EVALUATION OF PERMANENT DEFORMATION AND FATIGUE USING LIME MODIFIED BINDER

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DEDICATED

TO

HOLY PROPHET صلى الله عليه وسلم

&

MY PARENTS AND TEACHER

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(Engr.Haseeb Ali Khan)

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LIST OF ACRONYMS

AASHTO	–	American Association of State Highway & Transportation Official
AC	–	Asphalt Concrete
ESAL	–	Equivalent Single-Axle Loads
G_{mb}	–	Mix Bulk Specific Gravity
G_{mm}	–	Mix Theoretical Maximum Specific Gravity
HMA	–	Hot-Mix Asphalt
NCHRP	–	National Cooperative Highway Research Program
N_{des}	–	N+ umber of Gyrations at Design Level
NHA	–	National Highway Authority
N_{ini}	–	Number of Gyrations at Initial Compaction
NMAS	–	Nominal Maximum Aggregate Size
$P_{0.075}$	–	Percent Passing the 0.075 mm Sieve
P_b	–	Percent Binder (preferable over "AC")
P_{be}	–	Percent of Effective Binder
RZ	–	Restricted Zone
SGC	–	Superpave Gyratory Compactor
SHRP	–	Strategic Highway Research Program
TMD	–	Theoretical Maximum Density
TSR	–	Tensile Strength Ratio

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ABSTRACT

HMA is a common material widely used for paving purpose. Hot mix asphalt (HMA) pavements are subjected to continuously changing traffic wheel loads and environmental conditions. When environmental actions are combined with the imposed stresses from the repeated traffic loads moisture damage can occur and causes a reduction in pavement life due to the formation of "rutting and cracking failures". To prevent this damage, this research will resort to specifying anti-stripping additive in an attempt to increase adhesion at the aggregate-asphalt interface. Lime is the most common solid anti stripping additive used in Pakistan. Long term performance of HMA pavements treated with lime shows that it is effective in reducing the moisture sensitivity of the mixture.

Pavement industry is facing serious problem related to "rutting & fatigue cracking" in HMA pavement. Ever since the start of the use of Hot Mix Asphalt Pavements, rutting & fatigue cracking have been the major problem in the design and performance of these pavements. To help this problem Superpave mix design system was developed in 1993 as an attempt to improve the performance of HMA mixture. . Superpave mix design method was used in this research and the binder is modified with Lime primarily targeting its properties to produce a better mix that improves resistance to fracture growth (i.e. it improves fracture toughness).

Superpave gradation is bound by 0.45 power line that is surrounded by restricted zone and control pints 0.45 power line starts from zero to maximum aggregate size. The allowable ratio of the fine sand fraction to the total sand was to help reduce the incidence of moisture susceptible causing rutting. This research will help to evaluate the effect of the Lime Modified Binder on the above mentioned pavement performance measures of Superpave HMA mixtures on the basis of a statistically planned and properly controlled laboratory experiment. In this research the selected gradation will be Superpave 1 (19mm NMAS) as well as Superpave 2 (25mm NMAS).

The research will focus on rutting using HWT and fatigue cracking using UTM-25. The gradations are tested using Margalla quarry aggregate and bitumen grade 60/70 of Attock Oil Refinery will be used. The binder is modified with Lime with different percentage of lime with the total weigh of dry aggregate. The optimum asphalt content

of the binder has been determined using the superpave mix design method for both gradations, and then volumetric of gyratory sample has been figured out. Moreover, performance testing including Hamburg Wheel Tracker test and Indirect Tensile Fatigue test has been done on the mixes using the optimum content determined earlier. The performance tests were performed on the compacted mixtures and the results showed significant increase in resistance to rutting potential and fatigue cracking using lime as modifier and at the end statistical analysis was conducted on results obtained from Indirect Tensile Fatigue test and temperature was found to be the most significant factor followed by gradation and lime content.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The total road-network in Pakistan is about 263,415 km consists of 9,324 km (3.53%) of National Highways and 2,280 km of Motorways, strategic roads and expressways contribute 262 km and 100 km respectively, out of which most of the pavements are made up of hot mix asphalt (HMA) [1]. Ironically, most of the valuable assets have been lost due to the premature development of cracks in the asphalt bound layers progressing rapidly to levels of high severity in asphalt concrete pavements in Pakistan. The road way network plays an indispensable role in socio-economic growth of a country as it provides better accessibility to markets, employments and additional investments [2].The network of Pakistan roads is broadly consists of flexible pavement. In Pakistan, flexible pavements undergo premature failure, i.e. fatigue and rutting. This is owing to the drastic increase in congestion on roads during the last decades.

Rutting is defined as the longitudinal depressions along the wheel paths, which are an accumulation of small amounts of unrecoverable deformation caused by each load application [3]. It is a phenomenon that is developed in all layers of flexible pavements, under the application of repeated traffic loading, by the accumulation of permanent strains. Rutting occurs only in flexible pavements, as indicated by the permanent strains or rut depth along the wheel paths [4].

Different laboratory test methods are used in order to find out the rutting in flexible pavements. One of the methods in common practice is wheel tracking test. Wheel tracking device estimates the rut depth in flexible pavements by subjecting the specimen to a repeated loading under a moving wheel as the pressure of the steel wheel produces the same effect produced by a rear tire of a double-axle truck [5].

Besides, on the other hand, fatigue cracking is also a problem of concern in the performance and design of hot mix asphalt (HMA) pavements since the hot mix asphalt pavements are being used. Owing to repeated number of traffic loads, structural failure occurs in the pavements that causes fatigue cracks [5].

1.2 PROBLEM STATEMENT

With the onset of globalization and burgeoning population, the road congestion increase because of the ownership of vehicle and development of world transportation. This kind of situation increases the volume of traffic, traffic loads and tire pressure. Resultantly, these factors would play a pivotal role in pavement deformation such as the rutting and fatigue. These kinds of pavement deformation, in Pakistan, mostly occur on flexible pavements. Rutting exists when the inter locking between aggregate and bitumen not really strong and happen in the form of longitudinal depression in wheel path [6].Another possible factor that causes rutting is inadequate proportion of mixtures. The presence of rutting could reduce the serviceability life of the flexible HMA pavement and lead to certain safety risks a swell [7].

It is imperative that to provide pavement having characteristics in terms of durability, strength, moisture content and air void that can resist is the formation of surface deformation. Moreover, innumerable parameters are in concept in order to improve the serviceability of pavement. One of action is using additives such as polymer modified binder in hot mix asphalt to increase durability of pavement structures because additives have abilities to captivate amount of distress imposed by a continuous heavy traffic load.

The aim of this study is to evaluate the rutting and fatigue performance on the HMA mix design using Lime as modified binder in order to determine its effectiveness to be used in order to minimize the rutting and fatigue resistance on HMA pavement. In this research, different percentage of lime is used in order to find the effect of the polymer on the pavement by evaluating fatigue and rutting.

1.3 RESEARCH OBJECTIVES

The objectives proposed for this study are briefed as follows:

- To evaluate rutting potential of neat and lime modified asphalt mixtures through wheel tracker test.

- To figure out the fatigue cracking of neat and modified asphalt mixtures using Universal Testing Machine UTM-25.

- Statistical analysis will be conducted on the lab result i-e Fatigue test to compare results with simple 60/70 binder (without modified with lime).

1.4 SCOPE OF THE THESIS

To achieve the research objective described above, a comprehensive research plan was prepared and following research tasks were outlined.

- Literature review on the previous researches has been carried out.

- Preparation of specimens to find optimum asphalt content using superpave gyratory compactor by finding the volumetric properties of the gyratory samples.

- Hydrated lime with different percentage including 1%, 1.5% and 2% is used in samples and volumetric properties were find out.
- 1.5% hydrated lime is used in the laboratory samples and performance tests were carried out and results were compared with un-modified samples.

Table 1.1: Test Matrix

Method	**Aggregate Source / Size**	**Binder Type**	**Modified with Lime**	**Pavement Performance**			**Total Samples**
				Rutting using	**Indirect**		
					25°C	**40°C**	
Superpave	Margalla Crush / 19 mm NMAS	ARL 60/70	0 %	3	3	3	**9**
			1 %	3	3	3	**9**
			1.5 %	3	3	3	**9**
			2%	3	3	3	**9**
	Margalla Crush / 25 mm NMAS		0 %	3	3	3	**9**
			1 %	3	3	3	**9**
			1.5 %	3	3	3	**9**
			2%	3	3	3	**9**
Total Number of Samples				**24**	**24**	**24**	**72**

1.5 ORGANIZATION OF THESIS

This research is organized in five chapters brief description of each is as follows:

Chapter 1 includes a comprehensive introduction of premature failure of flexible pavements (Rutting and Fatigue), its performance and scope of the study.

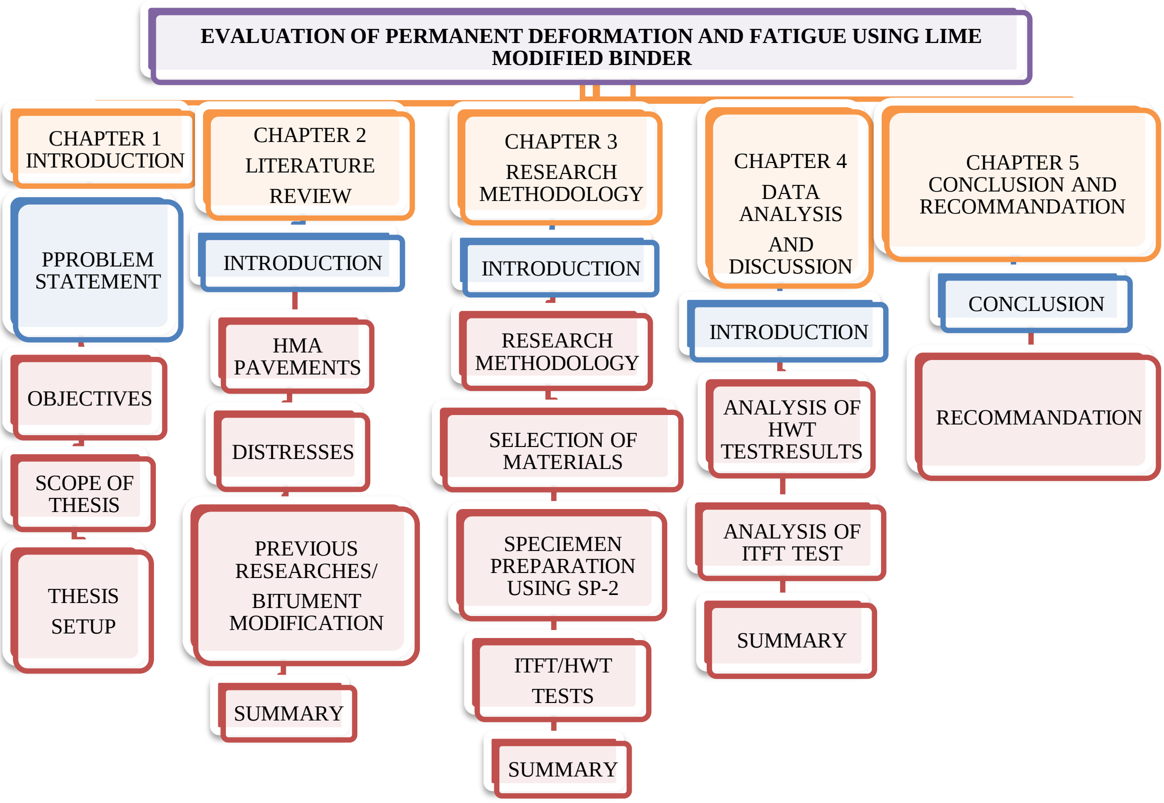
Chapter 2 describes the literature review on the flexible pavements, their distresses, and the concept of previous researches related to evaluation of flexible pavements premature failure, i.e. rutting and fatigue.

Chapter 3 explains the research methodology that is to achieve the objectives of this study. Explaining the source, specifications of materials and procedure used for determining the volumetric parameters of HMA mixes.

Chapter 4 includes the details of test results obtained by conducting rutting using wheel tracker and fatigue using UTM-25.

Chapter 5 includes the conclusions and recommendations for future work.

Figure1.1 Organization of Thesis



CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter gives an assessment of literature related with the thesis and the concept behind the fatigue cracking and permanent deformation in hot mix asphalt pavements. In this regard, previous research findings on permanent deformation and fatigue cracking using lime in asphalt pavements has also been quoted in this chapter. Moreover, bitumen modification in Pakistan is also discussed and also hydrated lime and its benefits as modifiers in asphalt pavements are also explained.

2.2 HOT MIX ASPHALT PAVEMENTS

In hot mix asphalt pavements, asphalt is an indispensable part of wearing surface of road structure because it plays pivotal role as a binder so, it has been modified a number of times against its failure [8]. In hot-mix asphalt (HMA) mixtures, use of hydrated lime showed innumerable effects on rutting as well as fatigue because in asphalt mixtures hydrated lime can decrease rut-depth of pavement because of its distinct stiffening effects and in order to improve bond between aggregate and asphalt [9].

2.3 FLEXIBLE PAVEMENTS

In flexible pavements, all the layers had an imperative role in maintaining the bearing capacity of the pavements and the load is applied over upper pavement surface i-e wearing course, and then the load s passed to the underlying layers and finally to the ground [10].Flexible pavement or asphalt concrete is one of the most commonly types of pavement used in highway construction projects in the world. The term of asphalt concrete describes the flexible pavement layer that constructed through mixing asphalt binder with aggregate, and resting on the sub base and subgrade soil layers [11]. Flexible HMA with more thickness perform better in resisting fatigue cracking and couldn’t show enough resistant to rutting than the flexible pavements having less thickness [12].

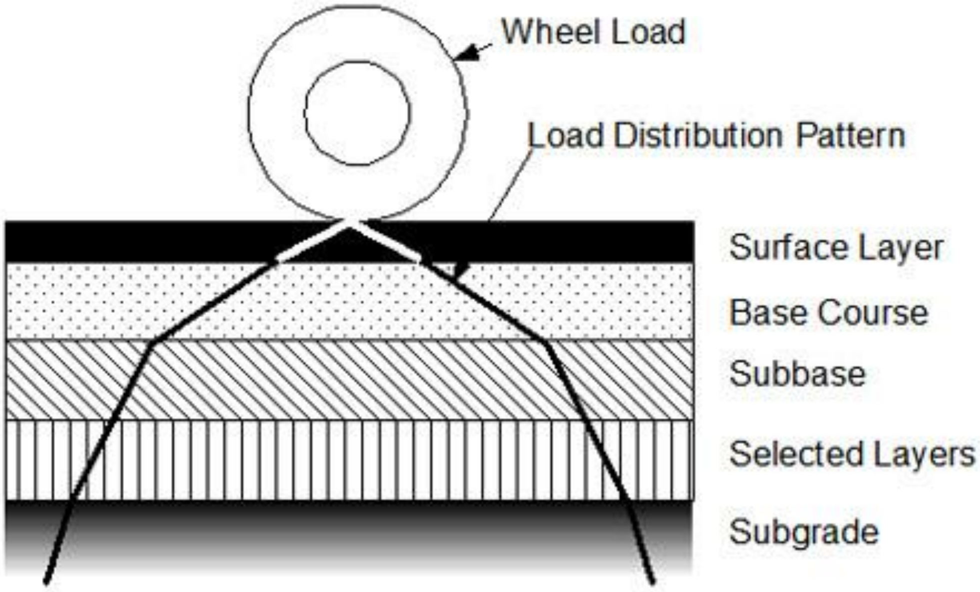


Figure 2.1 Layers of Flexible Pavement

(Source: www.google.com.pk/search?q=layers+of+flexible+pavement)

2.4 HOT MIX ASPHALT PAVEMENT DISTRESSES

Pakistan road network is around 260,000 kilometer in which the classification is around National Highway and Motorway network is around 9574 km long which became around 3.65% of total road network and 80 percent of traffic in Pakistan is carried by them. The worth of these assets of Pakistan is around 2.5 trillion [13]. Ironically, this asset is continually worsening due to a thousand a one reasons viz crippled design of pavements, inappropriate design mixtures and vice versa [14].

2.4.1 Permanent Deformation

By repeated loads at high temperature are typical distresses that cause rutting in asphalt pavements [15]. In the paving layers Rutting is adaptation of permanent deformation. In wheel paths, it occurred because of alliance of densification and shear deformation that appear longitudinal depressions [16].

In Pakistan majority of the highways and Motorways does not show resistance to rutting in the early life of the pavement. The prime reason behind this is the inadequate mix design, unexpected temperature variation or binder selection. Moreover, in pavement industry of Pakistan, old binder grading systems are practiced. All of these problems are being addressed by Superpave Mix Design method. Huge importance in binder characterization is given in this system [17].

- **Types Of Permanent Deformation**

Permeant deformation or rutting is broadly distributed in innumerable types, but in broader canvass, the types are classified into three main categories that are discussed below.

- **Structural Rutting**

When one or more layer is deformed in the flexible pavement it occur structural deformation. The underlying layers are unable to carry the load and this resulting the surface rutting.in order to differentiate structural rutting with other rutting, it is important that in structural rutting ,the humps may not occur on sides and they are also very wide comparative to other rutting [18].

- **Instability Rutting**

This rutting occurs because of scarce mix of the design. The primary rutting mechanism in HMA surface mixtures is the shear deformation when the supporting layers are reasonably stiff [18].

- **Wear rutting**

It occurred due to insufficient compaction of mixture. Resultantly, extra compaction to the asphalt layer occurred by vehicle loading without any base/sub base yielding or the formation of HMA humps [18].

2.4.2 Fatigue Cracking

In the bituminous layers, the most common type of cracking is the fatigue cracking that occurs because of progressive damage owing to repeated application of traffic [19]. Fatigue cracking occurred in the pavements because the structure is not capable to resist the repeated number of loads on it and the key asphalt pavement distresses in HMA pavements is fatigue cracking that occurs owing to repeated number of loads [20].

Fatigue can be defined as the fracture under repeated or fluctuating load. When the loads on the pavement or temperature variation in the pavement increases and the pavement could not withstand these changes owing to their less tensile strength, then the cracks will appear it pavements [21]. HMA fatigue cracking is related to asphalt binder content and stiffness. Higher asphalt binder contents will result in a mix that has a greater tendency to deform (i.e., more flexible) rather than fracture under repeated load [22].

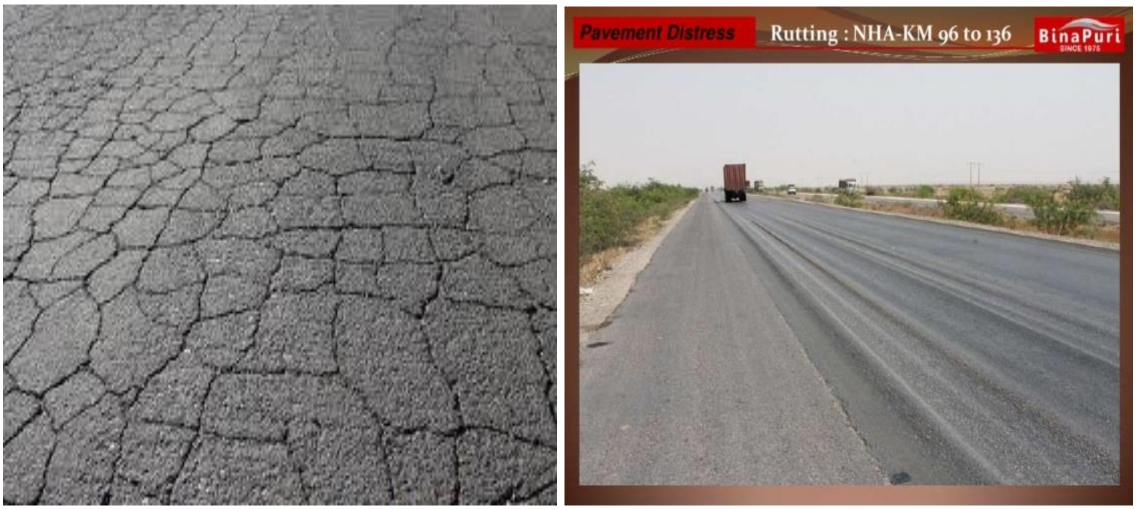


Figure 2.2 Fatigue and Rutting Pictures in Pakistan

2.6 RESEARCH FINDINGS ON PERMANENT DEFORMATION

Mehmet et al. (2016) conducted a research on the effects of using different bitumen modifiers and hydrated lime together on properties of hot mix asphalt pavements. Bitumen was modified with Iranian and American Gilsonite and styrene-butadiene-styrene. Hydrated lime was used by 2% as filler. Different tests were conducted including wheel tracking test, marshal stability flow and indirect tensile stiffness modulus test. It was concluded that the most effective among these modifiers were American Gilsonite on the top and then Iranian Gilsonite and finally hydrated lime.

Muhammad et al. (2015) performed a research on performance evaluation of Flexible Pavement and rutting. In this research, they used polythene, crumb rubber and lime in order to check the resistance of the asphalt mixtures. The test was conducted on wheel tracking device and the samples were subjected to 10,000 passes. Conclusively, the lime modified binder and polythene showed better results than the conventional mix. The order of performance was listed as polythene on the top, followed by lime.

Yu Wang et al (2015) carried a research on influence of hydrated lime on permanent deformation of Asphalt pavements. In this research, lime was used in the mixture with different percentages including 1-2.5% on different temperatures i-e 20, 40 and 60 degree, evaluation of permanent deformation was carried out. Resultantly, it was concluded that addition of lime resist the deformation at all three temperatures but showed good results at 40 degree temperature.

Thileepan et al. (2014) carried a research on evaluation of moisture damage of asphalt mixtures. In this research, the impact of untreated, liquid-treated and lime-treated was checked. Dynamic modulus and permanent deformation tests were conducted on the samples. Permanent deformation was checked by repeated load tri axial test. It was concluded that hydrated lime-treated performed well than liquid-treated mix in all the sources.

Kamran et al. (2013) worked on the rutting performance of polythene, Lime and Elvaloy modified asphalt mixes. In this research, the different additives were analyzed according to rutting potential. 1.5% hydrated lime was used in this research. All the samples were tested in the Wheel Tracker Machine and the rut depth was figured out. The result showed that the rutting that occurs in modified mixes is less than that of the conventional mix. Resultantly, the researcher concluded that the order of performance in polyethylene modified mix is better than lime and the performance of lime is better than that of elvaloy modified mix.

Taher et al. (2011) carried out a research on performance of asphalt mixture against fatigue and rutting. In this research different additives were used and then the rutting and fatigue life was determined. The primary focus was gradation of aggregate and asphalt content in asphalt mixture. Conclusively, the researchers analyzed that the mixture that have larger aggregate gradation and higher asphalt content has lower fatigue life. Contrary, the same specifications are positive for the rutting potential.

Peter et al. (2007) conducted a research on lime and liquid additives and their comparison on the Moisture Damage of Hot Mix Asphalt Mixtures. In this research, hydrated lime was used at 1% by the dry weight of aggregate. The samples for testing were compacted by using superpave gyratory compactor. The tests were conducted on Hamburg Wheel Tracker machine at two different temperatures i-e 50 and 40 degree centigrade. It was found that the test temperature 50 degree is not appropriate for the test because the binder used in the samples have softening point less than that of the test temperature. Furthermore, it was concluded that the test temperature should be less than that of the binder's softening point. Therefore, n this research, the researcher suggest the 40 degree temperature for binder having softening point below 50 degree centigrade.

2.5 RESEARCH FINDINGS ON FATIGUE

Akshay et al. (2016) carried a research on effect of aging on fatigue performance of hydrated lime modified bituminous mix. The research also conducted fatigue life of hydrated lime modifier mixture. Moreover, wet and dry addition of lime in the mixture was also checked. In this research, it was concluded that wet mixes with 30% lime in binder have greater fatigue life than that of the addition of 1.5% lime into dry mixture in thick pavements but in thin pavement the concept is opposite. Furthermore, lime modifier showed better aging result (short-term aging) than that of conventional mixtures.

Murugaiyah et al. (2015) conducted a research on impact of lime on mechanistic performance of hot mixed asphalt mixtures. In this research, laboratory tests were conducted for following types of pavement failure including moisture damage, permanent deformation, fatigue cracking and thermal cracking. Hydrated lime was added with 1.5 percentage on dry aggregate. The fatigue analysis showed that lime treated mixtures showed higher fatigue resistance than that of untreated mixtures.

Hanna et al. (2013) carried out a research on laboratory examination for the effects of adding hydrated lime on the moisture damage resistance of mixture. In this research, the indirect tensile test was carried out according to the ASHTO standard T283. The samples were conditioned at 60 degree centigrade and tested at 25 degree. The research stated that the tensile strength ratio increases at the samples having 2% hydrated lime mixed. Further, the TSR value become decreasing. In this way, the researcher analyzed that 2% addition of hydrated lime is the best and significant approach.

Aboel kasim et al. (2013) conducted a research on Fatigue characteristics of hydrated Lime modified HMA. In this research the fatigue life of mixtures modified with hydrated lime was carried out. The phenomenological model is used for finding fatigue failure. Six parameters were taken in this research i-e test temperature, mode of loading, asphalt content, aggregate gradation, a-b parameters of fatigue test and asphalt type. Resultantly it was concluded that the most significant parameters were testing temperature and the mode of loading. It was also illustrated that while using HL as modifier, fatigue parameter “b” will remains same and will not be affected but on the other hand, the fatigue parameter “a” is highly sensitive with the lime modified mixtures.

Francisco et al. (2010) conducted a research on effects of hydrated lime on the properties and performance behavior of asphalt mixtures. In this research, 0.5-3.5% lime was used in asphalt mixtures. Fatigue test was conducted and number of cycle to failure was obtained. Moreover, number of cycle to failure and deformation graph was plotted. It was concluded that the mixture show its maximum resistance to fatigue at 1.5% lime. If the percentage of lime increased, then the results would be weird.

Francisco et al. (2008) conducted a research on Fatigue of Asphalt Mixtures and Pavements in Nebraska. In this research it was analyzed that the number to cycle failure will reach to its maximum value (while using 1.5% hydrated lime) when subjected to controlled displacement fatigue test. Extra lime will show worse results.

2.7 RESEARCH FINDINGS ON LIME AS ANTI-STRIPPING AGENT

Vijay et al. (2016) performed a research on evaluation of sensitivity of moisture resistance of modified and unmodified mixtures. In this research, the addition of hydrated lime both in wet and dry mode is quantified. In dry mode, 1.5% lime was added to that of dry aggregate and in wet mode, 20-30% lime was added to that of asphalt binder weight. Moreover, the performance of lime and crumb rubber was also checked in this research. Resultantly, it was stated that the lime modified binder showed better result than the crumb rubber and also moisture damage resistance was also more than the crumb rubber modifier. Besides, dry and wet process of adding lime in the aggregate showed approximately similar results.

T.Schlegal et al (2016) conducted a research on the life cycle assessment of the use of hydrated lime modifier. In this research, the environmental impacts of mixtures modified with lime were compared with that of the conventional mixtures. In this research it was concluded that one of an indispensable benefit of lime is that it has the lowest environmental footprints as compared to simple HMA mixtures. Furthermore, around its environmental consumption is 435 less than the simple mixture and also it emission rate of greenhouse gases is 23% less than the conventional mix.

Nazirizad et al (2015) conducted a research on the evaluation of the effects of anti-stripping agent on performance of asphalt mixtures. In this research, two different additives were used i-e hydrated lime and liquid anti-striping agent. Different tests were performed including tensile strength test, boiling water test and figured out TSR values. The research concluded that the tensile strength of conditioned samples is approximately 30% more than that of unconditioned control sample.

Hayder et al. (2014) in the research laboratory examination of lime modified binder concluded that the stability increase with the increases of hydrated lime in the mixture. This increase is limit to 2.5% lime after that the value starts decreasing. So after that, value of air voids increases by adding further lime in the mixture.

Department of Highways, Thailand (2012) established a report on the laboratory evaluation of hydrated lime in asphalt mixture for Moisture Damage and Rutting. In this research, hydrated lime was used with different percentage i-e 0%, 1%, and 1.5%. The resilient modulus, wheel tracking test was performed on these samples. The wheel tracking test was performed on wet mode. The research concluded the 20% addition of lime correspond to asphalt binder or 1.5% lime to that f dry aggregate is considerable and showed better results than conventional mixtures.

D. Lesueur et al. (2010) carried research on increasing the durability of asphalt mixtures by hydrated lime addition. The beneficial effects of hydrated lime on asphalt mixture durability have also been figured out. The researchers estimate that hydrated lime increases the durability of asphalt mixtures by 2 to 10 years that is by 20 to 50%.

National Lime Association (2006) stated in their report viz; "Hydrated Lime – A solution for High Performance" stated that lime in the asphalt mixture stiffer the mixture and is active mineral filler. Furthermore, report explained that lime when combined with bitumen removes the undesirable components and make the material resistant to rutting and fatigue.

2.8 BITUMEN MODIFICATION.

Asphalt and bitumen modification is therefore on the increase everywhere. Road authorities throughout the world are now realizing that it is very good business to use modified asphalt in new road projects and thus it simply saves a lot of money on the medium and long term because the roads are less exposed to rutting and cracking [23]. Highway agencies have recognized the benefits of using modified asphalts to reduce the amount and severity of pavement distresses and to increase service life [24]

Modified bitumen is especially design to significantly reduces the asphalt pavement failures, such as rutting (Permanent deformation), fatigue, oxidative aging, and thermal cracking, polymer modified bitumen produce more durable asphalt pavement [25].

2.8.1 Bitumen Modification in Pakistan

In Pakistan, the competent highway authorities after doing vast research use different polymers in different sections of road in order to check the serviceability of roads. In the sections stated below, polymer Elvaloy was used [26].

- Motorway-1, 153 km from Islamabad to Peshawar, 6 lanes
- Motorway (N-5), 50 km from Lahore to Gujranwala, 6 lanes
- Motorway (N-5), 43 km from Hyderabad to Halla (southbound), 2 lanes

They use three modifiers i-e Polyethylene, Lime and Elvaloy. The results obtained by using these modifiers were then compared with simple pavements of National Highway Authority. After performing rutting tests on theses samples, resultantly they found that that the polyethylene perform best compared to lime and lime perform good than that of Elvaloy. They concluded that the results from modified hot mix asphalt pavement were too better than the conventional pavements of National Highway Authority [27]

National Highway Authority (NHA) of Pakistan laid 4 trial sections for assessing the field performance of Crumb rubber modified bitumen in August 2005 and February 2006. In August 2005 these trial sections were prepared between 1) Sanjwal more and Haro Bridge on outer lane of southbound carriageway and 2) Burhan flyover and rotary interchange M1 on outer lane of southbound carriageway. These trial sections were prepared using bitumen of National Refinery Limited Karachi. In February 2006 two more trial sections were prepared between 1) Burhan flyover and rotary interchange motorway on full width of southbound carriageway and 2) full width of southbound approach road of Haro Bridge on gradient towards Rawalpindi. In this case trial sections were prepared using Bitumen procured from Attock Refinery Limited. All these tests were performed on wearing course except the last section, wherein, CRMB was introduced in both wearing and base course. [28]

2.9 HYDRATED LIME

Historically by making back the hands of clock, in the sixth century, Roman people didn't use asphalt as a binder in their pavements because at that time the concept of asphalt as a binding material were not introduced. Roman people in their pavements used lime as a binding material. So the use of lime as a binding material is as old as history itself. Now a day, after bitumen use in asphalt pavements came into vague, the lime is used as modifier with asphalt [29]. Presently lime is used in asphalt mixtures to prevent two major pavement distresses i-e rutting, and fatigue cracking and it improves the aging behavior of the asphalt mixture. Hydrated lime content in asphalt mixture should me 10 to 20 percent by weight of the asphalt binder or it should be 1 to 2 percent by weight of the total dry material [30].

So in majority of researches, approximately 1% or 1.5% of lime is used in the asphalt mixtures in order to find appropriate results. By using more lime than the specified percentage, the results of performance test would be weird. Lime in asphalt mixture can be added in three different ways. Moreover, different percentage of lime is used in mixture to find the significant variable or lime quantity. Addition of lime in asphalt mixture could be possible nearly in three ways i-e dry lime in dry aggregate, dry lime in wet aggregate and wet lime in wet aggregate [31]

Hydrated lime, as anti-stripping agent has thousand and one benefits. Few among them are as follow.

I. Hydrated lime behaves just like mineral filler in order to harden the binder and HMA [31].

II. Improves resistance to breakage growth (i.e. improves fracture durability) at low temperatures [31].

III. Hydrated lime changes oxidation kinetics and interrelates with products of oxidation to reduce their harmful effects.

IV. Alters the plastic properties of clay fines to improve moisture sensitivity and durability.

2.10 SUMMARY

In this chapter, the background of the research is stated briefly about the hot mix asphalt pavements and also the road network of Pakistan and the problems related with them. Moreover, the roman use of lime was also discussed. Also the superpave mix design method and the process to find volumetric of the specimens that were prepared by superpave mix design method. Moreover, the fatigue and rutting behavior of asphalt mixtures is also discussed. In addition with this, the test that will conduct in this research are slightly discussed and also the procedure that how to conduct the test was also discussed. Different factors, that corporate an imperative role in the performance of test is also written in this chapter. Most important, in this chapter the addition of lime is also figure out and also the significant percentage of lime is also discussed. At the end, different views of the latest researchers are also at the end of this chapter.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter elucidates methodology used in this research work to achieve the objectives of this research work. Testing on laboratory prepared samples was conducted in three stages. In first phase, superpave mix design method was adopted to determine the volumetric properties of bituminous mixes using lime as modifier. In the second phase, wheel tracker test was performed on gyratory compacted HMA mixes to determine their rutting resistance. In the third and final stage, indirect tensile fatigue test was performed on gyratory compacted HMA mixes using lime as modifier.

In the initial phase, two different aggregate gradations superpave 19mm and superpave 25mm and two binders i.e. virgin and lime modified, were used to determine the volumetric properties of laboratory prepared HMA specimens.

3.2 FRAMEWORK

At first, material selection has done. Moreover, the material characterization was done, in which different properties of aggregate and bitumen was determined in accordance with applicable standards. In the preceding step, different percentages of lime were added in the mixture and their volumetric properties were determined. Moreover, samples were prepared, against the significant percentage of lime, for the performance testing. After this step tests were conducted using Wheel tracker to find rutting propensity and Indirect Tensile Fatigue Test using Universal Testing Machine. At last the test results were tabulated and statistical analysis was performed on the test results.

3.3 MATERIAL SELECTION

Material was selected. The source for aggregates (both coarse and fine) was the Margalla quarry. Bitumen source was Attock Refinery Limited (ARL) and penetration grade 60/70 was selected to be used. The reason for selecting the penetration grade 60/70 is that it is the commonly used bitumen grade across Pakistan.

3.3.1 Sieving of Material

After selection of material, next task was to characterize the material according to reference specifications. It has also been observed that aggregate gradation, shape and surface texture have a great influence on hot mix asphalt properties.

3.3.2 Aggregate Testing

To find the aggregate fundamental properties, such as, gradation detailed and specific gravity laboratory tests were carried out. Tests performed in the laboratory include;

- Aggregate Shape Test
- Specific Gravity and Water Absorption Test of aggregates
- Aggregate Impact Value Test
- Aggregate Crushing Value Test
- Los Angeles Abrasion Test on aggregate

Table 3.1 Result of Aggregate Test

Test Description	Specification	Result	Criterion
Elongation Index (EI)	ASTM D 4791	5.78 %	≤ 15 %
Flakiness Index (FI)	ASTM D4791	13 %	≤ 15 %
Aggregate Absorption	ASTM C 127	2.5 %	≤ 3 %
		1.73 %	≤ 3 %
Impact Value	BS 812	21 %	≤ 30 %
Los Angles Abrasion	ASTM C131	27	≤ 45 %
Specific Gravity	ASTM C128	2.62	-
	ASTM C127	2.67	-

3.3.3 Asphalt Binder Testing

Consistency of asphalt binder changes with change in temperature. Therefore, standard temperature is obligatory for comparing consistencies of asphalt binder. Consistency of bitumen binder is commonly find out through penetration test or a viscosity test (Asphalt Institute MS-4, 2003). Some other tests like softening point test and ductility test of binder provides additional info and confidence about consistency. So for characterizing the asphalt binder in laboratory following tests were carried out.

- Penetration Test of Bitumen
- Softening Point Test of Bitumen
- Ductility Test of Bitumen
- Flash and Fire Point Test of Bitumen
- Viscosity Test of Bitumen

Table 3.2 Results of Bitumen Test

S No.	Test Description	Specification	Result
1	Penetration Test @ 25 (°C)	ASTM 5	63
2	Flash Point (°C)	ASTM D 92	328
3	Fire Point (°C)	ASTM D 92	361
4	Specific gravity	ASTM D 70	1.03
5	Softening Point (°C)	ASTM D36-06	48
6	Viscosity Test (Pa.sec)	ASTM D4402	0.225
7	Ductility Test (cm)	ASTM D113-99	107

3.3.4 Gradation of Aggregate

For obtaining the required gradation, the combination of aggregates is the most important step of hot mix asphalt design. The selected gradations are shown in tables 3.3 and 3.4 shows that both gradations are plotted with percentage passing verses sieve sizes. The nominal maximum aggregate size selected for superpave 19mm and superpave 25mm respectively.

Table 3.3 19mm NMAS Gradation Chart

Sieve Size	19mm NMAS Gradation		
	Cumulative Percentage Passing (%)		
	Max	Superpave 19mm	Min
25.4 mm (1 inch)	100	100	100
19 mm (3/4 inch)	100	95	90
12.5 mm (1/2 inch)	90.0	75.0	60.0
9.5 mm (3/8 inch)	70.0	63.0	55.0
4.75 mm (No. 4)	50.0	42.5	35.0
2.36 mm (No. 8)	49.0	32.0	23.0
1.18 mm (No. 16)	30.0	20.0	15.0
0.6 mm (No. 30)	20.0	15.0	10.0
0.3 mm (No. 50)	15.0	8.5	6.0
0.15 mm (No. 100)	10.0	6.0	5.0
0.075 mm (No. 200)	8.0	5.0	2.0
Pan	0.0	0.0	0.0

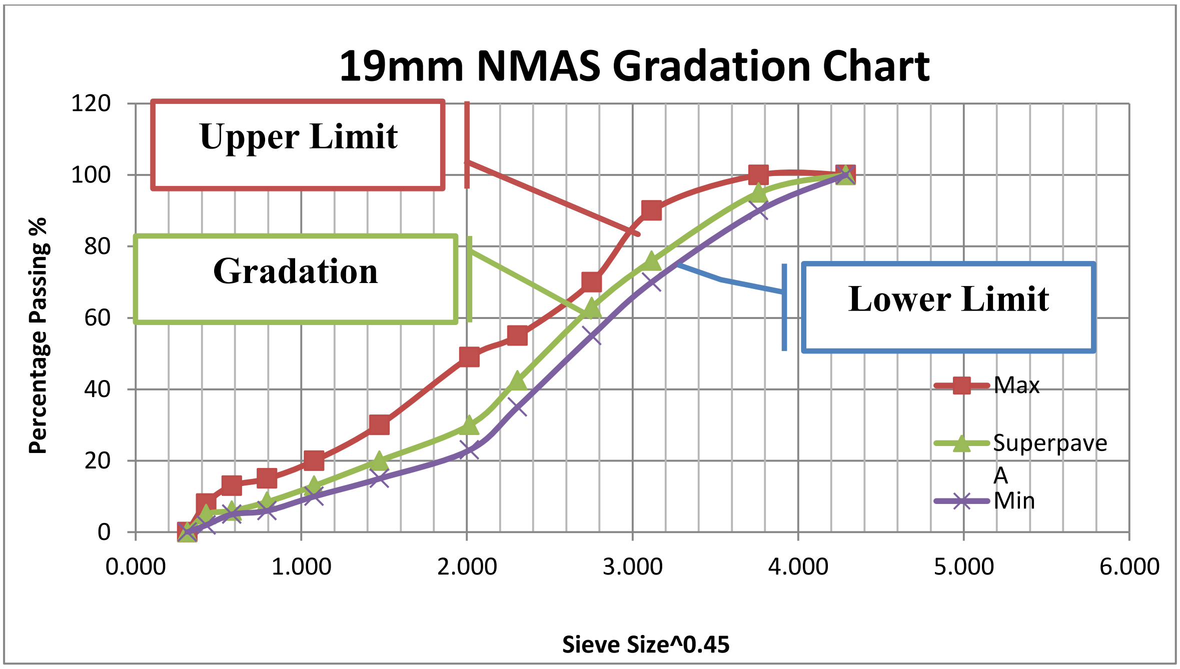


Figure 3.1 19mm NMAS Gradation Graph

Table 3.4 25mm NMAS Gradation Chart

25mm NMAS Gradation			
Cumulative Percentage Passing (%)			
	Max	**Superpave B**	**Min**
25.4 mm (1 inch)	100.0	94.0	90.0
19 mm (3/4 inch)	90.0	86.0	80.0
12.5 mm (1/2 inch)	80.0	73.0	55.0
9.5 mm (3/8 inch)	70.0	55.0	42.0
4.75 mm (No. 4)	50.0	38.0	28.0
2.36 mm (No. 8)	40.0	26.0	19.0
1.18 mm (No. 16)	20.0	16.0	10.0
0.6 mm (No. 30)	15.0	11.0	8.0
0.3 mm (No. 50)	10.0	7.0	6.0
0.15 mm (No. 100)	7.0	5.0	4.0
0.075 mm (No. 200)	4.5	4.0	3.5
Pan	0	0	0

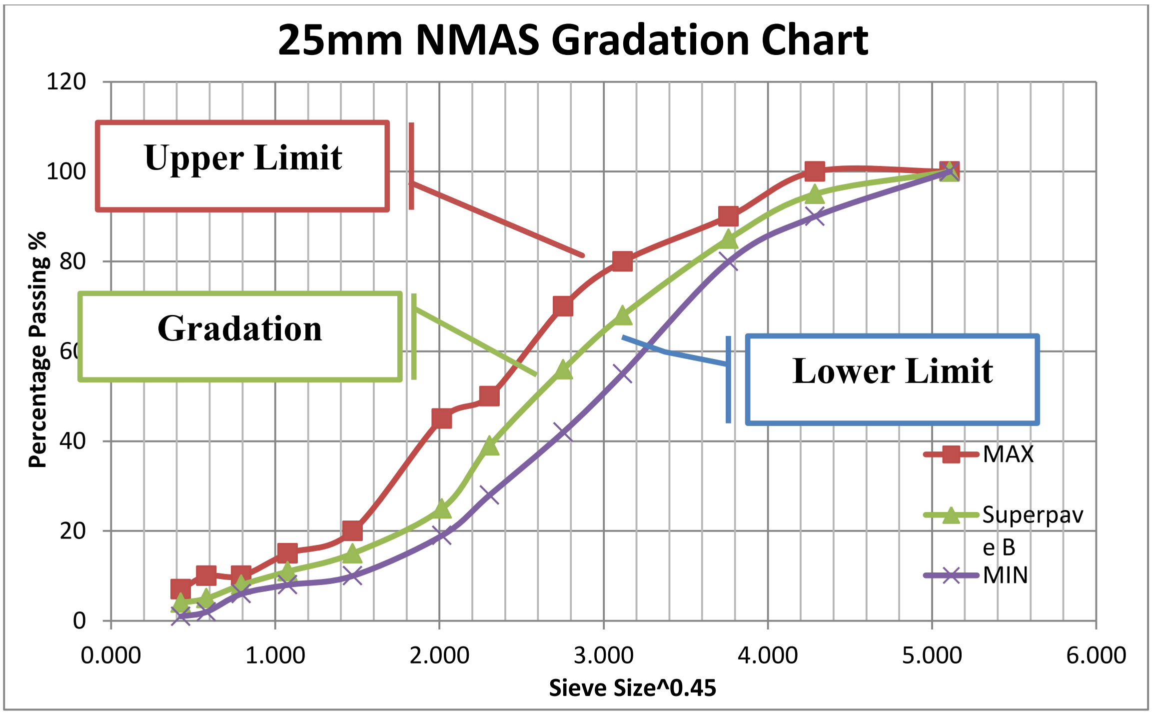


Figure 3.2: 25mm Gradation with specified limits

3.4 DETERMINATION OF OPTIMUM BINDER CONTENT

For both gradations, the samples were prepared according to superpave mix design manual (SP-2) in order to determine optimum asphalt content. In this way, binder with 3-4.5% with an interval of 0.5 is used and samples were prepared in gyratory compacter. Each sample weights approximately 4500 gram. The volumetric parameters theoretical maximum specific gravity Gmm, effective specific gravity Gse, Bulk specific gravity Gmb and %Gmm of prepared specimens were measured, verified in light of Superpave mix design criteria and finally optimum asphalt contents were determined.

For each gradation, two samples were prepared against each percentage of binder content. In this way, eight samples were prepared for superpave 19mm gradation. On the other hand, eight samples were also prepared for 25mm gradation. The percentage of binder content in this research was assumed within the range of 3 to 4.5 % with an interval of 0.5. From gyrated compacted samples, %Gmm was figured out according to Asphalt Institute of Superpave Mix Design Method (SP-2) manual and then voids ration, Voids in Minerals Aggregate (VMA), Voids Filled in Aggregate and Dust to Binder Ratio. Table 3.3 shows the average values of the samples for each gradation and also table 3.4 shows the design criteria according to Superpave Manual (SP-2).

Table 3.5 Average Values of 19mm and 25mm Gradations.

%AC	Gmb	Gmm	Gse	% Gmm	VMA (%)	VFA (%)	Va (%)	Dust to binder ratio
				SUPERPAVE 19MM SPECIMENS				
3.0	2392.50	2509.43	2689.669	95.33	13.326	69.682	4.660	1.236
3.5	2394.61	2506.94	2672.866	95.51	13.696	70.587	4.481	1.092
4.0	2397.43	2502.00	2653.229	95.84	14.022	71.410	4.157	0.991
4.5	2416.3	2495.77	2632.152	96.22	14.340	72.194	3.772	0.913

SUPERPAVE 25MM SPECIMENS								
3.0	2404.21	2519.55	2701.661	95.434	14.643	72.470	4.566	1.251
3.5	2413.56	2515.74	2683.236	95.93	14.765	72.884	4.016	1.144
4.0	2417.97	2511.52	2664.391	96.27	15.050	73.519	3.72	1.036
4.5	2420.13	2509.77	2648.467	96.43	15.411	74.191	3.56	0.931

Table 3.6 Optimum Asphalt Content and Design Criteria

Parameters	Measured Value		Criteria	Remarks
	Class A	Class B		
Optimum Asphalt Content (%)	4.1	3.7	NA	
VMA (%)	14.002	14.764	Min 13	Pass
VFA (%)	71.410	72.884	65-75	Pass
Dust to binder ratio	0.991	1.114	0.6-1.2	Pass
%Gmm @ Ninitial	85.523	88.404	<89	Pass

3.5 PREPARATION OF SAMPLES

For determining the optimum asphalt content bituminous paving mixes were prepared according to the method explained in Asphalt Institute's Superpave mix design manual (SP-2).HMA samples were prepared using 0%, 1%, 1.5% and 2% of lime "Francisco et al (2010)"**.**These percentages of lime were added in account of total dry weight of aggregate. The optimum asphalt content for each was determined by repeating the Superpave mix design procedure two times. The volumetric parameters i-e theoretical maximum specific gravity Gmm, effective specific gravity Gse, Bulk specific gravity Gmb and %Gmm of prepared specimens were measured, verified in light of Superpave mix design criteria and finally optimum asphalt contents were determined. Superpave mix design was carried out as follows:

3.5.1 Number of Samples

According to Asphalts Institute of Superpave Mix Design Method (SP-2), for each combination of aggregate and binder, two samples were prepared. As there were two gradations i.e. superpave 19mm and superpave 25mm for wearing coarse and two binders i.e. ARL virgin 60/70 and ARL 60/70 modified with Lime, eight specimens for each gradation were prepared. So, a total of sixteen specimens were prepared for determining the optimum binder content at three different binder contents (0, 1, 1.5 and 2%).

3.5.2 Preparation of Materials for Mix Design.

According to Asphalt Institute Superpave Mix Design Method (SP-2), the aggregates were dried to constant weight at 105º C to 110º C. The quantity of aggregates used for preparing the compacted 6 inch diameter each specimen by Superpave mix design method was 4500 gm. Figure 3.3 and 3.4 shows heating of aggregates and bitumen in an oven.

Figure 3.3: Heating Aggregates Before Mixing

Figure 3.4: Heating Bitumen Binder Before Mixing

3.5.3 Mixing of Aggregate and Bitumen

The Superpave mix design manual (SP-2) stated the use of mechanical mixer for mixing the aggregate that the heated dry aggregates and heated bitumen were charged immediately into the mechanical mixer and mixed thoroughly for 10 to 15 minutes at a temperature ranging from 160º C to 165º C respectively as shown in figure 3.5.

Figure 3.5: Mechanical Mixing Machine

Figure 3.6: Mixing of Mixtures

3.5.4 Compaction of Samples

As it is mentioned in Asphalt Institute Superpave Mix Design Method (SP-2), mixes were compacted using Superpave Gyratory Compactor (SGC) at 135º C as shown in figure 3.7. But before compacting the specimen, the mold in which the sample was to be poured was cleaned and placed in oven at 100º C for 30 minutes. The SGC mold is cylindrical wall (having 150 mm inside diameter) with a base plate at the bottom to provide confinement during compaction. Once the packed mold is placed in the SGC its base rotates at a constant speed of 30 revolutions per minute during compaction, while the mold is positioned at an angle of 1.25 degrees. A loading system applies a load to the loading ram, which imparts a 600 KPa compaction pressure to the specimen. The entire batch of mix was transferred to the mold also a filter paper was placed on both sides of mold i.e. top and bottom.

The design criteria of heavy traffic or design ESAL $\geq$ 30 were adopted. For compaction, the mold was placed in the superpave gyratory compactor. After the required gyrations and compaction was achieved, the mold was removed from compactor and the specimen was extracted from mold.

Figure 3.7: Compaction Mold

Figure 3.8: Gyratory Compactor

3.6 DETERMINING VOLUMETRIC PROPERTIES

The volumetric properties of mix including, air voids (Va), voids in mineral aggregates (VMA) and voids filled with asphalt (VFA) were determined using their respective formulae after determination of theoretical maximum specific gravity (Gmm) and bulk specific gravity (Gmb). Theoretical m aximum specific gravity (Gmm) and bulk specific gravity (Gmb) were determined in accordance with AASHTO T209 and AASHTO T166 respectively.

3.6.1 Superpave 19mmVolumetrics

The volumetric properties of sample with lime modified asphalt are shown below in table 3.5 respectively. These properties were found by varying the lime percentage from 0% to 2% by weight of the aggregate. It is quite cogent that the values of Gmb, Gmm and Gse show an increasing trend with increase in percentage modifier with a maximum value at 1.5% modifier and then it starts to decrease. Hence it is stated that optimum content of Lime to be added in the mix is 1.5%. The table 3.6 clearly shows that all of the volumetric properties are meeting the criteria given in the SP-2 manual. The minimum value of VMA for 19.0 NMAS should be 13% and in this case its value was 13.54%. VFA should be in between 65-75, its value calculated from the graph was 70.45, which was within the specified criteria. The dust to binder ratio value according to criteria should be within 0.8 – 1.6 and in this case it was 1.54. The measured value of required density (%Gmm) at Ninitial should be ≤ 89.0 and in this case it was 87.35 which lies in the range of criteria.

Table 3.7 Volumetric Properties of SP 19mm Gradation using Lime Modified Specimens.Table 0-1

Lime (%)	Gmb	Gmm	Gse	VMA (%)	VFA (%)	Va(%)	D/B Ratio	%Gmm
0	2389.14	2494.80	2642.04	13.192	69.579	4.216	0.960	95.787
1	2391.01	2495.01	2642.28	13.079	69.337	4.168	0.966	95.871
1.5	**2396.00**	**2496.12**	**2643.59**	**13.011**	**68.982**	**4.011**	**0.971**	96.007
2	2393.87	2493.10	2640.06	12.995	68.182	3.980	0.984	96.015

Table 3.8 Volumetric Properties of 19mm Gradation and design Criteria (SP-2 Manual)

Parameters	Measured Values	Criteria	Remarks
Optimum Asphalt Content (%)	1.5%	NA	
VMA (%)	13.011	Min 13	Pass
VFA (%)	68.982	65-75	Pass
Dust to binder ratio	0.971	0.6-1.2	Pass
%Gmm @ ini	83.619	<89	Pass

3.6.2 Superpave 25mmVolumetrics

The volumetric properties of specimen's superpave 25mm gradation with Lime modified asphalt are shown below in table 3.7 respectively. These properties were found out in order to use the lime percentage from 0% to 2% by weight of the aggregate. It can be clearly seen from table 3.7 that the values of Gmb, Gmm and Gse show an increasing trend with increase in percentage modifier with a maximum value at 1.5%

modifier and then it starts to decrease. This suggests that optimum content of Lime to be added in the mix is 1.5%. The table 3.8clearly shows that all of the volumetric properties are meeting the criteria of supper pave mix design.

Table 3.9 Volumetric Properties of SP 25mm gradation using Lime Modified Specimens

Lime (%)	Gmb	Gmm	Gse	VMA (%)	VFA (%)	Va (%)	D/B Ratio	%Gmm
0	2390.01	2495.12	2658.95	15.177	73.570	4.213	1.122	95.759
1	2391.45	2496.55	2660.57	15.1260	73.482	4.208	1.125	95.794
1.5	**2397.24**	**2498.15**	**2662.52**	**14.932**	**73.177**	**4.039**	**1.147**	95.985
2	2396.95	2495.90	2659.87	14.930	73.122	3.96	1.154	96.007

Table 3.10 Volumetric Properties of 25mm Gradation and Design Criteria (SP-2 Manual)

Parameters	**Measured Values**	**Criteria**	**Remarks**
Optimum Asphalt Content (%)	1.5%	NA	
VMA (%)	14.932	Min 13 Min 12	Pass
VFA (%)	73.177	65-75	Pass
Dust to binder ratio	1.147	0.6-1.2	Pass
%Gmm @ ini	84.722	<89	Pass

3.7 SAMPLE PREPARATION FOR PERFORMANCE TESTS

The quantity of aggregates required for preparing each 6 inch diameter gyratory compacted specimen was 7500 gm. The specimens were prepared using superpave gyratory compactor according to AASHTO TP 62-07. Compaction of specimens was controlled by providing 125 gyrations. Six specimens for both gradations were prepared using virgin 60/70 grade asphalt and six specimens for each gradation were prepared by modifying the asphalt with 1.5% Lime. A total of 12 cylindrical compacted specimens, having height 188 mm and 150 mm diameter were prepared for wheel tracker test.

3.7.1 Coring and Cutting

The size of the samples prepared in the gyratory compactor used is 6 inch (150 mm) in diameter and 7 inch (177.8 mm) in height. After the samples were compacted using the gyratory compactor the samples were left for 24hr to come to the room temperature. Once the samples were at room temperature core cutting machine (as shown in Figure 3.5) accompanied by the saw cutting machine was used to core out 4 inch (100 mm) diameter specimens from the 6 inch (150 mm) samples. Figure 3.5 Core cutting machine Further the saw cutting machine was used to cut the specimens into the required thickness, at least 1.57 inch (40 mm) for a maximum aggregate size of 25 mm as instructed in EN 12697 – 24, so that Indirect Tensile Test could be performed on the samples.

Figure 3.9: Gyratory Compacted and Core Cut HMA Specimens

Twelve specimens were selected at random for HWT test and remaining 24 samples were selected for fatigue test i-e ITFT. Specimens for Hamburg wheel tracker test were only saw-cut from top and bottom to obtain a standard specimen of 1.5 inch height and 6-inch diameter. Figure 3.5 shows the saw cut specimens for wheel tracker test.

3.8 HAMBURG WHEEL TRACKER TEST

The samples were tested in order to find the rut depth of the specified specimen using Hamburg Wheel Tracker (HWT). Wheel tracker is an electrically powered device, which is capable of moving a 203.2mm diameter, 47-mm wide steel wheel over a test specimen. The load on the steel wheel is 158±1.0 lb. and the average contact stress produced by the contact of wheel is approximately 0.73 MPa with a contact area around 970 mm^2. The contact pressure induced by the steel wheel produces the same effect as produced by the rear tire of a double-axle truck. With increase in rut depth the contact area increase as result of which the contact stress becomes variable. The steel wheel moves over the specimen in forward and backward direction. The steel wheel should complete approximately 50 passes over the specimen per minute. Its maximum speed is approximately 1 ft. /sec, which is reached at the midpoint of the specimen. Using this device rutting test can be performed on Air, Wet and Dry modes. These modes can be used by adjusting the device at desired test conditions.

Before conducting the test, the samples were saw cut from the top and bottom surface so that two 1.5-inch thick specimens could be obtained. These specimens were cut according to the silicon mold of the wheel tracker tray.

After placing the specimen in the mold, extra spaces were filled with plaster of Paris or ant hard material so that the specimen does not move with the movement of wheel. The steel tray with the specimen mounted in it was placed under the wheel and fixed. The speed of the wheel was adjusted to 50 ppm (passes per minute). The number of passes were fixed to 20,000. Wet mode of wheel tracker device was selected at 40 degree centigrade. Finally the test was run and wheel started moving to and fro on the mounted specimen. One complete to and fro movement of the wheel was taken as 2 passes. The LVDT measures the rut impression in millimeters of unit at the same time with the motion of wheel. The machine automatically stopped when required number of passes achieved. Results were saved for the further use.

3.8.1 Result of Hamburg Wheel Tracker Test (HWT).

The software gives two types of results as output i-e Graph which shows number of passes verses rut depth in mm and Excel Sheet data. Wheel Tracker graph is an application that will display graphs and header information for the Wheel Tracking

Machine. It has the ability to select a database upon startup so that archived data can be viewed and graphed. The application has the ability to save the graphs and header information to a file.

The graph will be displayed in the form of image and the rut depth at every number of passes can be obtained by generating report and then importing the report in the MS excel file.

3.9 INDIRECT TENSILE FATIGUE TEST (ITFT)

The indirect tensile fatigue test on cylindrical shaped samples to characterize modified and unmodified HMA mixes under repeated load applied with constant load mode. The cylindrical shaped test samples are subjected to repeated compressive load in the vertical direction. The vertical compressive load produces reasonably uniform tensile stress in the horizontal direction perpendicular to the load applied on the sample that is why it is known as an indirect tensile test as the tensile load is applied through compressive loading. The samples under the vertical compressive load fail by splitting along the vertical plane. Deformations are produced in the horizontal direction as the load is applied on the vertical dimension of the sample due to tensile stresses and those deformations are recorded which are further used to calculate the tensile strain at the center of the sample using an assumed Poisson's ratio. The fatigue life of the sample is defined as the number of cycles before the sample fractures. The haversine load applied to sample includes a loading time of 0.1 seconds and a rest time of 0.4 seconds. The testing was performed for 25 °C and 40°C with a load of 2500N. The samples were tested in Universal Testing Machine UTM 25, using the jig assembly shown in Figure 3.6 along with the transducers attached on the diametric plane, and at least three samples were tested for each level of stress. During the loading process deformation for the first 150 cycles were recorded and the transducer removed. The deformation reading of the transducers attached to the sample in the jig assembly were used to determine the initial strain at the center of the sample that is the strain developed in the sample at the 100th cycle of loading. Once the testing is completed the sample fractured as shown in Figure 3.6. Once completed with all the testing of all the stress levels, the n number of cycles to failure and the initial strain values are used to plot a log graph and from the graph equations can be developed for each type of mix.

Figure 3.10: Sample in Jig Setup and Fractured Sample

3.10 SUMMARY

This chapter envelope the methodology adopted in the research. The mixes selected for research and the laboratory tests used to determine the properties of the mixes has been discussed. Only the Margalla aggregate source is used for performance testing with ARL 60/70 modified with lime. Detailed methodology for the preparation of sample in the lab has been discussed including the mixing, compaction and sample molding. The preparation of samples for performance testing also discussed along with the methodology and test temperatures used in the research.

CHAPTER 4

ANALYSIS OF RESULTS

4.1 INTRODUCTION

This chapter enunciates the analysis of data that is obtained from laboratory testing. The effectiveness of lime as anti-stripping agent in order to reduce permanent deformation and fatigue failure was illustrated. In the first stage of testing that was performed via Hamburg wheel tracker test, the factors considered for the wheel tracker test were temperature that was taken 40 degree centigrade. The rut depth of neat and modified binder that was obtained via test was then compared. In the second stage of testing, indirect tensile fatigue testing was conducted via UTM-25. The initial analysis, to determine the initial strain for each specimen, was performed using Microsoft Excel as the data from the output of the software did not include the initial strain values. Once the initial strain values were determined, the results were compiled to develop relationship between the log of number of cycle to failure and the log of initial strain values. The screened data was further analyzed using SPSS and MINITAB-17 software to develop fatigue curves for each type of mix. The comparison of two different gradations i-e SP 19mm and 25mm has also been shown. The results established by analyzing the data are presented using graphs, figures and residual plots

4.2 PERMANENT DEFORMATION

Permanent deformation is assessed by comparing the specimen's resistance to rutting with and without lime modification. Gyratory compacted specimens were prepared with two proportions of lime (0% and 1.5%) for SP-19mm and SP-25mm aggregate gradations. Wheel tracking test was conducted on controlled specimens and then on lime modified specimens for each aggregate gradation separately. A total of six specimens were prepared for each gradation with and without modifier and the test was performed on 40 degree centigrade. Specimen's resistance to rutting was checked in wheel tracking machine. All the controlled specimens showed good resistance to rutting whereas the lime modified specimen's resistance to rutting was greater than that of controlled specimens. All of the specimens passed the wheel tracker test.

4.2.1 Wheel Tracker Outputs

The graphical output of specimens is shown in the figure 4.1. In the graph, the y-axis indicates the rut depth scale, where on the x-axis shown the number of passes. The red line demonstrates the rut in the wheel path whereas on the other hand, the green line shows the line of failure depth which was set 12.5 mm for all the tests. The reason for conducting the test at 20000 wheel passes is that the researchers found that after increasing the number of wheel passes to 19,200, some mixtures will deteriorate due to effect of moisture damage shortly after 10,000 passes. Therefore, greater than 10,000 wheel passes were generally needed to show the effect of moisture damage.

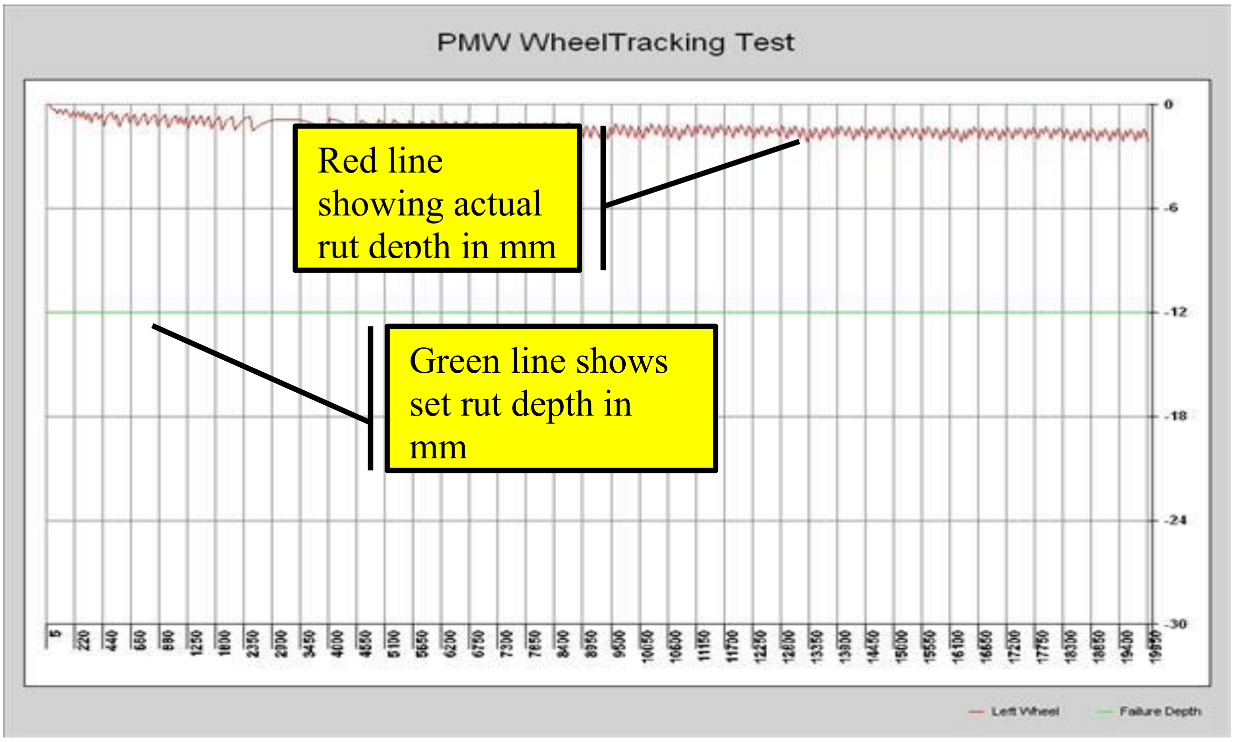


Figure 4.1: Result of Hamburg Wheel Tracker

4.2.2 Wheel Tracker Rutting Results

Rutting can be assessed by comparing the rut depths obtained for controlled mixtures of both gradations with the lime-modified mixtures. Rut depth obtained after 20,000 passes was used to calculate the percentage improvement in specimen's resistance to rutting with the addition of lime. Result of Hamburg Wheel Tracker test of

19mm gradation is shown in table 4.1. It is cogent from the table 4.1 that for 19mm gradation, the rut depth value of modified sample is 3.57mm for sample 1 and 3.63mm for sample 2. On taking average of both the values, the average rut depth became 3.6mm. On the other hand, the values of unmodified samples were 4.27mm and 5.02mm and their average became 4.645mm. Conclusively, it showed that average improvement in 19mm gradation with 1.5% lime was notes as 22.04%. So it is proved that samples that are modified with lime showed better resistance to rutting than that of unmodified samples. The graphical illustrations of 19mm gradation test results are shown in figure 4.2.

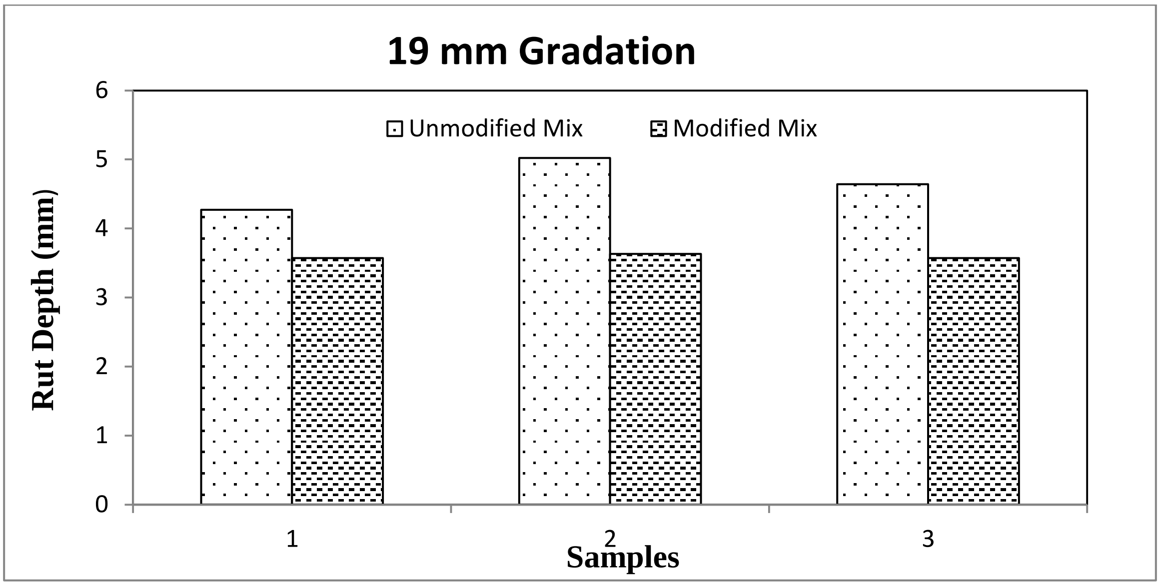
Likewise, results of Hamburg Wheel Tracker test of 25mm gradation also showed better results of samples that are modified with lime. For 25mm gradation, the rut depth value of modified sample is 1.87mm for sample 1 and 1.29mm for sample 2. The average rut depth of modified samples was 1.58mm. Furthermore, the values of unmodified samples were 3.64mm and 2.97mm and their average became 3.305mm. Finally it showed that average improvement in 25mm gradation with 1.5% lime was notes as 52.14%. Table 4.2 showed results of Hamburg Wheel Tracker test of 25mm gradation. The graphical illustrations of 25mm gradation test results are shown in figure 4.3.

Table 4.1 Rut Depth of 19mm Gradation

Rut Depth (mm)			
Sample	**Unmodified Mix**	**Modified Mix**	**Improvement (%)**
1	4.27	3.57	16.39
2	5.02	3.63	27.69
3	4.64	3.60	22.50

Table 4.2 Rut Depth of 25mm Gradation

Rut Depth (mm)			
Sample	**Unmodified Mix**	**Modified Mix**	**Improvement (%)**
1	3.64	1.87	48.63
2	2.97	1.29	55.65
3	3.30	1.58	52.19



4.2: 19mm Gradation @ 25^{o}C

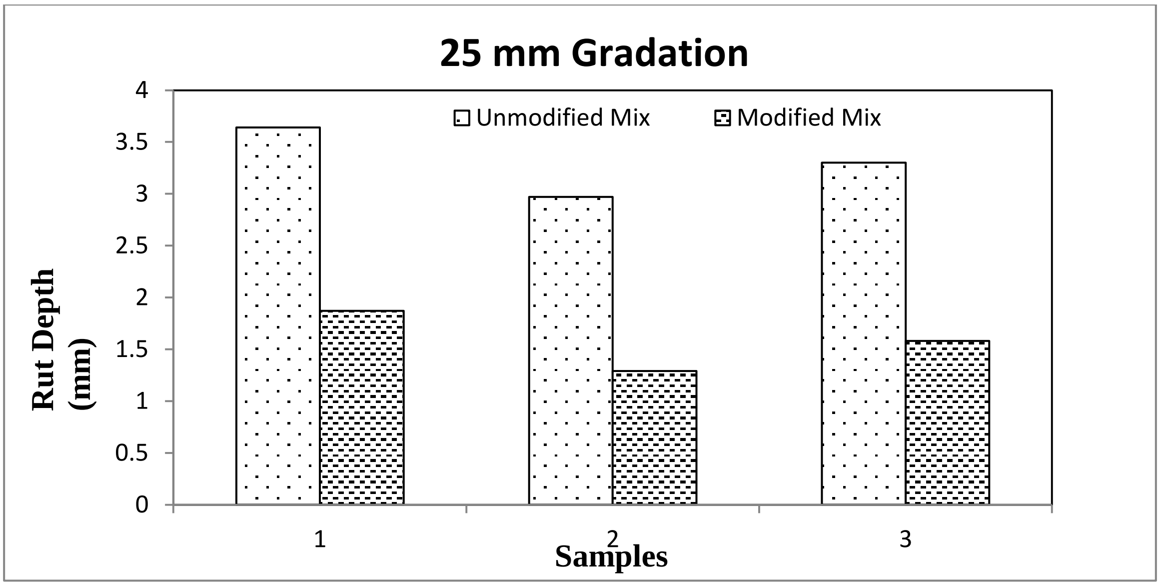


Figure 4.3: 25mm Gradation @ 25^{o}C

4.3 INDIRECT TENSILE FATIGUE TEST RESULTS

The research included the performance test of Indirect Tensile Fatigue that was performed on two gradations that were modified with lime. Testing were conducted on two different temperatures i-e 25 °C and 40 °C and the load applied on the samples were taken2500N. There were two replicate samples tested for each gradation both conventional and unconventional for both the temperatures.

4.3.1 Assessment of ITFT Results

It is cogent from the table 4.3 that for 19mm gradation, the number of cycles to failure of modified sample is 16839 for sample 1 and 15548 for sample 2. On taking average of both the values, the average value became 16193. On the other hand, the values of unmodified samples were 13169 and 14669 and their average became 13919. Conclusively, it showed that average improvement in 19mm gradation with 1.5% lime was notes as 15-18%. So it is proved that samples that are modified with lime showed better resistance to fatigue cracking than that of unmodified samples. The graphical illustrations of 19mm gradation test results are shown in figure 4.4.

Table 4.3 Cycles to Failure of 19 mm Gradation @ 25oC

Cycles to Failure			
Sample	**Unmodified Mix**	**Modified Mix**	**Improvement (%)**
1	13169	15548	18.07
2	14669	16839	14.79
3	13919	16193	16.34

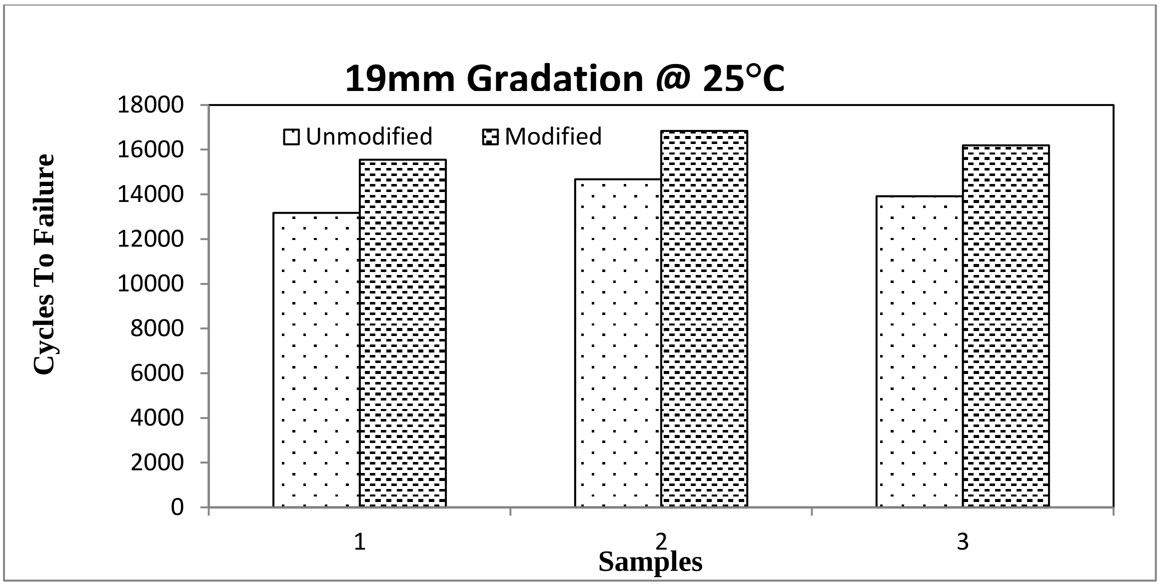


Figure 4.4: Cycle to failure of 19mm Gradation @ 25°C

Likewise, results of indirect tensile test of 25mm gradation also showed better results of samples that are modified with lime. For 25mm gradation, the number of cycle to failure value of modified sample is 23459 for sample 1 and 20945 for sample 2. The average value of modified samples was 22202. Furthermore, the values of unmodified samples were 19473 and 18979 and their average became 19226. Finally it showed that average improvement in 25mm gradation with 1.5% lime was notes as 10-20%. Table 4.4 shows the cycle to failure of 25mm gradation at 25°C. The graphical illustrations of 25mm gradation test results are shown in figure 4.5.

Table 4.4 Cycles to Failure of 25 mm Gradation @ 25oC

Cycles to Failure			
Sample	Unmodified Mix	Modified Mix	Improvement (%)
1	19473	23459	20.47
2	18979	22154	16.73
3	19226	22806	18.62

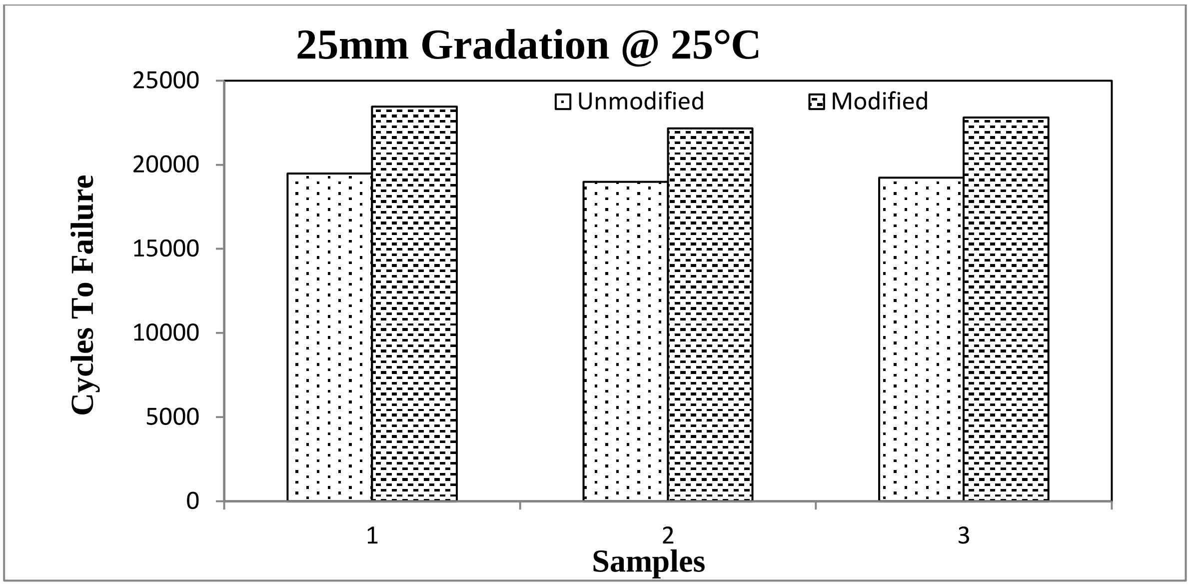


Figure 4.5: Cycle to failure of 25mm Gradation @ 25^{o}C

On the other hand, at 40^{o} C results of Indirect Tensile Test test of 19mm gradation also showed better results of samples that are modified with lime. For 19mm gradation, the number of cycle to failure value of modified sample is 2739 for sample 1 and 2549 for sample 2. The average value of modified samples was 2644. Furthermore, the values of unmodified samples were 2019 and 1979 and their average became 2044. Finally it showed that average improvement in 25mm gradation with 1.5% lime was notes as 29-30%. The graphical illustrations of 25mm gradation test results are shown in figure 4.6. Table 4.5 shows the cycle to failure of 19mm gradation at 40^{o}C

Table 4.5 Table 4.5 Cycles to Failure of 19 mm Gradation @ 40oC

Cycles to Failure			
Sample	**Unmodified Mix**	**Modified Mix**	**Improvement (%)**
1	2109	2321	10.05
2	1979	2298	16.12
3	1999	2309	12.99

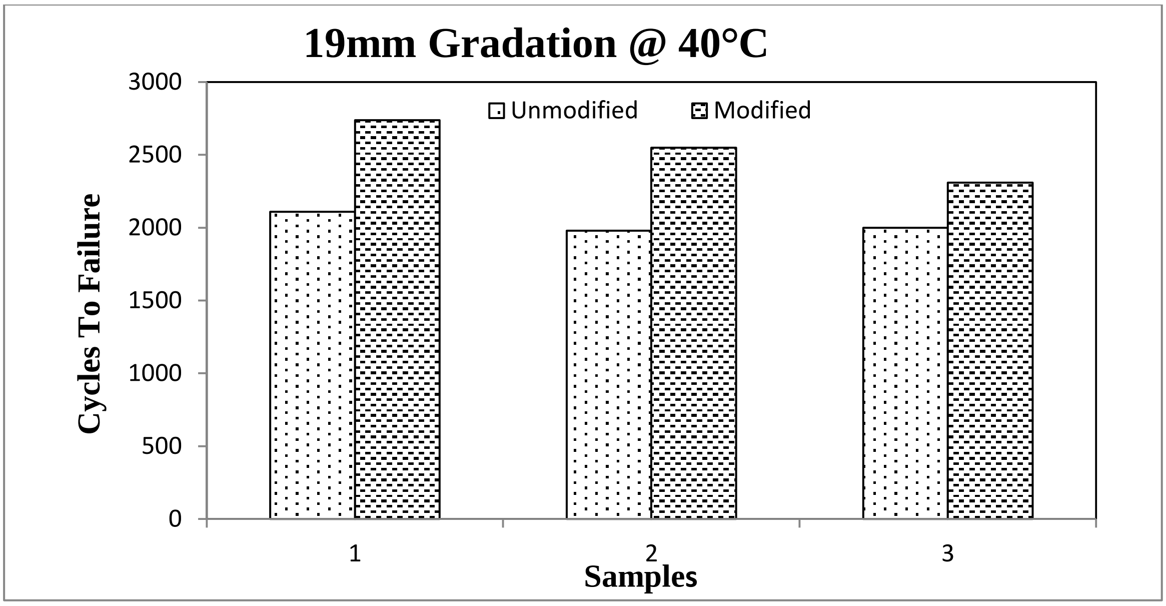


Figure 4.6: Cycle to Failure of 19mm Gradation @ 40°C

Similarly, at the same temperature results of Indirect Tensile Test test of 25mm gradation also showed better results of samples that are modified with lime. For 25mm gradation, the number of cycle to failure value of modified sample is 3879 for sample 1 and 3459 for sample 2. The average value of modified samples was 3669. Table 4.6 shows the cycle to failure of 25mm gradation at 40°C. the values of unmodified samples were 3059 and 3019 and their average became 3039. Finally it showed that average improvement in 25mm gradation with 1.5% lime was notes as 15-27%. The graphical illustrations of 25mm gradation test results are shown in figure 4.7.

Table 4.6: Cycles to Failure of 25 mm Gradation @ 40oC

Cycles to Failure			
Sample	**Unmodified Mix**	**Modified Mix**	**Improvement (%)**
1	3059	3547	15.95
2	3019	3459	19.41
3	3039	3576	17.67

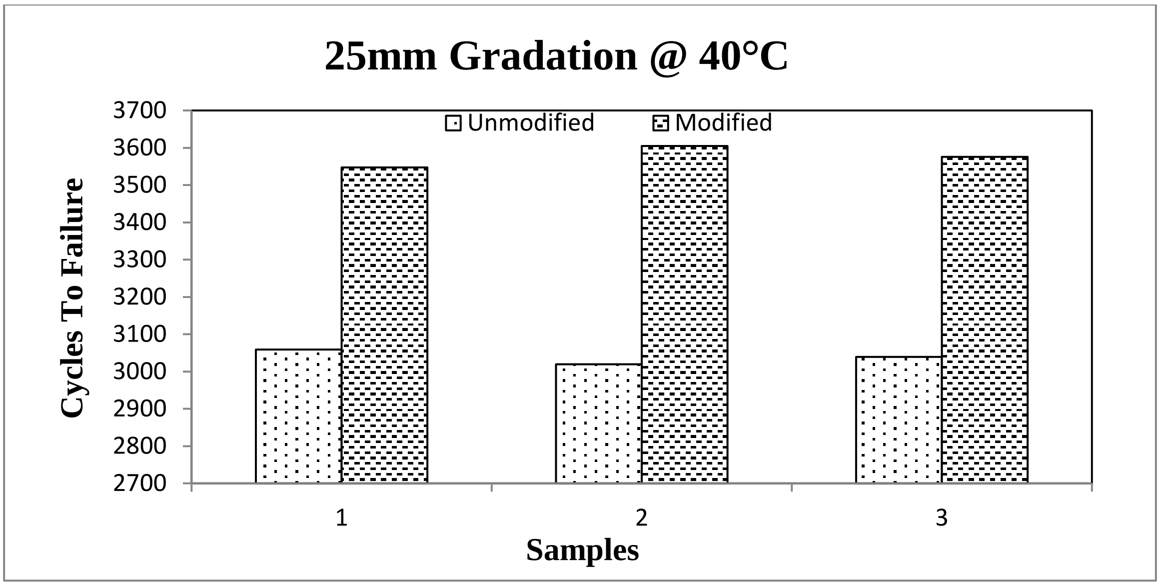


Figure 4.7: Cycle to Failure of 25mm Gradation @ 40^{o}C

4.4 Full Factorial Design of Indirect Tensile Fatigue Test

The statistical analysis of Indirect Tensile Fatigue Test data for both the gradations i-e 19mm and 25mm with two different temperatures and lime as modifier were carried out. Therefore, 2^3 full factorial design of experiment was performed using MINITAB-15 software. Table4.7 shows the factors that have been considered in the factorial design with their high and low levels and abbreviations for both stages.

Table 4.7 Factors and their Level for Factorial Design

Notations	Parameters	Low	High	Units
1	Gradation	19	25	Mm
2	Temperature	25	40	^{o}C
3	Lime	0	1.5	%

4.4.1 Significant Effects

In terms of Normal probability plot and Pareto plot generated using Minitab 15 software the factors and interaction of factors, which are most significant and affect fatigue cracking of asphalt mixtures, are also shown. Figure 4.8 shows the Pareto plot having a reference line with red color which shows that beyond this reference line a significant variable came up and have greater effect on the fatigue cracking. It is obvious that, temperature showed significant result and have greater influence on fatigue cracking of lab prepared mixtures at 5% significance level. The other plot is the normal probability plot which also shows the significant main effect as shown in figure 4.9 respectively. In the normal probability plot the factors or interactions away from the reference line are significant at 5% significance level and the factors which are near the reference line or on the reference line, are insignificant.

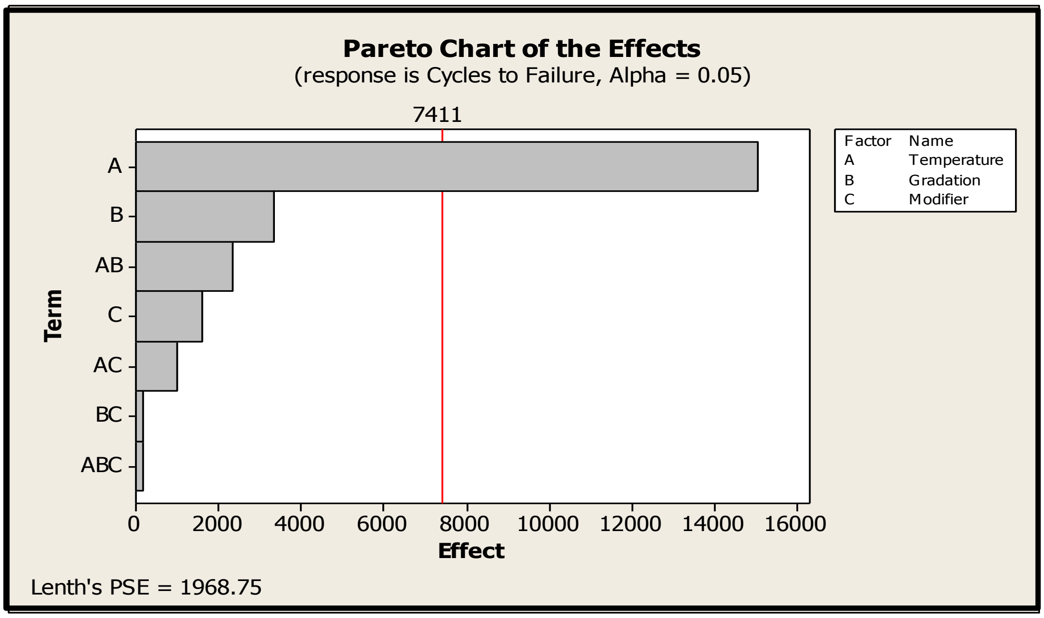


Figure 4.8: Pareto Chart of Samples

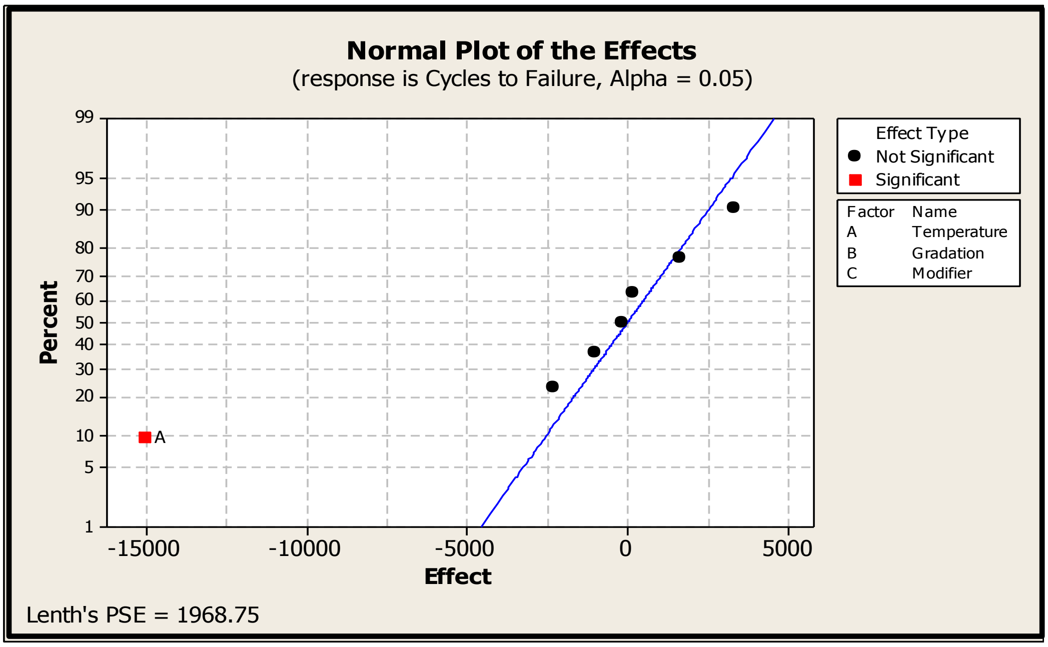


Figure 4.9: Normal Chart of Samples

4.4.2 Factorial Plots

The interaction and significant effects obtained from the Pareto chart and Normal Probability Chart can be described in detail by factorial plots. The effects of main factors are shown by main effects plot.

4.4.3 Main Effect Plots

The effects of gradation, temperature and lime %age of lab Prepared specimens are shown in figure 4.10 respectively. The graph between temperature and fatigue cracking reveals that with increase in temperature the number of cycle to failure decreases.

The graph between fatigue cracking and gradation indicates direct relationship i.e. the number to cycle failure increases if nominal maximum aggregate size increases.So from this analysis it is quite obvious that the temperature has greater effect on fatigue cracking as in the below figure, it is clear that the slope of temperature vs number of cycles is greater. Moreover, nominal maximum aggregate size has also greater impact on fatigue cracking as it also showed greater slope. At last, modifier also showed impact on fatigue cracking behavior as its slope in the figure is also liner and inclined that showing effects on fatigue cracking.

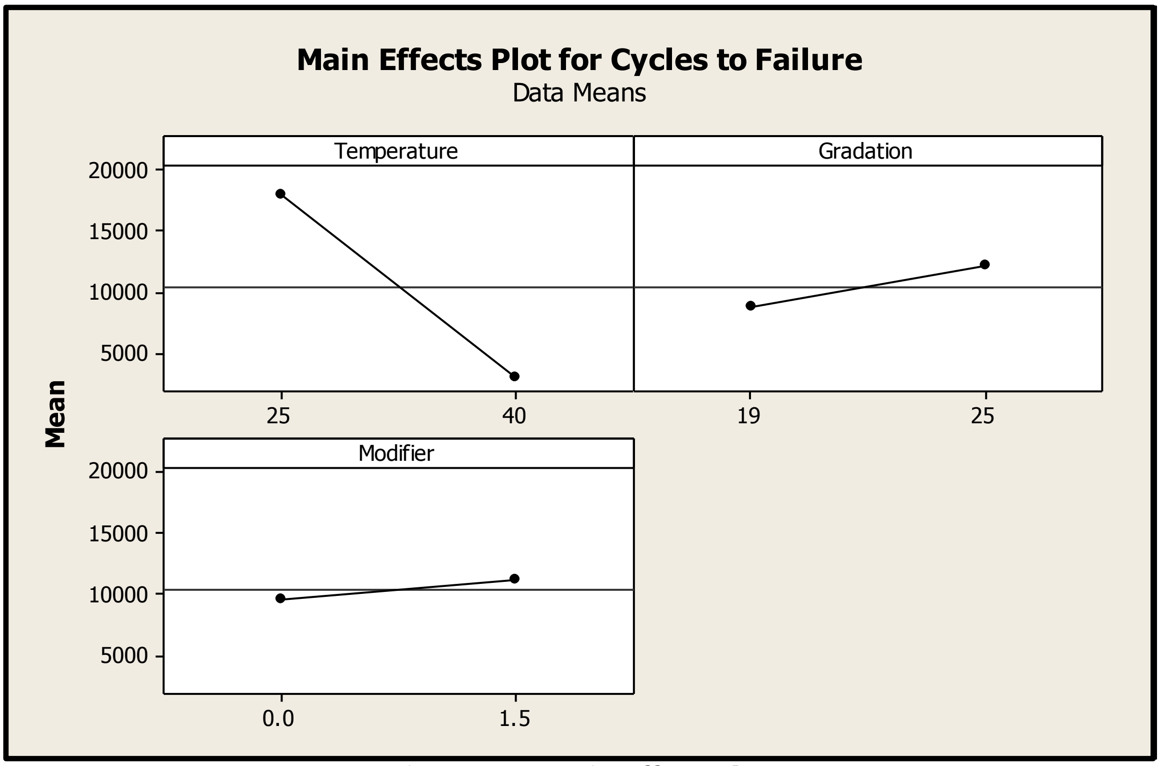


Figure 4.10: Main Effects Plot

4.5 SUMMARY

In this chapter the results of the performance tests conducted in a laboratory is explained. At first, the data analysis strategy was discussed and then results were shown in tables and graphs. The results of wheel tracker tests for lime modified and unmodified mixtures were presented in the form of bar charts which showed that lime modified mixtures have least rutting potential and fatigue cracking as compared to the unmodified mixtures. Finally, statistical analysis was done on indirect tensile fatigue test.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 BACKGROUND

This study was carried out to find the modification of lime modifier and to find out the improvement in the properties of asphalt mixture in terms of permanent deformation and fatigue cracking. Results of wheel tracker and indirect tensile fatigue test are used to evaluate the performance of asphalt mixtures in both unmodified and modified state. Lime was used as modifier to the asphalt mixtures to characterize the performance. The amount of lime used in modified mixture was 1.5%. The factors selected for indirect tensile fatigue tests were temperature, asphalt modifier and gradation d asphalt content while the factors selected for wheel tracker were temperature and asphalt modifier. The key findings of wheel tracker test and indirect tensile fatigue tests and analysis of results are concluded in this chapter.

5.2 CONCLUSIONS

The conclusions drawn from the analysis of tests as mentioned in chapter 4 are classified as follows:

- At 40° C, the use of 1.5% lime in asphalt mixtures increases resistance to rutting potential to approximately 22.50% as compared to unmodified asphalt mixtures for 19mm gradations. Likewise, for 25mm gradation, lime modified binder showed 52.19% better results than that of unmodified samples at 40° C because hydrated lime in asphalt mixtures can reduce pavement rut-depth due to its distinct stiffening effects and moisture-associated damage by improving the aggregate-asphalt bonding.

- With modification of lime the asphalt mixtures shows higher resistance to fatigue cracking as it is used as a mineral filler and an anti-stripping agent in HMA mixtures and has also been recognized to improve the properties and performance of asphalt mixtures at both 25^{o} C and 40^{o} C. At 25^{o}C, 16.34 % improvement in resistance to fatigue cracking is observed in 19mm gradation in lime modified mixtures whereas 18.62% improvement in resistance to fatigue cracking is also observed for 25mm gradation. Hydrated lime has been used

- Statistical analysis shows that temperature is the most significant factor which affects the indirect tensile fatigue test values followed by gradation and lime content.

5.3 RECOMMENDATIONS

The following recommendations must be made to completely characterize the asphalt mixtures using lime as modifier.

- The use of lime should be encouraged in our country as it reduces the rutting and fatigue cracking because with the rapid variation in temperature, pre mature failure of pavements occurred. In this regard, the use of modifiers would be encouraged in Pakistan to counter the adverse effects of temperature over the pavement life.

- Further evaluation of lime should be carried out by changing parameters such as test temperature in both Hamburg wheel tracker test and indirect tensile fatigue test because it should also be known that at temperature other than 25°C and 40°C, lime modified binder shows better resistance to fatigue and rutting or otherwise.

- Lime should be compared with other modifier in manufactured with NRL in terms of performance tests. NRL source of bitumen should also be used and to compare the overall results of both ARL and NRL binders that are modified with lime. In this way, one should know that with which source of bitumen, lime performed or showed better results.

- Further studies should be carried out to study the effect of modification on rheological properties of binder.

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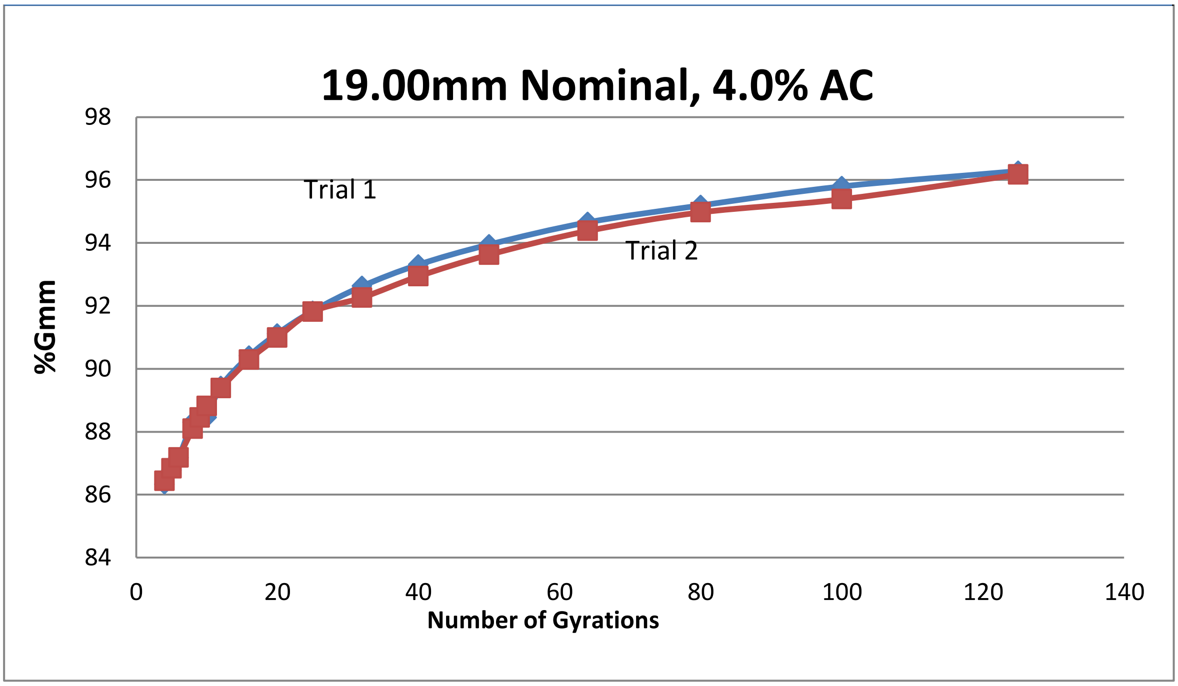
APPENDICES

Appendix A: Volumetric Properties of 19mm Gradation

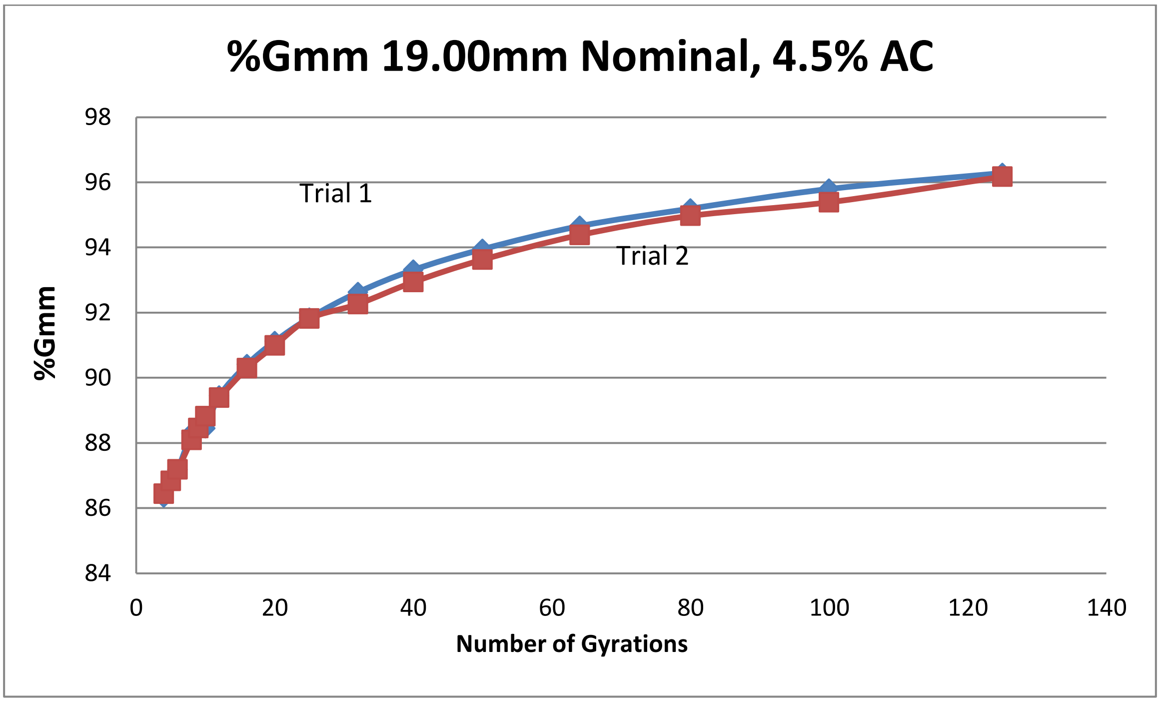
- **Data Copied : Excel Files**

Trial 1 4.0% AC			Trial 2 4.0% AC			AVG %Gmm
No of	Height,	% Gmm	No of	Height,	% Gmm	
4	175.1	85.23477119	4	175.4	86.43441685	82.45967649
5	173.9	85.82293522	5	174.3	86.97990084	83.2626241
6	172.8	86.36926178	6	173.2	87.5323136	83.9796308
8	171.8	86.87199322	8	171.6	88.34846571	84.94565345
9	170.65	87.45741831	9	171.2	88.55488736	85.52309662
10	169.5	88.05078723	10	170.8	88.76227586	86.10844483
12	168.5	88.57334383	12	169.1	89.6546228	86.83148229
16	166.7	89.52974466	16	167.4	90.56509388	88.08754618
20	165.4	90.23342464	20	166.3	91.16414141	89.01910286
25	164.1	90.94825372	25	165.1	91.82675176	89.94875919
32	162.2	92.0136155	32	163.8	92.55553551	91.09261368
40	161.6	92.35525022	40	162.6	93.23860219	91.81825904
50	160.5	92.98821455	50	161.6	93.81557374	92.65338477
64	159.3	93.68869074	64	160.2	94.63543518	93.53418927
80	158.3	94.28053338	80	159.5	95.05076311	94.29468616
100	157.4	94.81962157	100	158.7	95.52990999	94.98501704
125	155.9	96.013193351	125	158	95.99314377	95.00253864



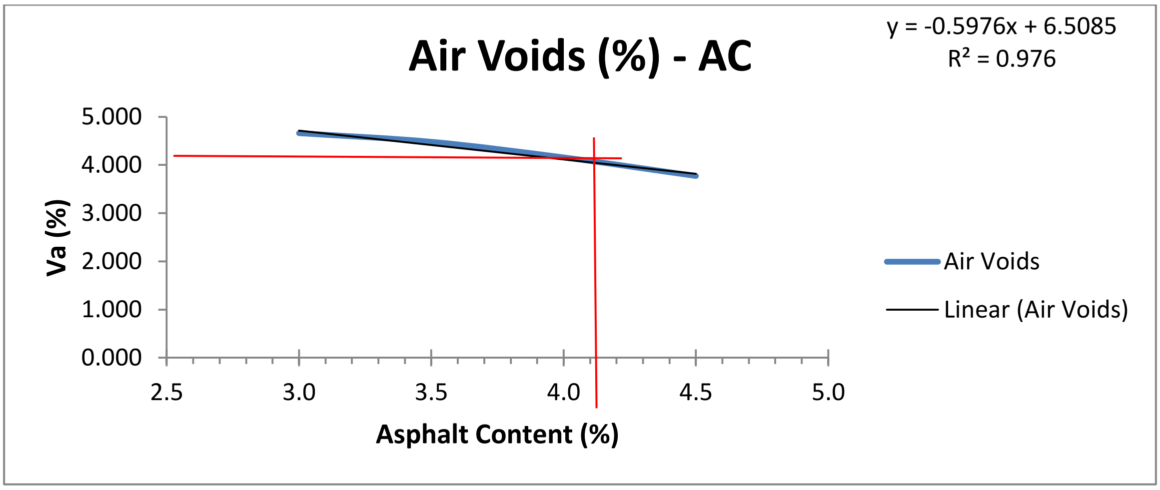
Graph between No of Gyrations and % Gmm @ 4% AC

Trial 1 4.5% AC				Trial 2 4.5% AC				AVG %Gmm
No of Gyrations	Height, mm	% Gmm		No of Gyrations	Height, mm	% Gmm		
4	175	86.325284		4	175.9	86.44015772		86.38272061
5	174.1	86.771537		5	175.1	86.83508705		86.80331209
6	173.3	87.172098		6	174.4	87.18362237		87.17786028
8	171.1	88.292955		8	172.6	88.09283744		88.19289626
9	170.95	88.370428		9	171.9	88.45156336		88.41099553
10	170.8	88.448036		10	171.2	88.81322279		88.63062959
12	168.9	89.443011		12	170.1	89.38755874		89.41528504
16	167.1	90.406491		16	168.4	90.28992721		90.34820901
20	165.8	91.115347		20	167.1	90.99236231		91.0538549
25	164.5	91.835408		25	165.6	91.81656849		91.82598824
32	163.1	92.623695		32	164.8	92.26227999		92.44298737
40	161.9	93.31022		40	163.6	92.93902043		93.1246202
50	160.8	93.948536		50	162.4	93.62576196		93.78714906
64	159.6	94.654916		64	161.1	94.38127711		94.51809662
80	158.7	95.191711		80	160.1	94.97079164		95.08125157
100	157.7	95.795337		100	159.4	95.38785284		95.59159482
125	156.9	96.183777		125	158.1	96.07219318		96.1279851

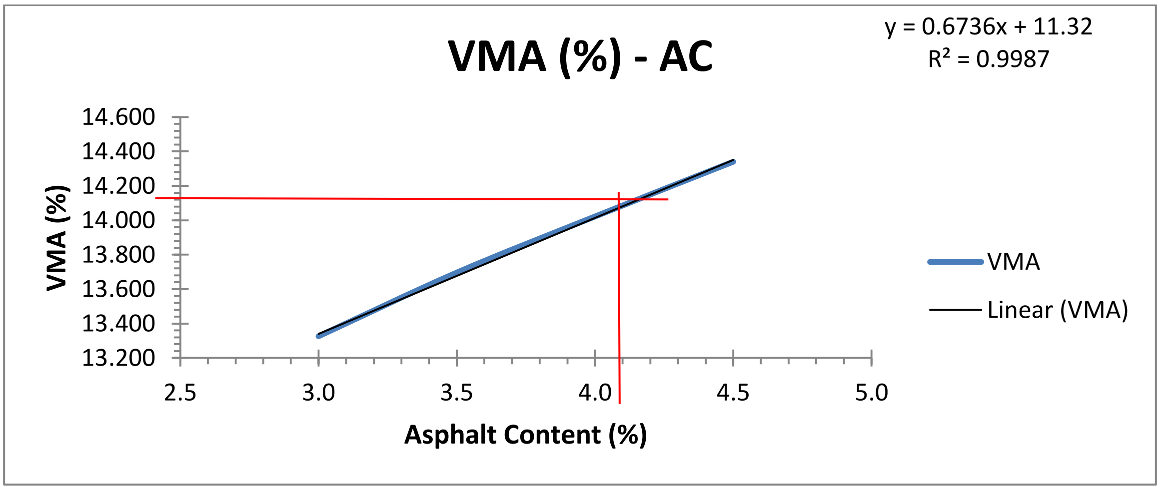


Graph between No of Gyrations and % Gmm @ 4.5% AC

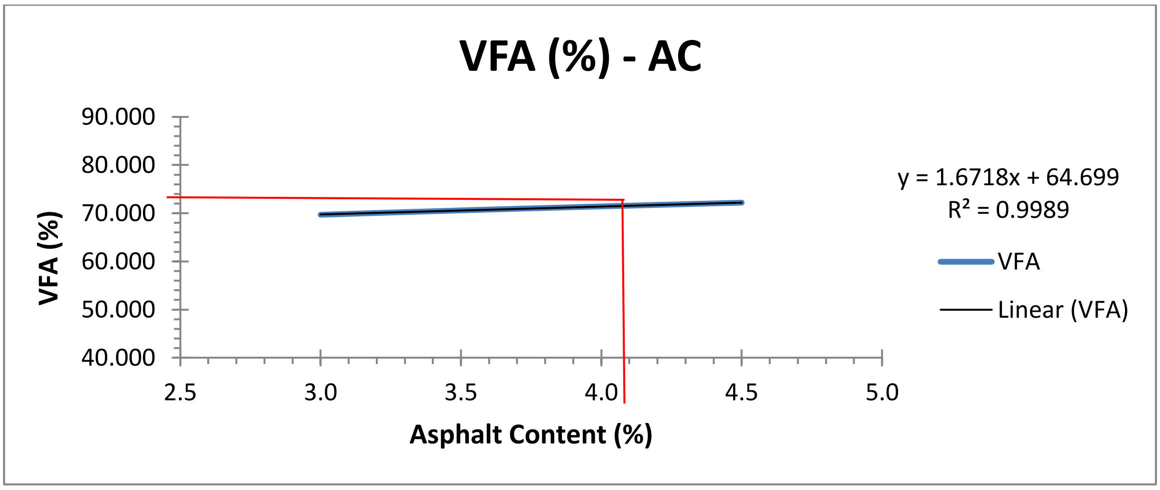
Appendix B: Graphs of 19mm Gradation @ 4.1% OBC



4% Air Voids (Va) @ 4.1% Asphalt Content (AC)



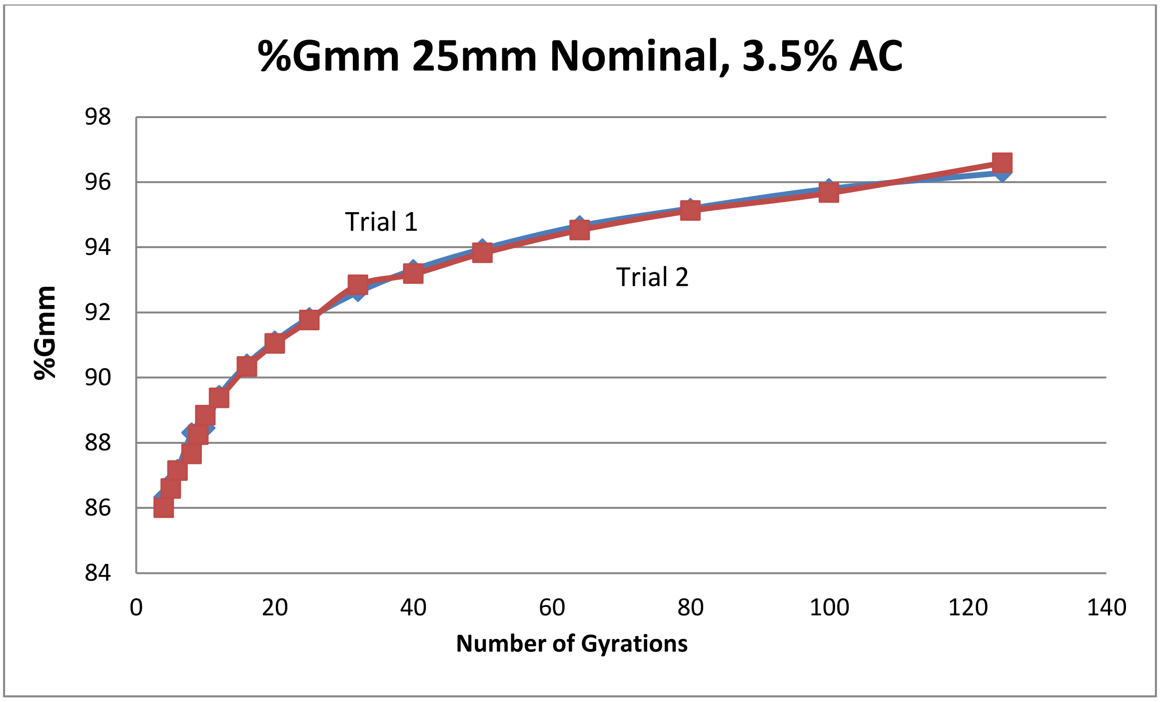
14.10 % VMA @ 4.1% Asphalt Content (AC)



72% VFA @ 4.1% Asphalt Content (AC)

Appendix C: Volumetric Properties of 25mm Gradation

Trial 1 3.5% AC				Trial 2 3.5% AC				AVG %Gmm
No of Gyrations	Height, mm	% Gmm		No of Gyrations	Height, mm	% Gmm		
4	175.9	86.41140817		4	176.9	86.3761631		86.39378564
5	175.1	86.80620615		5	174.2	86.7708001		86.78850311
6	174.4	87.15462556		6	173.4	87.1190774		87.13685146
8	172.6	88.06353822		8	172.5	88.0276193		88.04557876
9	171.9	88.42214483		9	171.7	88.3860796		88.40411224
10	171.2	88.78368398		10	170.9	88.7474713		88.76557765
12	170.1	89.35782891		12	169.1	89.3213821		89.33960549
16	168.4	90.25989725		16	168.5	90.2230825		90.24148987
20	167.1	90.96209873		20	165.1	90.9249976		90.94354814
25	165.6	91.78603078		25	163.6	91.7485935		91.76731216
32	164.8	92.23159404		32	164.8	92.1939751		92.21278455
40	163.6	92.9081094		40	163.1	92.8702145		92.88916194
50	162.4	93.59462252		50	162.4	93.5564476		93.57553506
64	161.1	94.34988639		64	161.9	94.3114034		94.3306449
80	160.1	94.93920485		80	159.9	94.9004815		94.91984319
100	159.4	95.35612733		100	159.7	95.3172339		95.33668064
125	158.4	95.99812309		125	158.9	96.0189842		96.00855362

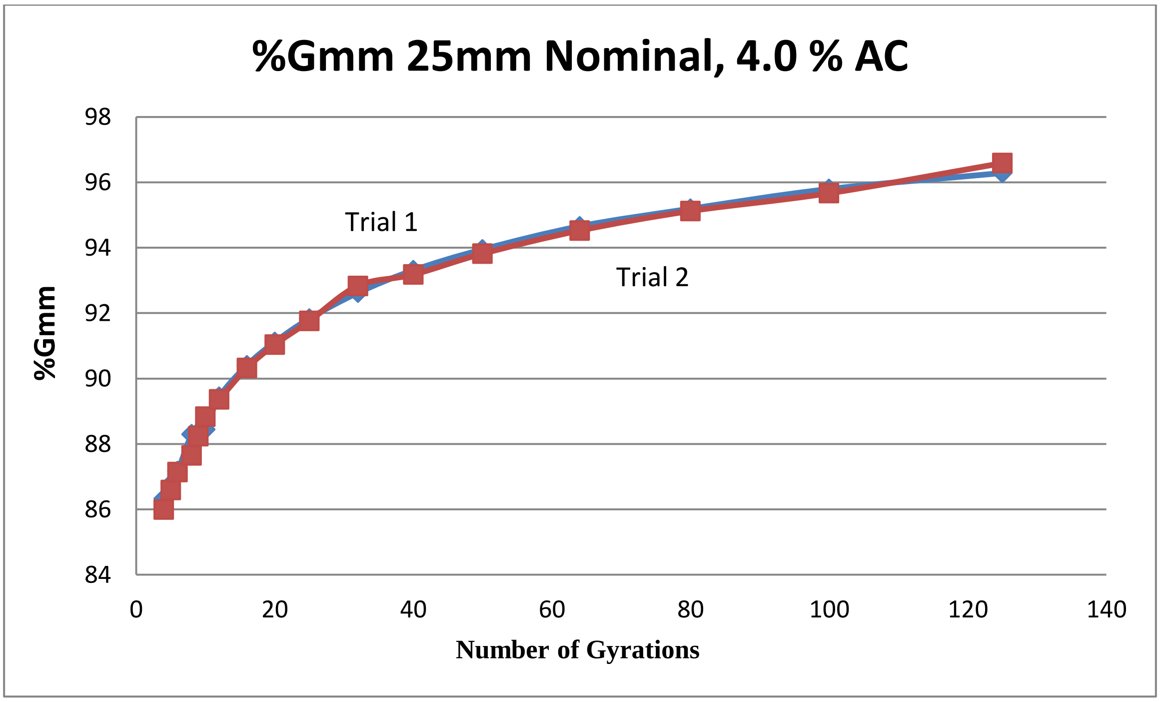


Graph between No of Gyrations and % Gmm @ 3.5% AC

Trial 1 4.0% AC		
No of Gyrations	**Height, mm**	**% Gmm**
4	178.2	86.53587714
5	176.9	87.17181066
6	175.9	87.66738662
8	174.2	88.52292369
9	173.6	88.82887849
10	173	89.13695553
12	171.9	89.70734908
16	170.3	90.55016621
20	169	91.24670595
25	167.8	91.89924497
32	166.5	92.61677661
40	165.3	93.28913071
50	164.2	93.91408835
64	163	94.60548041
80	162	95.18946485
100	161	95.78070377
125	160.2	96.2590094

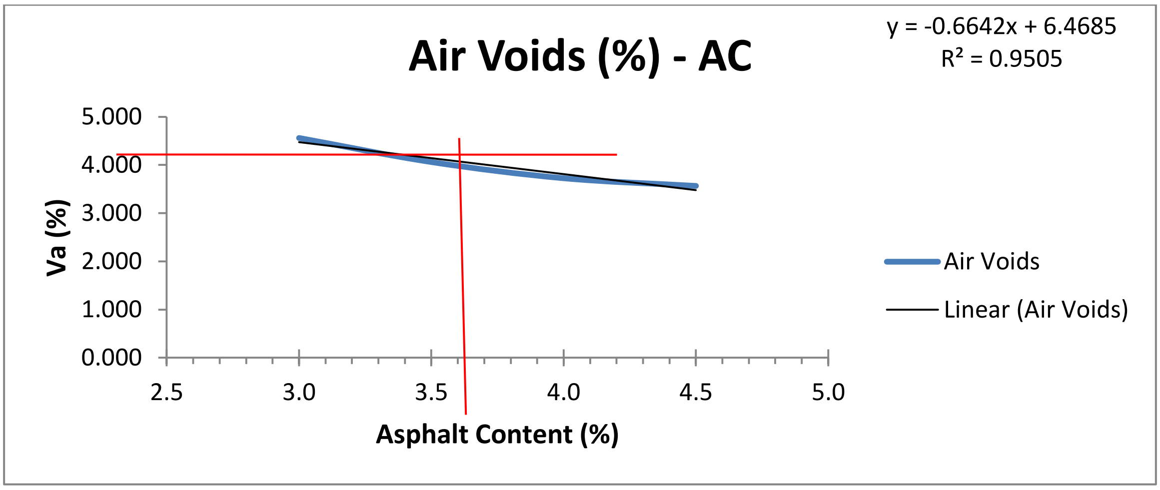
Trial 2 4.0% AC		
No of Gyrations	**Height, mm**	**% Gmm**
4	174.2	86.83910025
5	173.1	87.3909374
6	172.1	87.89872901
8	170.4	88.77565295
9	169.9	89.0369115
10	169.4	89.2997123
12	168.1	89.99031091
16	166.2	91.01908101
20	165.4	91.4593184
25	164.7	91.84803439
32	162.9	92.86292979
40	161.8	93.49425997
50	160.7	94.13423313
64	159.6	94.78302797
80	158.1	95.68229768
100	157.8	95.86420319
125	157.1	96.29135114

AVG %Gmm
86.68748869
87.28137403
87.78305782
88.64928832
88.932895
89.21833391
89.84882999
90.78462361
91.35301218
91.87363968
92.7398532
93.39169534
94.02416074
94.69425419
95.43588127
95.82245348
96.27518027

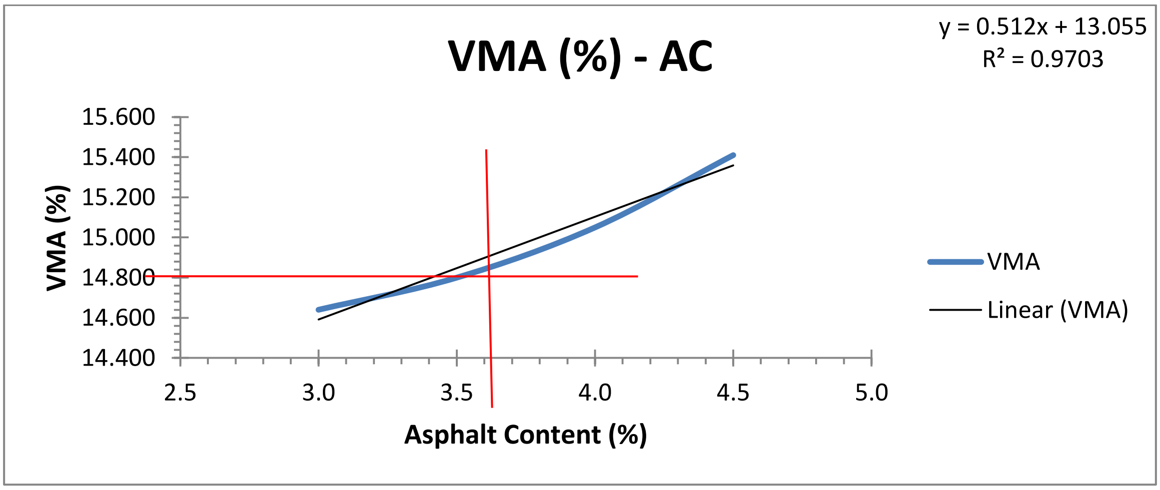


Graph between No of Gyrations and % Gmm @ 4.0% AC

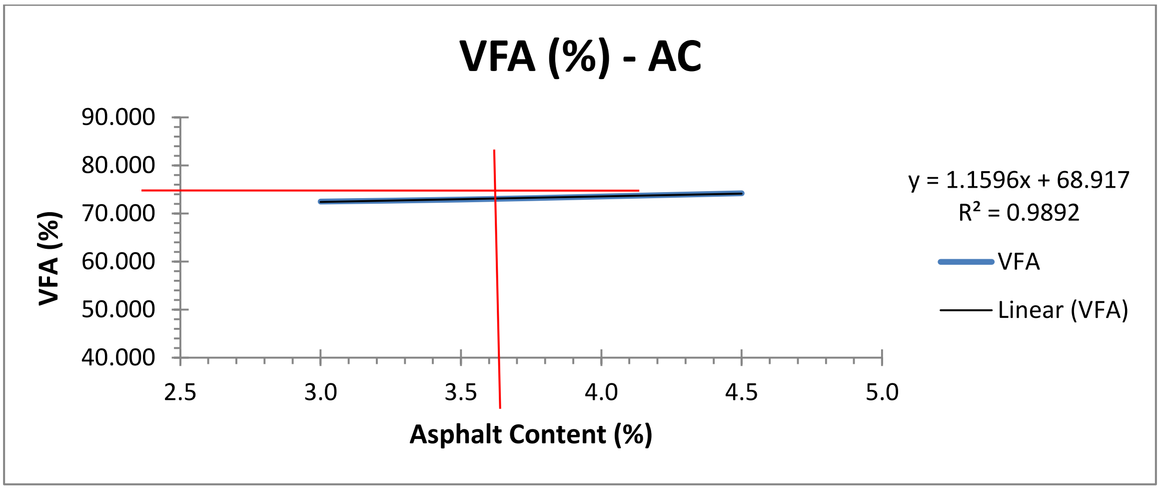
Appendix D: Graphs of 25mm Gradation @3.6% OBC



4% Va @ 3.6% Asphalt Content (AC)



14.810% VMA @ 3.6% Asphalt Content (AC)



74% VFA @ 3.6% Asphalt Content (AC)

Appendix E: 19mm Gradation @1.5% Lime

Mixture specification						Identification	1.5% 19mm.
Type	Margalla Wearing		Weight%	Specific Weight		Date	20-04-15
Aggregate	Limestone		95.9	2638.01	Gsb	Time	14:10
				2643.59225	Gse	Test No	
Filler			---			Mixture	HMA
Bitumen	ARL 60/70			1017.86			
TMD Gmm, (kg/m^3)				2496.12		Weight	7500
Asphalt content, % of total mix vol			4.1			Height	177.8
Gmb (measured), (kg/m^3)				2396.00		Test length	125
						Gyratory angle	22 mrad
						Pressure	600 kPa
						temperature	135 ºC
						Gyratory speed	36.7 rpm
	No of Gyrations	Height, mm	Gmb (Estimated),kg/m^3	Gmb (Corrected)	% Gmm		
	4	214.1	1982	1989.76553	79.71433		
	5	211.4	2008	2015.17880	80.73244		
	6	209.1	2030	2037.34481	81.62046		
	8	205.5	2065	2073.03552	83.05031		
Nini = 9	9	204.1	2079	2087.25526	83.61998		
averaged	10	202.7	2094	2101.67143	84.19753		
	12	200.5	2117	2124.73217	85.12139		
	16	196.9	2155	2163.57948	86.67770		
	20	194.3	2184	2192.53113	87.83756		
	25	191.8	2213	2221.10948	88.98248		
	32	189.2	2243	2251.63213	90.20528		
	40	186.9	2271	2279.34082	91.31535		
	50	184.8	2297	2305.24242	92.35302		
	64	182.7	2323	2331.73946	93.41455		
	80	180.9	2346	2354.94085	94.34405		
	100	179.3	2367	2375.95538	95.18594		
Ndes	125	177.8	2387	2396	95.98897		
	Correction factor, C =		1.003759587				

Mixture specification						Identification	1.5% 19mm(1)		
Type	Margalla Wearing		Weight%	Specific Weight		Date	20-04-15		
Aggregate	Limestone		95.9	2638.01	Gsb	Time	14:10		
				2643.5922	Gse	Test No			
Filler			---			Mixture	HMA		
Bitumen	ARL 60/70			1017.86		Test parameters			
TMD Gmm, (kg/m^{3})				2496.12		Weight	7500	gm	
Asphalt content, % of total mix vol			4.1			Height	177.8		
Gmb (measured), (kg/m^{3})				2396.00		Test length	125		
						Gyratory angle	22 mrad		
						Presure	600 kPa		
						Temperature	135 °C		
						speed	35.4 rpm		
	% Gmm	Va %	VMA %	Pb, estimated	VMA, estimated	VFA %	% Gmm EST @Nini	Pbe	Dust Prop
	79.71433	20.286							
	80.73244	19.268							
	81.62046	18.380							
	83.05031	16.950							
Nini = 9	83.61998	16.380					83.631	4.0	0.981
averaged	84.19759	15.802							
	85.12139	14.879							
	86.67777	13.322							
	87.83754	12.162							
	88.98247	11.018							
	90.20521	9.795							
	91.31539	8.685							
	92.35307	7.647							
	93.41454	6.585							
	94.34403	5.656							
	95.18597	4.814							
Ndes	95.98899	4.011	13.042	4.104	13.040	69.325			

Mixture specification						Identification	0% 19. (
Type	Margalla Wearing		Weight%	Specific Weight		Date	20-04-15
Aggregate	Limestone		95.9	2638.01	Gsb	Time	13:01
				2642.048456	Gse	Test No	1
Filler			---			Mixture	HMA
Bitumen	ARL 60/70			1017.86		Test parameters	
TMD Gmm, (kg/m$^{3)}$				2494.80		Specimen weight	7500
Asphalt content, % of total mix vol			4.1			Final specimen height	174.4
Gmb (measured), (kg/m^{3})				2389.14		Test length	125
						Gyratory angle	22 mrad
						Pressure in specimen	600 kPa
						Compaction temperature	135 °C
						Gyratory speed	36.7 rpm
	No of Gyrations	Height, mm	Gmb (Estimated),kg/m3	Gmb(Corrected)	% Gmm		
	4	207	2050	2012.879304	80.6829928		
	5	204.7	2073	2035.495926	81.58954228		
	6	202.9	2092	2053.553553	82.31335202		
	8	199.9	2123	2084.372266	83.54867198		
Nini = 9	9	198.75	2135	2096.432785	84.03209816		
averaged	10	197.6	2148	2108.633684	84.52115126		
	12	195.7	2169	2129.105856	85.34174507		
	16	192.7	2202	2162.252289	86.6703659		
	20	190.4	2229	2188.371933	87.71732926		
	25	188.2	2255	2213.953326	88.7427179		
	32	185.8	2284	2242.551216	89.88901781		
	40	183.6	2312	2269.422745	90.96611923		
	50	181.6	2337	2294.416388	91.96794884		
	64	179.4	2366	2322.553043	93.09576002		
	80	177.6	2390	2346.092433	94.03929904		
	100	175.9	2413	2368.766435	94.94814957		
Ndes	125	174.4	2434	2389.14	95.76479076		
	Correction factor, C = Gmb(measured)/Gmb(estimated)		0.981746171				

Mixture specification						Identification	0% 19mm(2)		
Type	Margalla Wearing		Weight	Specific Weight		Date	20-04-15		
Aggregate	Limestone		95.9	2638.01	Gsb	Time	13:01		
				2642.048456	Gse	Test No			
Filler			---			Mixture	HMA		
Bitumen	ARL 60/70			1017.86		Test parameters			
TMD Gmm, (kg/m$^{3)}$				2494.80		Specimen weight	7500	gm	
Asphalt content, % of total mix vol			4.1			Final specimen height	173.7		
Gmb (measured), (kg/m^3)				2389.14		Test length	125		
						Gyratory angle	22 mrad		
						Presure in specimen	600 kPa		
						Compaction temperature	135 °C		
						Compaction speed	35.4 rpm		
	% Gmm	Va %	VM	Pb, estimated	VMA, estimated	VFA %	% Gmm EST @Nini	Pbe	Dust Prop
	80.682992	19.317							
	81.589543	18.410							
	82.313353	17.687							
	83.548671	16.451							
Nini = 9	84.032098	15.968					84.267	4.166	0.960
averaged	84.521151	15.479							
	85.341745	14.658							
	86.670365	13.330							
	87.717329	12.283							
	88.742717	11.257							
	89.889017	10.111							
	90.966119	9.034							
	91.967948	8.032							
	93.095760	6.904							
	94.039299	5.961							
	94.948149	5.052							
Ndes	95.76479	4.235	13	4.194	13.100	69.466			

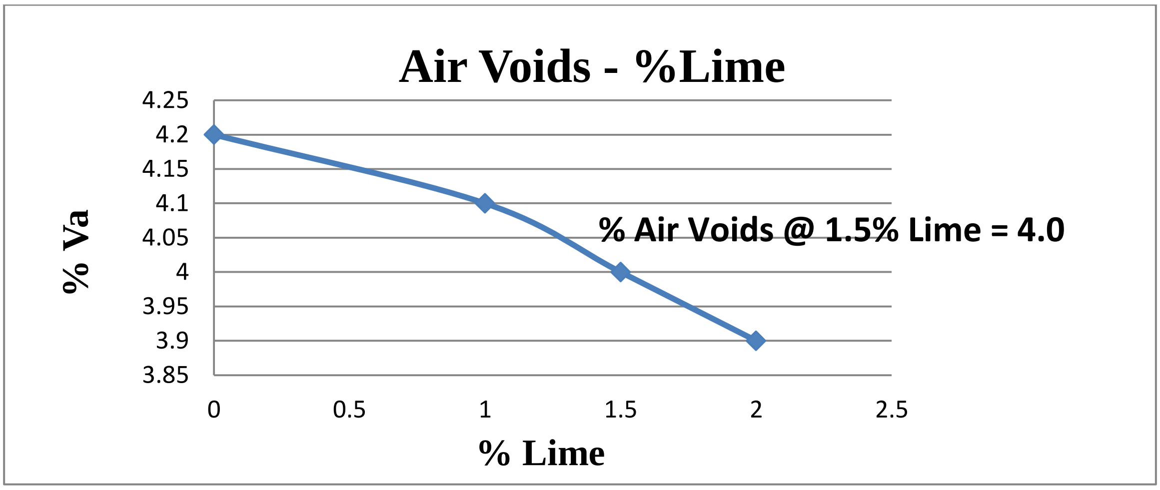
Mixture specification						Identification	1% 10mm
Type	Margalla Wearing		Weight%	Specific Weight		Date	20-04-15
Aggregate	Limestone		95.9	2638.01	Gsb	Time	13:30
				2642.153709	Gse	Test No	1
Filler			---			Mixture	HMA
Bitumen	ARL 60/70			1017.86		Test parameters	
TMD Gmm, (kg/m^{3})				2494.89		Specimen weight	7500
Asphalt content, % of total mix vol			4.1			Final specimen height	175.4
Gmb (measured), (kg/m^{3})				2392.10		Test length	125
						Gyratory angle	22 mrad
						Presure in specimen	600 kPa
						Compaction temperature	135 °C
						Gyratory speed	36.7 rpm
	No of Gyrations	Height, mm	Gmb(Estimated),kg/m^3	Gmb(Corrected)	% Gmm		
	4	209.8	2023	1999.8776	80.1589		
	5	207.3	2047	2023.9958	81.1256		
	6	205.2	2068	2044.7092	81.9558		
	8	201.9	2102	2078.1294	83.2954		
Nini = 9	9	200.6	2116	2091.5969	83.8352		
averaged	10	199.3	2130	2105.2400	84.3820		
	12	197.2	2152	2127.6589	85.2806		
	16	193.9	2189	2163.8697	86.7320		
	20	191.5	2216	2190.9887	87.8190		
	25	189.1	2244	2218.7960	88.9336		
	32	186.5	2276	2249.7283	90.1734		
	40	184.3	2303	2276.5835	91.2498		
	50	182.2	2329	2302.8229	92.3015		
	64	180.1	2357	2329.6742	93.377		
	80	178.4	2379	2351.8741	94.26764		
	100	176.8	2401	2373.1580	95.1207		
Ndes	125	175.4	2420	2392.1	95.8799		
	Correction factor, C = Gmb(measured)/Gmb(estimated)		0.988598748				

Mixture specification						Identification	1% 10mm(1)		
Type	Margalla Wearing		Weight%	Specific Weight		Date	20-04-15		
Aggregate	Limestone		95.9	2638.01	Gsb	Time	13:30		
				2642.15 2700	Gse	Test No			
Filler			---			Mixture	HMA		
Bitumen	ARL 60/70			1017.86		Test parameters			
TMD Gmm, (kg/m^{3})				2494.89		Specimen weight	7500	gm	
Asphalt content, % of total mix vol			4.1			Final specimen height	176.3		
Gmb (measured), (kg/m^{3})				2391.01		Test length	125		
						Gyratory angle	22 mrad		
						Presure in specimen	600 kPa		
						Compaction temperature	135 °C		
						Compaction speed	35.4 rpm		
	% Gmm	Va %	VMA %	Pb, estimated	VMA, estimated	VFA %	% Gmm EST @Nini	Pbe	Dust Prop
	80.4916289	19.508							
	81.46187515	18.538							
	82.25507744	17.745							
	83.5568393	16.443							
Nini = 9	84.07660068	15.923					84.245	4.139	0.966
averaged	84.60286883	15.397							
	85.45874004	14.541							
	86.86474502	13.135							
	87.9499891	12.050							
	89.06269323	10.937							
	90.25209886	9.748							
	91.32536706	8.675							
	92.37393606	7.626							
	93.44686342	6.553							
	94.28121041	5.719							
	95.13059069	4.869							
Ndes	95.83206413	4.168	13.083	4.167	13.049	69.347			

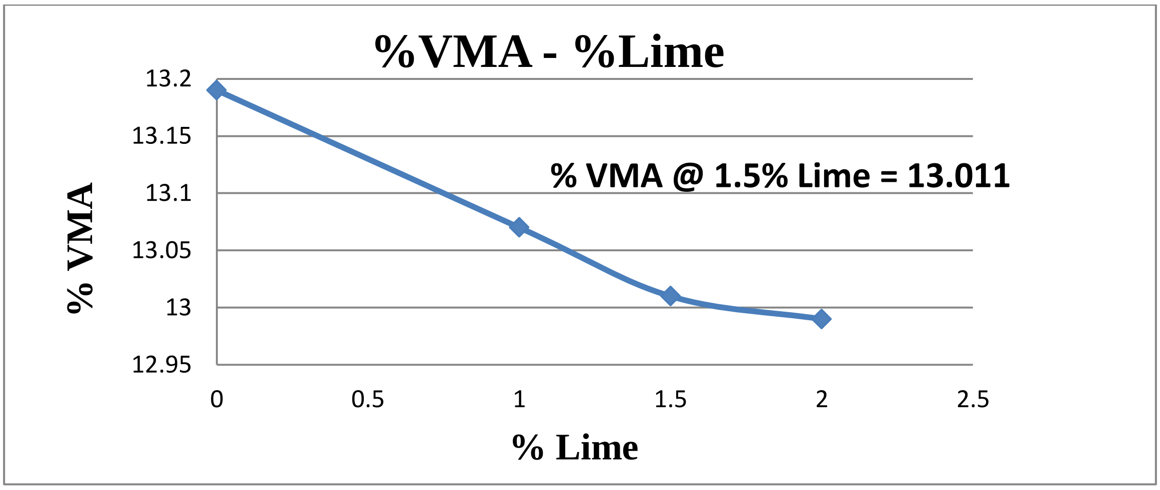
Mixture specification						Identification	2% 10mm
Type	Margalla Wearing		Weight %	Specific Weight		Date	21-04-15
Aggregate	Limestone		95.9	2638.01	Gsb	Time	9:15
				2642.29404	Gse	Test No	1
Filler			---			Mixture	HMA
Bitumen	ARL 60/70			1017.86		Test parameters	
TMD Gmm, (kg/m^3)				2495.01		Specimen weight	7500
Asphalt content, % of total mix vol			4.1			Final specimen height	177.5
Gmb (measured), (kg/m^3)				2393.87		Test length	125
						Gyratory angle	22 mrad
						Presure in specimen	600 kPa
						Compaction temperature	135 ^{o}C
						Gyratory speed	36.7 rpm
	No of Gyrations	Height, mm	Gmb Estimate	Gmb Corrected	% Gmm		
	4	215.3	1971	1973.580701	79.10111388		
	5	212.3	1999	2001.469265	80.21888751		
	6	209.8	2023	2025.318994	81.17478464		
	8	206	2060	2062.679248	82.67218358		
Nini = 9	9	204.5	2075	2077.808924	83.27858102		
averaged	10	203	2091	2093.162192	83.89393999		
	12	200.7	2115	2117.149601	84.85535535		
	16	197	2154	2156.913325	86.44908537		
	20	194.3	2184	2186.885872	87.65038506		
	25	191.8	2213	2215.390641	88.79285619		
	32	189	2246	2248.211243	90.10830591		
	40	186.7	2273	2275.907472	91.21837074		
	50	184.5	2300	2303.045664	92.30606947		
	64	182.3	2328	2330.838865	93.42002094		
	80	180.6	2350	2352.779208	94.29938991		
	100	179	2371	2373.809637	95.14228948		
Ndes	125	177.5	2391	2393.87	95.94630883		
	Correction factor, C = Gmb(measured)/Gmb(estimated)		1.001175137				

Mixture specification						Identification	2% 10mm(1)		
Type	Margalla Wearing		Weight %	Specific Weight		Date	21-04-15		
Aggregate	Limestone		95.9	2638.01	Gsb	Time	9:54		
				2640.060487	Gse	Test No			
Filler			---			Mixture	HMA		
Bitumen	ARL 60/70			1017.86		Test parameters			
TMD Gmm, (kg/m^3)				2493.1		Specimen weight	7500	gm	
Asphalt content, % of total mix vol			4.1			Final specimen height	173.7		
Gmb (measured), (kg/m^3)				2393.87		Test length	125		
						Gyratory angle	22 mrad		
						Presure in specimen	600 kPa		
						Compaction temperature	135 ^{o}C		
						Compaction speed	35.4 rpm		
	% Gmm	Va %	VMA %	Pb, estimate	VMA, estimated	VFA %	% Gmm EST @Nini	Pb e	Dust Prop
	79.16171439	20.838							
	80.28034436	19.720							
	81.23697382	18.763							
	82.73551994	17.264							
Nini = 9	83.34238194	16.658					83.323	4.064	0.984
averaged	83.95821235	16.042							
	84.92036426	15.080							
	86.51531527	13.485							
	87.71753529	12.282							
	88.86088169	11.139							
	90.17733919	9.823							
	91.28825446	8.712							
	92.37678649	7.623							
	93.49159137	6.508							
	94.37163404	5.628							
	95.21517937	4.785							
Ndes	96.01981469	3.980	12.97	4.092	12.979	69.182			

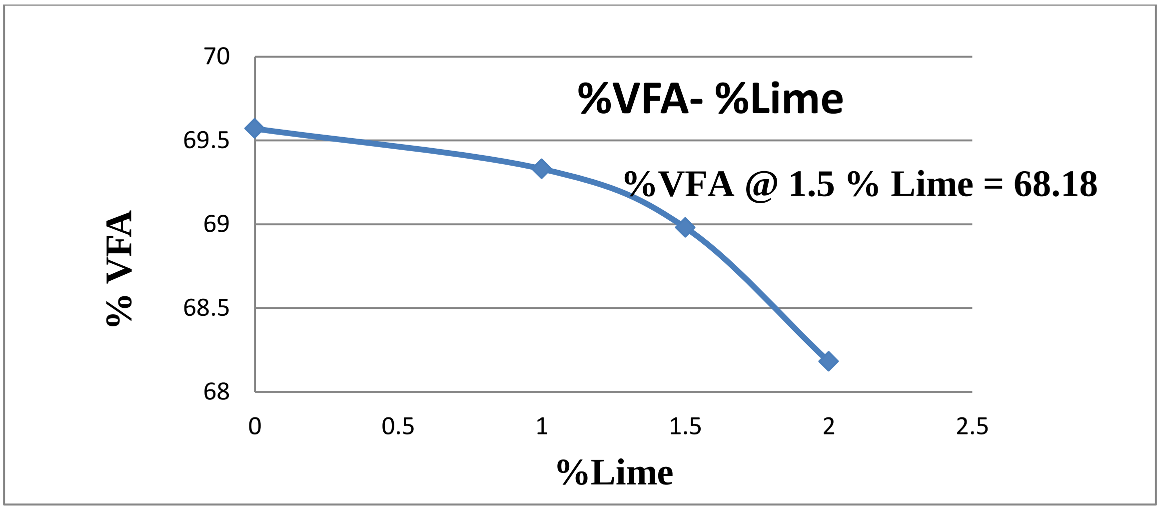
Appendix F: Graphs of 19mm Gradation @1.5% Lime



4% Va @ 1.5% Lime



13.2% VMA @ 1.5% Lime



69.6% VFA @ 1.5% Lime

Appendix G: Graphs of 25mm Gradation @1.5% Lime

Mixture specification						Identification	1.5% 25mm.
Type	Margalla Wearing		Weight%	Specific Weight		Date	23-04-15
Aggregate	Limestone		96.5	2719.02	Gsb	Time	10:15
				2661.403065	Gse	Test No	1
Filler			---			Mixture	HMA
Bitumen	ARL 60/70			1017.86		Test parameters	
TMD Gmm, (kg/m^3)				2497.20		Specimen weight	7200
Asphalt content, % of total mix vol			3.5			Height	176.8
Gmb (measured), (kg/m^3)				2396.90		Test length	125
						Gyratory angle	22 mrad
						Pressure	600 kPa
						Compaction temperature	135 °C
						Gyratory speed	36.7 rpm
	No of Gyrations	Height, mm	Gmb (Estimate	Gmb(Corrected)	% Gmm		
	4	208.5	1954	2032.479233	81.39032647		
	5	206.4	1974	2053.158527	82.21842572		
	6	204.5	1992	2072.234328	82.9823133		
	8	201.5	2022	2103.086452	84.21778198		
Nini = 9	9	200.3	2034	2115.686071	84.72233185		
averaged	10	199.1	2046	2128.437569	85.23296368		
	12	197.2	2066	2148.944828	86.05417378		
	16	194.2	2098	2182.14171	87.38353795		
	20	192	2122	2207.145417	88.38480765		
	25	189.8	2147	2232.728767	89.40928909		
	32	187.4	2174	2261.322946	90.55433868		
	40	185.4	2198	2285.716936	91.53119239		
	50	183.5	2220	2309.38376	92.47892681		
	64	181.5	2245	2334.831515	93.49797834		
	80	179.8	2266	2356.90723	94.38199705		
	100	178.2	2286	2378.069136	95.22942239		
Ndes	125	176.8	2305	2396.9	95.98350152		
	Correction factor, C = Gmb(measured)/Gm		1.040092774				

Mixture specification									
Type	Margalla Wearing		Weight	Specific Weight		Date	23-04-15		
Aggregate	Limestone		96.5	2719.02	Gsb	Time	10:15		
				2661.40 3065	Gse	Test No			
Filler			---			Mixture	HMA		
Bitumen	ARL 60/70			1017.86		Test parameters			
TMD Gmm, (kg/m^3)				2497.2		Weight	7200	gm	
Asphalt content, % of total mix vol			3.5			Height	176.8		
Gmb (measured), (kg/m^3)				2396.90		Test length	125		
						Gyratory angle	22 mrad		
						Presure	600 kPa		
						Compaction temperature	135 ^{o}C		
						Compaction speed	35.4 rpm		
	% Gmm	Va %	VMA %	Pb, estimate	VMA, estimated	VFA %	% Gmm EST @Nini	Pbe	Dust Prop
	81.39032647	18.610							
	82.21842572	17.782							
	82.9823133	17.018							
	84.21778198	15.782							
Nini = 9	84.72233185	15.278					84.739	3.479	1.150
averaged	85.23296368	14.767							
	86.05417378	13.946							
	87.38353795	12.616							
	88.38480765	11.615							
	89.40928909	10.591							
	90.55433868	9.446							
	91.53119239	8.469							
	92.47892681	7.521							
	93.49797834	6.502							
	94.38199705	5.618							
	95.22942239	4.771							
Ndes	95.98350152	4.016	14.9	3.507	14.929	73.206			

Mixture specification						Identification	0% 25mm.
Type	Margalla		Weight%	Specific Weight		Date	22-04-15
Aggregate	Limestone		96.5	2719.02	Gsb	Time	9:54
				2658.401959	Gse	Test No	1
Filler			---			Mixture	HMA
Bitumen	ARL 60/70			1017.86		Test parameters	
TMD Gmm, (kg/m^3)				2494.65		Specimen weight	7200
Asphalt content, % of total mix vol			3.5			Final specimen height	172.6
Gmb (measured), (kg/m^3)				2388.99		Test length	125
						Gyratory angle	22 mrad
						Presure in specimen	600 kPa
						Compaction temperature	135 °C
						Gyratory speed	36.7 rpm
	No of Gyrations	Height, mm	Gmb (Estimated),kg/m^3	Gmb (Corrected)	% Gmm		
	4	205.8	1980	2003.59414	80.31564107		
	5	203.3	2004	2028.232533	81.30329037		
	6	201.3	2024	2048.383875	82.11107269		
	8	198.2	2056	2080.42217	83.39535284		
Nini = 9	9	196.95	2069	2093.626169	83.9246455		
averaged	10	195.7	2082	2106.998845	84.4606997		
	12	193.8	2102	2127.655697	85.28874578		
	16	190.7	2137	2162.242653	86.67519104		
	20	188.4	2163	2188.639459	87.73332767		
	25	186.2	2188	2214.498786	88.76991908		
	32	183.8	2217	2243.414984	89.92904751		
	40	181.8	2241	2268.095017	90.91836596		
	50	179.8	2266	2293.324105	91.92969373		
	64	177.7	2293	2320.425853	93.01608853		
	80	175.9	2316	2344.170972	93.96793026		
	100	174.2	2339	2367.047497	94.88495369		
Ndes	125	172.6	2361	2388.99	95.76453611		
	Correction factor, C = Gmb(measured)/G		1.0120338 21				

Mixture specification						Identification	0% 25mm(2)		
Type	Margalla Wearing		Weight	Specific Weight		Date	22-04-15		
Aggregate	Limestone		96.5	2719.02	Gsb	Time	9:54		
				2658.401959	Gse	Test No			
Filler			---			Mixture	HMA		
Bitumen	ARL 60/70			1017.86		Test parameters			
TMD Gmm, (kg/m^3)				2494.65		Specimen weight	7200	gm	
Asphalt content, % of total mix vol			3.5			Final specimen height	172.6		
Gmb (measured), (kg/m^3)				2388.99		Test length	125		
						Gyratory angle	22 mrad		
						Presure in specimen	600 kPa		
						Compaction temperature	135 °C		
						Compaction speed	35.4 rpm		
	% Gmm	Va %	VMA	Pb, estimated	VMA, estimated	VFA %	% Gmm EST @Nini	Pbe	Dust Prop
	80.31564107	19.684							
	81.30329037	18.697							
	82.11107269	17.889							
	83.39535284	16.605							
Nini = 9	83.9246455	16.075					84.160	3.566	1.122
averaged	84.4606997	15.539							
	85.28874578	14.711							
	86.67519104	13.325							
	87.73332767	12.267							
	88.76991908	11.230							
	89.92904751	10.071							
	90.91836596	9.082							
	91.92969373	8.070							
	93.01608853	6.984							
	93.96793026	6.032							
	94.88495369	5.115							
Ndes	95.76453611	4.235	15.21	3.594	15.166	73.625			

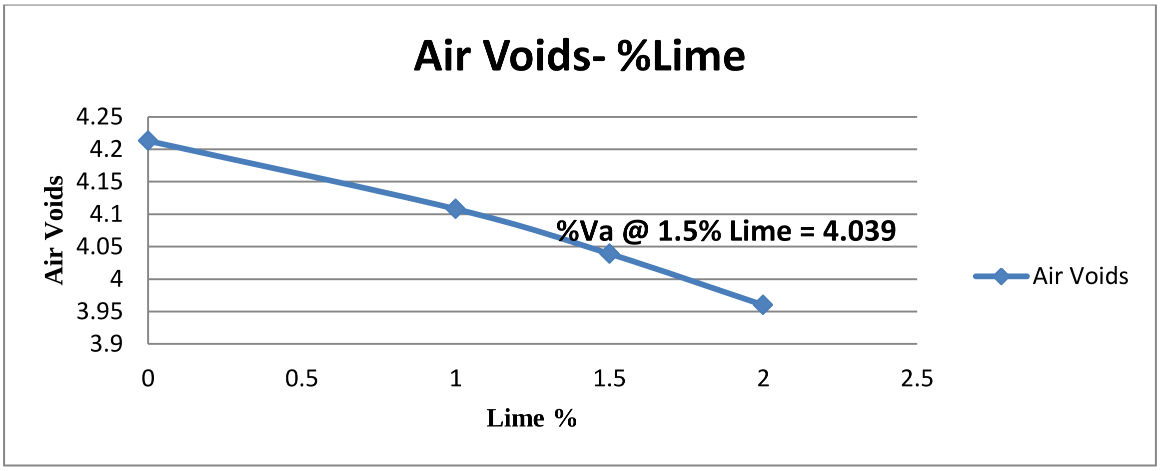
Mixture specification						Identification	1% 25mm
Type	Margalla Wearing		Weight%	Specific Weight		Date	22-04-15
Aggregate	Limestone		96.5	2719.02	Gsb	Time	10:18
				2660.579168	Gse	Test No	1
Filler			---			Mixture	HMA
Bitumen	ARL 60/70			1017.86		Test parameters	
TMD Gmm, (kg/m^{3})				2496.50		Specimen weight	7200
Asphalt content, % of total mix vol			3.5			Final specimen height	178.2
Gmb (measured), (kg/m^{3})				2391.45		Test length	125
						Gyratory angle	22 mrad
						Presure in specimen	600 kPa
						Compaction temperature	135 °C
						Gyratory speed	36.7 rpm
	No of Gyrations	Height, mm	Gmb(Estimated),kg/m^{3}	Gmb(Corrected)	% Gmm		
	4	213.9	1905	1992.315989	79.80436566		
	5	211.1	1930	2018.741781	80.86287928		
	6	208.8	1951	2040.978879	81.75361023		
	8	205.2	1986	2076.785526	83.18788409		
Nini = 9	9	203.85	1999	2090.539073	83.73879723		
averaged	10	202.5	2012	2104.476	84.29705588		
	12	200.4	2033	2126.528892	85.18040826		
	16	197.1	2067	2162.132877	86.60656426		
	20	194.6	2094	2189.909507	87.71918713		
	25	192.3	2119	2216.101872	88.76835057		
	32	189.7	2148	2246.475435	89.98499639		
	40	187.6	2172	2271.622548	90.99229113		
	50	185.5	2196	2297.33903	92.02239254		
	64	183.3	2223	2324.912111	93.12686206		
	80	181.5	2245	2347.969091	94.05043424		
	100	179.7	2267	2371.48798	94.99250871		
Ndes	125	178.2	2286	2391.45	95.79210895		
	Correction factor, C = Gmb(measured)/Gmb(estimated)		1.045945144				

Mixture specification						Identification	1% 25mm(1)		
Type	Margalla Wearing		Weight %	Specific Weight		Date	22-04-15		
Aggregate	Limestone		96.5	2719.02	Gsb	Time	10:18		
				2660.579168	Gse	Test No			
Filler			---			Mixture	HMA		
Bitumen	ARL 60/70			1017.86		Test parameters			
TMD Gmm, (kg/m^{3})				2496.50		Specimen weight	7200	gm	
Asphalt content, % of total mix vol			3.5			Final specimen height	178.6		
Gmb (measured), (kg/m^{3})				2391.45		Test length	125		
						Gyratory angle	22 mrad		
						Presure in specimen	600 kPa		
						Compaction temperature	135 °C		
						Compaction speed	35.4 rpm		
	% Gmm	Va %	VMA %	Pb, estima	VMA, estimated	VFA %	% Gmm EST @Nini	Pbe	Dust Prop
	79.80436566	20.196							
	80.86287928	19.137							
	81.75361023	18.246							
	83.18788409	16.812							
Nini = 9	83.73879723	16.261					83.947	3.555	1.125
averaged	84.29705588	15.703							
	85.18040826	14.820							
	86.60656426	13.393							
	87.71918713	12.281							
	88.76835057	11.232							
	89.98499639	10.015							
	90.99229113	9.008							
	92.02239254	7.978							
	93.12686206	6.873							
	94.05043424	5.950							
	94.99250871	5.007							
Ndes	95.79210895	4.208	15.126	3.583	15.084	73.482			

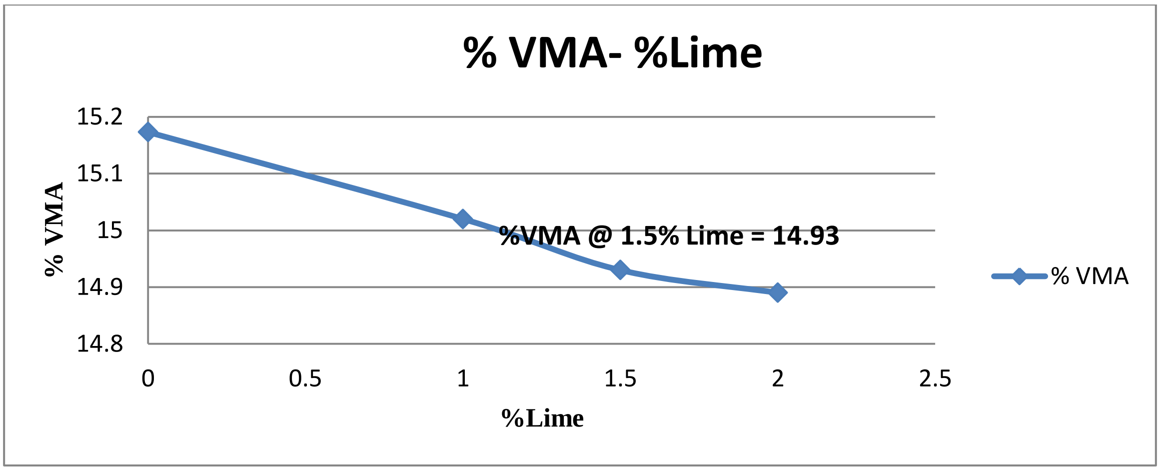
Type	Margalla Wearing		Weight%	Specific Weight		Date	23-04-15
Aggregate	Limestone		96.5	2719.02	Gsb	Time	11:37
				2658.696157	Gse	Test No	1
Filler			---			Mixture	HMA
Bitumen	ARL 60/70			1017.86		Test parameters	
TMD Gmm, (kg/m^3)				2494.90		Specimen weight	7200
Asphalt content, % of total mix vol.			3.5			Final specimen height	176.9
Gmb (measured), (kg/m^3)				2395.50		Test length	125
						Gyratory angle	22 mrad
						Presure in specimen	600 kPa
						Compaction temperature	135 °C
						Gyratory speed	36.7 rpm
	No of Gyrations	Height, mm	Gmb(Estimated),kg/	Gmb(Corrected)	% Gmm		
	4	214.6	1899	1974.668919	79.14821912		
	5	211.4	1927	2004.559839	80.34630002		
	6	208.8	1951	2029.520833	81.34678077		
	8	204.8	1989	2069.159912	82.93558508		
Nini = 9	9	203.3	2004	2084.426709	83.54750528		
averaged	10	201.8	2019	2099.920466	84.16852242		
	12	199.4	2043	2125.195336	85.18158387		
	16	195.8	2081	2164.269408	86.7477417		
	20	193.2	2109	2193.395186	87.91515437		
	25	190.8	2135	2220.985063	89.02100537		
	32	188.2	2165	2251.668172	90.2508386		
	40	186	2191	2278.300806	91.31832163		
	50	183.9	2216	2304.317292	92.36110834		
	64	181.8	2241	2330.934818	93.42798583		
	80	180.1	2262	2352.936979	94.30987132		
	100	178.4	2284	2375.358464	95.20856404		
Ndes	125	176.9	2303	2395.5	96.01587238		
	Correction factor, C = Gmb(measured)/Gmb(estimated)		1.040073213				

Mixture specification						Identification	2% 25mm(2)		
Type	Margalla Wearing		Weight	Specific Weight		Date	23-04-15		
Aggregate	Limestone		96.5	2719.02	Gsb	Time	11:37		
				2658.696157	Gse	Test No			
Filler			---			Mixture	HMA		
Bitumen	ARL 60/70			1017.86		Test parameters			
TMD Gmm, (kg/m^3)				2494.90		Specimen weight	7200	gm	
Asphalt content, % of total mix vol			3.5			Final specimen height	176.5		
Gmb (measured), (kg/m^3)				2395.50		Test length	125		
						Gyratory angle	22 mrad		
						Presure in specimen	600 kPa		
						Compaction temperature	135 °C		
						Compaction speed	35.4 rpm		
	% Gmm	Va %	VMA %	Pb, estimated	VMA, estimated	VFA %	% Gmm EST @Nini	Pbe	Dust Prop
	79.14821912	20.852							
	80.34630002	19.654							
	81.34678077	18.653							
	82.93558508	17.064							
Nini = 9	83.54750528	16.452					83.532	3.46	1.154
averaged	84.16852242	15.831							
	85.18158387	14.818							
	86.7477417	13.252							
	87.91515437	12.085							
	89.02100537	10.979							
	90.2508386	9.749							
	91.31832163	8.682							
	92.36110834	7.639							
	93.42798583	6.572							
	94.30987132	5.690							
	95.20856404	4.791							
Ndes	96.01587238	3.984	14.9	3.494	14.985	73.307			

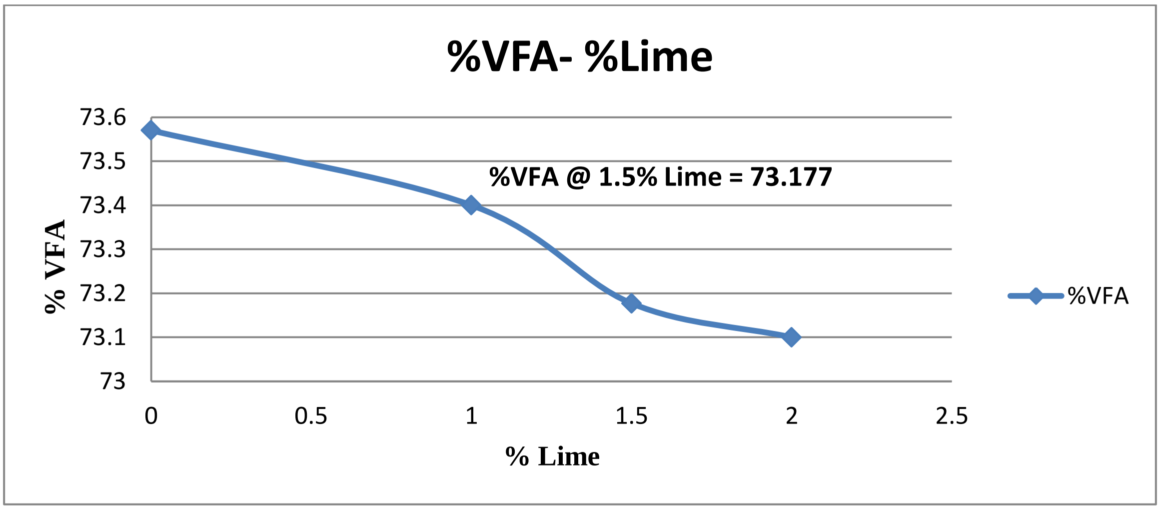
Appendix G: Graphs of 25mm Gradation @1.5% Lim



4.039% Va @ 1.5% Lime

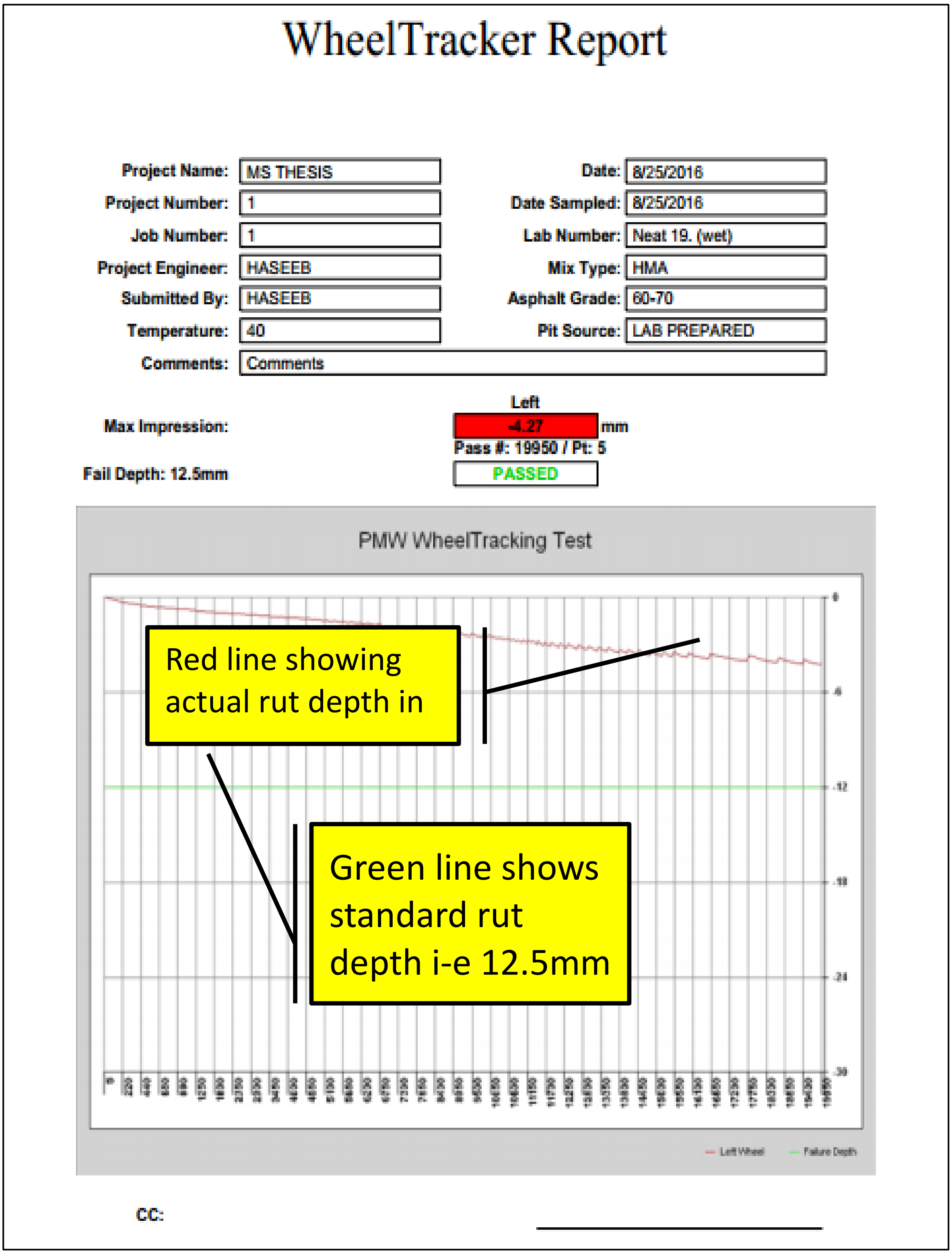


14.93% VMA @ 1.5% Lime



73.177% VFA @ 1.5% Lime

Appendix H: Hamburg Wheel Tracker Test Software Result



WheelTracker Report

Project Name:	MS THESIS	Date:	8/25/2016
Project Number:	1	Date Sampled:	8/25/2016
Job Number:	1	Lab Number:	Neat 19. (wet)
Project Engineer:	HASEEB	Mix Type:	HMA
Submitted By:	HASEEB	Asphalt Grade:	60-70
Temperature:	40	Pit Source:	LAB PREPARED
Comments:	Comments		

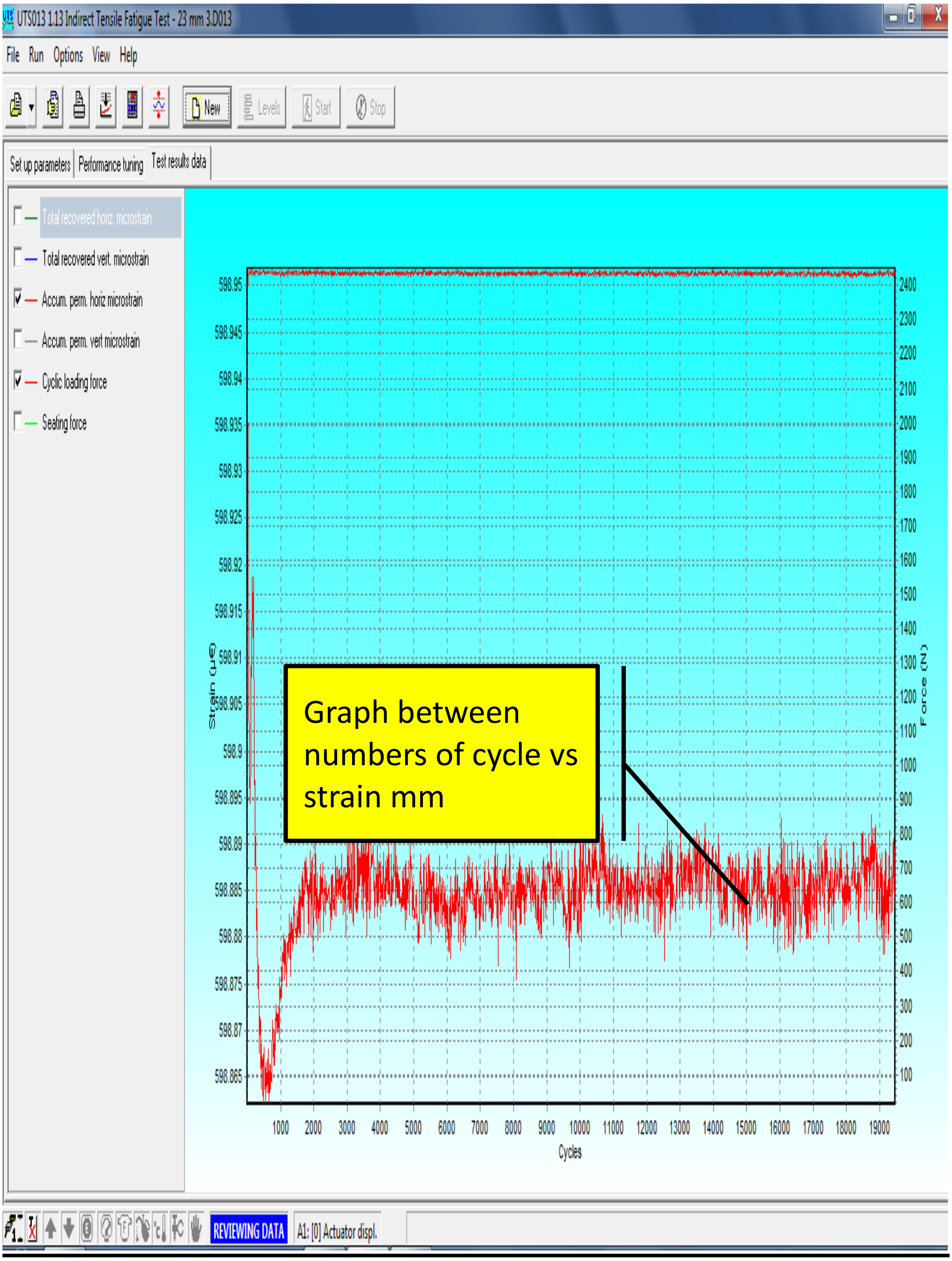
Max Impression: Left -4.27 mm

Pass #: 19950 / Pt: 5

Fail Depth: 12.5mm PASSED

CC:

Appendix I: Indirect Tensile Fatigue Test Software Result



Appendix J: Preparation of mixtures

(a) Heating Aggregates

(b) Mixing of Mixture

(c) Placing Mixture in Gyratory Mold

(d) SUPERPAVE Gyratory Compactor

(e) Specimen after compaction

(f) Saw Cutting of Specimen

(f) Wheel Tracker Machine

(g) Cored Samples