PERFORMANCE EVALUATION OF ASPHALT MIXTURES USING NEAT AND MODIFIED BINDER

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Certified that the contents and form of thesis titled **“Performance Evaluation of Asphalt Mixtures using Neat and Modified Binder”**, submitted by Nasir Iqbal, have been found satisfactory for the requirement of the degree.

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Dedication

This thesis is dedicated to my beloved

PARENTS

&

TEACHERS

Who taught me the value of education and has never failed to give me financial and moral support for giving all my needs during the time I developed my system and for teaching me that even the largest task can be accomplished if it is done one step at a time. I m deeply indebted to them for their continued support and unwavering faith in me.

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All acclamation and appreciations for Almighty Allah the Omni portent and Omni scientist. He showered his blessings and I successfully made the accomplishment.

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Last but not the least, I would like to Thanks my family from my heart for putting up with me in my most annoyed phases in the completion of this document and today I feel confident in presenting this work.

(Engr. Nasir Iqbal)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AASHTO	- American Association of State Highway and Transportation Officials
AC	- Asphalt Concrete
AMPT	- Asphalt Mixture Performance Tester
ANOVA	- Analysis of Variance
ASTM	- American Society for Testing and Materials
BS	- British Standard
DFITS	- Difference in the Fitted Values
ESALs	- Equivalent Single Axle Loads
DM	- Dynamic Modulus
PH	- Phase Angle
HMA	- Hot Mix Asphalt
IDT	- Indirect Tensile Strength
LVDT	- Linear Variable Differential Transformer
DCRM	-Devulcanized Crumb Rubber Modifier
ME	- Mechanistic-Empirical
M_R	- Resilient Modulus
NCHRP	- National Corporative Highway Research Program
SGC	- Superpave Gyratory Compactor
SPT	- Simple Performance Tester / Simple Performance Tests
UTM	- Universal Testing Machine
VA	- Air Voids
VFA	- Voids Filled with Asphalt
VMA	- Voids in Mineral Aggregates

ABSTRACT

Rutting is a common distress occurring in flexible pavements, mainly due to the gathering of permanent deformation in any or all of the layers in flexible pavement. The amassing of perpetual twisting in the black-top layers is presently perceived to be real reason of rutting in the flexible pavements. In Pakistan, this is an outcome of expanded tire weights and over loading, which subjects the black-top surfacing layer closest to the tire-asphalt contact zone to expanded burdens. Along these lines the investigation of change in perpetual twisting properties of black-top blends by adding modifiers to bitumen has turned into the center of examination, which expects to relieve or lessen rutting in flexible pavements. This study aims to evaluate the execution of asphalt mixtures modified with crumb rubber through resilient modulus, wheel tracker and dynamic modulus test. The research methodology incorporates two phase approach (1) Laboratory Prepared asphalt mixtures (2) Plant produced asphalt mixtures. Bitumen penetration grade of NRL 60/70 and an aggregate source of Margalla quarry were used for preparation of mixtures.

The overall findings revealed that with the modification of crumb rubber the asphalt mixtures rutting resistance potential significantly increases and also there is an expansion in resilient modulus and dynamic modulus. With modification of 7% crumb rubber the rut depth was reduced to be 33% for asphalt mixtures of lab prepared and 22% for asphalt mixtures of plant produced. Likewise the percentage increase in resilient modulus for rubber modified mixtures were found to be 44% and 36% at 25 and 40^{o}C for lab prepared asphalt mixtures, 42% and 31% improvement was noted for plant produced asphalt mixtures. Statistical analysis was done on dynamic modulus results and the findings showed frequency as the most critical factor which has a significant effect on the dynamic modulus of asphalt mixtures followed by temperature and rubber content.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The quality of bitumen plays an essential role in the efficiency of asphalt mixtures. The main cause of premature failure of the pavement is an instantaneous increase in number of commercial vehicles in most parts of the world. In all over the world and most recently in Pakistan, it has been practiced to use modified bitumen by adding certain modifier or additives, so that the pavement could perform satisfactorily against repeated loading and extreme temperatures. Crumb rubber modifier is one such form of modification.

Rutting in flexible pavement is a common problem. Rutting has become the superior form of failure of flexible pavement due to increase in pressure imposed by truck tire in past few years. Rutting can occurs in any or all of the layers of pavements due to accumulation of permanent deformation. Temperature has also a great impact and direct relation with rutting even under ideal loading conditions and asphalt mixtures with an increase in temperature rutting also increases. With the modification of asphalt mixtures the rutting resistance potential also increases. Longitudinal variability in rutting leads to the reduced skid resistance and roughness of the flexible pavements.

National Highway Authority (NHA) of Pakistan laid 4 trial sections for assessing the field performance of CRMB in August 2005 and February 2006. In August 2005 these sections were prepared on N-5 between

- Sanjwal more and Haro Bridge on outer lane of southbound carriageway and
- 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

- Burhan flyover and rotary interchange M1 on full width of southbound carriageway and
- 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.

1.2 PROBLEM STATEMENT

In spite of the fact that the rutting saw on pavement is the total of gathered changeless miss happenings in one or more layers of the asphalt structure and sub-grade, however the aggregation of lasting distortion in the black-top surfacing layer is just considered in this exploration as real reason for rutting. For minimizing this distress, it is important to give careful consideration to material determination and mix design.

The studies have demonstrated that the disappointment of flexible pavements is primarily happening because of powerlessness of ordinary asphalt mixtures to support repeated application of wheel burden in spite of the fact that the bitumen got from refineries meets the current specifications.

The pavement experts recognized a critical need for pavements to develop modifiers for bitumen that restores visco elastic balance of bitumen binders required for resistance to permanent deformation while maintaining high resistance to fatigue, thermal and low temperature cracking one of such modifier is crumb rubber.

An endeavor is carried out in this research to handle the issue raised in preceding paragraph by using Crumb Rubber in Bitumen, and compare its performance with conventional bitumen under severe climatic condition with daily and seasonal variations as in Pakistan.

1.3 Research Objectives

The objectives of this research are briefed as follows:

- To evaluate rutting potential of asphalt mixtures using neat and modified binder through wheel tracker test.
- To evaluate stiffness of Asphalt mixtures using neat and modified binder through dynamic modulus test.
- To evaluate dynamic stiffness of asphalt mixtures using neat and modified binder through resilient modulus test.
- To evaluate the variations in modified plant produced asphalt mixtures from lab prepared mixtures

1.4 Scope of Research

To achieve the research objectives the following tasks were carried out in this research.

- Literature Review on previous research findings were carried out.
- Various properties of aggregates and asphalt binder were characterized in the Laboratory.
- 7% crumb rubber by weight of bitumen was used in this research being recommended for overlay and modernization of Islamabad to Lahore Motorway (M-2).
- Same optimum binder content and gradation curve was selected being used in M-2 project.
- Performance tests were conducted on gyratory compacted specimens as per ASTM and AASHTO standards.
- The test matrix for the above performance tests is given below in table 1.1.

Gradation		NHA Class B				
Mix		Wearing Course				
Test	**Resilient Modulus Test**		**Dynamic Modulus Test**			**Wheel Tracker Test**	**Total**
Temp	**25°C**	**40°C**	**25°C**	**40°C**	**55°C**	**40°C**	
NRL 60/70	4	4	4	4	4	4	24
Rubber Modified Binder	4	4	4	4	4	4	24
Total	8	8	8	8	8	8	**48**

Table 1.1: Test Matrix for Performance Tests

1.5 Organization of Thesis

- This research is sorted out in five parts; brief explination of each is as per the following:

- Chapter 1 includes a brief but comprehensive introduction to the influence of premature failure of flexible pavements on its performance, the scope and objectives of study.
- Chapter 2 describes the literature review of various distresses in flexible pavements, review of the findings of previous researches related to evaluation of flexible pavements premature failure, i.e. rutting.
- Chapter 3 explains the research methodology used for achieving the objectives.
- Chapter 4 presents the details of test results obtained by conducting different Performance tests.
- Chapter 5 includes the conclusions and recommendations for future work.

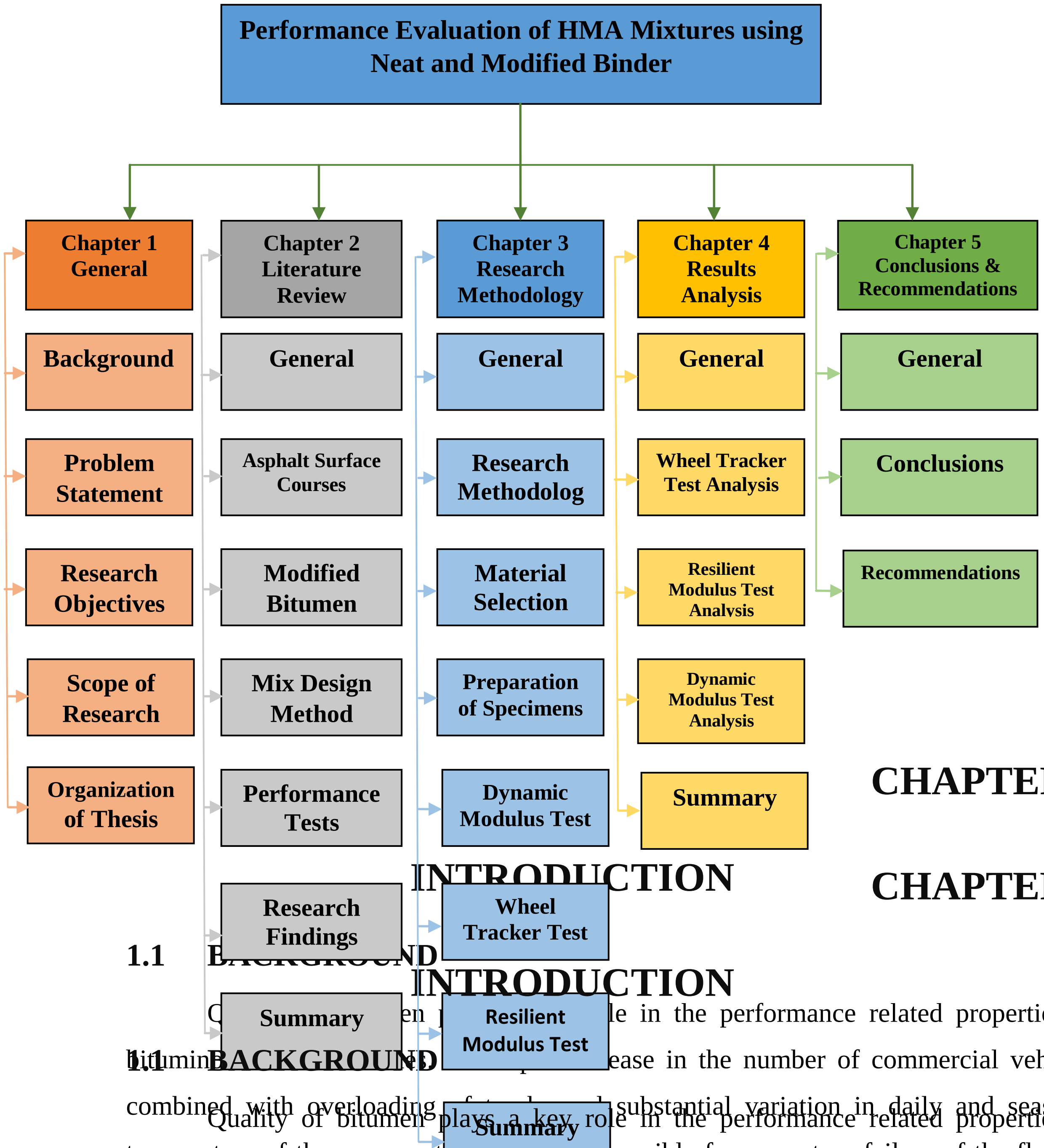

Figure 1.1: Organization of Thesis

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Quality of bitumen plays a key role in the performance related properties of bituminous concrete mixes. The rapid increase in the number of commercial vehicles combined with overloading of trucks and substantial variation in daily and seasonal temperature of the pavement have been responsible for premature failure of the flexible pavements in most parts of the World.

In all over the world and most recently in Pakistan, it has been practiced to introduce modified bitumen by adding certain additives, so the pavement could perform satisfactorily with reduced maintenance against repeated loading and extreme temperatures. One such form of modified bitumen is Crumb Rubber Modified Bitumen (CRMB), introduced in Pakistan by M/s Phoenix Commercial Company (Private) Limited in collaboration with an Indian manufacturer.

Permanent deformation in the form of rutting is one of the most important distress (failure) mechanisms in flexible pavements. With increase in truck tire pressure in recent years, rutting has become the dominant mode of flexible pavement failure. Pavement rutting, which results in a distorted pavement surface, is primarily caused by the accumulation of permanent deformation either in all or in any layer of the pavement

CHAPTER 1

INTRODUCTION

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CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Bitumen is man's oldest engineering material that has been used since the dawn of civilization. In sumeria, about 6000 BC, there existing a thriving ship building industry that produced and used bitumen. In building the ziggurats, of which the Tower of Babel was only one of many, bitumen was used as mortar. Near the cities of Sodom and Gamorrah, there was a thriving bitumen production. Bitumen was used by the Egyptians as water proofing material as early as 2600 BC. In ancient world, bitumen kept on being utilized broadly as mortar for building and clearing squares, caulking for ships and water proofing in numerous applications.

These early bitumen happened actually they were found in geologic strata both as delicate, promptly workable "mortars" furthermore as hard, friable dark veins of rock developments. The delicate bituminous material is encapsulated in the Trinidad Lake vault, on the islands of Trinidad, in Bermudez Lake in Venezuela and in broad "tar remains" all through western Canada. These soft bituminous products have come to refer as natural bitumen and were used extensively until the early part of this century.

In the mid 1900's the disclosure of refining bitumen from crude petroleum and the overwhelming popularity of the automobile created an expanding industry. Bitumen appeared to be a cheap and inexhaustible asset that would be utilized for smooth, advanced streets and various different applications.

As the bituminous mix paving industry blossomed, the physical properties and character of bituminous mix needed to be determined. To ensure bitumen roadways were durable and reliable, numerous tests and procedure were developed in the early 1900's. Probably the first scientific approach to design bituminous paving mixes was to determine the bitumen content based on aggregates voids.

In order for design samples to represent field performance, compacted samples needed to contain desired voids and asphalt cement content. In the middle 1920's Prevost Hubbard and F C Field developed a test method of evaluating the physical properties of a compacted asphalt mixtures. This test shows the stability of mix by punching shear failure.

Francis Hveem developed another test in the 1930's to ensure compacted asphalt pavement mixture were stable and did not bleed asphalt. The principles of Hveem method are based on tri-axial compression and an estimate of asphalt content determined by the surface area of the aggregate. The Hveem method is still practiced today.

With the advent of World War II, a sample test was required for proper design and construction of military airfields. Bruce Marshall conceived an asphalt mix design method for determination of desired density and asphalt binder content to withstand the heavy aircraft wheel loads. The Marshall method is extremely used throughout the world.

Another method Known as Gyratory method has gain wide acceptance all over the world. This method was initially developed in the 1930's in Texas by Texas Highway Department. Improvements have been made in this method by various researchers and organization. This compaction creates a kneading activity on the sample by gyrating the sample through a horizontal angle ranging from 1 to 6 degrees. Vertical load is applied during the process of compaction and the mould is gyrated in back and forth motion. The sample produced by this method is considered as best simulation of density achieved at the end of pavement life.

2.2 ASPHALT SURFACE COURSES

The purpose of the surface course is to give protected and smooth riding surface. Because of wide number of asphaltic material that are available for construction and flexibility of construction techniques, many types of asphalt surfaces can be built. The type of surface depends largely upon the loads that are applied to the pavement as well as upon economics and availability of construction materials; however asphalt surface can be divided in to following;

2.2.1 Surface Treatments

A surface treatment is a low cost surface that is constructed by applying a layer of asphalt which is in turn, covered with aggregates. Thickness may vary from ½ to ¾ inch. Generally surface treatments are less than 1 inch thick. They may consist of single, double or triple layers. These types of surface treatments are quite often used in secondary roads.

In areas of frost action and in those areas where freezing and thawing is a problem, this type of wearing courses are not used. Since the surface is relatively thin, alternate freezing and thawing may cause pot holes to develop. Furthermore, surface treatments are difficult to maintain, because dragging or blading the road will not bring the desired results; it is necessary in many cases to resort to considerable amount of patching.

2.2.2 Road Mix

A road mix surface is mixed in place by means of travel plants or conventional farm equipment such as discs and harrows. Untreated stabilized gravel surface can be scarified and converted into road mix surfaces. Both open graded and dense graded aggregates having Los Angeles Abrasion value less than 50 can be used for this type of construction. Dense graded variety is used primarily where locally available pit run material occur whereas open graded road mix surfaces are constructed, primarily for high type roads. The quantity of asphalt required depends upon the gradation of aggregates. Generally it ranges from 3% to 6%.

In this type of construction, the coarse aggregate is spread over the road surface. The asphaltic material is next sprayed on the aggregate and mass is than mixed with one of the several techniques. The material is than bladed to uniform thickness and compacted. This type of construction permits asphaltic surfaces of varying thickness, usually from 2 to 3 inches.

2.2.3 Penetration Macadam

Penetration Macadam indicates that type of asphalt surface in which asphaltic materials are sprayed over the stone and permitted to penetrate into the mass. To accomplish this, asphalt with penetration ranging from 90 to 150 are commonly used. Asphalt is first heated and then sprayed on the previously rolled aggregates by pressure distributor.

2.2.4 Asphalt Concrete

High type asphaltic concrete pavements are used where high loads are anticipated or on highways with high traffic volumes. The paving surface consists of binder course or surface course with necessary prime, tack and seal coats. In general, the type of bituminous material used is depending on climate. In areas of high air temperature, the heavier grades are used whereas for colder climates, the lighter grades are used.

The stability of asphalt mixtures depend on cohesion which in turn depends upon aggregate gradation, asphalt content and mixture density.

2.2.5 Stone Mastic Asphalt

In the early 1960s the European asphalt industry created stone mastic asphalt (SMA), a gap-graded mix containing expanded measure of coarse aggregate, mineral filler and asphalt cement as well as diminished measure of fine aggregates and sand. This mixture demonstrated so effective in Germany that its utilization was proceeded, even after the use of studded tires (the initial reason for its development) was eliminated. German road authorities eventually included SMA as a standardized class of mixtures in their pavement specifications. Use of SMA mixtures continues to increase throughout Europe and is Spreading across the world. In USA, where SMA is called Stone Matrix Asphalt, its use is gaining popularity amongst road authorities and the asphalt industry.

2.3 FUNCTIONS OF ASPHALT SURFACE COURSES

The primary goal of the asphalt surface is to give protected and smooth riding surface. The surface must possess skid resistance, resist load & non loaded associated fractures and resists permanent deformation. These and some other functions are briefly described below.

2.3.1 Stability

It is the ability to resists deformation under the load and depend upon both internal friction of aggregates and cohesion of bitumen.

Stability is the capacity of frictional and interlocking resistance of aggregates in the mix. Frictional resistance increases with the aggregate particles surface roughness and angularity. It also increases with particles contact area. Interlocking resistance depends on particle size and shape. For a given aggregates, compacted stability increases with the mass density. Excessive asphalt in the mix tends to acts as a lubricant and lowers the internal friction of the stone framework thereby reducing the stability of the mixture.

Cohesion is the binding force that is inborn in asphalt paving mixture. Asphalt works to keep up contact points between aggregates. Cohesion took the loading rate and the asphalt viscosity varies inversely with the temperature. With increase in asphalt content the cohesion increases up to the maximum point and then start decreasing.

2.3.2 Durability

This property of asphalt mixtures portrays the capacity to oppose the unfavorable impacts of air, water, temperature and movement. It is also defined as resistance to weathering, i.e. changes in the attributes of asphalt, such as oxidation and volatilization, and changes in asphalt and aggregates because of activity of water, which includes freezing and thawing.

Toughness can generally be improved by high asphalt contents, thick aggregates gradations and much compacted mixtures. One contention for an expanded measure of asphalt is the resultant thicker asphalt film, coating the total aggregates particles. Thicker films are more impervious to age-hardening. Another ideal contention is that the expanded measure of asphalt decreases the pore sizes of the interconnected voids or closes them in the mixtures, making it more troublesome for air and water to saturate in the mix. But extreme caution must be exercised since the greater film thickness may produce a mix that is more prone to rutting and shoving.

For resistance against the action of water an adequate asphalt content, dense graded aggregates and proper compaction is required. It is necessary to maintain the asphalt coating within the aggregates in the presence of water. A dense asphalt mixture is more resistant to displacement from aggregates. If however, the aggregates is of a hydrophilic nature it may be necessary to incorporate an anti strip additive in to the asphalt cement.

Enough asphalt must be provided in the mixture for bonding properties sufficient for resistance against the traffic stresses. The mixtures having insufficient asphalt would lead to raveling. Abrasion can also occur if the asphalt becomes too brittle. Later brittleness is a cause of overheating of asphalt during mixing process which would leads to abrasion of the pavement.

A mixture having all the voids completely filled with asphalt content can provide the ultimate durability but it is not desirable from stability point of view. The pavement would move under the traffic when placed in a roadway and as a result bleeding would take place.

With the asphalt coating the particles has reached some critical value then the maximum stability is reached in asphalt / aggregates. Additional asphalt is used then which would act as a lubricant rather than binder, thus reducing the stability and increasing the durability. It is therefore necessary to maintain the adequate stability and keeping the asphalt content as high as possible.

2.3.3 Flexibility

It is capacity to twist marginally without splitting and fit in with slow settlement and movement of the base and sub grade. In fill embankment differential settlements most probably occur. It is very difficult during construction to maintain uniform density in the sub grade because all the sections have the same support value. In this manner, the asphalt pavement must be able to fit in with minor confined and differential settlements without splitting. Generally the flexibility of asphalt mixtures can be increased by using open graded aggregates and high asphalt content however the general mix criteria must be adjusted to accomplish acceptable JMF.

2.3.4 Fatigue Resistance

It is the capacity of asphalt mixtures to resist repeated fluctuating stresses produced under the wheel load. Various test results has indicated that the quantity of asphalt content has a significant influence on the fatigue resistance when the asphalt content is higher the fatigue resistance would be greater. Some of the test results has also indicated that dense grade asphalt mixtures has also more fatigue resistance than open graded mixtures. Well graded aggregates should be used in the mix which allow higher asphalt content without causing bleeding in a compacted paving mixtures.

2.3.5 Skid Resistance

It is the capacity of asphalt surface, especially when wet, to provide resistance. Proper asphalt content and unpleasant surface aggregates are most prominent supporters to skid resistance. The aggregates that have a tendency to polish may be used in underlying courses but they should be avoided in the surface courses. Asphalt having non cleaning minerals aggregates with various wear or scrap area qualities gives nonstop restoration of the asphalt surface, keeping up a slide resistance surface.

Compacted mixtures having all the voids filled with asphalt content will probably leads to bleeding of asphalt surface which is undesirable and can also cause slippery conditions when the pavement is wet.

2.3.6 Permeability

Permeability is resistance to entry of water and air into the asphalt pavement. The air void substance might shows sensitivity of a compacted mixtures to the section of air or water. However, the interconnection of the voids and their access to the surface must be avoided. For durability of asphalt mixtures air and water imperviousness is also necessary.

2.4 FAILURE IN ASPHALT SURFACE COURSES

The failure of asphalt surface courses may occur in number of ways, however two types of failures that most commonly occurs in Pakistan are discussed here.

2.4.1 Permanent Deformation

Permanent deformation usually called as Rutting can be defined as longitudinal surface depression in the wheel path accompanied, in most cases, by asphalt change at the sides of rut. Critical rutting can prompt to a structural failure which is a safety hazard. Rutting can happen in all layers of the asphalt structure and results from lateral deformation and densification. In addition, rutting also represents a nonstop amassing of incrementally little lasting miss happenings from every load application.

In flexible pavement usually there are three reason for rutting: gathering of changeless distortion in the black-top surfacing layer, sub grade permanent deformation, and wear of asphalts brought on by studded tires. Previously the main cause of rutting was the sub grade deformation but the recent researches have shown that rutting usually occurs in the top layer of flexible pavement.

2.4.2 Fatigue Failure

Fatigue can be defined as “the phenomena of fracture under repeated or fluctuating stress having a maximum value generally less than the tensile strength of the material”.

When the resultant strain imposed by the repeated stresses and traffic loading or temperature changes exceed the tensile strength of the mixtures the asphalt mix will crack. This condition usually occurs in such countries where the temperature rises above 0^oC after a long period of below freezing point. The stability of sub grade tends to reduce during these conditions which would consequently leads to the development of high tensile stresses in the asphalt mixtures under the vehicle load and the cracks would occur in the pavement. It is also known as spring effect.

During period of cooling, asphalt mixes try to contract; however, asphalt within a road structure is effectively constrained and therefore cannot change its length. As a result the stresses caused by the traffic will combine with the thermal tensile stresses developed due to this conditions would exceed the strength of the mixtures and thermal cracks would appear in the pavement in the transverse direction. This problem may occur in areas where temperature falls as low as -40^oC.

2.5 MODIFIED BITUMEN

Asphalt binder plays a key role in visco-elastic property of all bituminous materials; it also plays an important role in many features of road performance. Typical examples are rutting resistance potential and fatigue cracking. Generally non recoverable strains increase with increasing load, time and temperature.

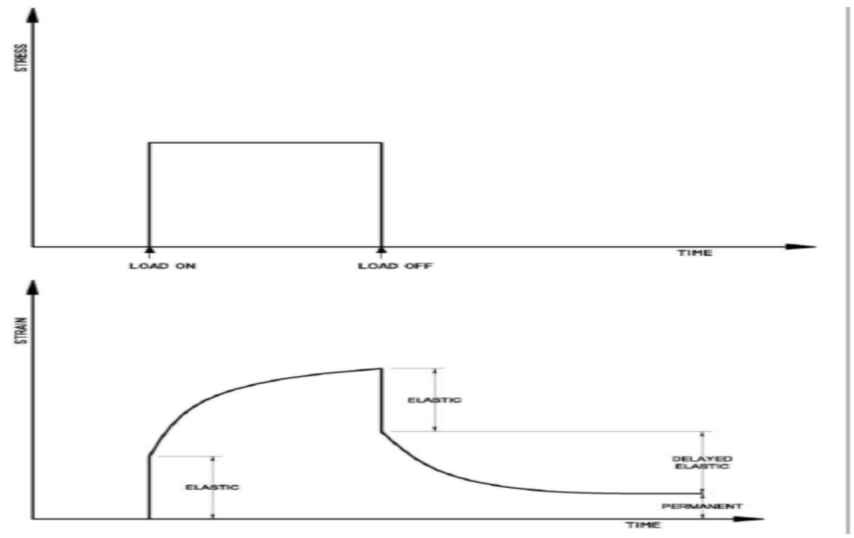


Figure 2.1 Visco Elastic Response to static Loading

The effect of this is illustrated in figures 2-1 & 2-2. Figure 2-1 shows the response of a bituminous material to a simple creep test. The strain coming about because of the connected stacking demonstrates a quick versatile reaction of a bituminous material to a straightforward drag. This prompt versatile reaction is trailed by a continuous increment in strain with time until the heap is evacuated. The adjustment in strain with the time is created by the viscous behavior of the material. On evacuation of the heap, the flexible strain is recouped immediately and some extra recuperation happens with time. This is known as postponed flexibility. At last, a perpetual leftover strain remains, which is gone and is straightforwardly brought about by gooey conduct.

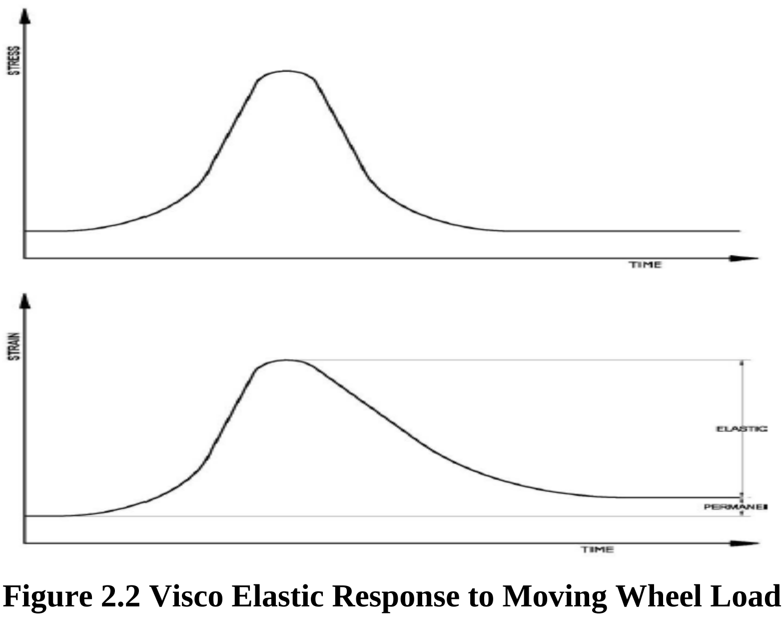


Figure 2.2 Visco Elastic Response to Moving Wheel Load

The reaction to load beat incited in a component of a bituminous material because of moving activity load is shown in Figure 2.2. It is impractical to recognize the two segments of versatile reaction, however the little lasting strain and bigger flexible strain are appeared. In spite of the fact that the changeless strain is little for a solitary heartbeat load, when numerous a great many burden applications are connected to an asphalt, a huge gathering will create and this is the part which results in surface deformation. This clearly explains more deformation due to slow moving or stationery traffic.

The primary role of bitumen modifier is to increase the rutting resistance potential at high temperature without affecting the binder properties at other temperatures. This can be achieved by making the bitumen so stiff such that the total visco elastic behavior of the mixture is reduced which would results in rutting reduction. Rutting can also be reduced by reducing the viscous component or increasing the elastic component.

The dynamic stiffness of the mixture also increases with increase in stiffness of bitumen, thus the load spreading ability of the material is improved, strength and life of the pavement also increases. The asphalt mixture flexibility also improves when the elastic component of the bitumen increases and it is important in the areas having high tensile stresses.

2.5.1 Modified Bitumen Why?

Modified Bitumen helps to

- Sustain progressively substantial movement conditions
- Resist extreme climatic conditions with day by day and occasional varieties of environmental temperature.
- Preserve pavement at good performance level.
- It resist the failure of asphalt mixtures occurs due to fatigue stresses
- At low temperature makes the mixture flexible to up to certain degree.
- Improve cohesive properties of bitumen makes the binder more resistant to weathering.
- Improve the adhesive properties of binder and minimize the risk of dismantling action by water.
- Increase the stiffness of mixtures to decrease the surface thickness to avoid milling in cities.

- Prevent the failure of pavement occurs due to major distresses.
- Reduce VOC and maintenance cost.

2.5.2 Modification of Bitumen

In the last 40 years many researchers have identified various materials for modifying bitumen used in road construction. The modifiers to be used for modification purpose must be practicable and economical, and possess the following properties.

- It should be easily available.
- Resists degradation in HMA plants.
- Easily mixed with asphalt binder.
- Increase flow resistance at high pavement temperature without forming the binder too viscous which leads difficulties during mixing and laying or without forming the binder too stiff which is dangerous for low pavement temperature.
- It must be economical.

When the modifier is mixed with the bitumen binder it must possess the following properties.

- During the application and storage the primary properties of the binder should not be adversely affected.
- It should be handled easily and no special equipment should be required.
- The stability of bitumen should not be affected physically or chemically in course of application and storage.
- Achieve a covering or splashing thickness at ordinary application temperature.

Some types of modified bitumen are briefly explained below

2.5.3 Sulphur Modified Bitumen

Sulphur is used in two types of asphalt paving processes. Sulphur extended asphalt utilizes a relatively small amount of sulphur as diluent to bitumen. The second process known as thermo pave uses high sulphur contents where excess sulphur behaves as moldable filler, producing a very workable mix which can be laid by machine without roller compaction and when cool is very resistant to deformation.

2.5.4 Organo-Manganese Compounds Modified Bitumen

Paving material of improved strength is obtained by adding the bitumen a soluble organo-manganese compound either alone or in combination of with organo-cobolt or organo-copper compound. The use of manganese modified bitumen in asphalt and macadam is claimed to improve the temperature susceptibility of the mixes, thereby improving their physical properties, resistance to permanent deformation and dynamic stiffness.

2.5.5 Thermoplastic Rubbers Modified Bitumen

Four major groups of thermoplastic electrometers are used for improvement of properties of bitumen are polyurethane, polyether polyester copolymers, definic copolymers and styrenic block copolymers. Out of these four styrenic block copolymers shows good results when mixed with polymers.

2.5.6 Polymer Modified Bitumen

Polyethylene, polypropylene, PVC etc are polymers which is used as modifier in binders during road construction. Polymers modified bitumen are evaluated on the basis of softening property when heated and hardening property when cooled.

This material has ability to meet the extreme climatic conditions. It is not be too soft in hot temperature so that rutting occurs and is not be too hard in cold temperature so that it will crack under load. It improves durability of the binder under all seasonal variations; reduce the life cycle cost of the road, decreases rutting potential and value of the total accumulated strain, reduce fatigue cracking resistance, improve impact resistance, less sensitive to moisture, reduce apparent age hardening and will be serviceable under wide range.

However the problems associated with this material is that the temperature of bitumen drops at a much faster rate limiting the haulage distance and laying time. The temperature falling gradient once the asphalt is laid is abrupt compared to typical 60/70-grade bitumen. In hot weather lying of Polymer Modified Bitumen is not as such a problem, however during winter when the ambient temperature is about 15 to 20oC it is very difficult to handle as the time margin during laying and compaction is very less. This resulted in poor riding quality and tire prints appear on top.

Polymer Modified Bitumen requires being heated up to 180oC before mixing with the aggregates. Bitumen has to be heated in the asphalt plant for 2 to 3 days to attain this much temperature. Excessive heat involved in preparing Polymer Modified Bitumen Asphalt mix causes more fuel, time consumption and plant wear and tear.

2.6 USE OF MODIFIED BITUMEN IN PAKISTAN

Use of modified bitumen in Pakistan has been recently started to overcome the failure associated with extreme climatic condition and increased loading.

2.6.1 Polymer Modified Bitumen

One of such modified bitumen has been used on Grand Trunk Road (N-5) in South Bound carriageway, from Margalla Nicholson Monument to Tarnol Railway Crossing. This section of approximately 11km in length is considered as one of the most critical section of Pakistan Highways. Bitumen was modified by adding polymer namely Elvaloy 4170, provided by Attock Refinery Limited. Elvaloy 4170, a material of DuPont – America is mixed with 60/70 penetration grade bitumen and is heated at 160^{o}C for 12 hours. Phosphoric acid is added @ 0.7% (7 kg/Ton) as catalyst for 1 to 2 hours. Elvaloy 4170 is used @ 0.8% (8kg/Ton) for asphaltic base course and @ 1.6% (16 kg/Ton) for asphaltic wearing course.

2.6.2 Crum Rubber Modified Bitumen

National Highway Authority (NHA) of Pakistan laid 4 trial sections for assessing the field performance of CRMB 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 M1 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.

2.7 CRUMB RUBBER MODIFIED BITUMEN

2.7.1 History and Use of CRMB in World

The use of rubber in road construction started way back in 1960s in USA. It was felt during that time, unprecedented growth of vehicles on the roads were leading to premature distress like rutting, potholing, cracks etc on the top layer of pavement surface. Initially cut pieces of rubber were added with the aggregate and it was found that the presence of rubber, added strength and stability to asphalt mix. The consistency in the results was not there due to coagulation of rubber. Over the years the process has been modified and innovated and now the combination of chemically treated crumb rubber, natural asphalt (hydrocarbon mineral) and cross linking additives is a well-known phenomenon across the globe. The growth of rubberized bitumen usage happened in 1980s. Since then the use of rubberized bitumen has been established in continents like Asia, North America, Europe and Australia.

Florida, Texas, Arizona and California are among the largest users of rubberized bitumen in USA. It is estimated that they collectively consume over 3 million Tones of rubberized bitumen.

Australia has wide network of rubberized bitumen roads with chip seal surfacing. Rubberized bitumen delays reflective cracking and acts as an excellent crack sealer. The maintenance cost on the roads has been brought down by over 50%. They have extensively used rubberized bitumen to avoid milling of the old road as they are confident that crack sealing done by rubberized asphalt with rubberized bituminous concrete overlay is a much more cost effective solution. State of Victoria in Australia has made use of rubberized bitumen mandatory in certain roads & highways with heavy traffics.

European countries like Belgium and UK are provocating the use of rubberized bitumen because of its cost effectiveness over other polymers and also its environmental benefits.

CRMB has also been successfully used in various highways of national importance in India. National Highway Authority of India, Ministry of Rural Development, Airport Authority of India, have made mandatory, the use of modified bitumen in pavements. Indian leading research institutes are propagating the use of rubberized pavement. Similarly use of CRMB has been specified on projects funded by International Donor Agencies.

2.7.2 Advantages

- Provide better protection against warm climate thereby increase the softening point of bitumen.

- Provide better resistance to cracking potential which occurs under various traffic stresses thereby increasing the elastic component of the bitumen.
- Lower Penetration, which makes the grade of binder sufficient hard to provide an extra strength to the pavement and minimize the damages caused by water.
- With modification of crumb rubber the bitumen life increases by providing better resistance to ageing.
- Improved adhesive properties of aggregates and binder, by providing greater stability and strength.
- CRMB is environment friendly as it is consumes non biodegradable rubber tires.
- Saves energy and natural resources.
- Higher fatigue life of mixes.
- It can be utilized under ordinary machinery equipments and construction practices.
- Special Product flexible pavement subjected to heavy traffic load and extreme ambient temperature and highly durable against various distresses occurs in a flexible pavement.
- The main advantage of rubber modified bitumen over conventional bitumen is that the life of pavement increases by 2-3 and the cost increase is about 10 % only.

2.7.3 Advantages over Normal Bitumen

Various researchers and manufactures claims following advantages of CRMB over Normal Bitumen.

- Provides better resistance to rutting potential at high pavement temperature and improves the driving comforts.
- Provides better grip and holding between the aggregates and asphalt binder, higher softening point, makes the binder more resistant against the flow and can takes overwhelming vehicular activity.
- Reduces the crash risk by provides better resistance against skidding and also improves the road grip.
- Improves Marshall Stability / impact resistance.
- Minimize the rutting potential and enhancing the driving comforts.

2.7.4 Manufacturing of CRMB

Crumb rubber modification can be done by two processes dry process and wet process. In wet process crumb rubber is thoroughly mixed with binder before integrating into the mix. And dry method can be defined as the method in which the rubber modifier is mixed into the asphalt mixture directly. Experiences have indicated that the performance of asphalt mixtures modified by dry process is usually unstable varying from satisfactory to unfavorable. The unstable performance of the modified mixtures by dry process is usually due to the poor control of aggregate gradation and crumb rubber and having insufficient knowledge of volume changes occurring due to swelling of crumb rubber during mixing.

The performance of crumb rubber modified mixture is usually effected by many factors like asphalt binder type, asphalt content, modifier content, aggregate gradation etc. And also there is insufficient information and guidance for obtaining superior quality of mixtures and a mixture design for a particular area may not be suitable for another area because of dissimilarity in loading and environmental conditions.

Three different size of modifier are mixed by wet process with PG 60/70 bitumen at rate of 15% by weight of total bitumen binder to get various modified binders. Firstly, the PG 60/70 binder and modifier are heated separately to 150^{o}C and then mixed in a mixer for about 5 minutes at low speed. Then at high speed of about 3000 rpm the binder and modifier blend is heated and stirred at a temperature ranging 175 to 185^{o}C for approximately 45 min to avoid segregation before mixing it with aggregates.

2.7.5 Problems Associated with CRMB

In wet process of manufacturing the dispersion of modifier with bitumen is quite difficult because high temperature and long time duration is required for proper dispersion. Improper addition may results in a heterogeneous binder. Also crumb rubber modified binder is thicker than ordinary bitumen so it requires special attention. Manufacturers usually specify the transportation & decantation process and loading & decantation temperature.

2.8 MARSHALL MIX DESIGN METHOD

This method of mix design was formulated by Bruee Marshall. The U.S Army Corps of Engineers, through various researches upgrade some features to this method and developed a criteria for mix design. This method has been standardized by (ASTM).

The original method is suitable only to asphalt mixtures having maximum aggregate size of 25mm or less and the new method is proposed for maximum aggregate size of 38 mm.

2.8.1 Preparation of Test Specimens

The procedure of marshall method of mix design starts with sample preparation. Steps prior to sample preparation are underlined:

- The material use in the project must be physically characterized in the light of specifications.
- The combined aggregate blend shall meet the requirement of gradation.
- For conducting voids analysis and density test bulk specific gravity of the aggregates and specific gravity of asphalt binder shall be determined.

For determination of optimum asphalt content by this method various samples are prepared with varying asphalt content so that the graph provides good understanding of the relationship. Test sample shall be prepared with ½ increments of two asphalt content above the expected design value and two below. The expected design asphalt content can be determined on the basis of past experience, formula and other tests taken out in Hveem procedure.

2.8.2 Test Procedure

In marshall method the following tests are conducted on the compacted sample in the order listed.

- Bulk Specific Gravity Determination.
- Stability and Flow Test.
- Density and Void Analysis.

2.8.3 Volumetric Properties

The volumetric properties of compacted mixtures such as Air Voids, VMA, VFA and effective asphalt content gives some information about the performance of paving mixtures.

- **Bulk Specific Gravity of Aggregate (G_{Sb})**

Bulk specific gravity is the ratio of mass of given volume of aggregate having all the voids permeable and impermeable to the mass of equal volume of water. When the total aggregate have separate fractions of coarse aggregate, fine aggregate and mineral filler all would have different specific gravities then the bulk specific gravity of total aggregate is calculated by using Eq 2.1:

$$G_{sb} = \frac{P_1 + P_2 + P_3 + \ldots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3} + \ldots + \frac{P_n}{G_n}} \qquad (2.1)$$

Where,

Gsb = Bulk specific gravity of total aggregate

P1, P2, Pn = Individual percentages by mass of aggregate

G1,G2, Gn = Individual bulk specific gravity (coarse, fine) of the aggregate

- **Effective Specific Gravity of Aggregate (G_{se})**

Based on the maximum specific gravity of paving mixture, Gmm, the effective specific gravity of the aggregate which includes all the void spaces in the aggregate particles except those that absorb asphalt is determined by using Eq 2.2

$$G_{se} = \frac{Pmm - P_b}{\frac{Pmm}{G_{mm}} - \frac{P_b}{G_b}} \qquad (2.2)$$

Where,

G_{se} = Effective specific gravity of aggregate

G_{mm} = Maximum specific gravity of paving mixture

Pmm = Percent by mass of total loose mixture (100)

P_b = Asphalt content, percent by mass of total loose mixture

G_b = Specific gravity of asphalt

- **Maximum Specific Gravity of mixture (G_{mm})**

It can be defined as the ratio of mass of unit volume of bituminous mixtures in loose form at a given temperature to the mass of equal volume of gas-free distilled water at a given temperature. Maximum specific gravity of mixture can be determined by using Eq 2.3.

$$G_{mm} = \frac{Pmm}{\frac{Ps}{G_{se}} + \frac{P_b}{G_b}} \tag{2.3}$$

Where,

G_{mm} = Maximum specific gravity of bituminous paving mixture

P_{mm} = Total loose mixture

P_s = Percent aggregate by total weight of the mixture

P_b = Percent asphalt by total weight of the mixture

G_{se} = Effective specific gravity of the aggregate

G_b = Specific gravity of asphalt

- **Bulk Specific Gravity of Mixture (G_{mb})**

The bulk specific gravity is defined as the ratio of the mass in air of a unit volume of a compacted mixture of HMA at a stated temperature to the mass of an equal volume of gas-free distilled water at a stated temperature. Bulk Specific Gravity of mixture is determined by using Eq 2.4.

$$G_{mb} = \frac{Wd}{W_{ssd} - W_{sub}} \tag{2.4}$$

Where,

G_{mb} = Bulk specific gravity of mixture

W_d = Dry weight, grams

W_{ssd} = Saturated surface dry weight, grams

W_{sub} = Saturated surface dry weight submerged in water, grams

- ## Voids in Mineral Aggregates (VMA)

Voids in mineral aggregates or VMA can be defined as the intergranular space between the aggregate particles of compacted mix which includes air voids and effective asphalt content Eq 2.5 can be used to determine the VMA.

$$VMA = 100 - \frac{G_{mb}P_s}{G_{sb}} \quad (2.5)$$

Where,

V_{ma} = Voids in mineral aggregate.

G_{mb} = Bulk specific gravity of the mixture

P_s = Aggregate content percent by total weight of the mixture

G_{sb} = Bulk specific gravity of the total aggregate

- **Percent Air Voids (Va)**

Air voids can be defined as the total volume of small air spaces between the coated aggregates particles in compacted mixtures. Percent air voids can be determined by using Eq 2.6.

$$V_a = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}} \quad (2.6)$$

Where,

V_a = Air voids in compacted mixture.

G_{mm} = Maximum specific gravity of the mixture

G_{mb} = Bulk specific gravity of the mixture

- **Voids Filled with Asphalt (VFA)**

VFA can be defined as the portion of the voids in the mineral aggregates that contains asphalt content. VFA is inversely proportional to air voids as air voids decreases the VFA increases and it can be determined by using Eq 2.7.

$$VFA = \frac{100\,(VMA - Va)}{VMA} \quad (2.7)$$

Where,

VFA = Voids filled with asphalt.

VMA = Voids in mineral aggregate.

Va = Air voids in compacted mixture.

- **Stability and Flow Tests**

Stability portion of test measures the maximum load supported by test sample and during the loading the flow value is recorded on a dial gauge attached with.

2.9 Performance Tests

Following are different tests use to check the performance evaluation of Hot Mix Asphalt Mixtures.

2.9.1 Hamburg Wheel-tracking Test

This test is used for determining the risk of premature failure which mostly occurs due to the weakness of overall aggregate structure, inadequate stiffness of bitumen or the damages caused by moisture. This test actually measures the rut depth against the number of passes and this test is usually run in conformity with AASHTO T 324-11. The apparatus used for this test is shown in Figure 2.3.

- **Wheel-tracking Device**

It is an electrically controlled gadget which is equipped for moving a steel wheel of about 8 in diameter 1.85 in width on the test sample. Approximately 185±5 lbs load is imposed by the wheel on sample.

- **Temperature Control System**

It consists of water bath it is capable of controlling the temperature within ± 2 °C (4 °F) over a range of 25 to 70 °C (77 to 158 °F). This water bath must have a mechanical circulating system to stabilize temperature within the tank carrying the specimen.

- **Rut Depth Measurement System**

Rut depth against the number of passes produced by the wheel is usually measure by the attached (LVDT) Linear Variable Differential Transducer having 20 mm as the minimum range.

- **Wheel Pass Counter**

It is a non-contacting solenoid, that counts each wheel passes over the specimen. The signal from this counter is coupled to the rut depth measurement system which allows the rut depth to be expressed as a fraction of the wheel passes.

- **Specimen Mounting System**

It is a stainless steel tray which can be mounted rigidly to the machine in the water bath. This mounting is used to restrict shifting of the specimen during wheel movements. It must suspend the specimen and allow a free circulation of the water on all sides.

Figure 2.3: Hamburg Wheel Tracking Machine

2.9.2 Indirect Tensile Strength Test

This test is normally conducted in UTM machine as shown in figure 3.12 in conformity with ASTM D6391 standards. Two salient features of asphalt mixture can be determined by conducting this test. Determination of moisture susceptibility of asphalt mixture and is usually done by measuring the indirect tensile strength of sample, before and after sample conditioning in water. Second property is determination of tensile strain at failure which further assess the cracking potential of asphalt mixtures. An HMA mixture with high tensile strain till failure is more likely to be more resistant to cracking. While performing this test a compressive load is applied along the vertical diametric plane to a cylindrical sample. For sample having 4 inch diameter 0.5 inch wide loading strip is used to provide uniform loading and uniform stress distribution in a direction perpendicular to load. Deformation rate of 50 mm/min is specified for 4 inch diameter sample at 25°C and if the diameter of sample is 6 inches then the applied deformation rate is 76.2 mm/min. The test conducted in UTM is shown in figure 2.4.

2.9.3 Resilient Modulus Test (MR)

Resilient modulus is define as the ratio of applied stress to strain it is an important design parameter for good pavement system.

$$M_R = \frac{\sigma_d}{\varepsilon_r} \quad (2.8)$$

σ_d = Deviator Stress

ε_r = Recoverable Strain

Resilient modulus test is performed after determination of indirect tensile strength of sample through ITS test according to the ASTM standard only 5 to 20 percent of indirect tensile strength is used as a peak loading force as an input parameter during the test the reason being that due to non elastic behavior of mixtures they would experience permanent deformation when greater load is applied. In order to avoid this issue the applied load is always kept small then the failure load of the sample it will make the deformation almost recoverable.

Resilient modulus of the mixtures can be determined by using other tests like beam flexural test, uniaxial tension and compression test, indirect tensile strength test and tri-axial compression test but most prominent are the results of ITS test. The advantages of this test over the other are as follows.

- It is relatively simple and can be easily managed.
- Properties like tensile strength, Poisson's ratio, and permanent deformation and fatigue characteristics can be checked.
- Fracture started in area having same stresses.
- For testing samples of different diameters can be used.
- For testing samples similar to marshall test sample can be used.

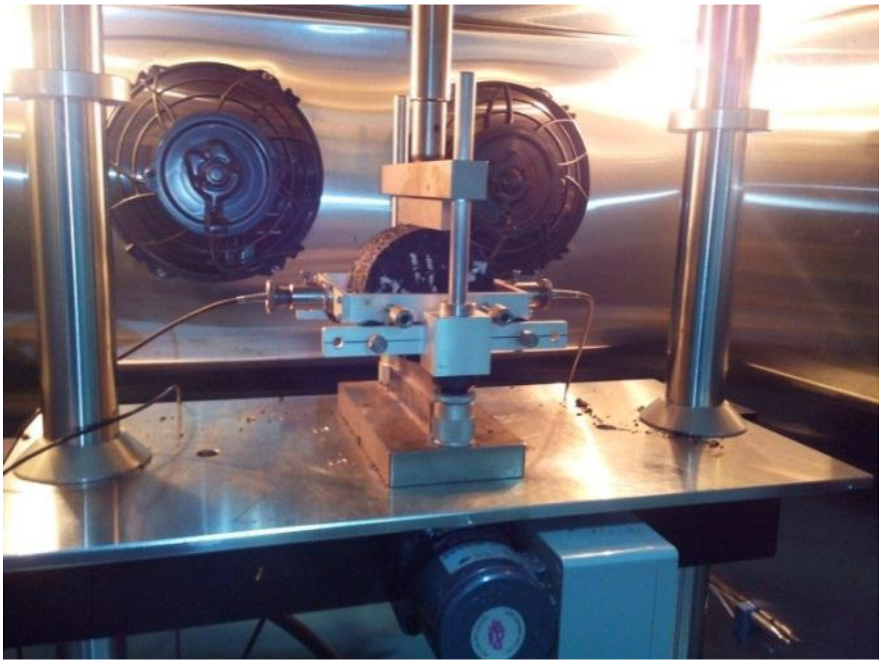


Figure 2.4: UTM for IDT Test and Resilient Modulus Test

2.9.4 Dynamic Modulus Test

"The complex modulus is defined as the complex number that relates stress and strain for a linear visco elastic material subjected to sinusoidal loading, the absolute value of complex modulus is commonly called as dynamic modulus". The two properties determined from complex modulus testing are dynamic modulus (E*), and phase angle (Ø). The dynamic modulus is a main input parameter for mechanistic empirical pavement design guide (MEPDG) of hot mix asphalt (HMA) due to which this property has gained more attention recently. Dynamic modulus can be determined by temperature and loading rate-dependent actions of Hot mix asphalt in MEPDG. In dynamic modulus test deformation are measured by application of sinusoidal loads. The ratio of stress to the strain amplitude is termed as dynamic modulus. The apparatus used for determination of this test is shown in figure 2.5.

$$|E^*| = \frac{\sigma_\circ}{\epsilon_\circ} \qquad (2.9)$$

Where,

$|E^*|$ = Dynamic modulus in psi

$\sigma_\circ$= Peak-to-peak stress amplitude in psi

$\epsilon_\circ$ = Peak to peak strain amplitude in inches/inch.

The phase angle is determined from equation 2.10

$$\text{Ø} = 2\pi f \Delta t \qquad (2.10)$$

Where,

Ø = Phase angle in radians

F = Frequency in Hz

Δt = Time lag between stress & strain in seconds

Figure 2.5: AMPT for Dynamic Modulus Test

2.10 Research Findings

Baha et al. (2015) investigated research on evaluation of crumb rubber and paraffin modified stone mastic asphalt. The aim of research was to analyze and compare the features of stone mastic asphalt prepared with crumb rubber and paraffin modifier mixtures. In his study he compared the various properties of rubber modified mixtures with unmodified mixtures such as moisture susceptibility, rutting, resistance to fatigue. Based upon the results he concluded that crumb rubber modified mixture show more elastic behavior in comparison with unmodified mixture. He also concluded that the mixture having 10% crumb rubber and 3% paraffin shows better results in terms of resistance to fatigue and permanent deformation.

Daryoush et al. (2015) carried out a research on impact of modification of rubber modified mixture and rheological properties of modified binder. In his research he added five different amount of rubber content 4%, 8%, 12%, 16%, 20% with ARL 60/70 (Pure binder) and tests were performed on rotational viscometer and DSR. Based upon the results he concluded that the asphalt mixture with crumb rubber in mass percent greater than 8 shows one or two degree improvement as compared to the pure asphalt binder. He also concluded that with the modification of asphalt mixture with crumb rubber will increase its viscosity.

Peiman et al. (2015) conducted a study on various sizes of crumb rubber modifier. The research aims to evaluate the characterization of mixture by adding 15% modifier by weight of bitumen. He has used four different size of crumb rubber in his research which are coarse (1mm-600μm), medium size (600μm-300μ m), fine (300μm-150μm); and superfine (150μm-75μm).The conventional tests are performed on the specimens and based upon the results he concluded that that the penetration value and softening point of modified bitumen gives better results as compare to the plain bitumen and the sample prepared with crumb rubber size (0.3-0.15mm) gives highest stability value, minimum flow value, maximum unit weight, maximum air voids and minimum VMA and VFB% values. So he recommends (0.3-0.15mm) the best crumb rubber size to be used in modification.

Louisiana et al. (2014) conducted study on rubber modified mixtures. The research focuses on evaluation of modified mixtures and unmodified mixtures through stability and flow test, ITS and resilient modulus test. Based upon the results he concluded that the unmodified mixture shows excessive laboratory strength features than modified mixture but the pavement section modified with crumb rubber indicated good performance in terms of rutting, fatigue cracks and IRI.

Giulio et al. (2014) conducted a study on modification of crumb rubber mixture which contains 100% cold recycled RAP with asphalt emulsion and cement. Ambient productive modifier and the modifier produced by cryogenic process were used. The objective focuses on physical and mechanical features of modifier motivated by the two different method. He also concluded that self compaction of HMA is achieved with replacement of fine RAP with rubber modifier. the replacement of the fine RAP with crumb rubber improved the self compaction of the mixtures and also effect the volumetric properties of mixture after compaction.

Adnan et al. (2014) conducted a study on characterization of asphalt mixtures using bakelite as modifier through wheel tracker and dynamic modulus test. Based upon the results he concluded that with modification of bakelite a significant improvement in performance is noted. Approximately 29% reduction in rut depth is noted by addition of 6% bakelite content with mixture of NHA class A gradation and 38% improvement were observed for NHA class B gradation in comparison with unmodified mixtures. Similarly the 36% increase in dynamic modulus was observed in mixture of class A gradation and 46% for mixture of class B gradation at 50^{o}C temperature.

Hassan et al. (2014) carried out a research on characterization of asphalt mixtures in terms of Rut Resistant using Flow test and Resilient Modulus test. He collected seven plant-produced HMA mixtures and prepared two HMA mixtures in the laboratory for the purpose of performance characterization. Based upon the results he concluded that the asphaltic mixtures produced at plant were found to be more resistant towards flow characteristics (less accumulated strains) as compared to the lab prepared mixtures. The results of the resilient modulus tests come out to be in a good evenness as compare to the flow tests.

Yousaf et al. (2014) study the asphalt mixture using Bakelite as modifier through Resilient Modulus Test, Marshall Stability, flow and retained stability test. Based upon the results he concluded that modified mix containing 6% Bakelite by weight of optimum bitumen content provides best resistance against moisture damage, rutting and increase the stability of asphalt concrete, than the other modifier percentages. In the end resilient modulus test was performed under variable Bakelite (0% & 6%), temperature (25˚C & 40˚C) and load duration (100 ms & 300 ms) conditions. Based upon the laboratory experiments and analysis he also concluded that addition of Bakelite as an additive in hot mix asphalt mixes gives better results regarding pavement performance.

Omer et al. (2014) conducted a study on evaluation of rubber modified mixtures. In his research he used two types of binder 60/70 and 80/100 of ARL source. He characterized the performance on the basis of wheel tracker, ITS and resilient modulus test. The results indicated that 8% modifier with 60/70 and 12% modifier with 80/100 shows more resilient modulus values and least rut susceptible values.

Francisco et al. (2013) Investigated the interaction of rubber modifier and asphalt binder in mixture by microscopic analysis. The objective focuses on evaluation of rubber modified mixtures using dry process. Modification includes transfer of maltenes to the rubber and carbon black to the bitumen due to which the stiffness properties of the bitumen enhanced. He concluded that the modification tends to reduce the fatigue cracking and also make the binder more resistant to rutting.

Atlan et al. (2013) carried out a research on performance of HMA with varying sizes of modifier. The objective of his research focuses on size distribution effect and concentration of crumb rubber on the performance of porous asphalt mixture. The mixtures were modified by dry process using crumb rubber in three different size distributions of #4-#20, #20-#200, and #4-#200 and rubber content of 10%, 15%, and 20% as weight of optimum binder. Various laboratory tests were conducted on the sample and then he concluded that #20 - #200 sized rubber particles reduced air voids and coefficient of permeability while an increased in Cantabro abrasion loss is noted. Generally when the crumb rubber size increases there is a decrease in performance properties of porous asphalt mixture.

Mojtaba et al. (2013) Conducted a study on crumb rubber modified HMA using recycled glass powder. The objective focus on the efficiency of rubber modified asphalt mixtures. The use of RGP shows a very good behavior from an environmental point of view because it prevents the accumulation of waste glass in the environment. The rheological properties of modified asphalt mixture were studied by different laboratory tests which include bitumen conventional tests, Dynamic Shear Rheometer, Stability test, ITS Test, Compressive Strength and Resilient Modulus. The results indicated that with use of RGP instead of CR there is a good impact on the properties of bitumen and Asphalt mixture except for the toughness index. He also concluded that with a use of 5% RGP and 5% CR in asphalt mixture it shows overall good performance.

Hainian et al. (2013) carried out a research on fatigue cracks occurs in crumb rubber modified HMA. The objective focuses on the study of fatigue cracking property of asphalt mixture. Semi circular bending test was performed for achieving the objective and the influence of gradation type, asphalt content, test temperature, stress ratio, loading frequency, fatigue life and crack growth laws were studied by this method. The results showed that the gap graded CRM asphalt mixture had a longer fatigue life and a lower crack growth rate then the continuous graded mixture. At optimum content i.e. 20% rubber concentration the fatigue life was much longer and crack growth rate was much lower at smaller loading time with higher loading frequency.

S.E Paje et al. (2013) conducted a study on rehabilitation of pavement by using higher content of rubber modified binder. The research focus on the examination of higher content of rubber modifier manufactured by wet process on the surface of HMA. 20% of modifier by weight of asphalt binder was added with gap graded mix. After investigation he finally concluded that the noise emitted by tire is reduced by using higher content of rubber modified binder.

Hainian et al. (2012) carried out a research to investigate the effect of warm mixture asphalt additive on the properties of crumb rubber modified binder. The research include includes Sasobit, RH and Advera, and different content of modifier are 10%, 15%, 20% and 25% modifier by weight of bitumen are used. To achieve the goal phase angle was measured by using dynamic shear rheometer at different temperature. The results indicated that these WMA additives could all improve modified binder resistance against rutting potential and enhanced the higher temperature portion of PG binder. He also concluded that Sasobit has a significant effect on dynamic modulus of aged and unaged binder.

F Moreno et al. (2011) carried out a research on performance of crumb rubber modified HMA blend by dry process. There are two methods for adding crumb rubber with bituminous mixes i.e. Dry method and Wet method, The dry method has less popular because it has initially shown poor results. The objective focus on development of technique which improves the application of this method by examining the effect of rubber content and digestion time. The objective is achieved by conducting moisture sensitivity test and wheel tracker test. From the results of these two tests he concluded that with the use of 0.5 and 1% rubber content and a digestion time of 45 min leads in to the best performance of mixtures.

Ruikun et al. (2011) carried out a research on modification of asphalt mixture with Devulcanized Crumb-Rubber Modified Asphalt. The objective focuses on evaluation of asphalt mixture properties modified with DCRMA with different proportions through wheel tracker, stability, dynamic modulus and flexural fatigue test. From the experimental outputs he concluded that the DCRMA mixtures shows good performance in resistance against rutting potential, moisture susceptibility, anti cracking and anti fatigue. It also proves to be cost-effective modifier in dense graded HMA.

Li Xiang et al. (2009) conducted a study on characterization of rubber modified asphalt mixtures. Matrix asphalt preblending process was used for the preparation of mixture in this research. The objective focus on investigation of the effects of proportion of preblending matrix asphalt and properties of crumb rubber. Fluorescene and scanning electronic microscope were adopted for characterization purpose. The results indicated that CRMA has better performance than matrix asphalt.

Salman et al. (2008) conducted a study on crumb rubber modified mixture. The objective of research focus on determination of effects of different temperature on modified mixtures as compare to unmodified mixtures through resilient modulus test. Based upon the results he concluded that crumb rubber modified mixture shows excellent performance and its Resilient Modulus values are as high as 40% when compared with Conventional Mix.

Soon et al. (2007) investigated the performance of asphalt mixtures modified with crumb rubber**.** The objective was to study the properties of modified binder through various laboratory tests which includes viscosity test at high temperature, cracking and performance properties at low, high and intermediate temperature. The results shown that with the use of higher percentage of crumb rubber higher viscosity and greater resistance against rutting potential and low chance for cracking is achieved.

2.11 SUMMARY

This chapter discussed the Asphalt Wearing Course their functions and different types of failures associated. Then modification of bitumen is discussed and the focus is towards the use of different types of modification of bitumen in Pakistan. Afterwards the performance tests i.e. Wheel Tracker, Resilient Modulus and Dynamic Modulus Tests are discussed, and at the end related research findings with this research are quoted.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 GENERAL

This chapter portrays the philosophy embraced to accomplish the goals. Research Work is carried out in two phase approach (1) Laboratory prepared asphalt mixtures (2) Plant produced asphalt mixtures. In the first phase the performance tests i.e. Wheel Tracker, Dynamic and Resilient Modulus tests were performed on laboratory prepared gyratory compacted samples and in second phase performance tests were directed on plant produced gyratory compacted samples.

For the first phase the Job Mix Formula (JMF) for unmodified and modified bitumen was taken from NHA that was being used in Overlay and Modernization of Islamabad to Lahore Motorway (M-2). Using that JMF the asphalt mixtures were prepared in the laboratory and was then compacted using Superpave gyratory compactor and then the performance tests were conducted. For the Second phase the asphalt mixtures were collected from the plant being produced for M-2 project and it was then brought to NIT laboratory and was reheated at desired temperature and then compacted using Superpave gyratory compactor. The performance tests were conducted on the compacted Specimens.

3.2 RESEARCH METHODOLOGY

The complete Research Work is explained in figure 3.1. First of all selection of material was done. Then the conventional tests were conducted on the aggregates and binder as per guidelines of AASHTO and ASTM. In the next step the volumetric properties of the mix were determined as per designed optimum binder content. In the next step Samples were prepared and Performance tests i.e. wheel tracker, dynamic modulus and resilient modulus tests were conducted on the prepared samples, then statistical analysis was done on dynamic modulus values and at last the conclusions and recommendations were made.

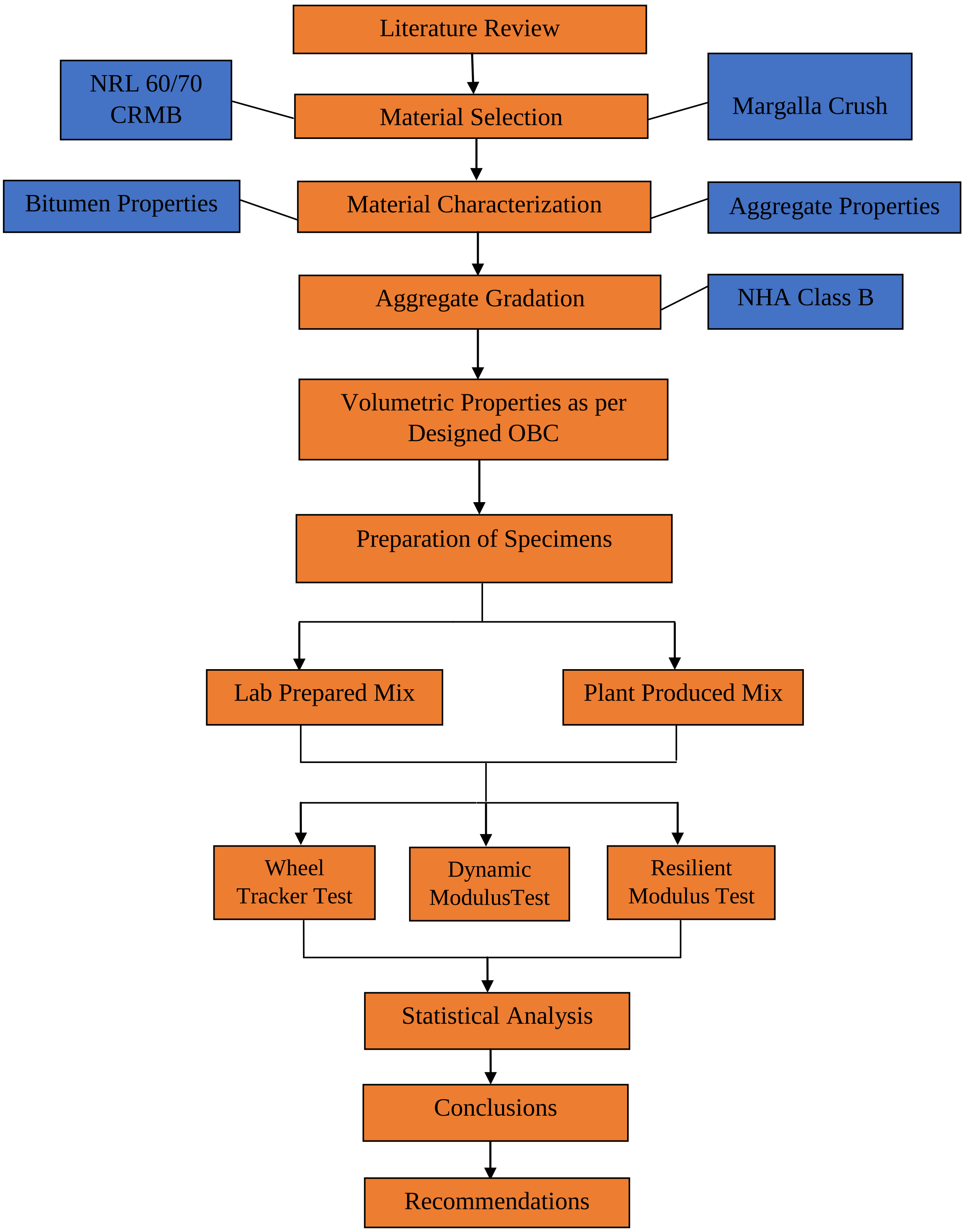


Figure 3.1: Research Methodology

3.3 MATERIAL SELECTION

As mentioned earlier this research is carried out in two phases. For the first phase the material was collected from the plant and it was then brought into laboratory. The aggregates used were of Margalla source and the source for binder was National Refinery Limited (NRL). Three types of aggregate sizes were used i.e. 0-5, 5-10 and 10-20 mm and the penetration grade 60/70 was selected. The reason for selecting this penetration grade was that it is commonly used bitumen grade across Pakistan and is suitable for colder to moderate temperature regions and secondly the performance grade 70/16 is used on M-2 Project, for obtaining the required performance grade the penetration grade 60/70 is mixed with 7% crumb Rubber. For the second phase the plant produced mixtures were collected and brought into laboratory.

3.3.1 Laboratory Characterization of Material

After selection of material next task was to distinguish the material according to the specifications. Researchers have concluded that aggregate structure provides higher resistance to rutting in asphalt mixtures. It has also been observed that aggregate gradation and other properties have a significant influence on asphalt mixtures. The suitability for aggregates and bitumen binder for use in preparing bituminous paving mixes needs to be checked. Tests were conducted on the aggregates of Margalla quarry and asphalt binder of NRL 60/70 and the results were verified according to the ASTM and AASHTO standards as shown in table 3.1 and 3.2 respectively.

Test Name	Designation	Specifications	Test Results
Flakiness Index	BS 812	15% (Maximum)	5.8%
Elongation Index			5.2%
Soundness	AASHTO T-104	12% (Maximum)	3.27%
Los Angeles Abrasion	AASHTO T-166	30% (Maximum)	21.8%

Table 3.1: Lab Tests Performed on Aggregates

Test Name	Designation	Specifications	Test Results
Penetration (mm)	AASHTO T 49-93	60-70	62
Flash Point (^{o}c)	AASHTO T48	232 ^{o}C (Minimum)	302 ^{o}C
Fire Point (^{o}c)	AASHTO T48		305 ^{o}C

Specific Gravity	AASHTO T 228	(ASTM) 1.02-1.05	1.03
Softening Point (^{o}c)	AASHTO T 53-92	46-56	50 ^{o}C
Ductility (cm)	AASHTO T 51-93	>100	104
Solubility in trichloroethylene	AASHTO T 44	99 (Minimum)	99.2

Table 3.2: Lab Tests Performed on Asphalt Binder

3.3.2 Aggregate Gradation

For obtaining the required gradation, the combination of aggregate is the most important step of asphalt mixtures design. In Pakistan the maximum size used in highways is related with specific layer thickness. Pakistan's National Highway Authority has specified class A and B gradation respectively for wearing coarse and base coarse. Therefore in this research work the same gradation curve i.e. Class B was selected being used in M-2 Project. The selected gradations are shown in table 3.3 and figure 3.2.

Sieve Size		**Sieve Power 0.45 Gradation**	**JMF Limits**		**Selected % Passing**
(mm)	**(U.S.)**		**Upper**	**Lower**	
19	¾ In	3.76	100	100	100
12.5	½ In	3.12	90	76	83.2
9.5	3/8 In	2.75	77	63	69.8
4.75	No.4	2.02	54	46	49.6
2.36	No.8	1.47	34	26	29.6
0.3	No.50	0.58	15	7	10.2
0.075	No.200	0.31	7	5	5.8

Table 3.3: Class B Gradation Selected for Testing

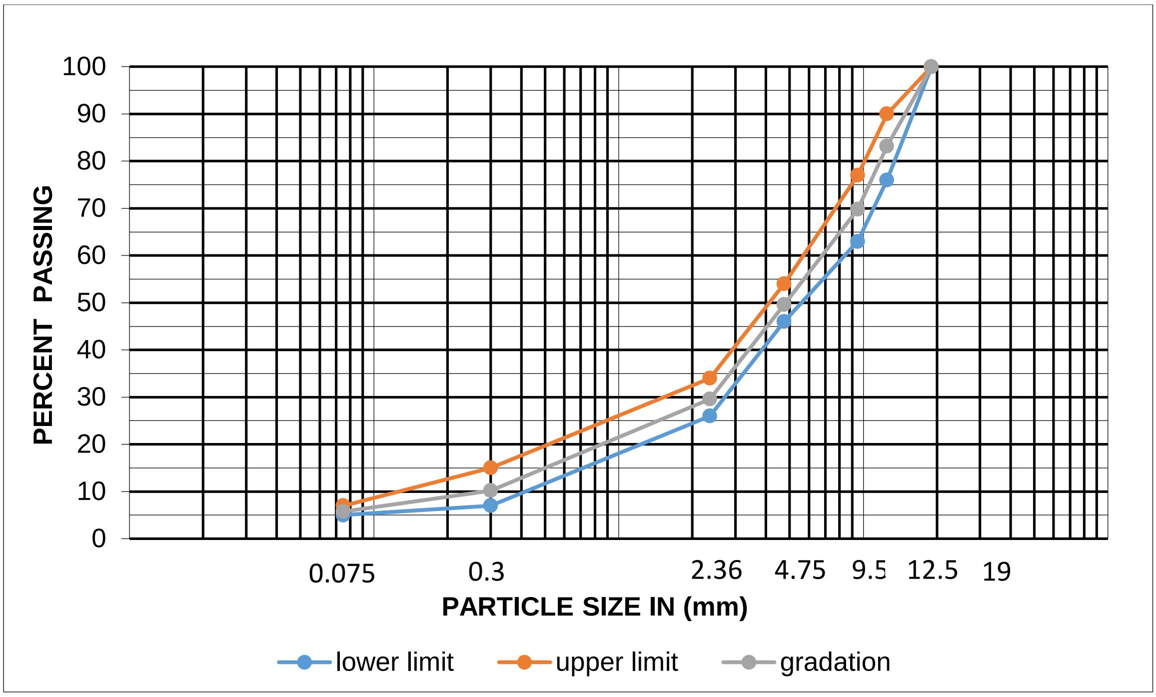


Figure 3.2: Class B Gradation with NHA Specified JMF Limits

3.4 PREPARATION OF ASPHALT MIXTURES

As mentioned earlier this research work is carried out in two phases i.e. Lab prepared and Plant produced HMA. The component of these mixtures are clarified in the accompanying headings.

3.4.1. Laboratory Prepared Asphalt Mixtures

In laboratory the mixtures of aggregates and bitumen were prepared on designed optimum binder content (OBC) i.e. the optimum binder content designed for Overlay and Modernization of Islamabad To Lahore Motorway (M-2) project. In M-2 project the OBC for NRL 60/70 was 4.3% and for NRL 60/70 modified with 7% crumb rubber was 4.6%. Using the same OBC the samples were prepared in the Laboratory.

3.4.1.1 Preparation of Materials

Three different sizes of materials were collected and brought into laboratory 0-5, 5-10 and 10-20mm. These different sizes of aggregates were sieved to get the required size of aggregates according to NHA Class B Gradation. These aggregates were dried to consistent weight by placing it in an oven at a temperature of 105 to 110^{o}C for about one to two hours as shown in figure 3.3. The quantity of aggregates used for preparing 6 inches diameter each specimen by Marshall Mix design method was 4400 grams. The amount of binder content used for preparing each sample was calculated by using equation 3.2.

$$MT = Ma + Mb \quad (3.1)$$

$$Mb = \frac{X}{100}(Ma) \quad (3.2)$$

Where,

MT = Mass of Total mix

Ma = Mass of Aggregates

Mb = Mass of Bitumen

X = Percentage of Bitumen

Figure 3.3: Heating Aggregates Before Mixing

Figure 3.4: Heating Bitumen Binder Before Mixing

3.4.1.2 Mixing of Aggregates and Bitumen

Mechanical mixer is recommended by Marshall Mix design manual (MS-2) for mixing the aggregates and bitumen binder as shown in figure 3.5. The purpose of using mechanical mixer is that it provides proper mixing of aggregates and bitumen binder. The oven dried aggregates and binder was transferred into the mixer and was mixed thoroughly for about 10 to 15 minutes at a temperature ranging from 160 to 165^{o}C respectively it correlates to the temperature during manufacturing of asphalt mixtures in Pakistan as specified by NHA shown in figure 3.6.

Figure 3.5: Mechanical Mixing Machine

Figure 3.6: Mixing of Mixtures

3.4.1.3 Conditioning

Marshall Mix Design Manual (MS-2) recommends conditioning of Asphalt mixtures for about 2 hours before compaction. Therefore, the mixtures taken from mechanical mixer as shown in figure 3.7 were put in a steel tray and placed it in an oven for about two hours at 135^{o}C as shown in figure 3.8.

Figure 3.7: Mixed HMA

Figure 3.8: Loose Mixtures

3.4.1.4 Compaction of Mixture

After the conditioning the mixtures were then compacted using Superpave gyratory compactor at 135 ^{o}C. But before compaction the mould into which the mixtures were placed was thoroughly cleaned and kept in an oven at about 100 ^oC for 30 minutes. Before purring the mixtures into mould filter paper was placed at the bottom of mould as shown in figure 3.9 and the second filter paper was placed immediately above the mixtures and then the mould was taken into gyratory compactor shown in figure 3.10.

Figure 3.9: Compaction Mold

Figure 3.10: Gyratory Compactor

The asphalt mixtures were compacted to designed air voids i.e. 4% and it can be achieved at 125 gyrations (N_{design}), design ESALs ≥ 30 million was adopted as traffic criteria. After compaction the sample was extracted from the mould shown in figure 3.11. Compacted sample is shown in figure 3.12.

Figure 3.11:Extraction of Sample

Figure 3.12: Compacted Sample

3.4.2. Plant Produced Asphalt Mixtures

The asphalt mixtures collected from the site were brought into laboratory and then reheated for an hour to homogenize the temperature of aggregates and asphalt, as during production these mixtures have been already aged, and then mixed in a mechanical mixer at a temperature of about 165℃. The mixtures were then put into the mould and was then compacted at 125 gyrations (N_{design}) to the designed targeted air voids and prepared the required samples.

3.4.3. Volumetric Properties of HMA Mixtures

Various volumetric properties of the samples prepared in the laboratory on designed optimum binder content of both types i.e. with modifier and without modifier was determined and checked in the light of specifications. Table 3.4 shows the JMF of AWC without modifier and Table 3.5 shows the JMF of AWC with modifier.

Volumetric Properties	Values	Specifications	Remarks
OBC (%)	4.3		
Air Voids, AV (%)	5.6	4—7	
VMA (%)	15	14 Min	Pass
VFA (%)	61.1		
Stability (Kg)	1300	1000 Min	Pass
Flow	10.1	8—14	Pass

Table 3.4: JMF of asphalt mixtures without modifier

Volumetric Properties	Values	Specifications	Remarks
OBC (%)	4.6		
Air Voids, AV (%)	4.96	4—7	
VMA (%)	14	14 Min	Pass
VFA (%)	67.1		
Stability (Kg)	1400	1000 Min	Pass
Flow	9.8	8—14	Pass

Table 3.5: JMF of asphalt mixtures with modifier

3.5 SAMPLE PREPARATION FOR PERFORMANCE TEST

Using the Job mix formula obtained from Marshall Mix Design the samples were prepared for performance tests. In the first phase samples were prepared from laboratory prepared mixtures the optimum binder content was designed as 4.3% for NRL 60/70 and 4.6% for NRL 60/70 with modifier. The quantity of aggregates required for dynamic modulus and resilient modulus test was 7000 grams and the quantity of aggregates required for wheel tracker test was 4500 grams. All the samples were compacted using gyratory compactor according to AASHTO T 62 the compaction of specimen was controlled by providing 125 gyrations. For the first phase 24 specimens were prepared out of which 12 samples were prepared with virgin NRL 60/70 and the remaining 12 were prepared with modifier. Out of total samples 8 samples were selected for wheel tracker test, 10 specimens were selected for dynamic modulus test and 8 specimens were selected for resilient modulus test. All the specimens were of height 188mm and 150 mm diameter. For dynamic modulus test the selected specimens were cored to reduce the diameter from 6 inches to 4 inches and it was then further saw cut to obtain a standard height of about 6 inch presented in figure 3.13. The remaining specimens for other two tests were only saw cut to obtain a height of 1.5 inch and 6 inch diameter. Figure 3.14 shows the specimen for wheel tracker test.

Figure 3.13: Cored Sample for Dynamic Modulus Test

Figure 3.14: Saw Cut Sample for Wheel Tracker Test

For the second phase the plant produced mix is collected and brought into laboratory it was then reheated to homogenize the condition and then the specimens were prepared using Superpave gyratory Compactor. For this phase 24 samples were prepared out of which 12 samples were prepared with virgin NRL 60/70 and 12 samples were prepared with crumb rubber modifier. Out of total specimens 4 were selected for wheel tracker test, 12 were selected for dynamic modulus test and 8 were selected for resilient modulus test. For dynamic modulus test the coring and cutting of the specimens were done in the same manner as explained above.

3.6 WHEEL TRACKER TEST

This test was used for determining permanent deformation in asphalt mixtures which is generally due to weakness of the aggregate structure, having inadequate bitumen stiffness, or moisture damage. This test usually measures the rut depth against the number of passes. The test is usually conducted with reference to AASHTO T 324-11. The apparatus used for this test is presented in figure 3.15. Wheel tracker is an electrically controlled gadget which is fit for moving 202.3 mm distance across 46 mm expansive steel wheel over a test sample. The load on the steel wheel is 158+4.0 lb and the normal contact stress delivered by the contact of wheel is roughly 0.72 MPA with a contact region around 971 mm^2. The weight induced by the steel wheel makes the same impact as brought on by the back tire of double axle truck. With increase in rut depth the contact area increase as a result of which the contact stress become variable. The steel wheel moves over the sample in forward and backward direction. The steel wheel approximately completes 50 passes over the sample per minute. The most extreme rate is 1 ft/sec roughly which is come to at the midpoint of test. By using this equipment this test can be done with various modes such as Air, Wet and Dry.

Figure3.15:Hamburg Wheel Tracker Machine

Before conducting the test the sample were prepared i.e. it was saw cut at the bottom and top face to obtain a sample having a standard dimensions recommended by the standard i.e. 1.5 inch thick and 6 inch diameter. These samples were then cut in accordance with silicon mould of wheel tracker tray. With Plaster of Paris the extra spaces were filled after placing the sample in mould to prevent the sample movement with wheel passes. The steel tray having the sample mounted was placed under the wheel and fixed. The test equipment was on and the details of sample were entered in the software. 50 ppm were adjusted to be the speed of wheel and 20,000 were the number of passes. Wet mode of wheel tracker device was selected and finally the test was run when the target temperature was achieved and the wheel started moving in forward and backward direction over the mounted sample. One complete forward and backward movement of the wheel was taken as 2 passes. At the same time with movement of wheel the LVDT measures the rut depth in millimeters. The machine automatically stopped when the target number of passes was achieved and results were saved for further usage.

The software provides two types of results as an output.

Graph: It shows the number of passes and rut depth in mm.

Excel sheet data: It provides the numerical information of the rut depth at 11 points of the wheel path.

3.7 RESILIENT MODULUS TEST

Indirect tension test was done prior to the determination of resilient modulus of HMA. The test was done by using (UTM–25) Universal Testing Machine. Indirect tensile strength of asphaltic paving mixes was determined before resilient modulus in the following order.

3.7.1 Indirect Tensile Strength Determination

Various tests such as uniaxial compression and tension, beam flexural test, tri axial compression test and indirect tension test can be used for the determination of resilient modulus of asphalt mixtures but most prominent are the results of indirect tension test and also this test has many advantages over other tests which are as follows.

- It is relatively simple and can be easily managed.

- Properties like tensile strength, Poisson's ratio and permanent deformation and fatigue characteristics can be checked.
- Failure started in an area having same stresses.
- For testing samples of various diameters can be used.
- For testing the sample similar to marshall test sample can be used.

Resilient modulus test is performed after determination of indirect tensile strength of sample through ITS test according to the ASTM standard only 20% of indirect tensile strength is used as a peak loading force as an input parameter during the test the reason being that due to non elastic behavior of mixtures they would experience permanent deformation when greater load is applied. In order to avoid this issue the applied load is always kept small then the failure load of the sample it will make the deformation almost recoverable. Figure 3.16 shows the failure of sample during Indirect Tension test.

Figure 3.16: Failed Samples during IDT Test

3.7.2 JIG SETUP FOR RESILIENT MODULUS TEST

Resilient modulus test was directed after ITS test on the sample having diameter of 6 inch and thickness 2.5 inch. Resilient Modulus test was usually carried out on two test temperatures i.e. 25 and 40^{o}C. Figure 3.21 shows the accessories of jig for the test. The LVDTs are attached with jig used for measuring the displacement. The sample was then loosely fitted into the jig on the bottom loading platen. Figure 3.17 shows the accessories of jig and figure 3.18 shows the specimen fitted in jig setup for resilient modulus test.

Figure 3.17:Jig Set up

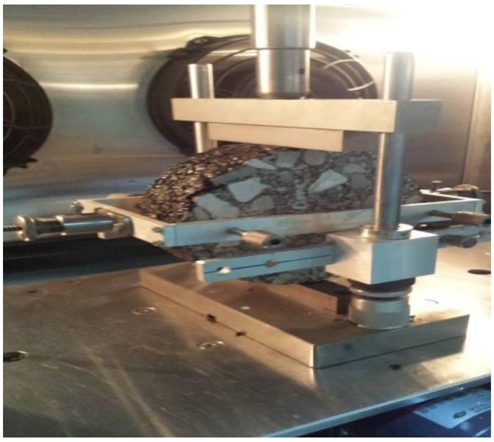


Figure 3.18: Resilient Modulus Test

The yoke support cross-arm was raised by lifting then turning the support spacers. The height of the support cross-arm was adjusted in such a way that the displacement transducers remain exactly in line with the horizontal center of the specimen. The displacement transducer yoke was then placed on the specimen and adjusted with the help of clamping screws so that the specimen sit centrally within the yoke. Knurled locking nuts on the clamps were tightened at one end of the specimen and slightly loosen the clamps at the other end. Top loading platen was then placed and lowered it onto the specimen as shown in Figure 3.18.

3.7.3 LOADING

After the jig setup, the jig was transferred into UTM and the LVDTs were installed and were adjusted as shown in figure 3.19. The levels display view helped to adjust the LVDTs. The virtual pendant window contains the functionality controlled the hydraulic power pack and service manifold of the machine. Therefore, by using axis jog control, the loading ram was lowered to such a level that it just a made contact with the jig but without applying any loading force. As specified by ASTM D7369, 20% of ITS was taken as peak loading force and 0.4 was assumed as the poison ratio.

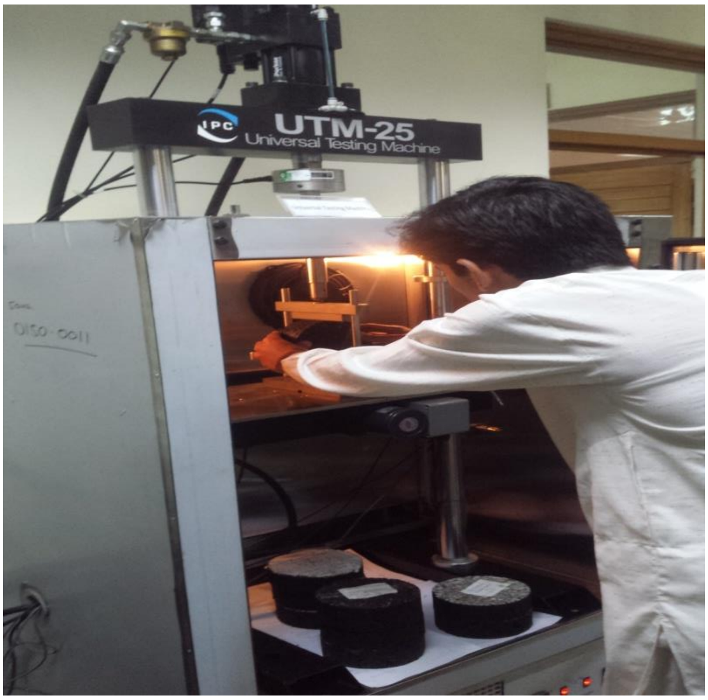


Figure 3.19: LVDTs Setup in UTM for Resilient Modulus Test

After inputting all the parameters required for running the test the specimen was subjected to haversine loading. The indirect tension modulus software charted and tabulated the force and displacement as the conditioning stage proceeded. At the end of the conditioning stage, i.e. after 100 conditioning pulses, the Levels display automatically invokes. The range of LVDTs is then to be adjusted again and thereby upon closing the Level display window, five pulses of nearly constant deformation are automatically applied to conclude the test.

3.7.4 RESULTS

When the load is applied over the sample the software records deflection and load readings for the last five pulses, resilient modulus is then determined by averaging those five readings.

3.7.5 INPUT PARAMETER

The following input parameters were provided to the software when the resilient modulus test was conducting on the specimen as per ASTM D4123.

- Peak Loading Force : 20% of IDT strength
- Seating Force : 10% of Peak Loading Force
- Poisson’s Ratio : 0.4

- Conditioning Pulses : 100
- M_R data collection pulses : 5

3.8 DYNAMIC MODULUS TEST

This test was conducted in conformity with AASHTO TP 62-07 . The Asphalt mix Performance tester (AMPT) was used for determination of dynamic modulus its other name is Simple Performance Tester (SPT). The AMPT consists of Tri axial cell, Pump, Environmental Chamber, Hydraulic Actuator, Refrigeration and heating unit with heat exchanger and data acquisition system.

Prior to placing the specimen in AMPT the studs were fixed using R-Bellite epoxy glue as shown in figure 3.20. Once the studs were fixed then clamps were fixed to each specimen. The purpose of this clamp is to accommodate the (LVDT's) Linear Variable Displacement Transducer which measures the axial deformation/strain during the test. Figure 3.21 shows the specimen having the LVDT'S attached.

Figure 3.20:Studs Fixed Sample

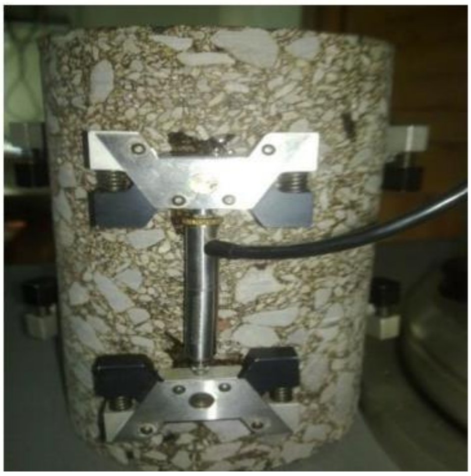


Figure 3.21: LVDT's Attached Sample

The sample was then placed in the environmental chamber and allowed to achieve the target temperature within $\pm$ 0.5 ^{o}C. Each sample was tested at 25, 40 and 55^{o}C using the following frequencies 25, 10, 5, 0.5 and 0.1 HZ respectively. The continuous uniaxial sinusoidal compressive stress was applied to the test sample. The deformation of the sample was measured using LVDT's fixed at 120^{o} apart. The final results were created by the software at the end of test and dynamic modulus were noted at corresponding frequencies.

3.9 SUMMARY

This chapter described the methodology adopted for this research work. The first part of this chapter explained the project and the sources where the materials were collected and was characterized in the laboratory. Then the volumetric properties of the mix were determined as per deigned OBC. In the second part the complete testing procedures adopted for different performance tests had explained.

CHAPTER 4

ANALYSIS OF EXPERIMENTAL RESULTS

4.1 GENERAL

This chapter portrays the results of the performance tests conducted on the samples and then the statistical analysis is done on the obtained results of dynamic modulus using MINITAB-15 software to find out the significant factors. Different factors like temperature, frequency, effectiveness of crumb rubber as an anti-rutting agent to reduce permanent deformation are discussed in detail. Statistical analysis mainly includes analysis of variance (ANOVA) and two way factorial design. Results from data analysis include normal plot, interaction plot, main effect plot, Pareto chart.

4.2 RUTTING PROPENSITY

Resistance against rutting potential can be assessed by comparison of measured rut depth obtained in modified and unmodified mixtures. In the first phase the samples were prepared from laboratory prepared mixtures and in the second phase the plant produced mixtures were brought into Lab and Gyratory compacted samples were prepared. Gyratory compacted samples were prepared with two proportions of crumb rubber (0% and 7%). Wheel tracker test was conducted on each unmodified and rubber modified sample at 40^{o}C temperature. A total of 8 samples were prepared with and without crumb rubber modification. Each sample was tested in wheel tracking machine. The results showed that all the unmodified samples shows good resistance to rutting whereas the rubber modified samples resistance to rutting was exceptional as compare to unmodified sample. All of the samples passed the wheel tracker test and the same behavior was observed in the plant produced mixtures.

4.2.1 WHEEL TRACKER TEST

The graphical software output of this test is shown in figure 4.1. The rut depth is located on y-axis and the x-axis shows the number of passes. Actual rut depth of the sample is represented by red line whereas the green line represent the failure criteria which was set as 12.5 mm. This test is usually conducted at 20000 wheel passes the reason being that after 10000 passes the sample will get moisture damage effect. Therefore for predicting the moisture damage effect the wheel passes generally greater then 20000 is required.

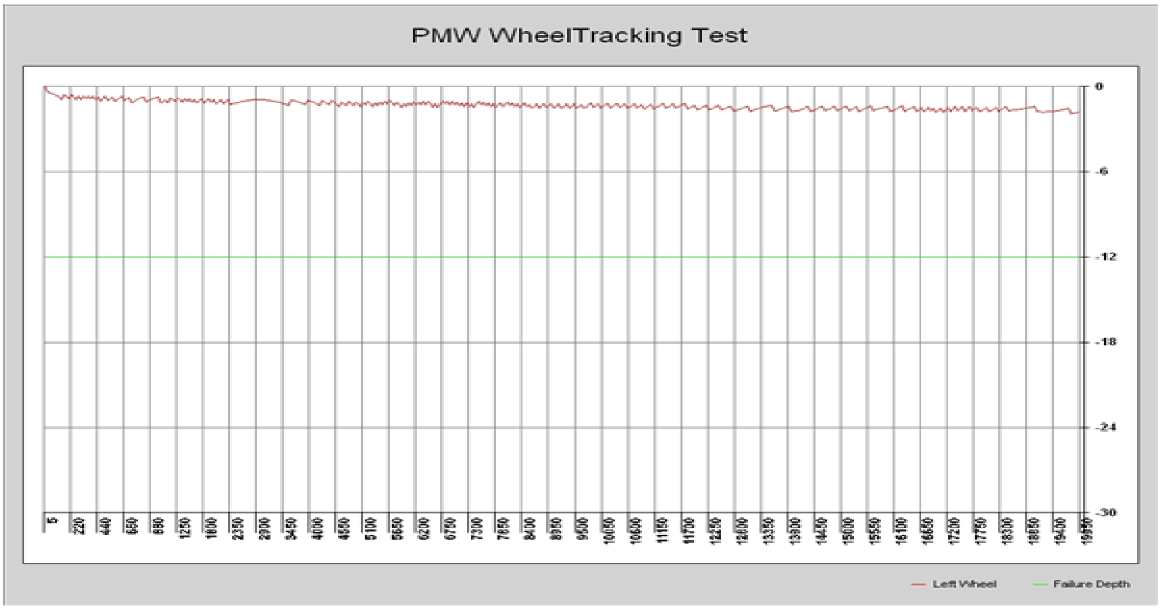


Figure 4.1: Graphical output of Wheel Tracker Test

4.2.2 RUTTING ASSESSMENT

The obtained results of wheel tracker test are evaluated by comparing the rut depth of rubber modified and unmodified mixtures. Rut depth of both type of mixtures are used to determine the percentage improvement of modified mixtures as compare to unmodified mixtures. Table 4.1 and 4.2 shows the percentage improvement in rutting for laboratory prepared asphalt mixtures and plant produced asphalt mixtures.

Rut Depth (mm)			
Sample	**Unmodified Mix**	**Modified Mix**	**Improvement (%)**
1	5.03	3.43	31.81
2	5.14	3.47	32.49
3	5.27	3.51	33.40

Table 4.1: Rut Depth of Lab Prepared Asphalt Mixtures

Rut Depth (mm)			
Specimen	**Unmodified Mix**	**Modified Mix**	**Improvement (%)**
1	6.07	4.68	22.90
2	6.13	4.74	22.68
3	6.21	4.79	22.87

Table 4.2: Rut Depth of Plant Produced Asphalt Mixtures

With addition of crumb rubber (7%) in asphalt mixtures the resistance to rutting is improved significantly. Table 4.1 shows that approximately 33% improvement is observed in rubber modified mixtures as compare to unmodified mixtures after 20,000 passes in case of lab prepared asphalt mixtures. Table 4.2 shows that the rubber modified mixtures resistance to rutting is improved up to 22% in comparison with unmodified mixtures in case of plant produced asphalt mixtures. Figure 4.2 and 4.3 shows the graphical view of specimens after rutting test.

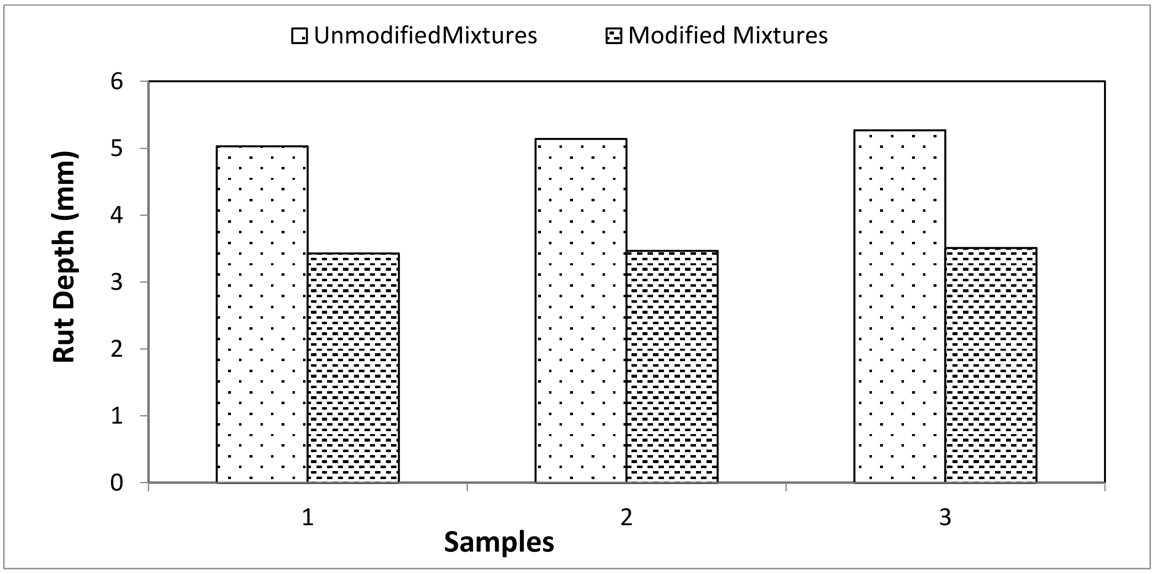


Figure 4.2: Rut Depth of Lab Prepared Asphalt Mixtures

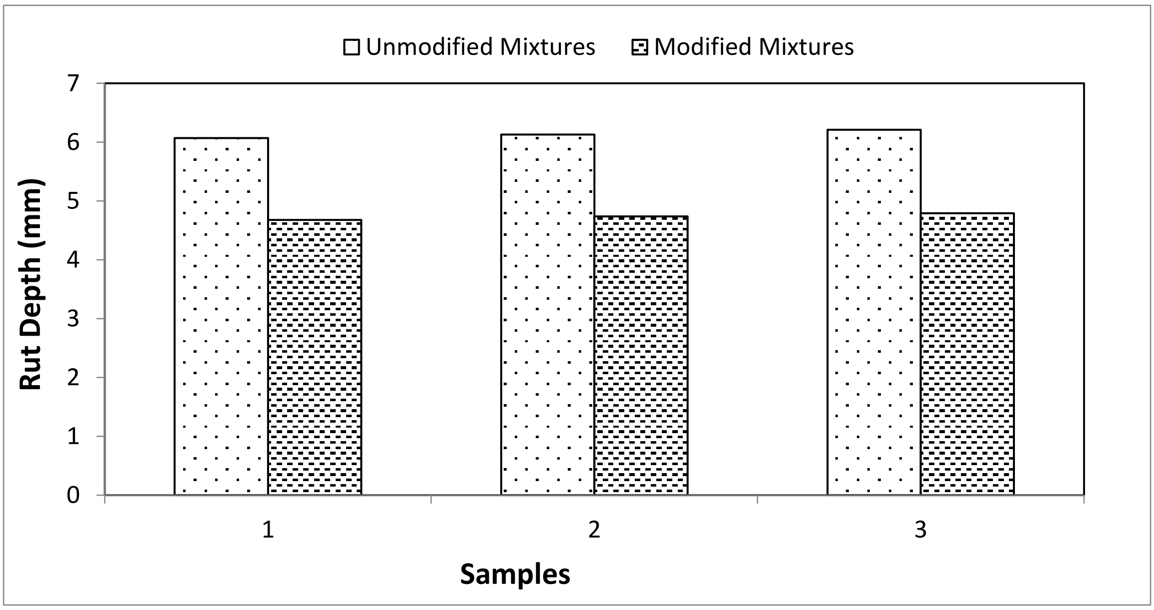


Figure 4.3: Rut Depth of Plant Produced Asphalt Mixtures

4.3 INDIRECT TENSILE STRENGTH TEST

This test was conducted on two test temperatures i.e. 25 and 40 ^{0}C on the asphalt mixtures of lab prepared and plant produced samples. The test is explained in previous chapter whereas the results are presented herein table 4.3 and 4.4. The influence of modification and temperature on the tensile strength is evaluated in the following sections.

	ITS (N)		Improvement (%)
Temperature	**Unmodified Mix**	**Modified Mix**	
25^{o}C	8534	9322	8.45
40^{o}C	3807	6120	37.79

Table 4.3: ITS Test Results of Lab Prepared Mixtures

	ITS (N)		Improvement (%)
Temperature	**Unmodified Mix**	**Modified Mix**	
25^{o}C	8440	9050	6.74
40^{o}C	3102	4503	31.11

Table 4.4: ITS Test Results of Plant Produced Mixtures

Figure 4.4 and 4.5 shows the graphical view of the sample after the ITS test. It is clear from the figures that rubber modification significantly affects the tensile strength of asphalt mixtures. Tensile strength of rubber modified samples are higher than tensile strength of unmodified samples. Similarly temperature has also a great influence on asphalt mixtures. At low temperature high value of tensile strength has observed whereas at high temperature a decrease in tensile strength value has noted for both type of mixes. Reduction in tensile strength occurs with the rise in temperature because of the softening of asphalt concrete mix at high temperature.

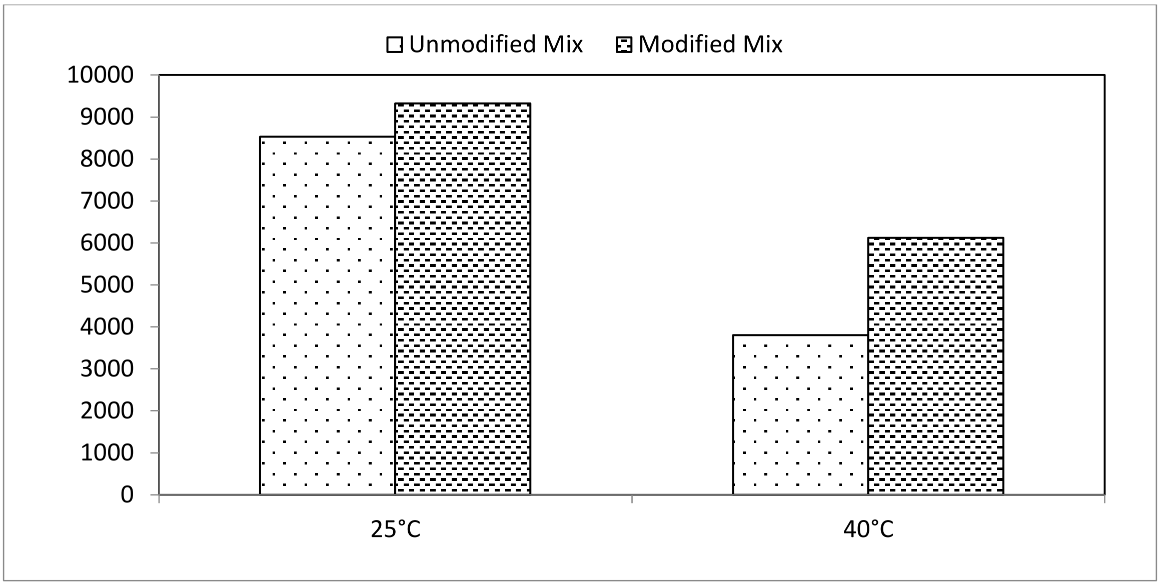


Figure 4.4: Indirect Tensile Strength Test of Lab Prepared Mixtures

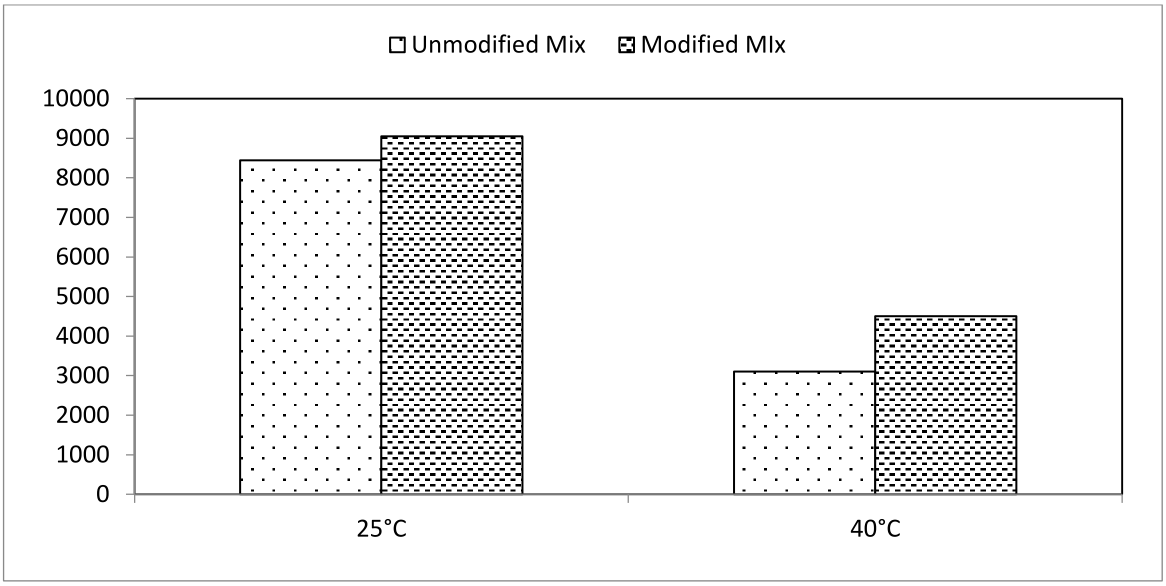


Figure 4.5: Indirect Tensile Strength Test of Plant Produced Mixtures

4.4 RESILIENT MODULUS TEST

This test was done at 25 and 40^{o}C on modified and unmodified mixtures of lab prepared and plant produced. The test is described in previous chapter whereas the results of both phases are presented in table 4.5 and 4.6. The influence of modification and temperature on the resilient modulus is evaluated in the following sections.

	Resilient Modulus at 25°C (MPA)		Improvement (%)
Sample	Unmodified Mix	Modified Mix	
1	6282	11249	44.16
2	6891	12368	44.28

	Resilient Modulus at 40°C (MPA)		Improvement (%)
Sample	Unmodified Mix	Modified Mix	
1	1725	2716	36.49
2	1670	2590	35.52

Table 4.5: Resilient Modulus Results of Lab Prepared Mixtures

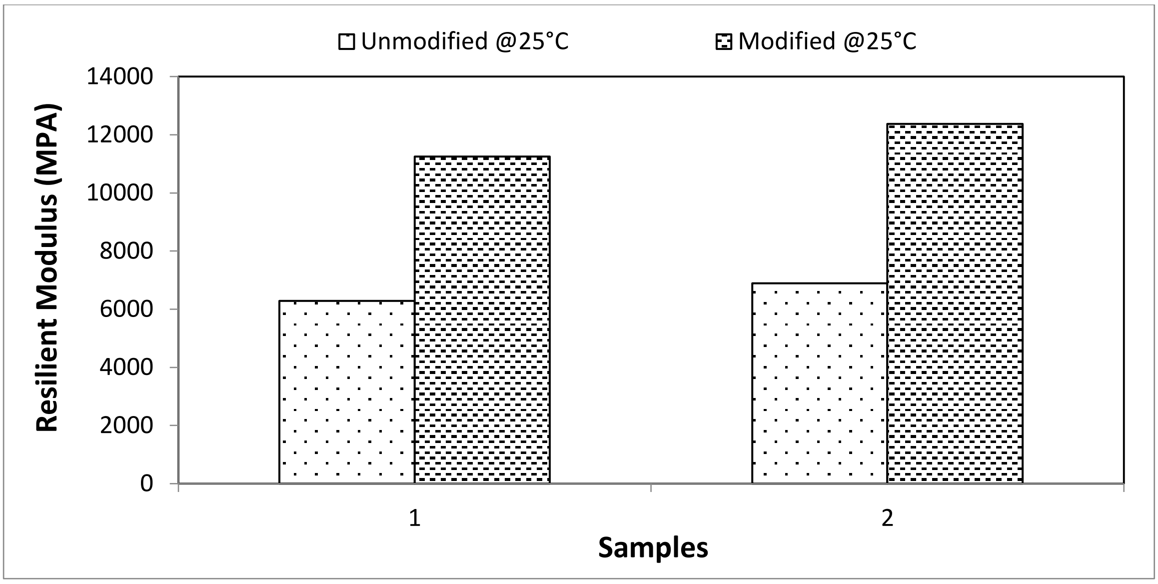
Test results of resilient modulus of plant produced asphalt mixtures are presented in table 4.6.

	Resilient Modulus at 25°C (MPA)		Improvement (%)
Sample	Unmodified Mix	Modified Mix	
1	5511	9535	42.20
2	5840	9440	38.14

	Resilient Modulus at 40°C (MPA)		Improvement (%)
Sample	Modified Mix	Modified Mix	
1	1587	2273	30.18
2	1613	2349	31.33

Table 4.6: Resilient Modulus Results of Plant Produced Mixtures

The graphical illustration of results of resilient modulus of lab prepared asphalt mixtures conducted at both test temperature are presented in figure 4.6. Whereas figure 4.7 shows the graphical illustration of plant produced asphalt mixtures. It is clear from the figures that rubber modification significantly affects the resilient modulus of asphalt mixtures. Resilient modulus of rubber modified mixture is higher than unmodified mixture. Similarly temperature has also a great influence on asphalt mixtures. At low temperature high value of resilient modulus has observed whereas at high temperature low value of Resilient Modulus has noted for both type of mixtures. Figure 4.8 shows the output of M_R Test result by software of UTM machine.



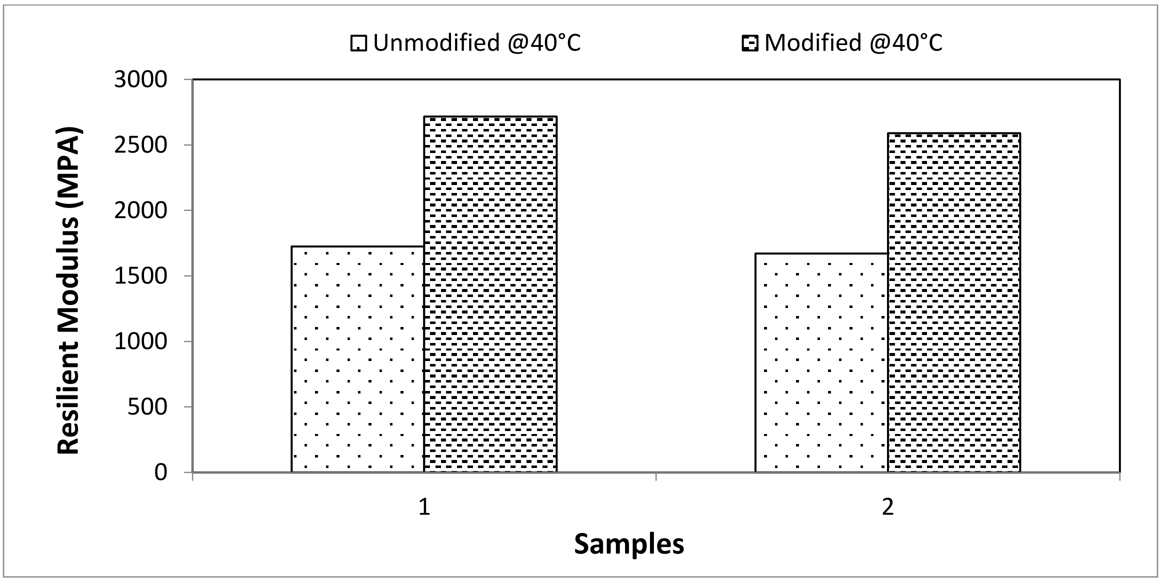


Figure 4.6: Resilient Modulus Results of Lab Prepared Mixtures

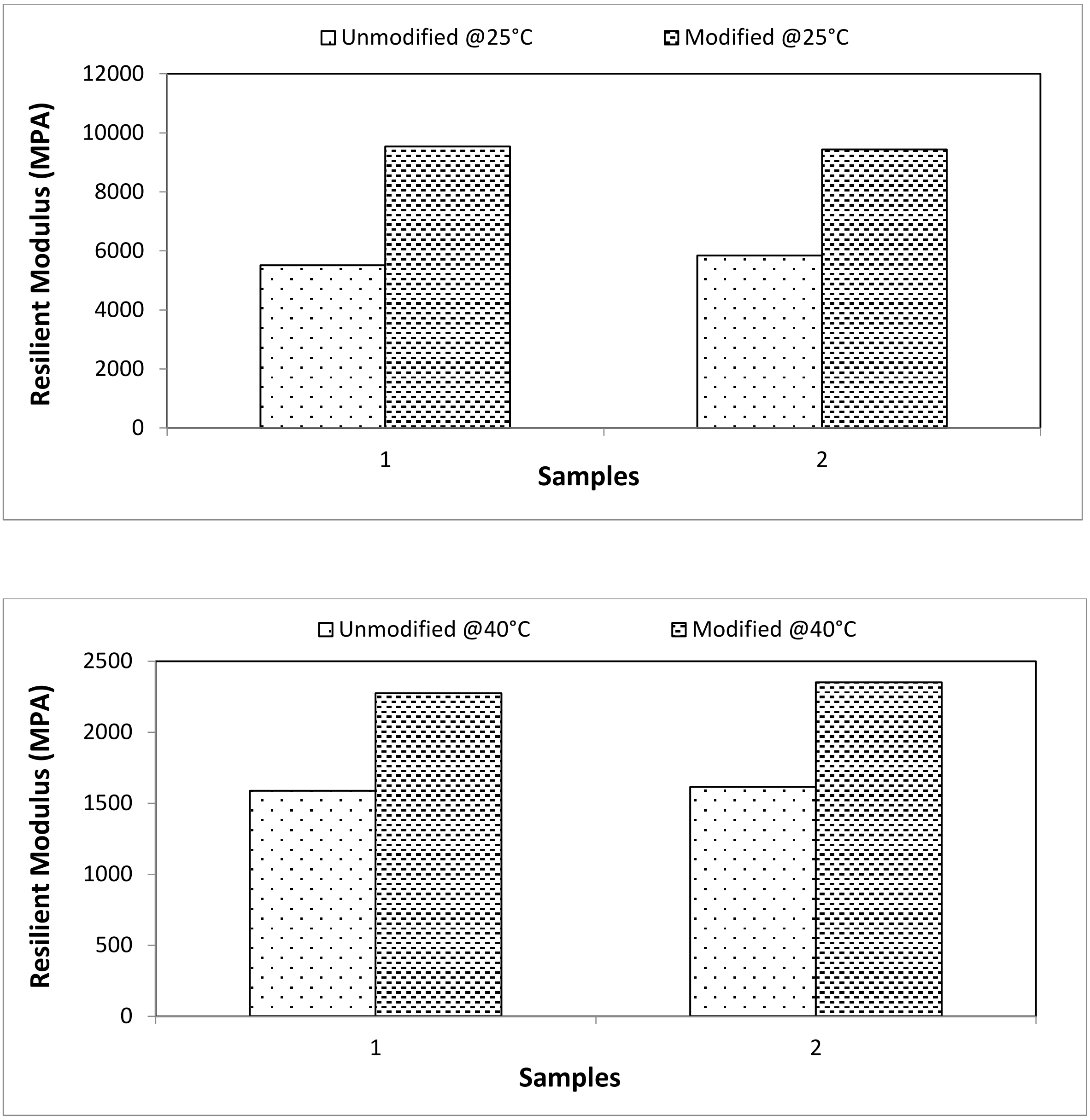
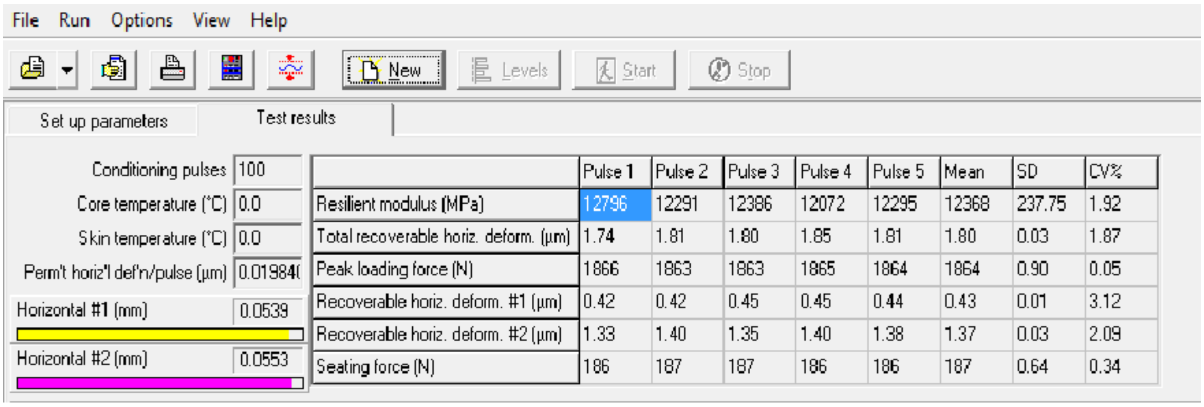


Figure 4.7: Resilient Modulus Results of Plant Produced Mixtures

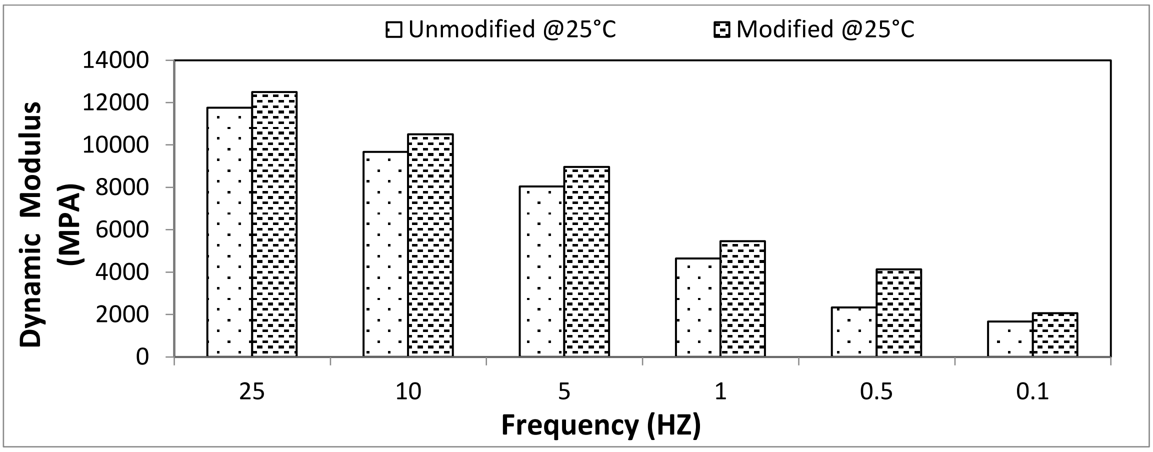


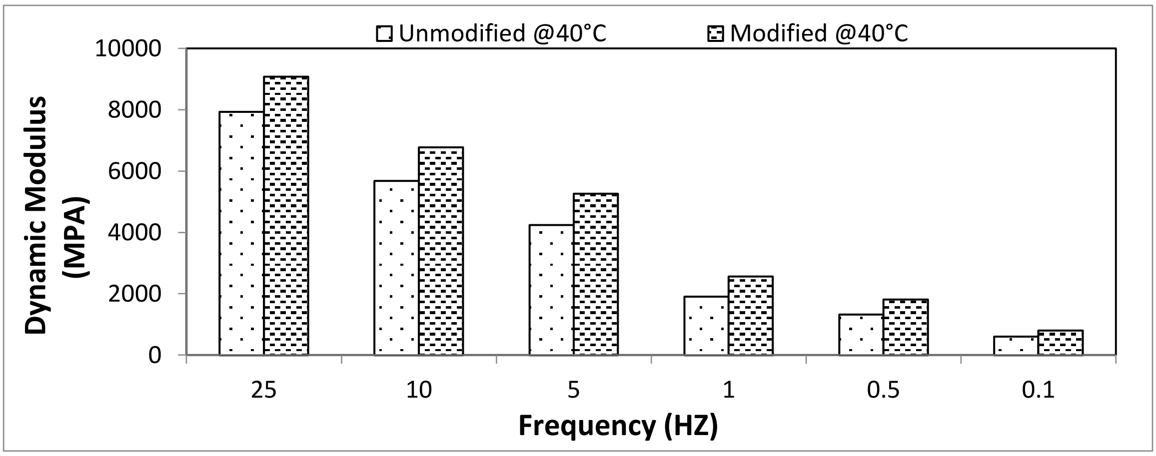
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	SD	CV%
Resilient modulus (MPa)	12796	12291	12386	12072	12295	12368	237.75	1.92
Total recoverable horiz. deform. (µm)	1.74	1.81	1.80	1.85	1.81	1.80	0.03	1.87
Peak loading force (N)	1866	1863	1863	1865	1864	1864	0.90	0.05
Recoverable horiz. deform. #1 (µm)	0.42	0.42	0.45	0.45	0.44	0.43	0.01	3.12
Recoverable horiz. deform. #2 (µm)	1.33	1.40	1.35	1.40	1.38	1.37	0.03	2.09
Seating force (N)	186	187	187	186	186	187	0.64	0.34

Figure 4.8: UTM Machine Software Numerical Output for M_R Values

4.5 DYNAMIC MODULUS TEST

Dynamic modulus of asphalt mixture shows that the dynamic stiffness of rubber modified mixtures of lab prepared and plant produced were slightly higher as compare to unmodified mixtures. Results of modified and unmodified mixtures are compare separately to find the improvement. The comparison was done on the results obtained on all corresponding frequencies at given temperature. The results of lab prepared mixture are shown in figure 4.9 and figure 4.10 shows results of plant produced mixtures. The tabulated values of these results are shown in appendix vi at the end. Significant increase in dynamic modulus were noted for modified mixtures of lab prepared and plant produced with increase in temperature.





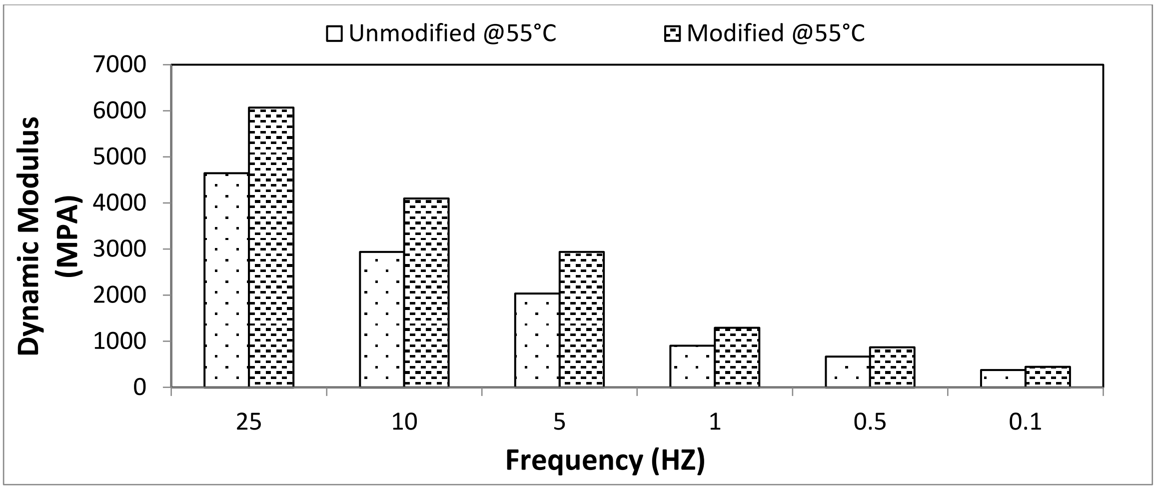
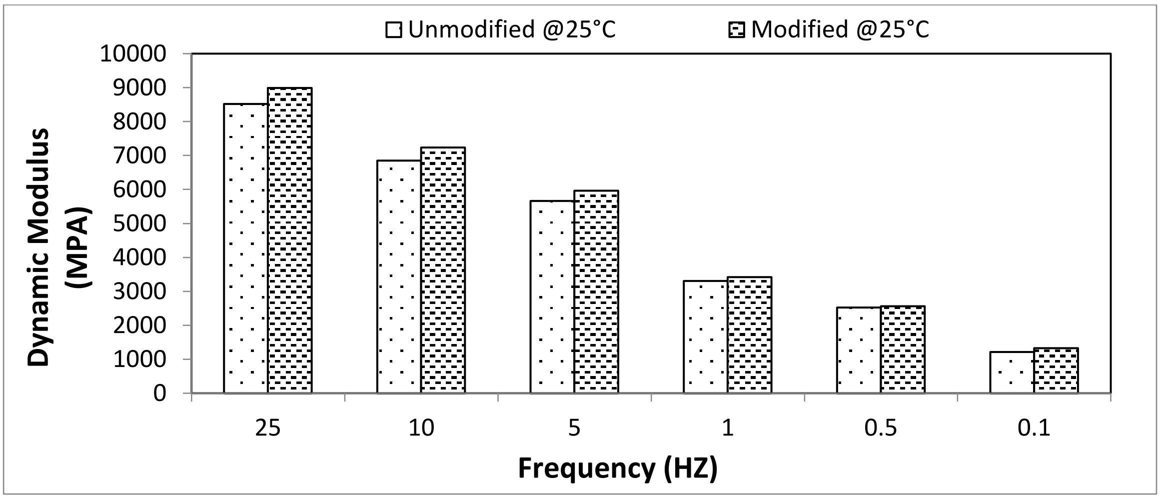
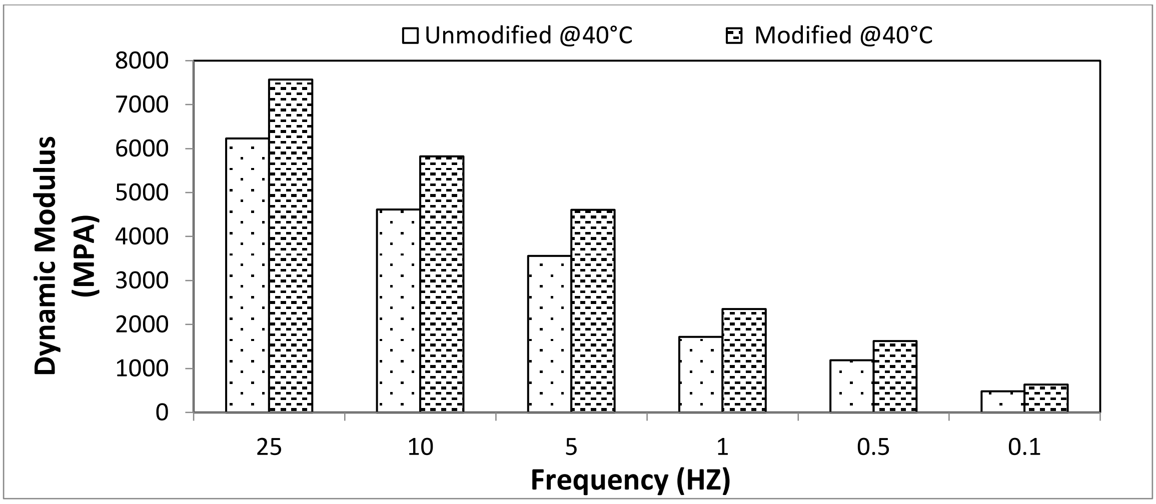


Figure 4.10: Dynamic Modulus of Lab prepared Asphalt Mixture





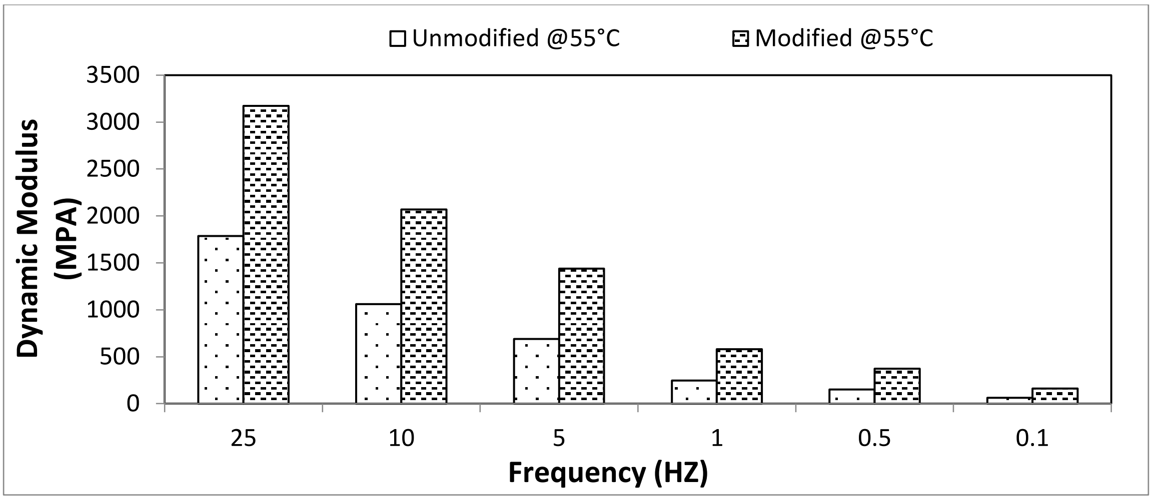


Figure 4.10: Dynamic Modulus of Plant Produced Asphalt Mixtures

4.6 VARIATIONS IN PLANT PRODUCED HMA

The mixture collected from the plant and were brought into the laboratory and the various properties are checked to determine the variations in the mixture the results showed that all the variations are within the tolerable range according to the NHA specifications. Table 4.7 shows the results.

	Lab Prepared	Plant Produced	Variations (%)	Specifications
Asphalt Content (%)	4.6	4.8	4	$\pm$ 0.3
Air Voids (%)	4.96	4.90	1.2	4 - 7
Stability (Kg)	1400	1462	4.2	1000 Min
Flow (mm)	9.8	9.6	2	8 - 14

Table 4.7: Variations in Plant produced mixtures

4.7 FULL FACTORIAL DESIGN OF DYNAMIC MODULUS

The statistical analysis of dynamic modulus data for each stage with and without considering three performed rubber modification separately factors i.e. frequency, test temperature and rubber percentage each with two levels. Therefore, 2^3 full factorial design of experiment was performed using MINITAB-15 software. Table 4.7shows the factors that have been considered in the factorial design with their high and low levels and abbreviations for both stages.

Notations	Parameters	Low	High	Units
1	Frequency	0.1	25	Hz
2	Temperature	25	55	^{o}C
3	Rubber	0	7	%

Table 4.7: Factors and their Level for Factorial Design

4.7.1 EFFECTS AND COEFFICIENT TABLE

Table 4.8 and 4.9 shows the effects and coefficients values obtained by Minitab 15 software for the significant effects of each stage. The factors and interaction of factors with high (negative or positive) values of effects and coefficients indicate that they have a greater impact on dynamic modulus. The effect of each term is equal to the twice of coefficient. The factors or interaction of factors with P- value greater than significance level indicates that these main effect and two way interactions are notable and have greater effect on dynamic modulus at significance level of 5%. Also for each gradation the calculated value of t-statistic for the terms greater than the critical value of t-statistic (t *critical*= 2.05 for degree of freedom 23 and 5% significance level) shows that the interactions and main effects are significant.

Term	Effects	Coefficient	SE Coefficient	T-Test	P-Value
Constant		5956	283.7	21.00	0.000
Frequency (HZ)	7065	3533	338.8	10.43	0.000
Temperature (C)	-5531	-2766	347.4	-7.96	0.000
Rubber (%age)	922	461	283.7	1.63	0.115
Frequency * Temperature	-2195	-1098	414.9	-2.65	0.013
Frequency * Rubber	290	145	38.8	0.43	0.672
Temperature * Rubber	60	30	347.4	0.09	0.932
Frequency * Temperature * Rubber	381	190	414.9	0.46	0.650

Table 4.8: Effects and Coefficients Table of Lab Prepared Mixtures

Term	Effects	Coefficient	SE Coefficient	T-Test	P-Value
Constant		4092	198.9	20.58	0.000
Frequency (HZ)	4839	2419	236.1	10.25	0.000
Temperature (C)	-4799	-2399	248.5	-9.65	0.000
Rubber (%age)	877	439	198.9	2.20	0.036
Frequency * Temperature	-2180	-1090	296.8	-3.67	0.001
Frequency * Rubber	524	262	236.1	1.11	0.277
Temperature * Rubber	301	150	248.5	0.60	0.550
Frequency * Temperature * Rubber	184	92	296.8	0.31	0.759

Table 4.9: Effects and Coefficients Table of Plant Produced Mixtures

4.7.2 SIGNIFICANT EFFECTS AND INTERACTION PLOTS

The factors and interaction of factors, which are most significant and affect dynamic modulus of asphalt mixtures, are also shown in terms of Normal probability plot and Pareto plot generated using Minitab 15 software. Figure 4.11 shows the Pareto plot of lab prepared mixtures having a reference line with red color which shows that the main effect and two way interactions beyond this reference line are significant and have greater effect on the dynamic modulus. The main effects frequency, temperature and the 2-way interactions of frequency and temperature are significant and have greater influence on dynamic modulus of lab prepared mixtures at 5% significance level. The other plot is the normal probability plot which also shows the significant main effect and two way interaction as shown in figure 4.12 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.

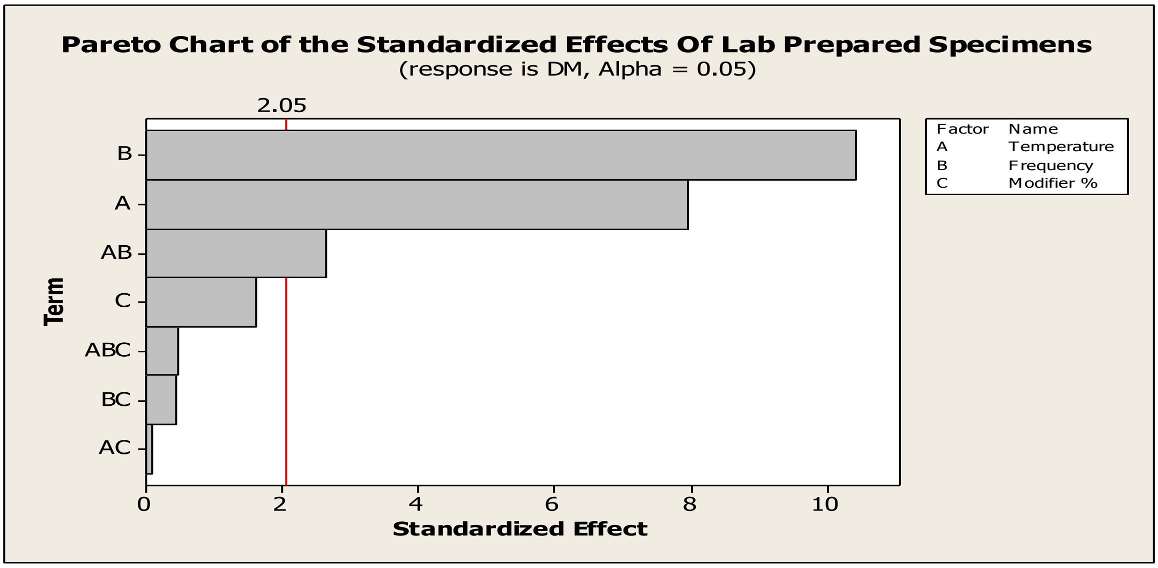


Figure 4.11: Pareto Chart of Lab Prepared Mixtures

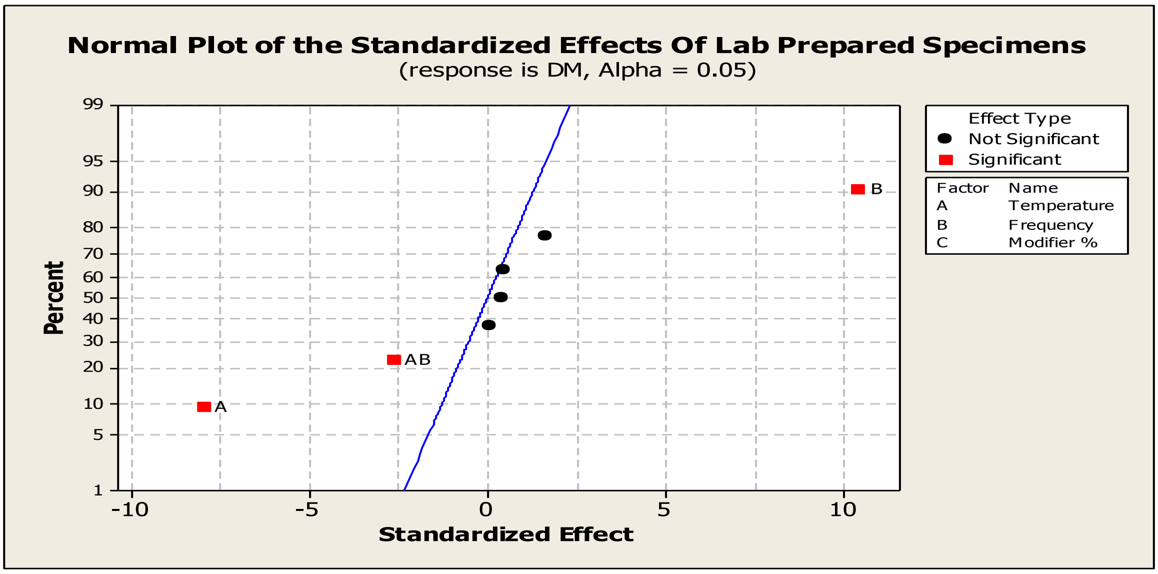


Figure 4.12: Normal Chart of Lab Prepared Mixtures

Figure 4.13 shows the Pareto plot of plant produced mixtures having a reference line with red color which shows that the main effect and two way interactions beyond this reference line are significant and have greater influence on dynamic modulus. The main effects frequency, temperature and the 2-way interactions of frequency and temperature are significant and have greater influence on dynamic modulus of lab prepared mixtures at 5% significance level. The other plot is the normal probability plot which also shows the significant main effect and two way interaction as shown in figure 4.14 respectively. In the normal probability plot the factors or interactions away from the reference line are significant at 5% significant level and the other factors which are near the reference line or on the reference line, are insignificant.

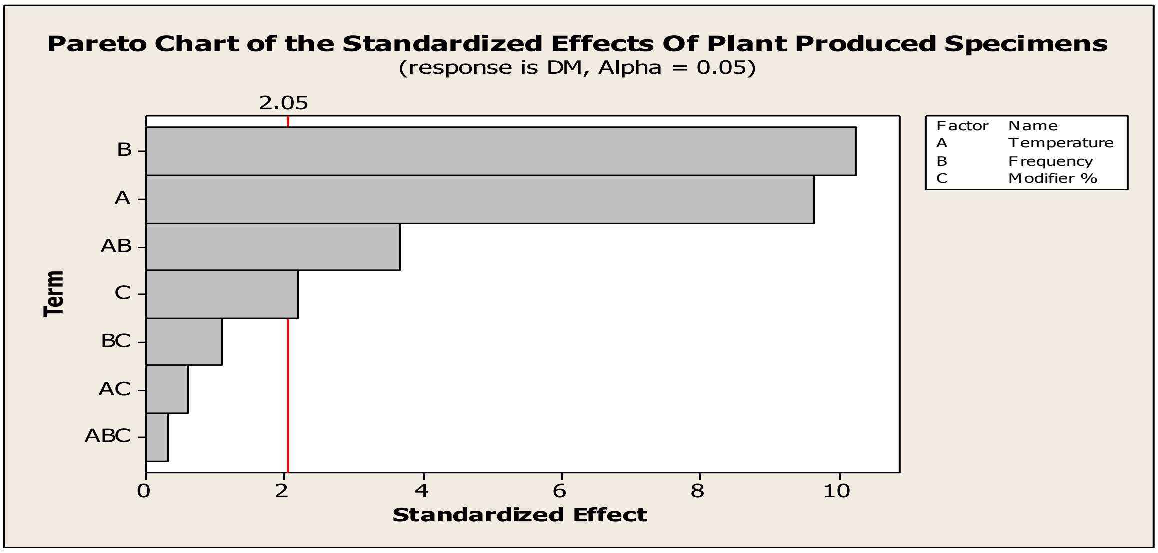


Figure 4.13: Pareto Chart of Plant Produced Mixtures

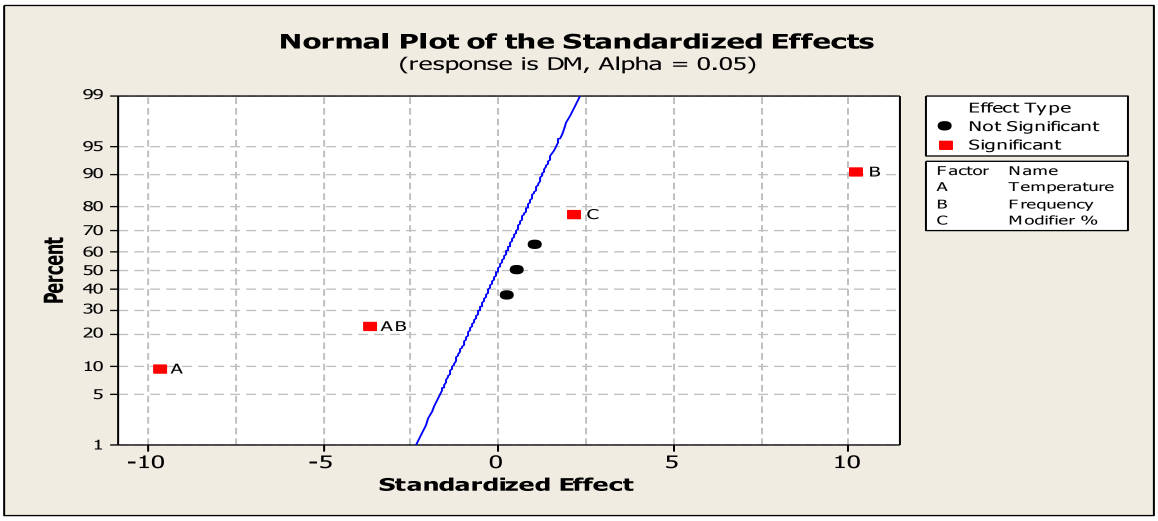


Figure 4.14: Normal Chart of Plant Produced Mixtures

4.7.3 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, 2-way interactions by interaction plots.

4.7.3.1 Main Effect Plots

The effects of frequency, temperature and bakelite %age of Lab Prepared specimens are shown in figure 4.15 respectively. The graph between frequency and dynamic modulus reveals that with decrease in frequency the dynamic modulus also decreases the reason being that with decrease in frequency the loading duration increases and more strains would be produced and ultimately the dynamic modulus would be decreases. Dynamic modulus at 25HZ frequency is high as compare to 0.1 HZ.

The graph between dynamic modulus and temperature indicates an inverse relationship i.e. the dynamic modulus decreases with increase in temperature the reason being that the stiffness of mixtures reduces with increase in temperature and the graph between dynamic modulus and rubber %age shows a very mild slope the reason being that the effect of rubber modification is less as compare to temperature and frequency.

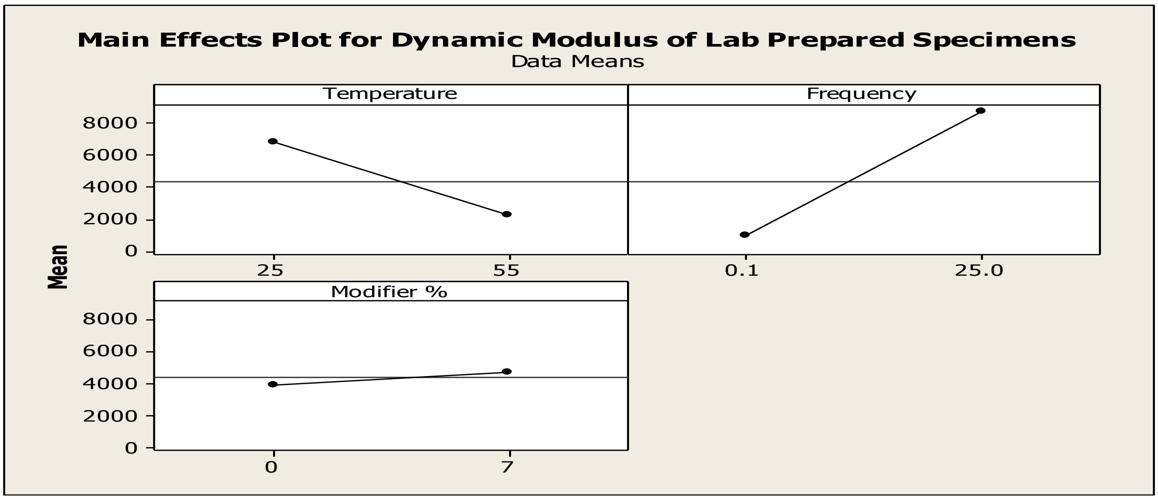


Figure 4.15: Main Effect Plot of Lab Prepared Mixtures

Main effect graph of frequency, temperature and bakelite %age of plant produced HMA are presented in figure 4.16 respectively. The plot of frequency, temperature, rubber modifier and dynamic modulus shows the same behavior as observed in lab prepared mixtures.

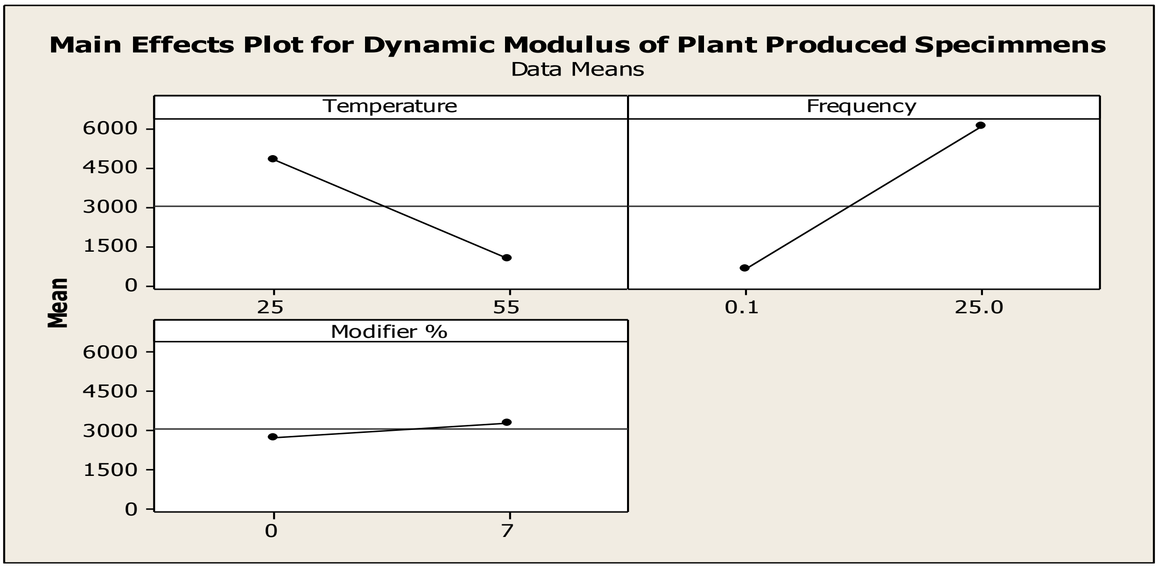


Figure 4.16: Main Effect Plot of Plant Produced Mixtures

4.7.4 ANALYSIS OF VARIANCE (ANNOVA)

In Analysis of Variance ANNOVA, three F-Test are made. In order to evaluate these tests, probability values are given below in table 4.10 of Lab Prepared HMA. The P-value < 0.05 indicates that these tests are satisfied.

Source	DF	Seq SS	Adj SS	Adj MS	F-Test	P-Value
Main Effect	3	352952680	359316838	119772279	58.26	0.000
2-Way Interactions	3	14843141	14782993	4927664	2.40	0.089
3-Way Interactions	1	433211	433211	433211	0.21	0.650
Residual Error	28	57566995	57566995	2055964		
Total	35	425796027				

Table 4.10: Analysis of Variance of Lab Prepared Mixtures

Similarly, table 4.11 shows the analysis of Variance obtained for Dynamic Modulus of plant produced mixtures.

Source	DF	Seq SS	Adj SS	Adj MS	F-Test	P-Value
Main Effect	3	199495251	211397866	70465955	66.98	0.000
2-Way Interactions	3	15763609	15864266	5288089	5.03	0.007
3-Way Interactions	1	101034	101034	101034	0.10	0.759
Residual Error	28	29456551	29456551	1052020		

Total	35	244816445				

Table 4.11: Analysis of Variance of Plant Produced Mixtures

4.8 PHASE ANGLE RESULTS

Phase angle can be defined as the angle by which the axial strain lags behind the stress. An increased in phase angle was initially observed with increasing temperature and decreasing frequency but when the temperature reached up to 40^{o}C the phase angle start decreasing with some exceptions as shown in figure 4.17 and 4.18 for lab prepared and plant produced phase angle results. The graph shows that when the temperature is increased the phase angle also increases initially when reached a maximum value it start decreasing. Phase angle and temperature are directly proportional each other at low temperature and high frequencies phase angle is usually effected by the binder and at high temperature and low frequency, the phase angle is effected by the aggregates so therefore when the frequency is decreases the phase angle also decreases and similar behavior is noted by increasing temperature the reason being greater influence of aggregates.

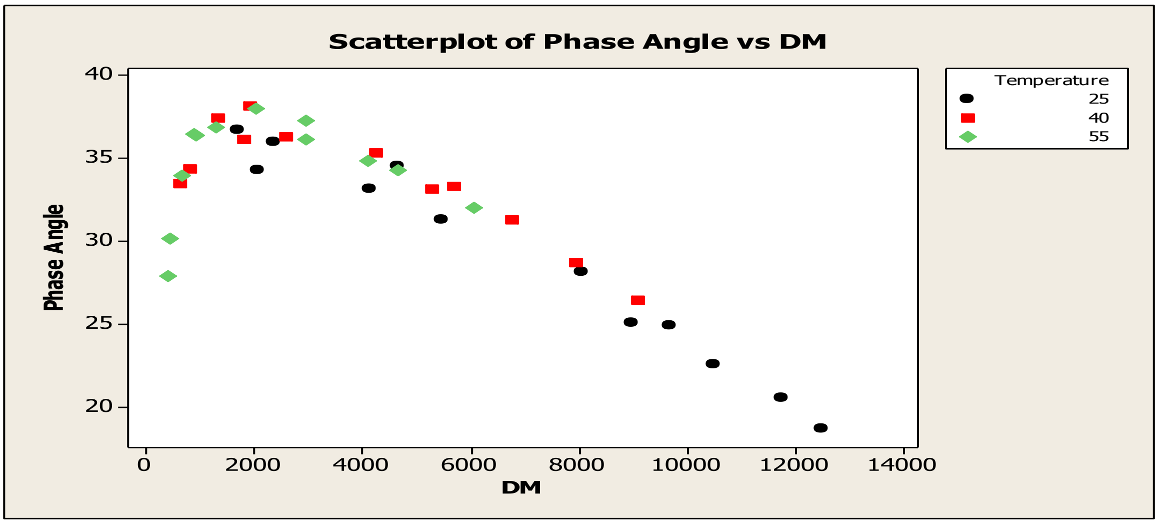


Figure 4.17: Variation of Phase Angle of Lab Prepared Mixtures

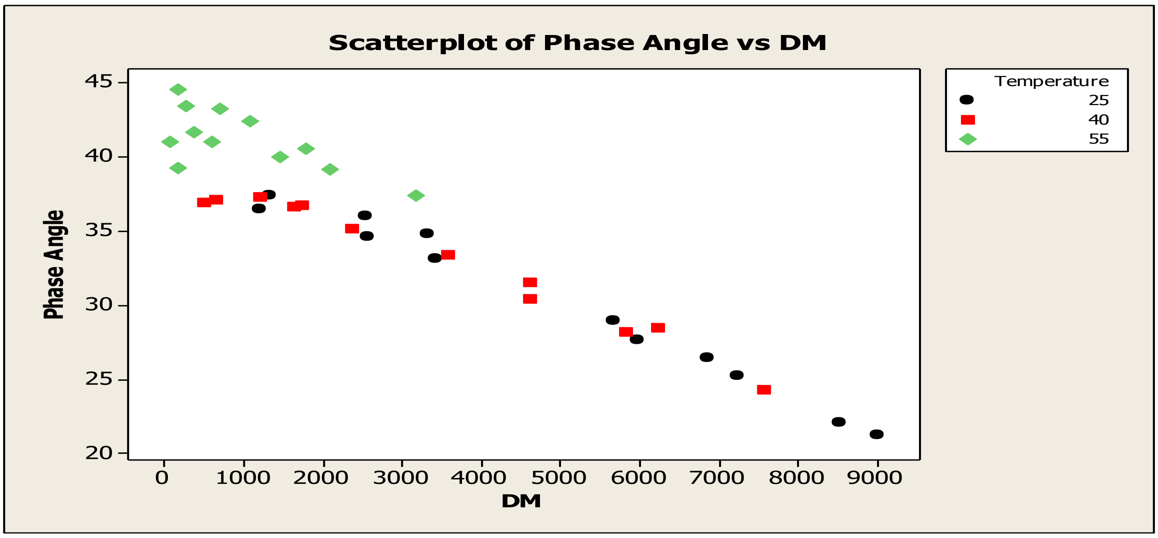


Figure 4.18: Variation of Phase Angle of Plant Produced Mixtures

4.9 FULL FACTORIAL DESIGN FOR PHASE ANGLE

Factorial design was done for response variable as phase angle. The analysis of phase angle data for Lab prepared and Plant produced mixtures with and without rubber modification was performed separately by considering three factors i.e. frequency, test temperature and rubber percentage each with 2 levels. Therefore, 2^3 full factorial design of experiment was performed using MINITAB -15 software. Same factors as described in Table 4.7were used for the said analysis.

4.9.1 EFFECTS AND COEFFICIENTS

Table 4.12 and 4.13shows the effects and coefficients values obtained by Minitab 15 software for the significant effects of Lab Prepared and Plant Produced Specimens. The factors and interaction of factors with high (negative or positive) values of effects and coefficients indicate that they have a greater impact on the Phase angle values. The effect of each term is equal to the twice of coefficient. The negative sign shows that this factor and phase angle is inversely proportional to each other and a positive sign shows the direct relationship.

Term	Effects	Coefficient	SE Coefficient	T-Test	P-Value
Constant		30.503	0.5526	55.20	0.000
Frequency (HZ)	-8.012	-4.006	0.6599	-6.07	0.000

Temperature (C)	9.097	4.549	0.6768	6.72	0.000
Rubber (%age)	-1.792	-0.896	0.5526	-1.62	0.116
Frequency * Temperature	7.541	3.770	0.8083	4.66	0.000
Frequency * Rubber	-0.792	-0.396	0.6599	-0.60	0.553
Temperature * Rubber	0.599	0.300	0.6768	0.44	0.661
Frequency * Temperature * Rubber	-1.339	-0.670	0.8083	-0.83	0.414

Table 4.12: Effects and Coefficients Table of Lab Prepared Mixtures

Term	**Effects**	**Coefficient**	**SE Coefficient**	**T-Test**	**P-Value**
Constant		32.728	0.4721	69.32	0.000
Frequency (HZ)	-9.256	-4.628	0.5638	-8.21	0.000
Temperature (C)	13.416	6.708	0.5782	11.60	0.000
Rubber (%age)	-2.316	-1.158	0.4721	-2.45	0.021
Frequency * Temperature	5.723	2.861	0.6905	4.14	0.000
Frequency * Rubber	-0.653	-0.326	0.5638	-0.58	0.567
Temperature * Rubber	-0.943	-0.471	0.5782	-0.82	0.422
Frequency * Temperature * Rubber	-0.340	-0.170	0.6905	-0.25	0.807

Table 4.13: Effects and Coefficients Table of Plant Produced Mixtures

4.9.2 SIGNIFICANT EFFECTS AND INTERACTIONS

The factors and interaction of factors, which are most significant and affect phase angle of HMA mixtures, are also shown in terms of Normal probability plot and Pareto plot generated by using Minitab 15 software for each gradation separately. Figure 4.19 shows the Pareto plot having a reference line with red color which shows that the main effects and two way interactions beyond this reference line are critical and have a significant influence on the phase angle. The main effects of frequency, temperature and rubber %age and the 2-way interactions of. frequency and temperature are beyond the reference line which reveals that they are significant and have a greater influence on phase angle of lab prepared asphalt mixtures at 5% significance level. The other plot for getting the significant main effects and interactions is the normal probability plot as shown in figure 4.20 respectively. The factors or interactions in the normal probability plot away from the reference line is significant at 5% significance level while the factors or interactions, which are near the reference line or on the reference line, are insignificant.

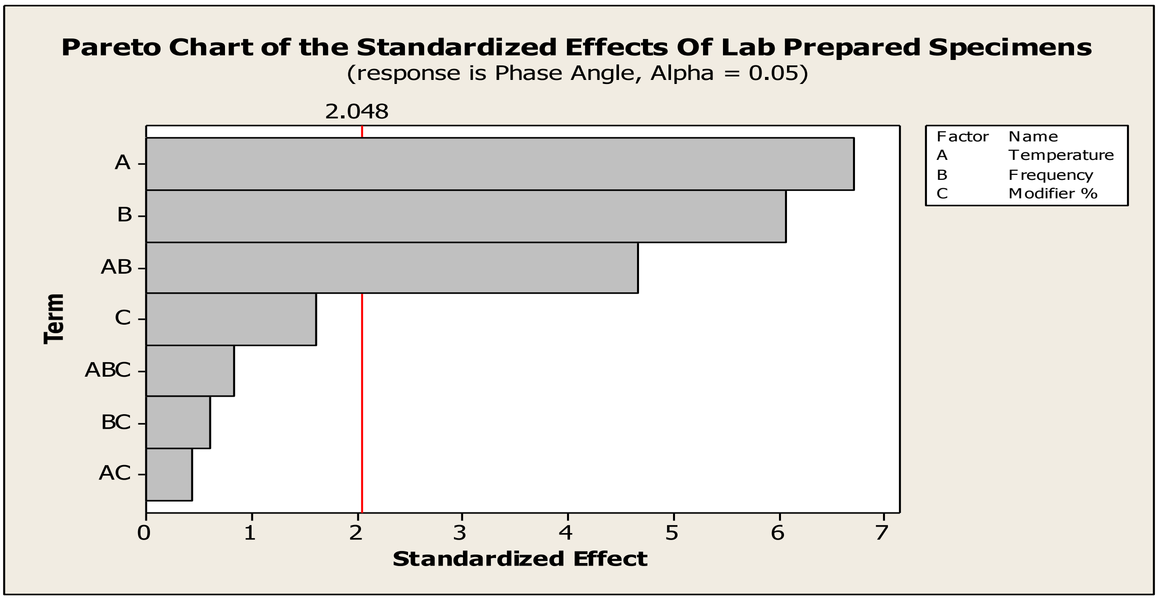


Figure 4.19: Pareto Chart of Lab Prepared Mixtures

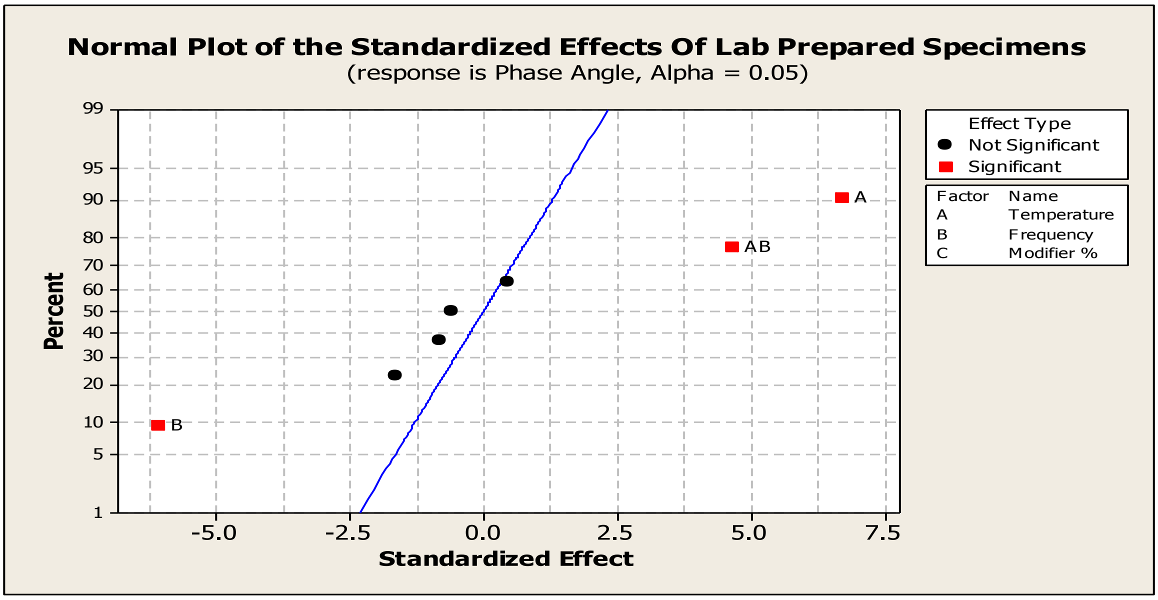


Figure 4.20: Normal Chart of Lab Prepared Mixtures

Similarly, figure 4.21 shows the pareto plot of plant produced asphalt mixtures having a reference line with red color. The main effects i.e. frequency, temperature and rubber %age and the 2-way interactions i.e. frequency and temperature are beyond the reference line which reveals that they are significant at 5% significance level. The other plot for getting the significant main effects and interactions is the normal probability plot as shown in figure 4.22 respectively. The factors or interactions in the normal probability plot far away from the reference line, are considered as significant at 5% significance level while the factors or interactions that are near the reference line or on the reference line are insignificant.

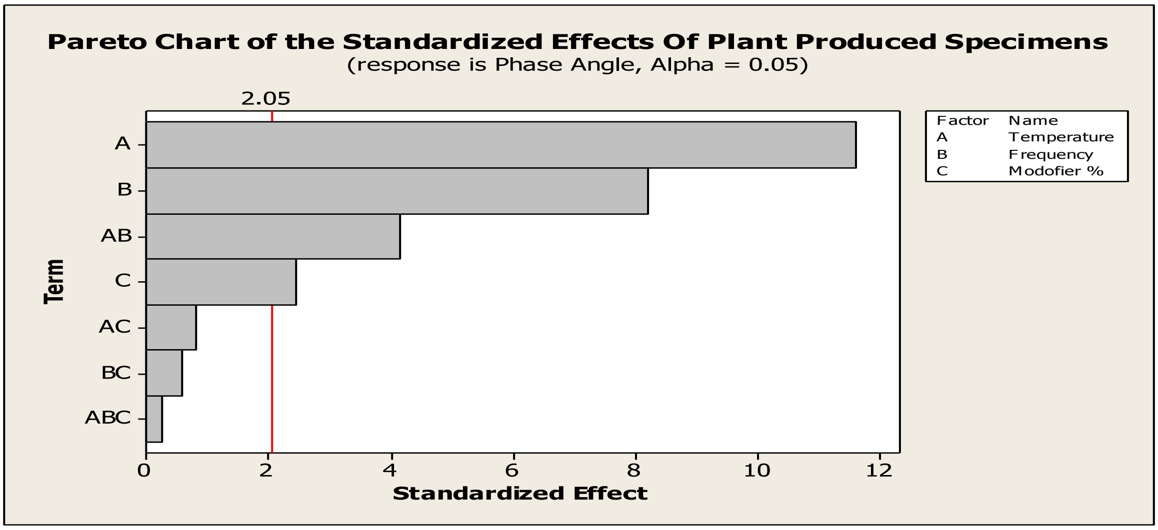


Figure 4.21: Pareto Chart of Plant Produced Mixtures

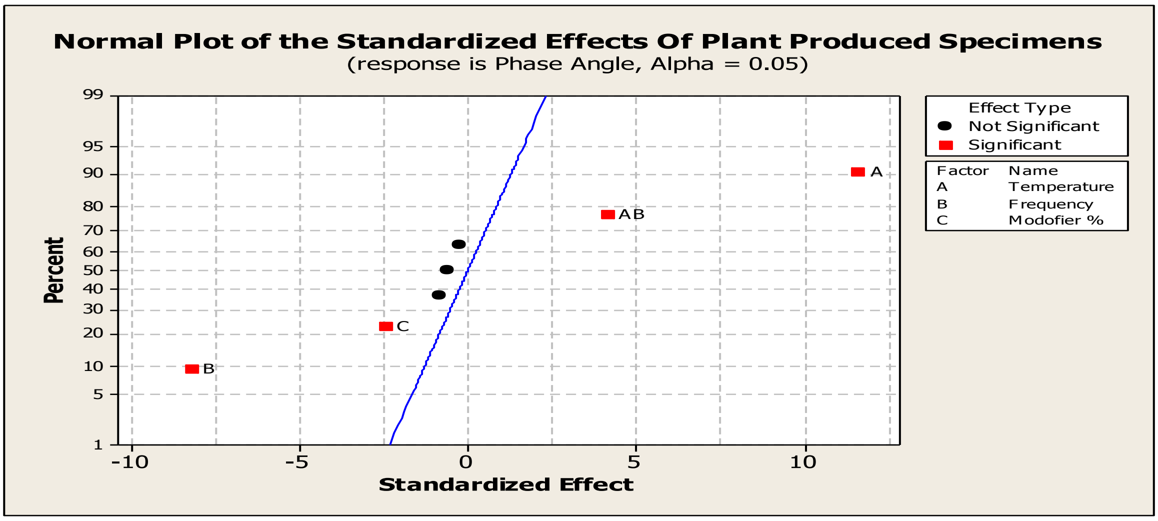


Figure 4.22: Normal Chart of Plant Produced Mixtures

4.9.3 FACTORIAL PLOTS

The interaction and significant effects obtained from the normal probability plot and Pareto plots can be described in detail by factorial plots. The effects of main factors are shown by main effects plot, 2-way interactions by interaction plots.

4.9.3.1 Main Effect Plot

The effects of frequency, temperature and bakelite %age of lab Prepared mixtures are shown in figure 4.23 respectively. It can be predicted from the graph between frequency and phase angle that the phase angle is low at 25 HZ frequency as compare to 0.1 HZ.

The graph between the phase angle and temperature indicates that the phase angle is low at lower temperature as compare to higher temperature. The graph between rubber %age and phase angle present a mild slope but the effect is significant.

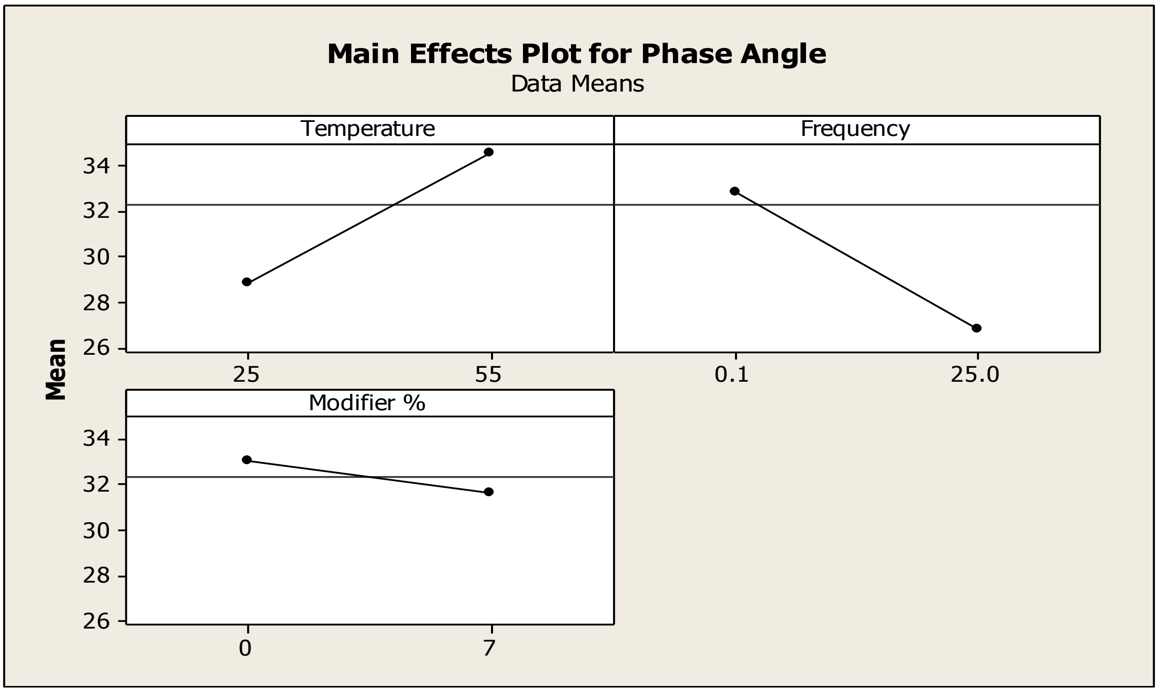


Figure 4.23: Main Effect Plot of Lab Prepared Mixtures

The effects of frequency, temperature and rubber %age of plant produced mixtures are shown in figure 4.24 respectively. Similar behavior was observed as noted in lab prepared asphalt mixtures.

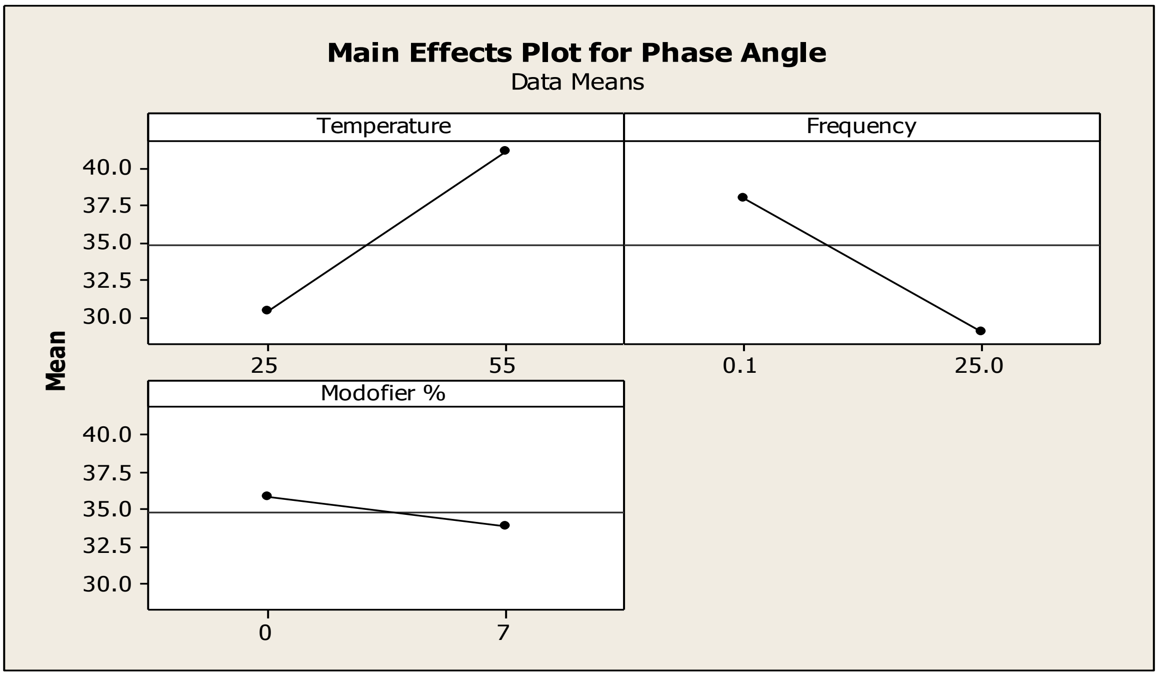


Figure 4.24: Main Effect Plot of Plant Produced Mixtures

4.10 SUMMARY

In this chapter the results of the performance tests conducted in a laboratory is explained. First of all, the data analysis strategy was discussed and then results were shown in tables and graphs. The results of wheel tracker tests for rubber modified and unmodified mixtures of both phases were presented in the form of bar charts which showed that rubber modified mixtures have least rutting potential as compared to the unmodified mixtures. Then Statistical analysis was done on dynamic modulus and phase angle results of each phase separately.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

This study was carried out to evaluate the modification of rubber modifier and to find out the improvement in the properties of asphalt mixture in terms of performance. Results of wheel tracker, resilient modulus and dynamic modulus tests are used to evaluate the performance of asphalt mixtures. This research work is completed in two phases in the first phase the bitumen penetration grade of NRL 60/70 and Margalla aggregates were brought into laboratory and gyratory compacted samples were prepared. In the second phase the plant produced mixtures were collected and brought into laboratory and it was then reheated to the desired test temperature and then compacted samples were prepared using Gyratory compactor. Crumb rubber was used as modifier to the asphalt mixtures to characterize the performance. The same optimum binder content was used for preparation of samples being used in M-2 project for performance tests. The amount of crumb rubber used in rubber modified mixture was 7%. The factors selected for dynamic modulus tests were temperature, asphalt modifier, loading Frequencies and asphalt content while the factors selected for wheel tracker and resilient Modulus tests were temperature, asphalt content and asphalt modifier. The key findings of wheel tracker, resilient modulus and dynamic modulus tests and analysis of results are concluded as follows:

5.2 CONCLUSIONS

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

- With modification of crumb rubber the asphalt mixtures shows higher resistance to rutting. 33 % improvement in rutting resistance is observed in lab prepared asphalt mixtures and 22% improvement in rutting resistance is observed with modification of crumb rubber in plant produced asphalt mixtures.
- An increased in Indirect Tensile Strength test has been noted at both test temperature i.e. 25^{o}C and 40^{o}C for rubber modified mixtures in lab prepared and plant produced asphalt mixtures.

- An increased in resilient modulus has been observed for rubber modified mixtures at both test temperature as compared to unmodified mixtures in lab prepared asphalt mixtures 44% and 36% increase in Resilient Modulus value is observed for rubber modified mixtures at 25^oC and 40^oC respectively. While in plant produced asphalt mixtures 42% and 31% increase in resilient modulus is noted for rubber modified mixtures at 25^oC and 40^oC respectively..
- With modification of crumb rubber modifier the dynamic stiffness of mixtures increased sufficiently. 24% increase in dynamic modulus is noted at 25Hz frequency at 55^oC temperature in lab prepared asphalt mixtures and 21% increase in dynamic modulus is observed in plant produced asphalt mixtures at same frequency and temperature.
- All the variations observed in plant produced mixtures are within the NHA specifications.
- Statistical analysis shows that frequency is the most significant factor which affects the dynamic modulus values followed by temperature and rubber content and the two way interaction between frequency and temperature is observed to be a significant.

5.3 RECOMMENDATIONS

- The use of CRMB should be encouraged in our country as it has been used widely all over the world, also in countries having similar loading and environmental conditions.
- Further evaluation of CRMB should be carried out by changing parameters such as test pulse width, gradation, percentage of Crumb Rubber etc.
- CRMB should be compared with other modifier in manufactured with NRL in terms of performance.
- Further studies should be carried out to study the effect of modification on rheological properties of binder.

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APPENDICES

APPENDIX: I - WHEEL TRACKER TEST SOFTWARE RESULT

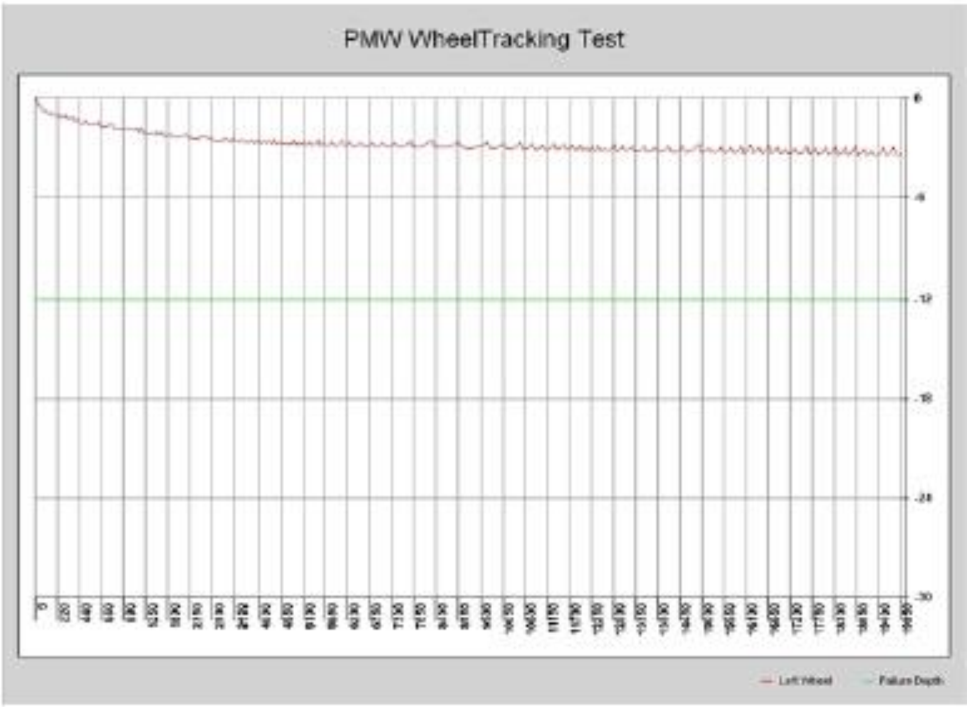
WheelTracker Report

Project Name:	MS THESIS	Date:	2/16/2006
Project Number:	1	Date Sampled:	2/16/2006
Job Number:	21	Lab Number:	RUBBER 3 @ 40
Project Engineer:	NASIR IQBAL	Mix Type:	HMA
Submitted By:	NASIR IQBAL	Asphalt Grade:	60-70
Temperature:	40	Pit Source:	LAB PREPARED
Comments:	Comments		

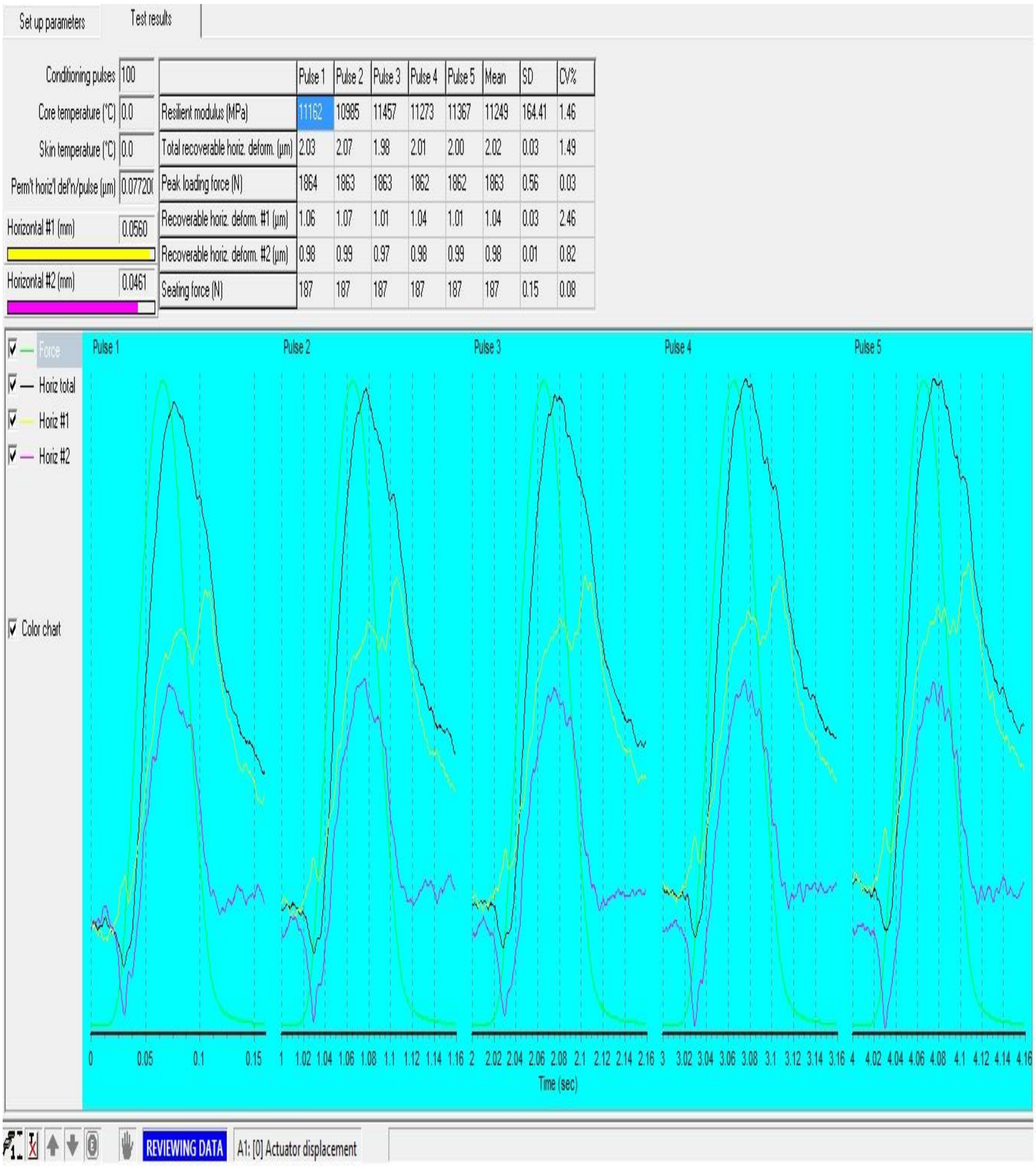
Max Impression: Left -3.43 mm

Pass #: 15800 / Pt: 8

Fail Depth: 12.5mm PASSED

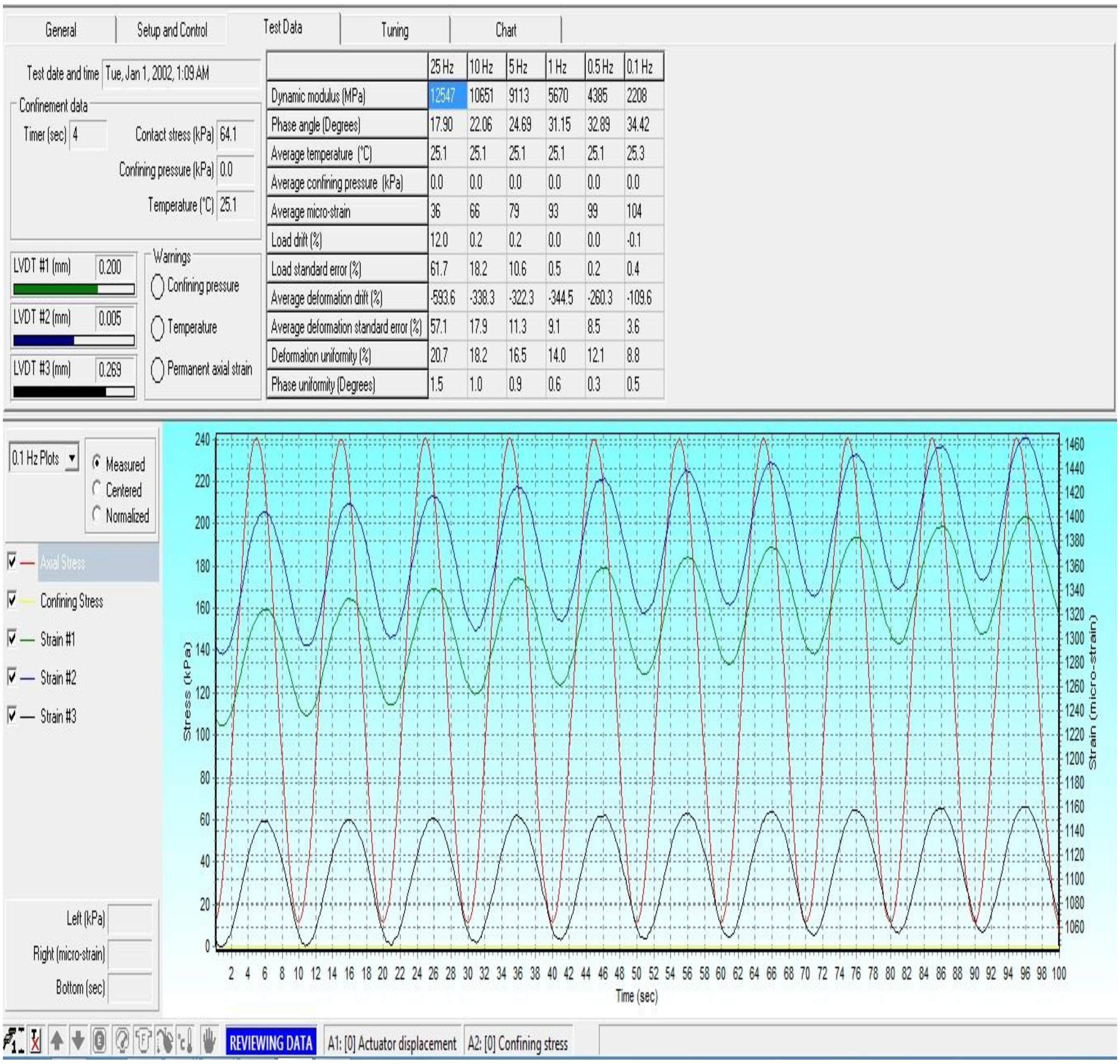


APPENDIX: II - RESILIENT MODULUS TEST SOFTWARE RESULT



	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	SD	CV%
Resilient modulus (MPa)	11162	10985	11457	11273	11367	11249	164.41	1.46
Total recoverable horiz. deform. (µm)	2.03	2.07	1.98	2.01	2.00	2.02	0.03	1.49
Peak loading force (N)	1864	1863	1863	1862	1862	1863	0.56	0.03
Recoverable horiz. deform. #1 (µm)	1.06	1.07	1.01	1.04	1.01	1.04	0.03	2.46
Recoverable horiz. deform. #2 (µm)	0.98	0.99	0.97	0.98	0.99	0.98	0.01	0.82
Seating force (N)	187	187	187	187	187	187	0.15	0.08

APPENDIX: III - DYNAMIC MODULUS TEST SOFTWARE RESULT



	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
Dynamic modulus (MPa)	12547	10651	9113	5670	4385	2208
Phase angle (Degrees)	17.90	22.06	24.69	31.15	32.89	34.42
Average temperature (°C)	25.1	25.1	25.1	25.1	25.1	25.3
Average confining pressure (kPa)	0.0	0.0	0.0	0.0	0.0	0.0
Average micro-strain	36	66	79	93	99	104
Load drift (%)	12.0	0.2	0.2	0.0	0.0	-0.1
Load standard error (%)	61.7	18.2	10.6	0.5	0.2	0.4
Average deformation drift (%)	-593.6	-338.3	-322.3	-344.5	-260.3	-109.6
Average deformation standard error (%)	57.1	17.9	11.3	9.1	8.5	3.6
Deformation uniformity (%)	20.7	18.2	16.5	14.0	12.1	8.8
Phase uniformity (Degrees)	1.5	1.0	0.9	0.6	0.3	0.5

APPENDIX: IV- FACTORIAL ANALYSIS OF DYNAMIC MODULUS

Dynamic Modulus Analysis of Lab Prepared Asphalt Mixtures

Estimated Effects and Coefficients for DM (coded units)

Term	Effect	Coef	SECoef	T	P
Constant		5956	283.7	21.00	0.000
Temperature	-5531	-2766	347.4	-7.96	0.000
Frequency	7065	3533	338.8	10.43	0.000
Modifier %	922	461	283.7	1.63	0.115
Temperature*Frequency	-2195	-1098	414.9	-2.65	0.013
Temperature*Modifier %	60	30	347.4	0.09	0.932
Frequency*Modifier %	290	145	338.8	0.43	0.672
Temperature*Frequency*Modifier %	381	190	414.9	0.46	0.650

S = 1433.86 PRESS = 119851603

R-Sq = 86.48% R-Sq(pred) = 71.85% R-Sq(adj) = 83.10%

Analysis of Variance for DM (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	352952680	359316838	119772279	58.26	0.000
2-Way Interactions	3	14843141	14782993	4927664	2.40	0.089
3-Way Interactions	1	433211	433211	433211	0.21	0.650
Residual Error	28	57566995	57566995	2055964		
Total	35	425796027				

Dynamic Modulus Analysis of Plant ProducedAsphalt Mixtures

Estimated Effects and Coefficients for DM (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		4092	198.9	20.58	0.000
Temperature	-4799	-2399	248.5	-9.65	0.000
Frequency	4839	2419	236.1	10.25	0.000
Modifier %	877	439	198.9	2.20	0.036
Temperature*Frequency	-2180	-1090	296.8	-3.67	0.001
Temperature*Modifier %	301	150	248.5	0.60	0.550
Frequency*Modifier %	524	262	236.1	1.11	0.277
Temperature*Frequency*Modifier %	184	92	296.8	0.31	0.759

S = 1025.68   PRESS = 83816230

R-Sq = 87.97%   R-Sq(pred) = 65.76%   R-Sq(adj) = 84.96%

Analysis of Variance for DM (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	199495251	211397866	70465955	66.98	0.000
2-Way Interactions	3	15763609	15864266	5288089	5.03	0.007
3-Way Interactions	1	101034	101034	101034	0.10	0.759
Residual Error	28	29456551	29456551	1052020		
Total	35	244816445				

APPENDIX: V- FACTORIAL ANALYSIS OF PHASE ANGLE

Phase Angle Analysis of Lab Prepared Asphalt Mixtures

Estimated Effects and Coefficients for Phase Angle (coded units)

Term	Effect	Coef	SECoef	T	P
Constant		30.503	0.5526	55.20	0.000
Temperature	9.097	4.549	0.6768	6.72	0.000
Frequency	-8.012	-4.006	0.6599	-6.07	0.000
Modifier %	-1.792	-0.896	0.5526	-1.62	0.116
Temperature*Frequency	7.541	3.770	0.8083	4.66	0.000
Temperature*Modifier %	0.599	0.300	0.6768	0.44	0.661
Frequency*Modifier %	-0.792	-0.396	0.6599	-0.60	0.553
Temperature*Frequency*Modifier %	-1.339	-0.670	0.8083	-0.83	0.414

S = 2.79338 PRESS = 443.238

R-Sq = 75.88% R-Sq(pred) = 51.07% R-Sq(adj) = 69.85%

Analysis of Variance for Phase Angle (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	500.661	660.453	220.151	28.21	0.000
2-Way Interactions	3	181.295	174.131	58.044	7.44	0.001
3-Way Interactions	1	5.358	5.358	5.358	0.69	0.414
Residual Error	28	218.483	218.483	7.803		
Total	35	905.795				

Phase Angle Analysis of Plant Produced Asphalt Mixtures

Estimated Effects and Coefficients for Phase Angle (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		2.728	0.4721	69.32	0.000
Temperature	13.416	6.708	0.5782	11.60	0.000
Frequency	-9.256	-4.628	0.5638	-8.21	0.000
Modofier %	-2.316	-1.158	0.4721	-2.45	0.021
Temperature*Frequency	5.723	2.861	0.6905	4.14	0.000
Temperature*Modofier %	-0.943	-0.471	0.5782	-0.82	0.422
Frequency*Modofier %	-0.653	-0.326	0.5638	-0.58	0.567
Temperature*Frequency*Modofier %	-0.340	-0.170	0.6905	-0.25	0.807

S = 2.38635 PRESS = 504.884

R-Sq = 88.51% R-Sq(pred) = 63.63% R-Sq(adj) = 85.64%

Analysis of Variance for Phase Angle (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	1124.81	1184.49	394.829	69.33	0.000
2-Way Interactions	3	103.44	103.48	34.495	6.06	0.003
3-Way Interactions	1	0.35	0.35	0.345	0.06	0.807
Residual Error	28	159.45	159.45	5.695		
Total	35	1388.04				

APPENDIX: VI- DYNAMIC MODULUS VALUES

Lab Prepared Asphalt Mixtures With 0% Crumb Rubber

Temperature (^oC)	Frequency (HZ)	Dynamic Modulus (MPA)		Mean	StdDev	CV (%)
		Sample 1	**Sample 2**			
25	25	11631	11884	11757.50	178.90	1.52
	10	9823	9523	9673.00	212.13	2.19
	5	8223	7860	8041.50	256.68	3.19
	1	4732	4565	4648.50	118.09	2.54
	0.5	3536	3479	2338.50	40.31	1.72
	0.1	1637	1701	1669.00	45.25	2.71
40	25	7983	7892	7937.50	64.35	0.81
	10	5823	5554	5688.5	190.21	3.34
	5	4408	4084	4246.00	229.10	5.40
	1	2091	1730	1910.50	255.27	13.36
	0.5	1465	1191	1328.00	193.75	14.59
	0.1	637.4	581.1	609.25	39.81	6.53
55	25	4907	4378	4642.50	374.06	8.06
	10	2977	2892	2934.50	60.10	2.05
	5	2007	2056	2031.50	34.65	1.71
	1	876.6	932	904.30	39.17	4.33
	0.5	646.9	682	664.45	24.82	3.74
	0.1	379	374.9	376.95	2.90	0.77

<u>**Lab Prepared Asphalt Mixtures With 7% Crumb Rubber**</u>

Temperature (^oC)	Frequency (HZ)	Dynamic Modulus (MPA)		Mean	StdDev	CV (%)
		Sample 1	**Sample 2**			
25	25	12547	12456	12501.50	64.35	0.51
	10	10651	10367	10509.00	200.82	1.91
	5	9113	8818	8965.50	208.60	2.33
	1	5670	5255	5462.50	293.45	5.37
	0.5	4385	3873	4129.00	362.04	8.77
	0.1	2208	1912	2060.00	209.30	10.16
40	25	9126	9032	9079.00	66.47	0.73
	10	6936	6618	6777.00	224.86	3.32
	5	5428	5105	5266.50	228.40	4.34
	1	2727	2417	2572.00	219.20	8.52
	0.5	1948	1676	1812.00	192.33	10.61
	0.1	844.9	772	808.45	51.55	6.38
55	25	6539	5601	6070.00	663.27	10.93
	10	4261	3929	4095.00	234.76	5.73
	5	2972	2905	2938.50	47.38	1.61
	1	1255	1328	1291.50	51.62	4.00
	0.5	871.9	867.1	869.50	3.39	0.39
	0.1	453.2	435.5	444.35	12.52	2.82

Plant ProducedAsphalt Mixtures With 0% Crumb Rubber

Temperature (^oC)	Frequency (HZ)	Dynamic Modulus (MPA)		Mean	StdDev	CV (%)
		Sample 1	Sample 2			
25	25	8606	8445	8525.50	113.84	1.34
	10	6917	6787	6852.00	91.92	1.34
	5	5720	5608	5664.00	79.20	1.40
	1	3321	3288	3304.50	23.33	0.71
	0.5	2566	2479	2522.50	61.52	2.44
	0.1	1300	1350	1325.00	35.36	2.67
40	25	6796	5667	6231.50	798.32	12.81
	10	5090	4137	4613.50	673.87	14.61
	5	3993	3125	3559.00	613.77	17.25
	1	1993	1450	1721.50	383.96	22.30
	0.5	1388	986.2	1187.10	284.12	23.93
	0.1	554.7	399.7	477.20	109.60	22.97
55	25	1850	1723	1786.50	89.80	5.03
	10	1100	1021	1060.50	55.86	5.27
	5	712.7	664.7	688.70	33.94	4.93
	1	256	239.9	247.95	11.38	4.59
	0.5	154	146.4	150.20	5.37	3.58
	0.1	62.4	62.8	62.60	0.28	0.45

Plant Produced HMA Mixtures With 7% Crumb Rubber

Temperature (^oC)	Frequency (HZ)	Dynamic Modulus (MPA)		Mean	StdDev	CV (%)
		Sample 1	Sample 2			
25	25	9110	8873	8991.50	167.58	1.86
	10	7309	7171	7240.00	97.58	1.35
	5	6020	5916	5968.00	73.54	1.23
	1	3463	3378	3420.50	60.10	1.76
	0.5	2612	2523	2567.50	62.93	2.45
	0.1	1229	1160	1194.50	48.79	4.08
40	25	7832	7305	7568.50	372.65	4.92
	10	6172	5469	5820.50	497.10	8.54
	5	4987	4226	4606.50	538.11	11.68
	1	2618	2082	2350.00	379.01	16.13
	0.5	1834	1412	1623.00	298.40	18.39
	0.1	718.8	553.5	636.15	116.88	18.37
55	25	2042	2470	2256	302.64	13.41
	10	1868	2271	2069.50	284.96	13.77
	5	1290	1589	1439.50	211.42	14.69
	1	498.9	660.7	579.80	114.41	19.73
	0.5	304.3	438.7	371.50	95.04	25.58
	0.1	150	176.5	163.25	18.74	11.48

APPENDIX: VII-SEQUENCE OF PREPARATION OF MIXTURES


(a) Heating Aggregates Prior to Mixing


(b) Heating Asphalt prior to Mixing


(c) Mixing Machine


(d) Mixing of Mixture


(e) Mixed Sample


(f)Loose Mixture for Conditioning


(g) Placing Mixture in Gyratory Mold


(h) SUPERPAVE Gyratory Compactor

(i) Placing Gyratory Mold in SGC

(j) Extraction of Compacted Sample

(k) Coring of Specimen

(l) Cored Specimen

(m) Saw Cutting of Specimen

(n)Cored and Sawed Specimen

(o)Specimens for Dynamic Modulus Test

(p) Sawed Specimens for Resilient Modulus Test

APPENDIX: VIII-WHEEL TRACKER TEST

(a) Setting Test Parameter

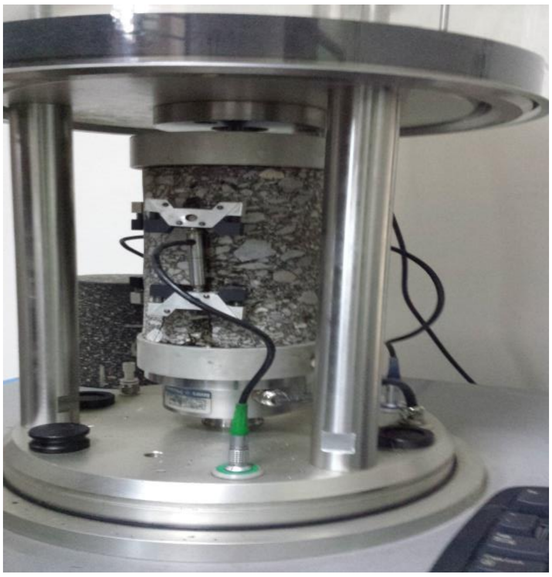
(b) Fixing Specimen in Mold

(c) Placing Mold in Machine

APPENDIX: IX- DYNAMIC MODULUS TEST

(a) Fixing Studs

(b) Mounting Clamps



(c) Fixed Sample in Environmental Chamber

(d) Running the Test