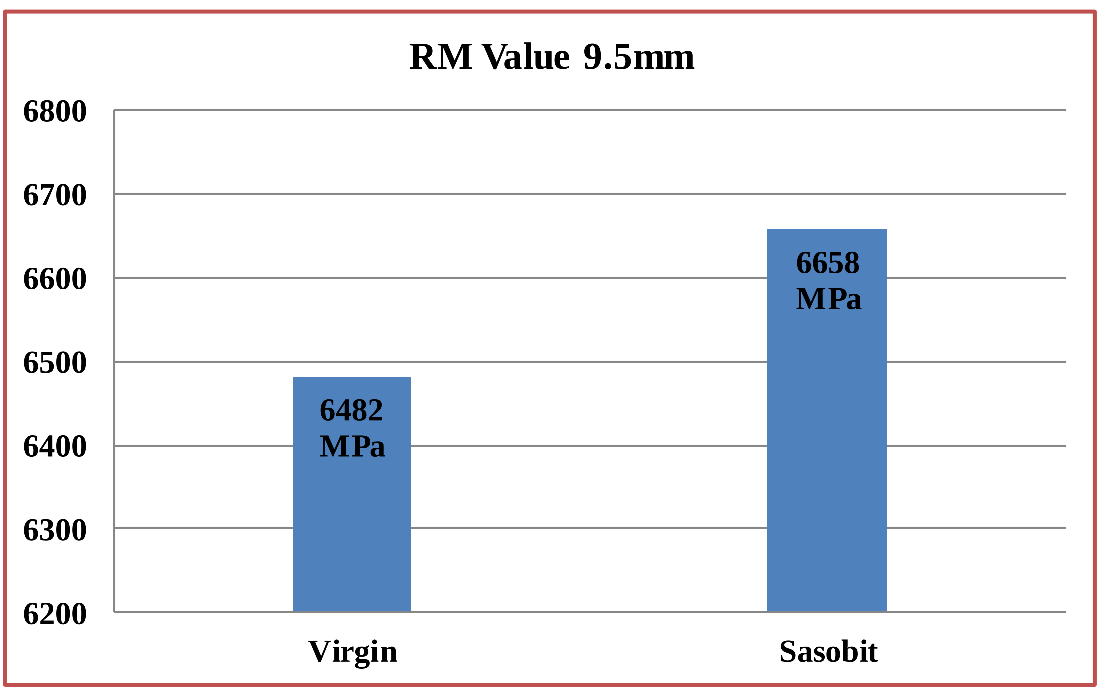
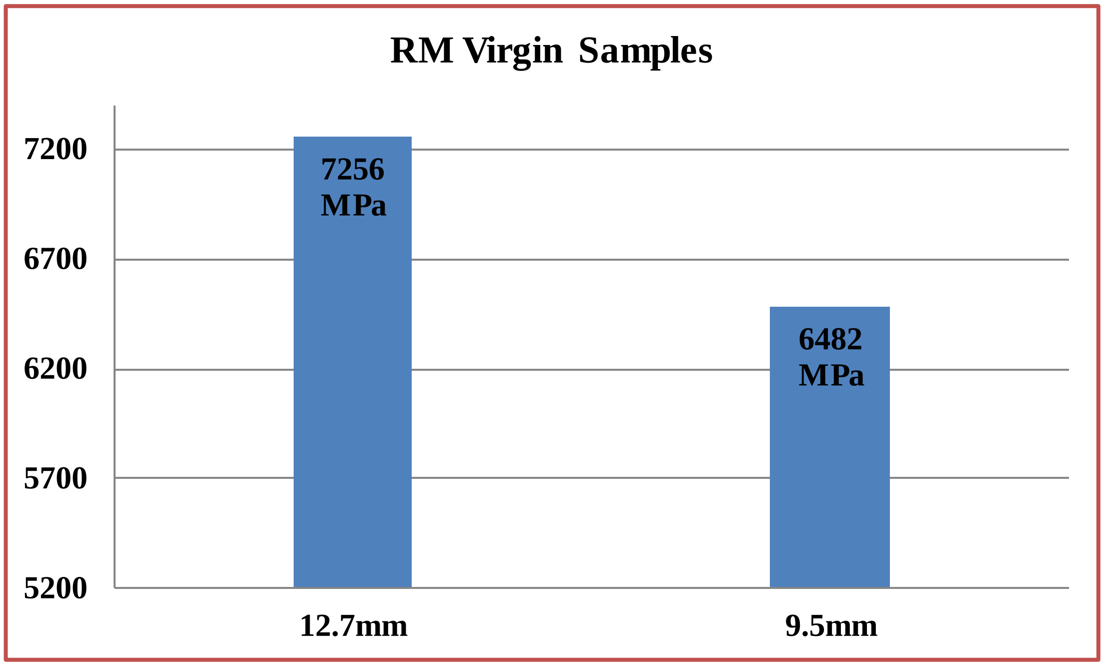
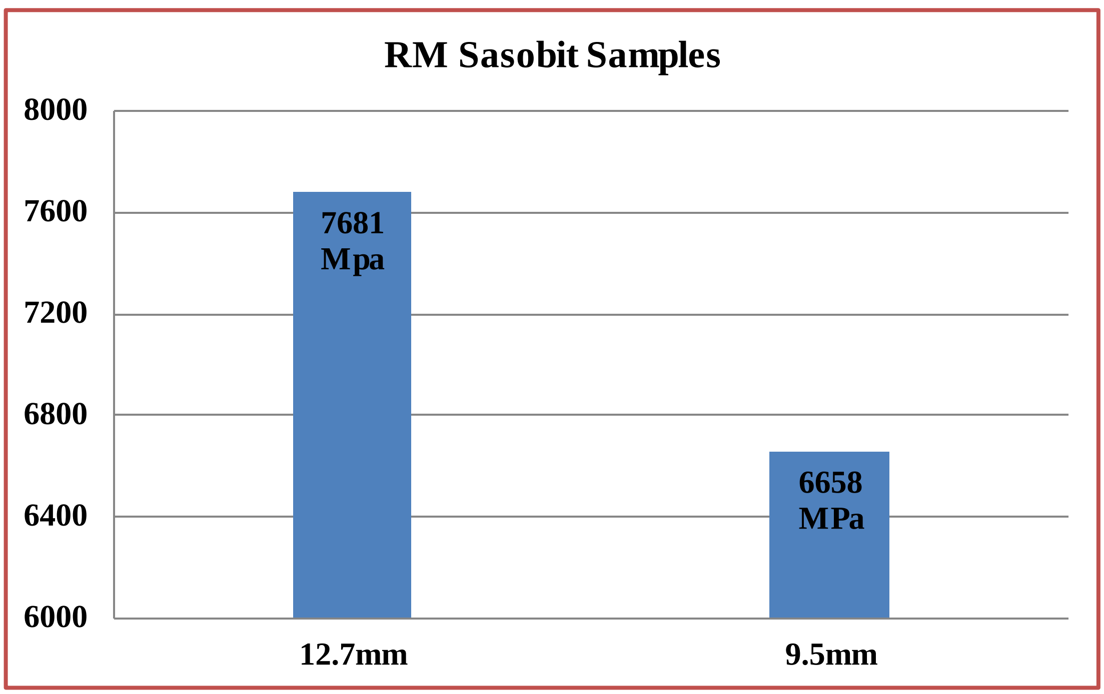
4.5.2 Graphical Representation






RM Virgin Samples
7200
6700
6200
5700
5200
7256 MPa
6482 MPa
12.7mm
9.5mm


RM Sasobit Samples
8000
7600
7200
6800
6400
6000
7681 Mpa
6658 MPa
12.7mm
9.5mm

From first two graphs i.e. 12.7mm and 9.5mm Nominal maximum aggregate size the Sasobit samples providing more resistance than the Virgin samples it means they are performing better. If we compare two gradations with each other i.e. from Virgin and Sasobit samples graphs the 12.7mm Nominal maximum aggregate size samples providing more resistance than 9.5mm Nominal maximum aggregate size. So the final conclusion is Sasobit with 12.7mm gradation is best for usage on roads.

4.6 Wheel Tracking Test for Rut Resistance

The Purpose of this test is to determine the Rut depth of pavement or rut resistance provide by the pavement. The device used for this purpose is the Hamburg wheel tracking device (HWTD). In the past few years Hamburg wheel tracking device gained popularity and commonly used to determine the moisture susceptibility and rut depth. HWTD was introduced into the U.S by Germany in early 1990. The AASHTO T324 specification permits either use one slab specimen or two cylindrical specimen to determine the rut depth. For this research two cylindrical specimen were used on each gradation to determine the rutting of pavement. The apparatus commonly used for this test is Gyratory mold, automatic mixer, gyratory compactor, cutting machine and HWTD.

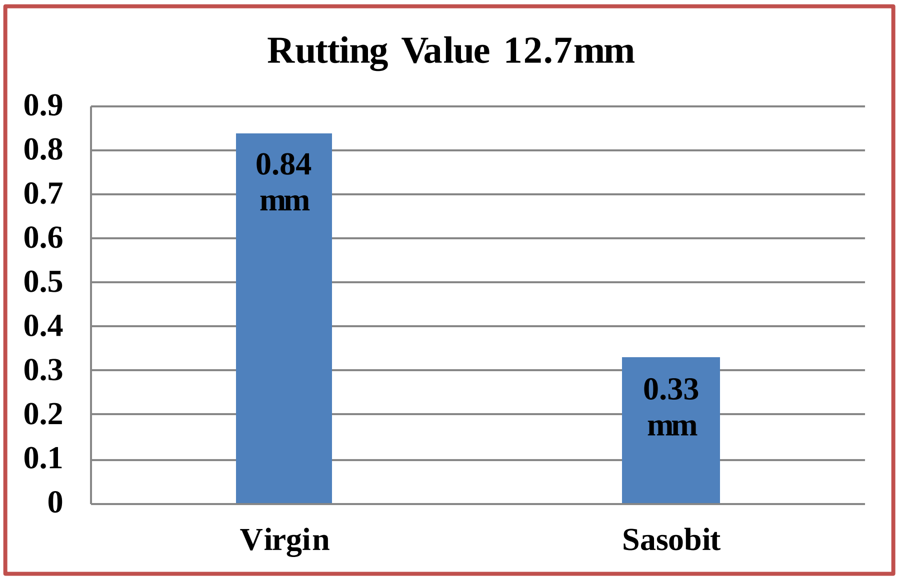
Sample Preparation: For this research 6Kg Gyratory Samples were prepared on each gradation. Automatic mixer was used for properly mixing of samples. The compaction of samples were also done by gyratory compactor in which gyratory compactor gave 125 passes on each sample. The diameter and thickness of specimen was 150mm and 38mm respectively. After preparation of samples proper cutting of samples takes place through cutting machine in which we take top and bottom of samples.

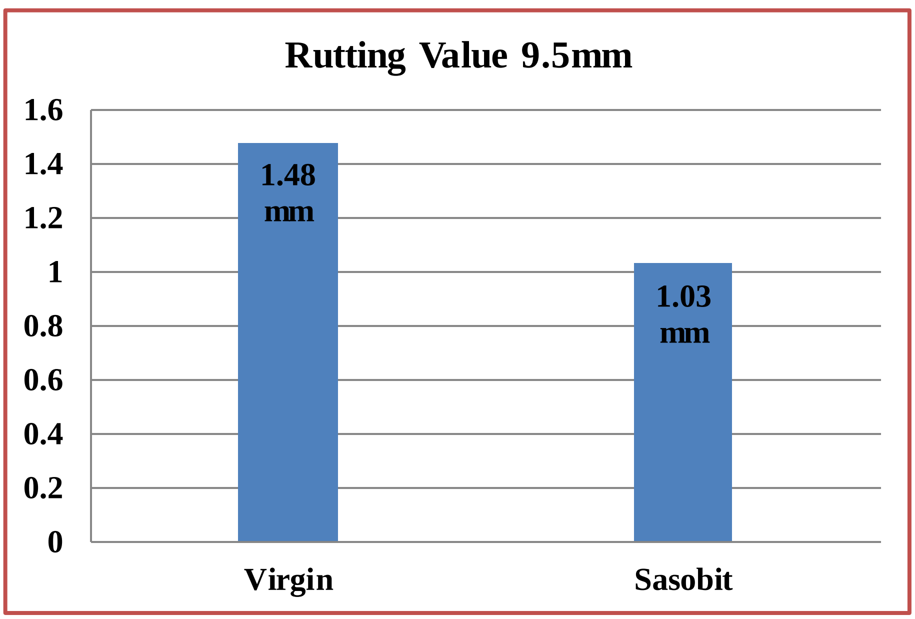
Sample testing: After preparation of samples the samples were placed on the Hamburg wheel tracking molds. These molds have same diameter as of gyratory molds. At different conditions the test can be performed on Hamburg wheel tracking device. For this research 10000 passes were selected to determine the rut depth. The weight of wheel was 158 lb. The test was performed on dry condition at 25C. Actually this research was conducted on two gradations 12.7mm Nominal maximum aggregate size and 9.5mm nominal maximum aggregate size. On these two gradations total four samples were prepared using Sasobit as an additive and without additive. After preparation of four samples, top and bottom of each sample were taken for this test. The wheel starts moving over the samples after placement and gives the rut depth after completion of 10000 passes. This all process takes almost 3 hour. The Hamburg wheel tracking device gave us the rutting depth in millimeter and graphical representation of the whole test.

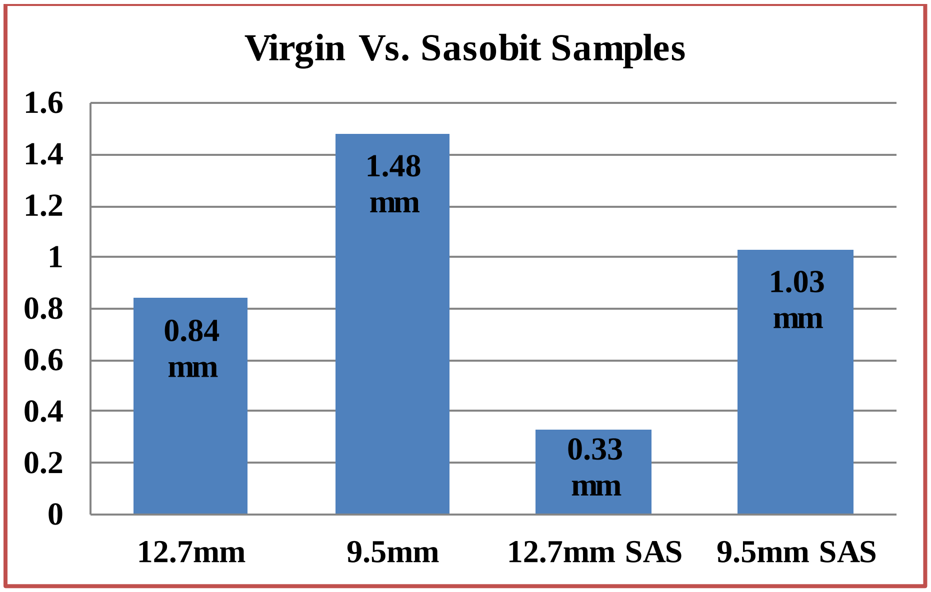
4.6.1 Test Results for Rut Resistance on Wheel Tracking

Sr. No.	Sample	Rutting Depth(mm)	No. of Passes
1	12.7 mm Virgin	0.84	10000
2	9.5 mm Virgin	1.48	10000
3	12.7 mm Sasobit	0.33	10000
4	9.5 mm Sasobit	1.08	10000

Table 4-19, Test Result for Rut Resistance on Wheel Tracking


Rutting Value 12.7mm
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.84 mm
0.33 mm
Virgin
Sasobit


Rutting Value 9.5mm
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1.48 mm
1.03 mm
Virgin
Sasobit



From above graph if we compare 12.7mm Nominal maximum aggregate size with the 9.5mm size the rutting depth is less in case of 12.7mm nominal maximum aggregate size and if the comparison is between virgin and Sasobit samples than Sasobit samples are performing better in case of rutting.

CHAPTER 5

CONCLUSIONS
AND
LEARNING OUTCOMES

5.1 General

This research aimed at finding the working of SMA with two different gradations of aggregates by adopting Marshal Mix Design. This research aimed at the comparison of the performance of SMA with and without the addition of the additive. Here in the project every sample was prepared according to the standard specifications determined by ASHTO, ASTM and other working authorities. This research is useful as this includes the comparison of various aspects of the SMA. This research shows the difference of performance of SMA with12.7mm NMA Gradation and 9.5mm NMA gradation and this research also extends to study the performance of SMA with the addition of Sasobit. In the whole project there are many notable points which will be highlighted under Conclusions.

5.2 Conclusions

- Sasobit reduces the viscosity of the bitumen and the temperature of mix.
- In Tensile Strength Ratio (TSR) Test the 12.7 mm NMA gradation shows its less susceptibility towards water as compare to the 9.5 mm NMA gradation.
- Through TSR it is observed that Virgin Samples show less susceptibility towards water in comparison with Sasobit samples.
- 12.7 mm NMA gradation contains large size aggregate thus has more strength than 9.5 mm NMA gradation.

- On addition of Sasobit the value resilient modulus increases and this shows their good stiff behavior in comparison with virgin samples.
- Large sized aggregates shows higher rut resistance.
- Addition of Sasobit improves the rut resistance in asphaltic pavements but does not change the trend.
- Larger gradations gives better results than smaller aggregate gradations in all performance tests of SMA.

5.3 Learning Outcomes

- Using Sasobit in the mix gives even better results and at the same time using Sasobit in lower percentages.
- Temperature control and Compaction are the main things one must cater while making samples through Marshal Mix technique because it can vary results to large extent.
- Stone-stone Skelton like structure is best against rutting and SMA have high Stone-Stone contact.
- We learned about the marshal procedure to determine the OBC, about TSR test for the purpose of Moisture induced damage, about RM test.

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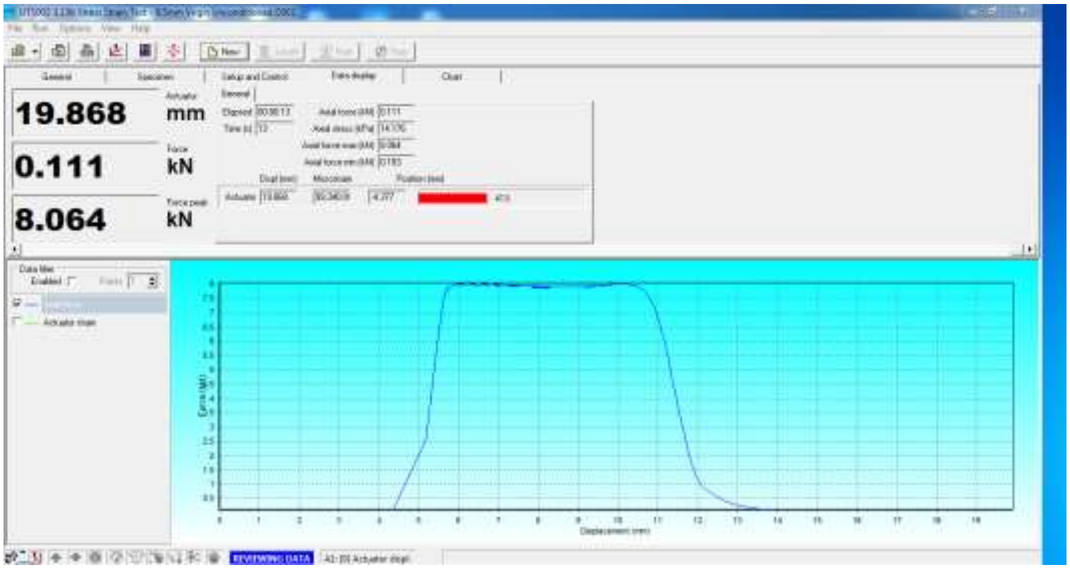
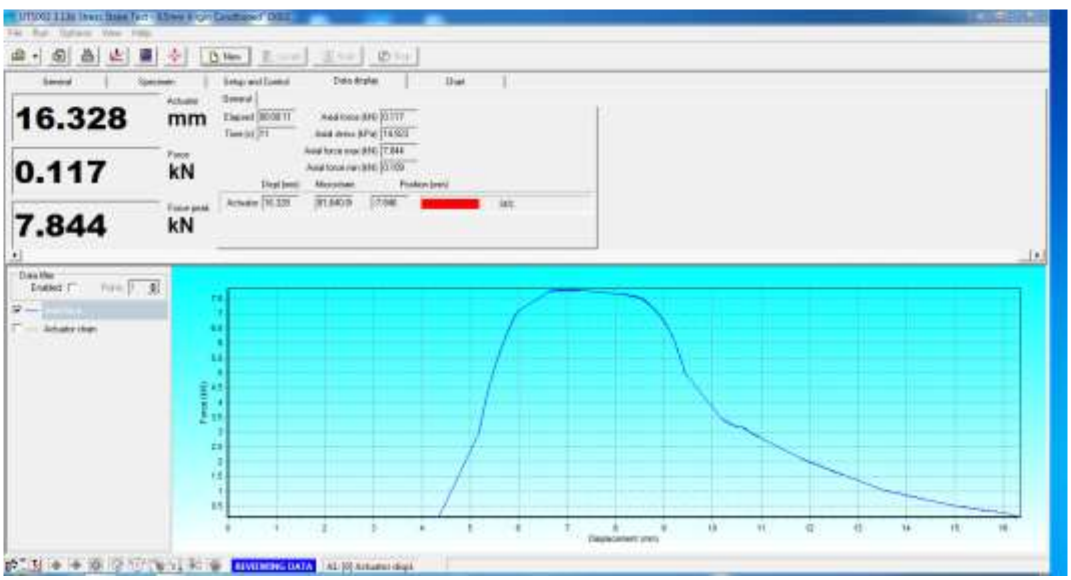
APPENDIX

TSR (UTM Graphs)

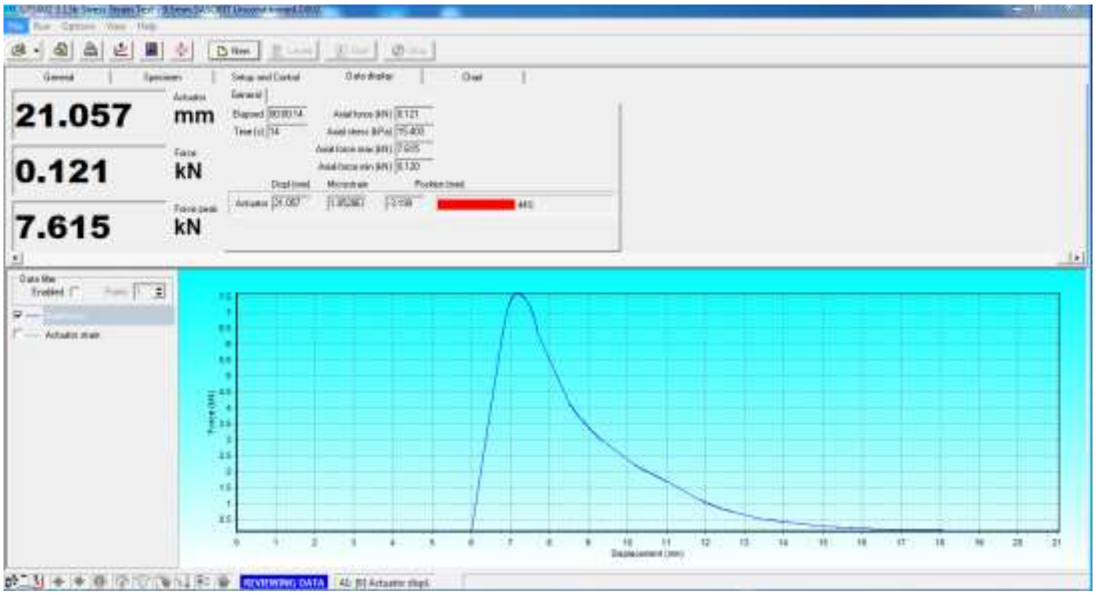
9.5mm Virgin Unconditioned Sample graph:



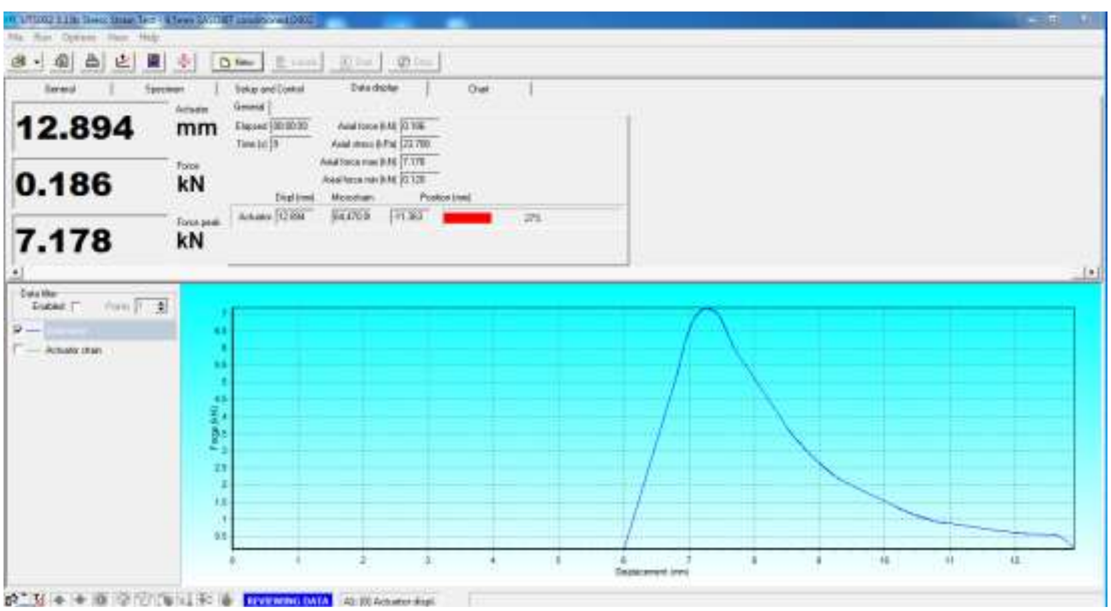
9.5mm Virgin Conditioned Sample graph



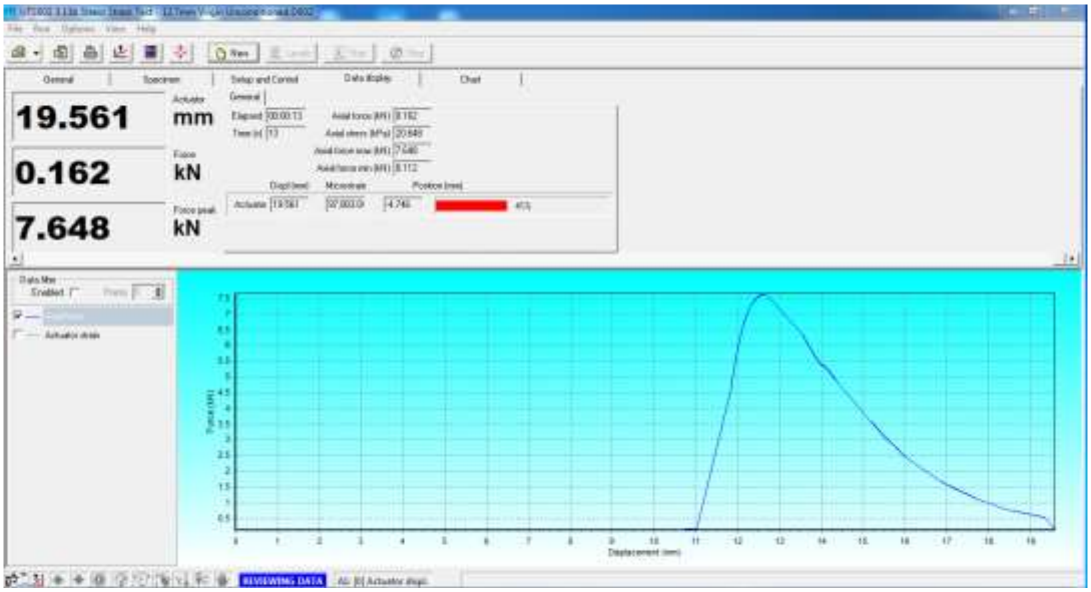
9.5mm Sasobit Unconditioned Sample graph:



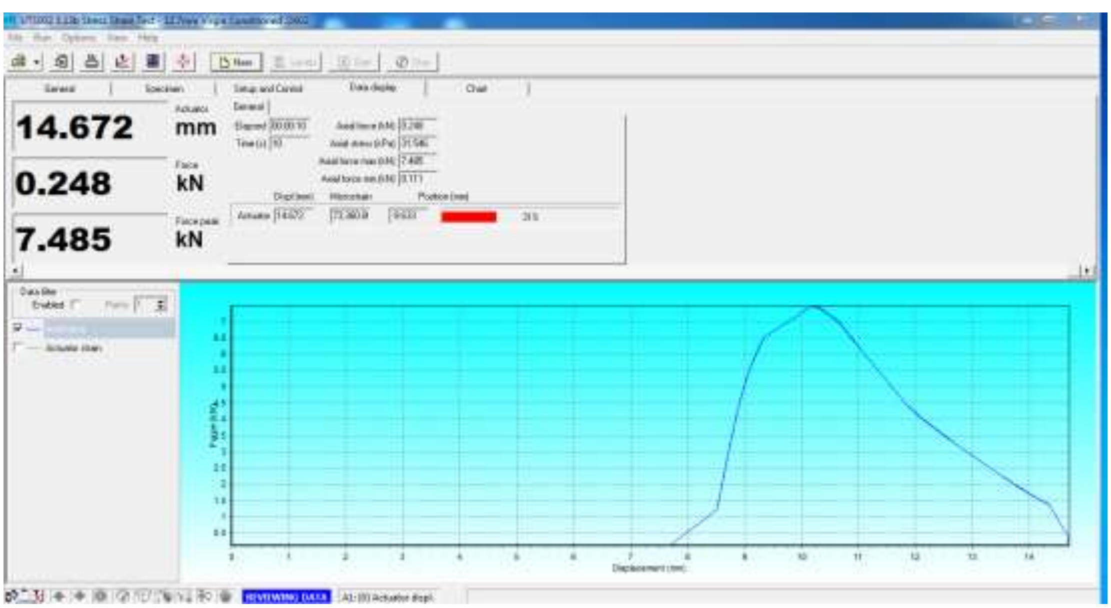
9.5mm Sasobit Conditioned Sample graph:



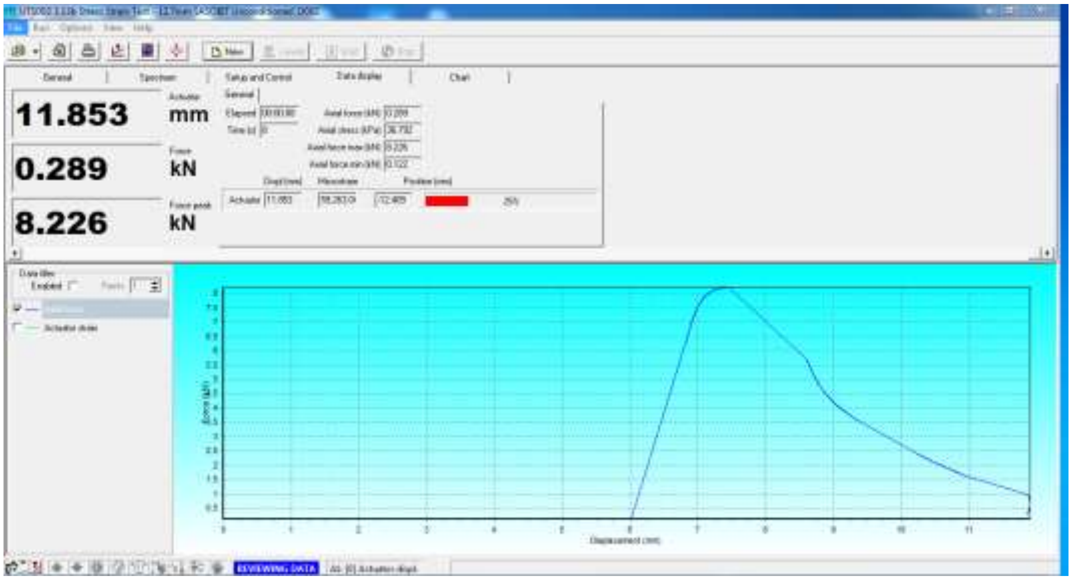
12.7mm Virgin Unconditioned Sample graph:



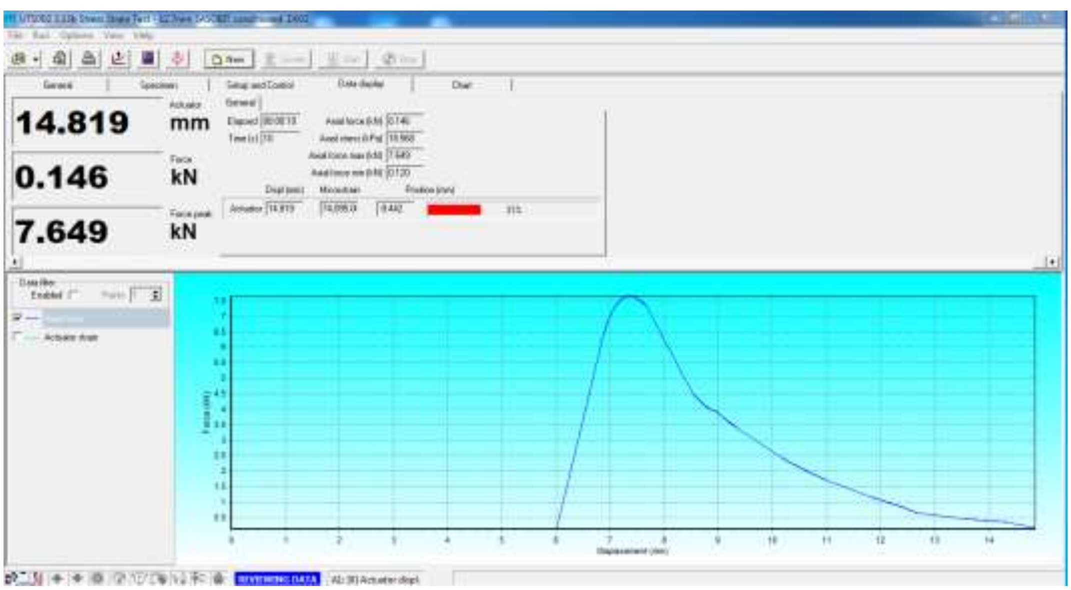
12.7mm Virgin Conditioned Sample graph:



12.7mm Sasobit Unconditioned Sample graph:

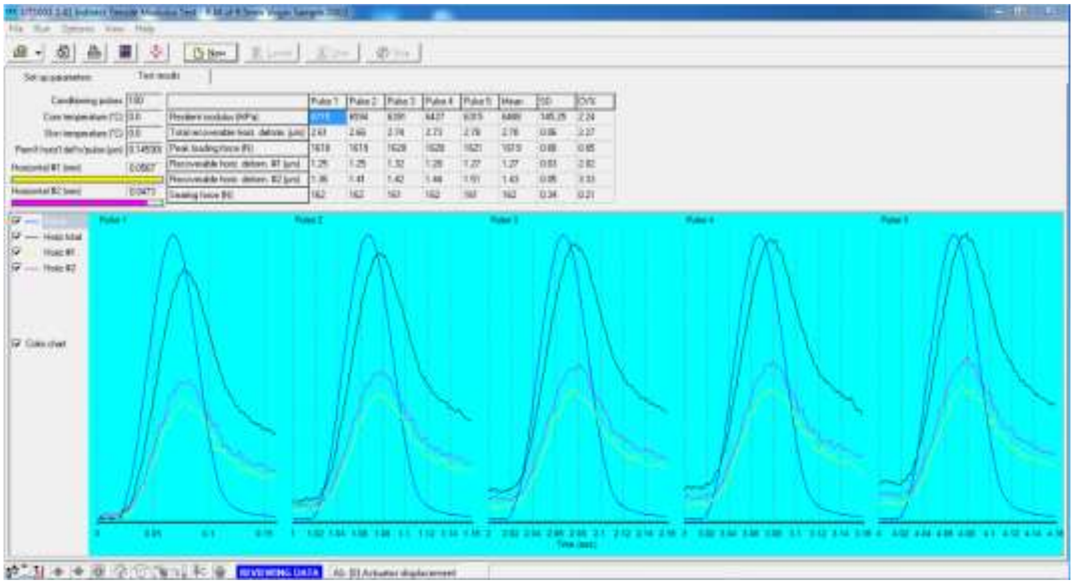


12.7mm Sasobit Conditioned Sample graph:

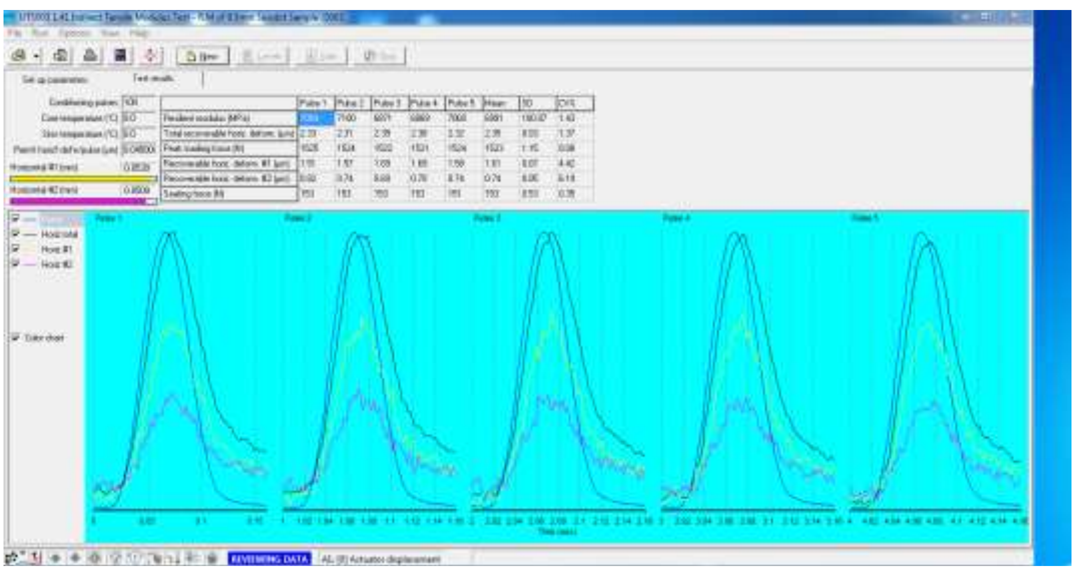


RM (UTM Graphs)

9.5mm Virgin Sample graph:



9.5mm Sasobit Sample graph:



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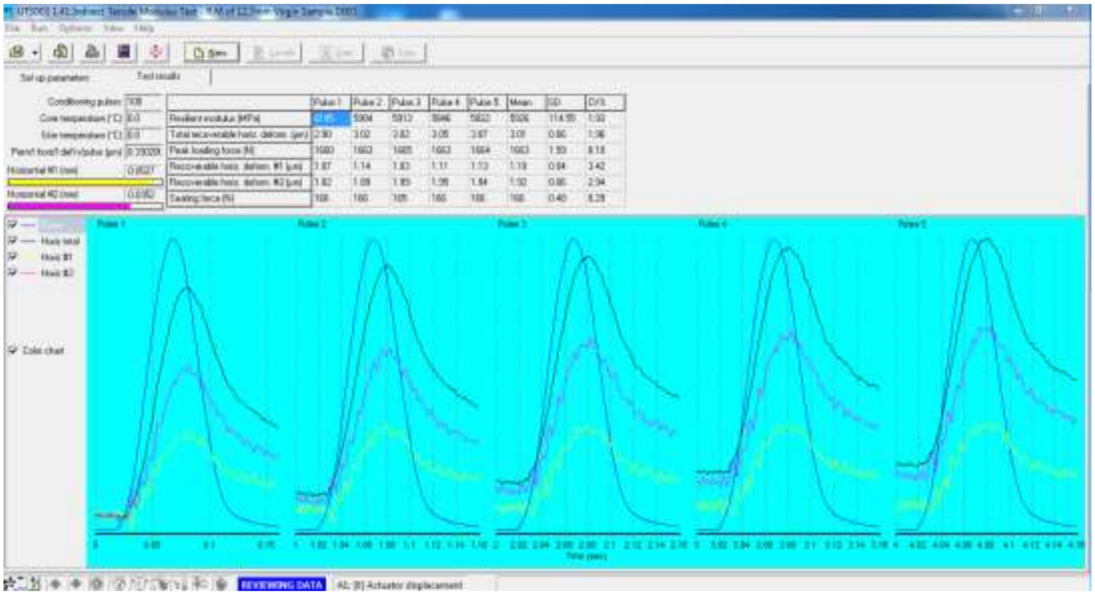
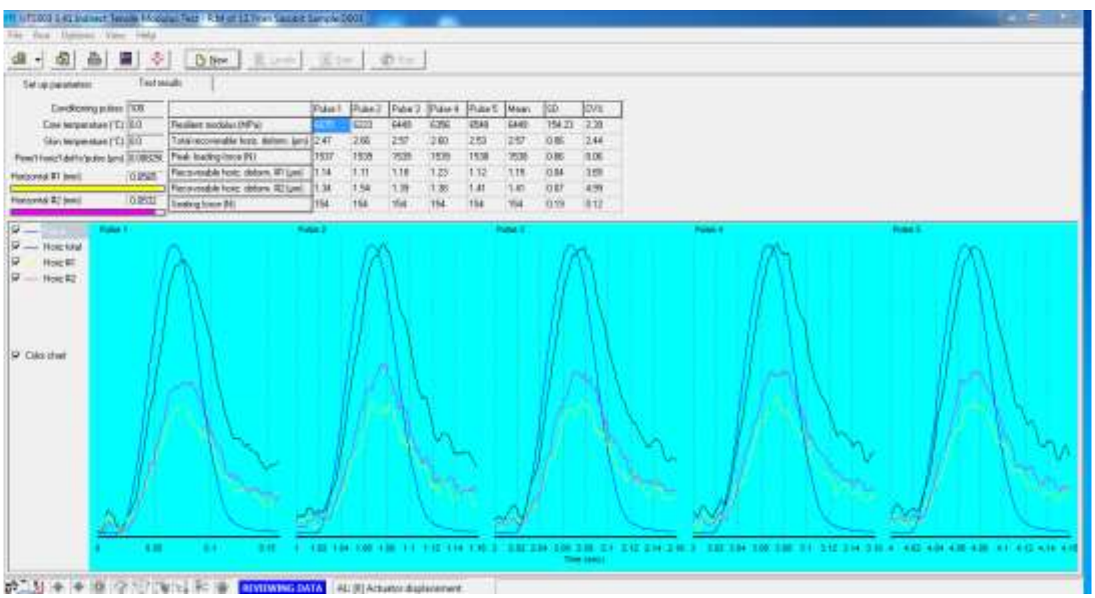
12.7mm Virgin Sample graph:



12.7mm Sasobit Sample graph:



Marshal Test Results

9.5mm Virgin samples tables for graphs:

Bitumen Content %	Air Voids %
5.0	12.17
5.5	6.53
6.0	3.695
6.5	1.92

Bitumen Content %	VMA %
5.0	15.175
5.5	14.75
6.0	14.65
6.5	15.675

Bitumen Content %	VFA %
5.0	26.405
5.5	54.97
6.0	74.77
6.5	87.75

Bitumen Content %	Stability (KN)
5.0	14.088
5.5	15.116
6.0	15.806
6.5	10.806

Bitumen Content %	Displacement (mm)
5.0	3.005
5.5	3.622
6.0	4.212
6.5	4.550

9.5mm Sasobit samples tables for graphs:

Bitumen Contents	% Air Voids
5.0	13.10
5.5	12.34
6.0	5.57
6.5	3.92
7.0	3.5

Bitumen Contents	VMA
5.0	13.98
5.5	13.38
6.0	14.44
6.5	15.59
7.0	16.19

Bitumen Contents	VFA
5.0	6.13
5.5	9.26
6.0	63.18
6.5	76.67
7.0	78.59

Bitumen Contents	Stability(KN)
5.0	11.328
5.5	12.378
6.0	12.943
6.5	12.785
7.0	10.075

Bitumen Contents	Displacement(mm)
5.0	2.611
5.5	2.991
6.0	3.424
6.5	3.86
7.0	4.20

12.7mm Virgin samples tables for graphs:

Bitumen Contents	% Air Voids
5.0	7.96
5.5	4.9
6.0	3.11
6.5	2.15
7.0	1.5

Bitumen Contents	VMA
5.0	14.83
5.5	14.24
6.0	14.63
6.5	15.05
7.0	15.47

Bitumen Contents	VFA
5.0	46.3
5.5	65.63
6.0	78.73
6.5	85.71
7.0	90.6

Bitumen Contents	Stability(KN)
5.0	14.28
5.5	15.41
6.0	13.62
6.5	10.58
7.0	9.78

Bitumen Contents	Displacement(mm)
5.0	3.33
5.5	3.78
6.0	4.13
6.5	4.71
7.0	4.88

12.7mm Sasobit samples tables for graphs:

Bitumen Contents	% Air Voids
5.0	9.73
5.5	5.495
6.0	4.115
6.5	3.305
7.0	2.35

Bitumen Contents	VMA
5.0	15.375
5.5	14.85
6.0	15.05
6.5	16.54
7.0	16.98

Bitumen Contents	VFA
5.0	39.08
5.5	63.03
6.0	72.66
6.5	79.84
7.0	86.16

Bitumen Contents	Stability(KN)
5.0	11.86
5.5	12.43
6.0	13.06
6.5	11.52
7.0	9.96

Bitumen Contents	Displacement(mm)
5.0	2.891
5.5	3.16
6.0	3.721
6.5	4.321
7.0	5.150