OPTIMIZATION OF RAP AND SASOBIT FOR PERMANENT DEFORMATION AND MOISTURE DAMAGE OF ASPHALT MIXES

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A thesis submitted in partial fulfillment of

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DEDICATED

TO

HOLY PROPHET ﷺ

MINARET OF KNOWLEDGE

AND

MY LOVING PARENTS & INSTITUTE

WHO GAVE ME LOT OF INSPIRATION

COURAGE &

SUPPORTED ME MORALLY &

FINANCIALLY FOR MY STUDIES

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(Engr. Fazal Haq)

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LIST OF ABBREVIATIONS

AASHTO	–	American Association of State Highway & Transportation Official
AC	–	Asphalt Concrete
ARL	–	Attock Refinery Limited
ASTM	–	American Standard Test Method
BS	–	British Standard
CIPR	–	Cold-In-Place Recycling
Gmb	–	Bulk Specific Gravity
Gmm	–	Maximum Specific Gravity
HIPR	–	Hot-In-Place Recycling
HMA	–	Hot-Mix Asphalt
HWTD	–	Hamburg Wheel Tracking Device
ITS	–	Indirect Tensile Strength
JMF	–	Job Mix Formula
LEA	–	Low Energy Asphalt
LOS	–	Level of Service
MS-2	–	Manual Series (Asphalt Institute)
NHA	–	National Highway Authority
NMAS	–	Nominal Maximum Aggregate Size

OAC	–	Optimum Asphalt Content
OBC	–	Optimum Bitumen Content
Pb	–	Percent Binder (preferable over “AC”)
Pbe	–	Percent of Effective Binder
PG	–	Performance Grade
RAP	–	Reclaimed Asphalt Pavement
RAS	–	Recycled Asphalt Shingles
RxSy	–	RAP=X%,S=Y%
SGC	–	Superpave Gyratory Compactor
SMA	–	Stone Mastic Asphalt
SP-2	–	Superpave mix design
UTM	–	Universal Testing Machine
Va	–	Air Voids
VFA	–	Voids Filled with Asphalt
VMA	–	Voids in Mineral Aggregates
WMA	–	Warm Mix Asphalt

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ABSTRACT

Transportation infrastructure plays a substantial role in the everyday life of social beings. The preservation of this vast infrastructure needs appropriate and cost-effective design technique which depends upon the selection and proportion of binder and aggregate. To save precious aggregates Reclaimed Asphalt Pavement (RAP) recycling is one of critical need, which also reduces the use of expensive asphalt binder. The production temperature limits the amount of recycled Hot Mix Asphalt (HMA). Warm Mix Asphalt (WMA) technology offers the option of recycling at a reduced temperature than conventionally used, thus a higher percentage of RAP can be recycled, and saving energy and cutting CO_2 emission. The purpose of this experimental study (funded by the Higher Education Commission of Pakistan) was to evaluate the effects of WMA additive (sasobit) on permanent deformation and moisture susceptibility of HMA containing RAP. The mixtures' durability (moisture susceptibility) was measured by the Universal Testing Machine (UTM) performing Indirect Tensile Strength (ITS) test and permanent deformation (Rutting) by Hamburg Wheel Tracking (HWT) test. The mixes with five different percentages of RAP i.e. 0%, 15%, 25%, 35% and 50% were prepared and tested for volumetric properties according to Marshall Mix Design procedure, and then preparing samples with further addition of four different percentages of sasobit i.e. 0%, 1%, 2% and 3% of Optimum Bitumen Content (OBC) for each mentioned percentages of RAP for rutting and moisture damage testing. The rutting potential of mixes were improved by addition of either RAP or sasobit or both as compared to control asphalt mixes. But for lower percentages of RAP i.e. up to 15% highest rut resistance was observed at 2% sasobit addition and for higher percentages of RAP highest rut resistance was observed at 3% sasobit addition. On the other hand, increasing RAP and sasobit content increased the moisture susceptibility of mixes so best recommended combination is to use 30-40% RAP in addition of 3% sasobit as far as permanent deformation and moisture susceptibility criteria's are concerned. Overall, sasobit seems to be a workable tool for dropping production temperatures that can be readily mixed with HMA. Reductions in production temperatures can probably decrease fuel costs, reduce emissions of CO_2 and many other hazardous gases, extend the winter paving window and facilitate specialized applications, such as construction of airport runway, where quick opening to traffic is necessary.

Chapter 1

INTRODUCTION

1.1 BACKGROUND

The emergent plea on our nation's thoroughfares over the past couple of decade's results in a decrease of budgetary funds, and to offer a cost effective, safe, and efficient roadway transport system has steered to a histrionic intensification in the necessity to rehabilitate and manage our current pavements. Asphalt reclaiming and recycling has also shown a dramatic progress in the last 25 years which is technically and naturally desired way to rehabilitate the present pavements.

Asphalt reclaiming and recycling encounters all of our social objectives of providing efficient and safe thoroughfares and addition to that significantly plummeting both energy (oil) ingestion and environmental effect as compared to conservative pavement reconstruction. Thus it has a long term effect which accord vendor agencies to expand their available fund. But need to be appropriately applied as not all roadways are suitable nominees for asphalt recycling and in turn it will help the roving public with a reliable and safe driving surface.

The asphalt paving industry has continuously encouraged recycling, inclusive Recycled Asphalt Shingles (RAS), RAP, tires, etc. The pristine asphalt pavement recycling dates back to 1915, as noted by Zhou et al, (2013). However, momentous use of RAP in HMA indeed initiated in the mid-1970s due to excessive prices of asphalt binder as a result of the oil impediment. Many latest researches such as performed by Moghaddam et al, (2016) Tayebali et al, (2015), MAHA et al, (2015) etc. have been carried out to better use RAP in both WMA and HMA.

Moreover, historical data as mentioned by R. West, (2009) revealed that the RAP mixes could have the same performance to that of virgin HMA mixtures, when accurately designed and constructed. One of the major flexible pavement distresses is premature rutting, which is encountered by country due to high temperatures and increased axle load. Rutting in asphaltic concrete depends on many factors i.e. gradation and quality of aggregates, stability of asphalt mixes, type of binder, percentage of the bituminous binder, air void contents, degree of compaction, environmental conditions including traffic, temperature and humidity, repeated traffic loading cycles, the substructure and the bearing capacity of the sub grade (Khan, 2008).

According to O'Sullivan (2009) Moisture susceptibility is the propensity of asphalt mixtures to weaken the bond between aggregate and asphalt binder and is one of the major concerns with the performance of pavement, whether it is hot mix, warm mix, or RAP. Moisture damage is caused when the moisture present in air voids adversely affects the durability and strength of asphalt mix. Moisture damage can be of two types: adhesive failure and cohesive failure. Adhesive failure is between the aggregate and binder while cohesive failure is the reduction in binder strength due to moisture damage.

Environmental and Economic concerns have motivated the recycling of many materials such as aluminum, steel, and plastic etc. One of these recyclable materials is RAP.

In typical asphaltic mix design RAP rarely crosses the limit of 20% to 25% in addition Hot-In-Place Recycling (HIPR) or Cold-In-Place Recycling (CIPR), which can make use of 80% to 100% RAP. Variability in aggregate gradation is among the causes for RAP's limited use specially when stockpiles of different RAP sources are not correctly separated, managed and processed to reduce inconsistency such as segregation. Due to economic crises together with environmental concerns, transportation departments in the United States are being enforced to rise the amount of RAP up to 50% in asphaltic concrete pavements. Increased percentage of RAP usage has the potential to impact structural performance and durability of the pavements. Researches have shown that higher content of RAP impact on rutting, fatigue and fracture characteristics of HMA as mentioned by Al-Qadi et al. (2012).

Also many innovative procedures and materials have become presented having the proficiency of dropping HMA temperature at which it is mixed and trodden without negotiating the concert and harmony of the pavement materials. These innovative materials can decrease mixing and compaction temperatures up to 40 %.

Reduced mixing temperatures results in energy cost savings to the producer and verdicts have revealed that reduced temperatures in plant can lead to a 30 % drop in fuel energy consumption mentioned by Hurley & Prowell (2006) and a substantial cost savings results from decrease in emissions, and emission control at an asphalt plant, attributed to about 30-50% of overhead costs at an asphalt plant. Also Zhang et al (2012) stated that reduced temperatures will help in reduction of visible or non-visible emissions and will ultimately help in reduction of health problems, odor problems and greenhouse gases emissions. Thus we can site an asphalt plant in non-attainment areas with reduced emissions, where we have austere guidelines for air pollution. By locating asphalt plant in a non-attainment zone for producing HMA with a product that permits for a reduced functioning temperature will permit smaller haul distances thus help in production progress and curtail the period of construction, also will help in reducing the conceivable bother of traffic jamming. WMA will also permit lengthier haul distances and a lengthier period for construction for the blends which are produced at more normal functioning temperatures. With the lower operating temperatures another prospective added benefit in that it reduces the oxidative hardening of asphalt which may upshot performance of pavement such as decreased block cracking, thermal cracking, and averting the mixes from being tender when placed.

The idea of producing asphalt mixes at reduced temperature is not new. First effort of producing asphalt with binder was conducted in 1956 by Prof. Ladis Csanyi at Iowa State University, US that was designed by steam. After that foaming technology has been investigated and used in various countries, including Australia, US and Europe. Waxes have been used for the last twenty years, as viscosity modifier in Germany; primarily they were just used for better workability of mastic asphalt and not for dropping the temperature, and only about fifteen years ago, reduction of mixing and compaction temperatures were avowed a primacy.

There are fifteen different WMA technologies presently available. Some of them are: Double Barrel Green, Synthetic Zeolite, WAM Foam , Low Energy Asphalt, Evotherm, REVIXTM, RedisetTM WMX, and Sasobit. The first four technologies are foaming based WMA, while the second four are based on organic additive or chemical(s). A small amount of water is introduced into hot asphalt in foaming based WMA. The added water will result in a large and quick asphalt binder expansion as it turns into steam and disperse in hot binder, thus increasing mixture workability and also help in coating of aggregate. The addition of this small quantity of water can be introduced by either using moist aggregate (Low Energy Asphalt), a foaming nozzle (Double Barrel Green) or adding a hydrate (Synthetic Zeolite). But chemical or additive-based WMA drops the binder viscosity that permits comparative reduced production temperature and results in increase of the mixture workability.

Among these process is the use of trademarked Sasobit, an artefact of Sasol Wax. Sasobit is a fine crystalline, long-chain hydrocarbon (aliphatic poly-methylene) formed from natural gas gasification or coal feed stocks by the Fischer-Tropsch (FT) process (in which methane is partly oxidized to carbon monoxide (CO) and later react with hydrogen (H)) in the presence of catalyst which produce a mix of hydrocarbons with molecular chain lengths of C5 to C100 plus carbon atoms. Sasobit is also known as FT hard wax.

By assessment of Goh, S. W. (2012), sasobit is macro crystalline bituminous paraffin waxes with carbon chain lengths ranging from C25 to C50. A higher melting point results from the carbon chains length in the FT wax. As compared to bitumen paraffin waxes the smaller crystalline structure of the FT wax lessens brittleness at reduced temperatures. Sasobit is an “asphalt flow improver” (equally during mixing and compaction tasks of asphalt production), because of its capability to reduce the viscosity of the asphalt binder. This reduction in viscosity permits production temperatures to be reduced by 18-54°C (32-97°F). Sasobit has a melting temperature of about 102°C (216°F) and is totally soluble in asphalt binder at temperatures higher than 120°C (248°F). Sasobit apparently forms a crystalline grid structure in the binder, at a temperature below its melting point that leads to the added permanency.

For production of HMA, Sasol endorses to add Sasobit at a rate of 0.8% to 3% by mass of bitumen, but not to exceed 4 %. In marketable uses in Europe, Asia, South Africa, and the United States, Sasobit has been introduced directly onto the aggregate mix as melted liquid through a dosing meter or solid prills (small pellets). Marshall tests executed on blends produced in this way signposted no variance in Flow or Stability values as associated to premixing with the binder as evaluated by Hurley & Prowell (2005).

Since 1997, Sasobit were used in paving of more than 142 projects, totaling more than 2,271,499 square meters of pavement. Projects were constructed in Belgium ,Austria, China, Denmark, Czech Republic, Hungary, France, Italy ,Germany, Malaysia, New Zealand, Macau, South Africa, Sweden, Netherlands, Russia, Switzerland, the United States and the United Kingdom,. These projects involved an extensive array of aggregate types and mix types, including: stone mastic asphalt, dense graded mixes and Gussaphalt. Sasobit introduction rates varied from 0.8 to 4 % by mass of binder.

Reduced mixing and compaction temperatures will reduce aging, and allows for using higher percentages of RAP without an addition of any rejuvenating agent for asphalt binder. Some WMA additives attain reduced production temperatures by shifting the viscosity-temperature link of the binder. Though, in all WMA additives, the direct calculation of mix workability, coating and compatibility are mandatory to establish operating temperatures. Numerous research studies one of them is conducted by Ahmed (2014) described that WMA may be more vulnerable to moisture damage, that may be accredited to the reduced operating temperatures of WMA.

Therefore, an inclusive field and laboratory examinations should be accomplished to explore the moisture susceptibility and rutting of WMA technology as compared to the HMA technology conventionally in use.

1.2 PROBLEM STATEMENT

An estimated length of road network in Pakistan is slightly above 260,000 km at present and NHA Budget Report for FY 2015-16 shows substantial annual amount is required to maintain this asset in good condition but the maintenance and preservation funds allocated yearly cover less than 10% of the pavements that are in need of repair. Therefore, recycling of RAP is a critical necessity to not only save the depleting resources of aggregates, but to decrease the use of costly bitumen, as 95% of the world surface transportation infrastructure system is paved with HMA.

In present scenario pavement recycling is the best option to construct the pavements by maintaining the desired volumetric as various motorway links construction and rehabilitation has been announced with the fact that HIR and CIR technology already been introduced and tested at few places. Similarly, WMA technology provides a solution to apply current state of the art recycling technology to enable us to consume more RAP at a comparatively reduced than conventional temperature in Asphalt mixes. By the use of WMA additives in recycled material, we can make project more economical, and funds saved as a result can be used for preservation of longer length of road, and/or for construction of new pavements.

The problem discussed above endorses the requirement of a study to promote the pavement recycling approach in Pakistan with lower temperature by WMA technology. For which, this research has been planned to explore the permanent deformation and moisture damage of asphalt mixes with different percentages of RAP and sasobit as WMA additive and to categorize any special attentions that must be met to consume higher RAP content at lower temperature. For all the performance tests, cylindrical samples were compacted using Superpave Gyratory Compactor (SGC) to characterize the effect of RAP content along with the addition of sasobit from 0 to 3 % on asphalt mixes and analysis of obtained experiment data from HWT test and ITS test was carried out by using statistical software (Excel). Test matrix for Marshall Mix Design is shown in Table 1.1 and Performance Test matrix is shown in Table 1.2

Table 1.1: Test Matrix for Marshall Mix Design

S. no	RAP Replaced (%)	Bitumen Content (%)	No: of samples for Volumetric Analysis
1	0	3.5	3
		4	3
		4.5	3
		5	3
		5.5	3
2	15	3.5	3
		4	3
		4.5	3
		5	3
		5.5	3
3	25	3.5	3
		4	3
		4.5	3
		5	3
		5.5	3
4	35	3.5	3
		4	3
		4.5	3
		5	3
		5.5	3
5	50	3.5	3
		4	3
		4.5	3
		5	3
		5.5	3
Total			75

Table 1.2: Test Matrix For Performance Testing

S. no	RAP replaced (%)	Sasobit content (% of OBC)	Number of Samples			
			Moisture damage by UTM		Permanent Deformation by HWT	Total
			For Un-Conditioned Testing	For Conditioned Testing		
1	0	0	3	3	3	9
		1	3	3	3	9
		2	3	3	3	9
		3	3	3	3	9
2	15	0	3	3	3	9
		1	3	3	3	9
		2	3	3	3	9
		3	3	3	3	9
3	25	0	3	3	3	9
		1	3	3	3	9
		2	3	3	3	9
		3	3	3	3	9
4	35	0	3	3	3	9
		1	3	3	3	9
		2	3	3	3	9
		3	3	3	3	9
5	50	0	3	3	3	9
		1	3	3	3	9
		2	3	3	3	9
		3	3	3	3	9
Total			60	60	60	180

1.3 RESEARCH OBJECTIVES

The objectives of the present study are:

1. To find the volumetric properties of HMA containing different percentages of RAP using Marshall Mix Design Method.
2. To evaluate the Rutting Susceptibility of, Hot Mix Asphalt (HMA) mixes with and without RAP content and Warm Mix Asphalt (WMA) mixes having different percentages of Sasobit and RAP by using Hamburg wheel-tracking device.

3. The effect of RAP content in the mix on Moisture Damage of, HMA and WMA containing varying Sasobit percentages by performing Indirect Tensile Strength (ITS) test through Universal Testing Machine(UTM)
4. To compare the results of different mixes on the basis of RAP and Sasobit percentages.

1.4 SCOPE OF THE THESIS

To attain the planned research objectives as stated above, a research plan was premeditated and the outline of the research tasks is given below:

- Literature review of the standard Marshall Mix design, the previous research finding on the permanent deformation and moisture damage of laboratory fabricated asphalt mixes containing RAP and Sasobit, the test procedures for permanent deformation, moisture damage and interpretation of results.
- Determination of OBC for HMA containing RAP (0%, 15%, 25%, 35%, and 50%) by Marshall Mix design using MS-2 manual.
- Performing Wheel tracker test to determine permanent deformation of control and uncontrolled asphalt mixtures according to AASHTO T-324-04 on Superpave Gyratory Compacted samples.
- Conditioning of the specimens was conducted in accordance with ALDOT-361.
- Testing of unconditioned and conditioned specimens were conducted, for indirect tensile strength through test equipment UTM-25 according to ASTM D 6931-07.
- Interpretation of results obtained from performance tests.

1.5 ORGANIZATION OF THE THESIS

The thesis is ordered in five chapters; brief description of each is as follows:

Chapters 1 elaborate an overview of WMA technology especially the use and properties of sasobit, in addition to RAP, their effect on permanent deformation and moisture damage of asphalt mixes, objectives and scope of the study.

Chapters 2 includes a literature review on findings of the previous studies related to the utilization of RAP and WMA, material characterization, factors affecting the bituminous mixes containing RAP. Finally, the design of experiments are illustrated.

Chapters 3 describes the methodology used to achieve the objectives of the study.

This explains the aggregate gradation and the bituminous mix preparation procedures for Marshall Mix design and performance testing. The results of Marshall Mix design for all percentages of RAP are presented and discussed.

Chapter 4 presents the experimental results and their analysis using the software Microsoft Excel 2016.

Chapter 5 summarizes the findings and conclusions of laboratory testing. The future work and suggestions are also discussed.

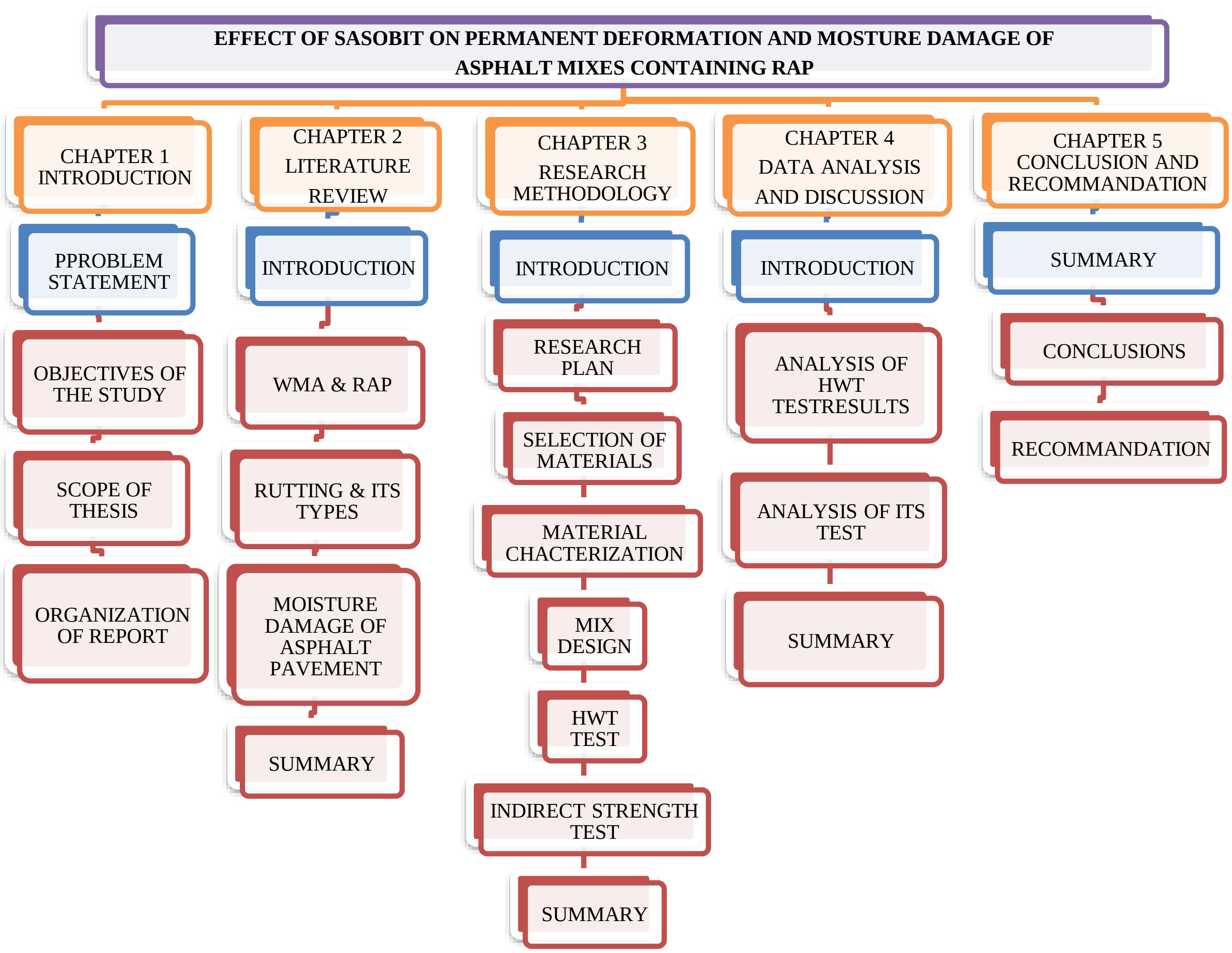


Figure 1.1: Organization of Report

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter contains a brief review of the literature and theory related to the response of asphalt mixes containing RAP and sasobit to the Hamburg wheel tracker tests (for permanent deformation)) and ITS test for (moisture damage). This chapter deals with RAP and sasobit, its impact on different performance properties and researches carried out previously to predict permanent deformation and moisture damage of asphalt mixes using HWT test and ITS test. The detail of HWT tests and ITS test on asphalt mixes are also explained.

2.2 BACKGROUND

It is well accepted that for a good economy and with satisfactory level of growth we need a sound infrastructure, inclusive roadways. Studies have directed that owner can reduce cost if he sustained a roadway, at an adequate level of service. A World Bank study quantified that expanding $1 during first 40% drop in a roadway quality will save $3 to $4 associated to the expense which would be mandatory at the 80 percent drop in quality, as shown in Figure 2.1

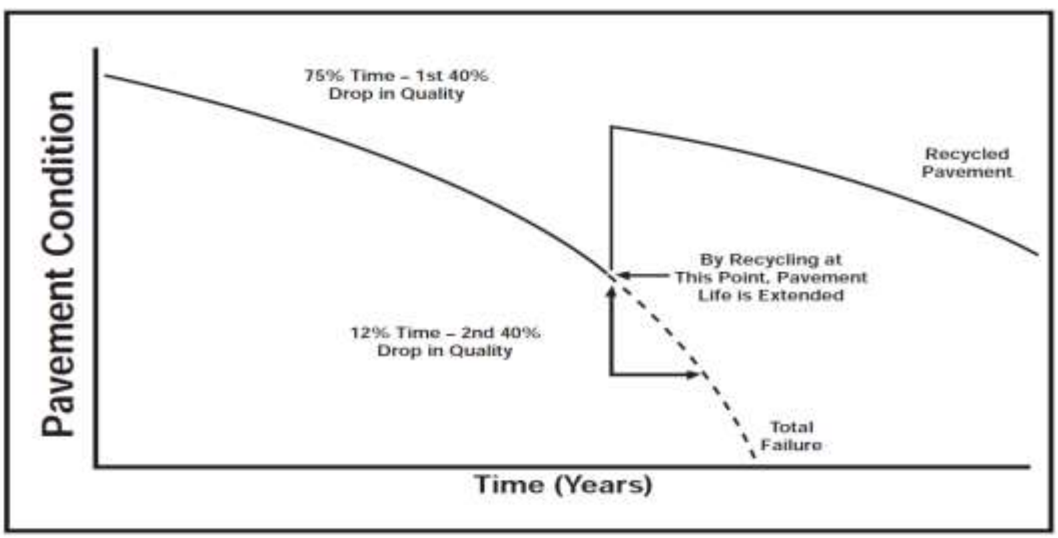


Figure 2.1: Pavement deterioration and recycling rehabilitation vs. time (U.S. Department of Transportation)

With growing traffic and age the rate of pavement deterioration also increases. Which results in dramatic increase in rehabilitation cost. If we don't undertake rehabilitation or any other preventative maintenance at the suitable times, it will result in the quick deterioration of roadway to the point where the only option left will be expensive reconstruction. Fortunately, we can achieve substantial extensions to the roadway's service life through appropriate and timely application of rehabilitation or any other preventive maintenance activities as indicated in Figure 2.2.

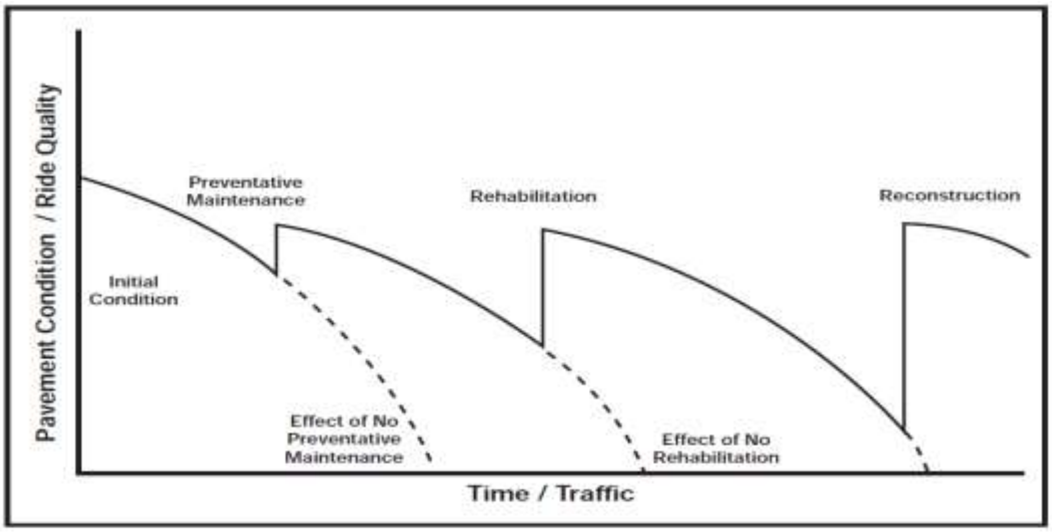


Figure 2.2: Pavement Deterioration vs. Time (U.S. Department of Transportation)

Environmental and economic thoughts have encouraged the recycling of aluminum, plastic, steel and many other materials. One of these recyclable materials is RAP.

2.3 FINDINGS ON USING WMA, RAP AND THEIR BENIFITS

A new asphalt binder selection and mix design practice is introduced in the asphalt paving industry, resulted from superpave mixture design procedure development (Asphalt Institute Superpave Mix Design). In superpave there was no attention for recycled mixtures as initially it was established for virgin binder-aggregate mix. However, environmental and economic concerns prescribe the utilization of recycled materials in pavement. Thus, for incorporating RAP in the mix we need a modified methodology while using superpave system.

WMA technology, initiated in Europe, is achieving high interest in the world. WMA additives increases the workability of asphalt mix and/or decreases the viscosity of asphalt binder using nominal heat. WMA technology permits the mixing, transporting, and paving practice at considerably reduced temperature. Using this latest technology, we can produced asphalt mix as much as 100ºF lower than ordinary HMA.

According to Moghaddam et al, (2016) recycling of HMA is an old idea which was recognized as far back as 1915, although its gain extreme acceptance due to oil embargo of the mid-1970. Due to insufficiency of excellence aggregates close to the point of application and higher costs for asphalt, increased the demand for RAP. Which also have a lot of incentives in terms of environmental and economic benefits. It is estimated that since the mid-1970's, 10 million tons of RAP have been utilized, with equal performance characteristics along with considerable saving in cost as compared to virgin HMA mixes.

To increase our survival period on this planet, we must have to improve techniques to lower energy consumption, generation of heat, emissions of greenhouse gases and fossil fuel. The mandatory research should be conducted by the scientists, and then agencies must impose those concepts that make sense. Research needs to be carry out for WMA to check if WMA is logical, cost effective and environmentally beneficial, and if so, engineers must progress the tools that will bring WMA into use.

For probable economic and environmental benefits of the WMA mixes, Almeida-Costa, A., & Benta, A., (2016) conducted a research in which they produced a warm asphalt concrete of high modulus by adding a chemical additive and a warm rough asphalt concrete by the inclusion of organic additive. For both cases, they evaluated the maximum theoretical cost of additive. The results obtained from this study dictates that the maximum cost obtained for warm mixture confirms that the production of the respective warm mix is economically beneficial. Fall in CO_2 release was also measured. Reduced carbon dioxide emissions along with significant reduction of energy consumption was observed for both mixtures under study. Thus it is obvious that we can achieve all these environmental and economic benefits with assuring an enhancement of the pavements.

Maha et al, (2015) specified that there are two aspects i.e. durability and strength of the end product and the temperature regimes at which WMA are manufactured, which will distinguish WMA from other asphalt mixes. He stated that cold asphalt mix is produced at temperature (e.g., 68°F to 120°F), while 285°F to 340°F is the typical temperature range for

HMA while WMA are those mostly manufactured in the temperature range of 200°F to 275°F. Cold-mix asphalt has lower durability and stability than HMA, due to which cold mix is used in the down layers of pavement of low-volume roads. The aim of WMA technology is to achieve a level of strength and durability that is comparable to HMA.

According to McCormack et al (2014) there are a lot of implications for WMA technology. Info obtained from manufacturers and materials suppliers show that, roundabout 30% CO2 emission and energy consumption are possible using WMA as compared to typical HMA.

According to Braziunas et al, (2013) improved compaction is a key performance related parameter. While the majority of asphalt binder in HMA aged in the plant when exposed to raised temperatures. Reduced mixing temperature will help in reduced oxidative hardening, and in turn enhancing pavement longevity and flexibility with reduced vulnerability to cracking.

Rossi, et al, (2013) stated that positive impacts will be demonstrated by technologies with lower HMA production temperatures on pavement performance. Because these technologies will improve mix workability and will enhance in-place density because they should decrease (or, at least, surely not increase) compaction energy required. According to Jamshidi et al. (2013) sasobit saves energy, because it reduces fume emissions, and drops the production cycle times.

Capitao et al. (2012) and Liu et al. (2011) stated that there is an opportunity of lowering the production temperatures by 18–54^{o}C (32–97^{o}F). They also indicated that the viscosity of the asphalt binder can be lowered by adding sasobit, throughout the asphalt production process. According to Sasol Wax, sasobit is able to transfer softer grades of asphalt into harder grades, and simultaneously it attempts to stop bleeding and deformation at high performance temperature. Rubio et al. (2012) designated that beneath the sasobit melting point it can create a crystalline network structure which provides additional stability.

According to Al-Rawashdeh et al. (2010), producing HMA 30-50% of an overhead cost is specified for emissions control; thus substantial cost reductions are possible by plummeting CO_2 emission. For WMA, 50-60% reduction in dust generation was detected by some technologies, because using WMA technology injurious fumes in the locality of labors were often lower than the limits of detection.

Room, D. B. (2010) and Kristjansdottir et al. (2007) stated that, 20-75% reduction in energy consumption on few WMA jobs was measured as compared to HMA, and the main factor for reduced energy consumption was reduction of production temperature. The type and cost of energy is also contributing factor due to which the level of this benefit changes. For example, high energy cost will off course results in greater benefit. Whether the power source is electricity or fossil fuel. A ton of HMA production roughly requires 300,000 BTUs, which is equivalent to 2.5-3.5 therms of natural gas or about 2-3 gallons of diesel or fuel oil. Expenditures for definite materials and plants will vary.

According to Chowdhury et al, (2008) by reducing the production temperature, we can extend the paving season, because it enhances the ability to accomplish paving in late/early-season. And starting the mixture at a reduced temperature, it will not cool as quickly, thus permitting longer haul distances and/or periods of time to compact the mat. They also recorded some other benefits resulting from reduced temperature such as pavement construction in ozone non-attainment zones and/or additional plant process during daylight hours in these areas.

Romier et al. (2006) stated that 50% less energy is required to heat LEA as compared to a similar HMA. Based on those intentions, they also reported that we can decrease greenhouse gas (N_2O, CH_4 and CO_2,) discharges using LEA by 50%. Generally, we can say that using WMA technology its certain that working conditions and safety of workers will be improved because with reduced heat of mixture the discharge of polycyclic aromatic hydrocarbons and volatile organic compounds will also reduce.

Measurements by Larsen et al., (2004) in Norway from a drum plant disclosed that WAM-Foam manufacturing resulted the following reductions, comparing with HMA at equal production rates: 40% in diesel consumption, 29% in CO emissions, 62% in NOX emissions and 31% in CO2 emissions

Barthel and Von Devivere (2003) used WMA additive Aspha-Min, calculations indicate that because of reduction in mix temperature by 54°F to 63°F causes a 30% reduction in energy consumption and 75% decrease in fume emissions was observed due to reduction in production temperature by 47°F. Calculations at the site of application indicated even more than 90% reduction in fume emissions, due to further reduction of mix temperature from 345°F to 285°F and, in all cases, odor has decreased when Aspha-Min has been added with reduced temperature.

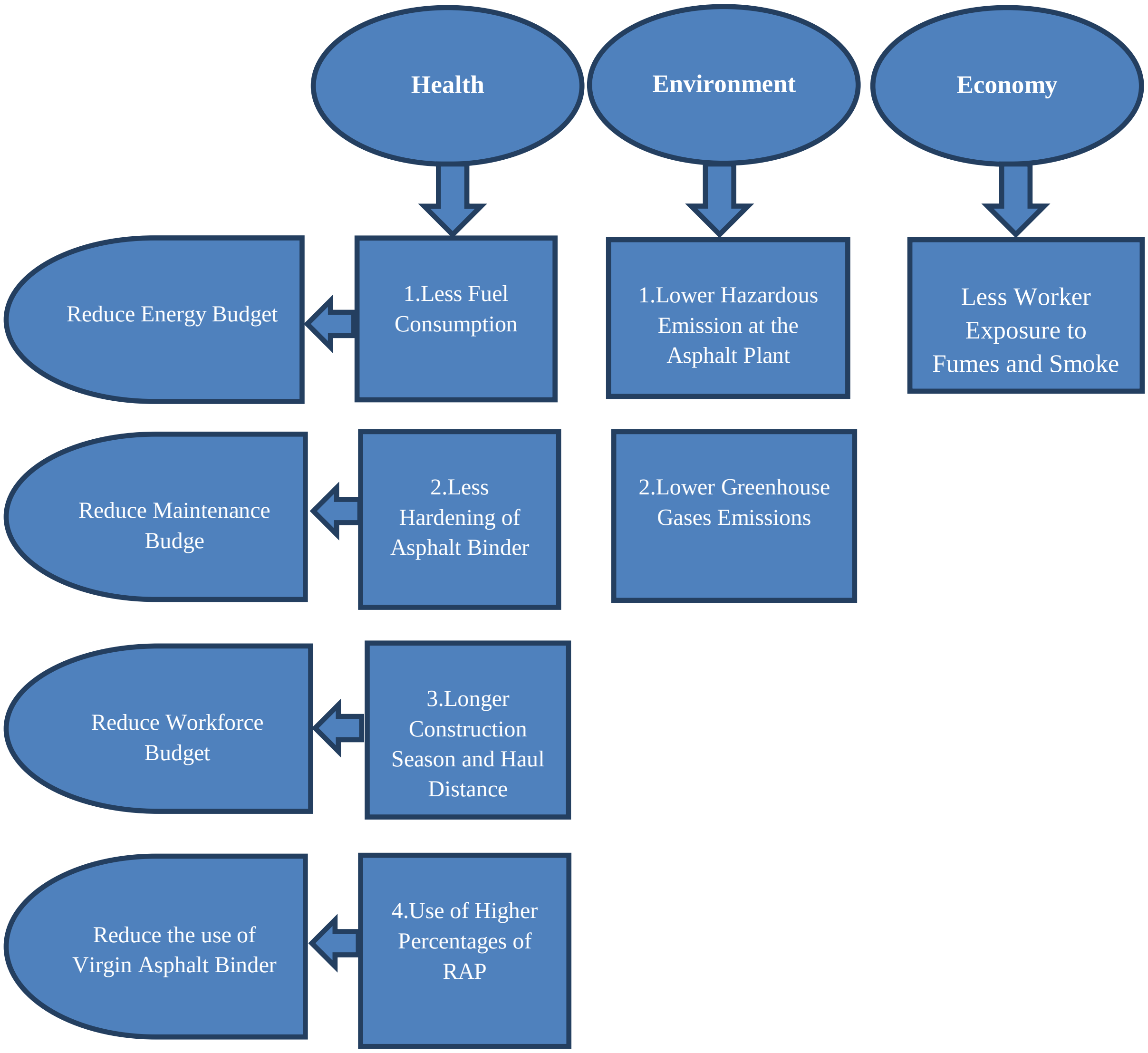


Figure 2.3: Advantages of Warm Mix Asphalt

2.4 STRUCTURAL DESIGN CONSIDERATION WITH WMA

To date, most of the research on WMA has performed in the US by NCAT (National Center for Asphalt Technology). In their laboratory studies they used standard HMA production temperatures and modified superpave mixture design processes with 125 gyrations of the superpave gyratory compactor. Until further research is conducted, NCAT recommended to determine the OBC without addition of the WMA additive using standard HMA design procedures, the main reason behind this is that WMA additives will effectively improve compaction thus it reduces OBC near one-half a percentage point than that of an equivalent

HMA. This carried out concerns about permeability, durability and moisture susceptibility of the resulting mix.

According to Tutu et al. (2016) It is certain that most of the highway agencies, worldwide, who have conducted research on any of the WMA technologies in the field and in the laboratory, have used typical dense-graded mix similar to those they conventionally use in HMA, so it is obvious that currently no need to modify the gradation of conventional dense-graded HMA mixes for accommodating WMA additives.

When describing the LEA method, Padhi, (2014) indicates that we can apply the same laboratory mix design methods to WMA paving mixtures as we use for design of HMA. However, they also stated that laboratory production procedures need to be adjusted to the mixtures temperature resulting from the plant mixing procedure.

Padhi, (2014) pointed that LEA mixtures use similar grades of asphalt in the same proportions as HMA and this is also true for WMA additives. He also stated that sasobit has not only been used in dense-graded mixes but also in gussasphalt and in stone mastic asphalt.

According to Newcomb, (2009) there is only limited indication that, it may be likely or even desirable to use one grade harder asphalt with certain WMA technology, than that normally used with HMA.

Romier, et al. (2006) indicated that WMA procedures should be likewise pertinent to conventional asphalt mixes other than dense-graded mixes. Several WMA procedures have proved success in mixes containing RAP including WMA-Foam and LEA.

Hurley and Prowell (2006a) clearly pointed that using the same aggregate type and gradation, sasobit, Evotherm and Aspha-min significantly reduced the compaction temperature necessary to attain essentially equivalent air voids as a HMA. They also pointed that unlike Marshall hammer, the superpave gyratory compactor was relatively unaffected to compaction temperature.

Based on conclusions carried out from the review of current literature, the authors presently consider that WMA should offer at least equal structural performance as HMA.

2.5 RUTTING IN ASPHALT PAVEMENT

According to Ahmed (2014) Rutting, also known as permanent deformation, can be defined as the accumulation of small amounts of unrecoverable strains as a result of applied loading to a pavement, Moreover, rutting characterizes a continuous accumulation of small permanent deformations caused by the application of each load.

Rutting is the significant distress mechanisms in asphalt pavements in the form of permanent deformation. Due to increase in truck pressure in last decades, rutting has become the foremost mode of failure in flexible pavement. Rutting is principally due to the accumulation of permanent deformation in different layers and in different portion of layers in the pavement structure. Studded tires usage on pavements can also cause rutting. Longitudinal irregularity in the magnitude of rutting causes roughness. Due to rutting, skid resistance is reduced and also increases the potential for hydroplaning which results in reduced visibility because of water trapping. As rutting developed it leads to cracking of the pavement and ultimately disintegration or failure of pavement takes place. Highways and secondary roads accounts for a substantial percentage of maintenance and associated costs due to these distresses.

Garba, R. (2002) described that the average gross weight of trucks has increased and is functioning near to the limits of legal axle loads. Countries with relaxed implementation of the legal axle load limits the trucks operate at axle loads and thus exceed the legal limit of axle load. Due to increase in axle loads and the use of increased pressure in tires results in high stresses due to the contact area between the tire and the pavement which causes larger deformation in flexible pavements in the form of excessive wheel track rutting. Permanent deformation in wearing coarse thus accounts for a larger percentage of rutting on flexible pavements exposed to high tire pressures due to heavy axle load. Thus rutting is a longitudinal depression in top layer along the wheel path with pavement disruption through the edges of the rut. Major structural failure and hydroplaning caused by rutting is a safety hazard. Rutting can take place in all pavement layers and results from lateral side densification and distortion.

2.5.1 Types of Rutting

Rutting in flexible pavements is mainly caused by an asphalt mix that cannot resist the repetitive heavy axel loads to which that pavement is subjected having reduced shear strength.

2.5.1.1 Rutting caused by weak asphalt layer - Instability Rutting (Hussain, 2012)

Rutting due to weak asphalt mixture is because of high temperature which typically occurs in summer season when temperature of pavements are high. Figure 2.4(a) illustrates rutting caused due to weak asphalt mix. As discussed that the rutting in asphalt mix is due to shear deformation and densification. Shear deformation occurs with no variation in volume, i.e., it is distortional. Asphalt concrete may also expand under load, causing an increase in volume. Deformation comprising expansion in some literatures is also stated to as plastic flow or shear flow. These types of deformation can also lead to dis-bonding or segregation at the interface of binder aggregate and causes deterioration of the pavement. So, when mixture is evaluated for their resistance to rutting, it is compulsory to be careful about their dilatant and shearing behavior in which viscosity increases with the rate of shear strain.

2.5.1.2 Rutting from weak subgrade - Structural Rutting (Hussain, 2012)

Another type of rutting can be caused below the asphalt layer to base, subbase or subgrade layer due to repeated applied load. In various cases due to inadequate depth of top layers on the subgrade and too thin asphalt layer are unable to decrease the stresses due to applied loads to supportable level. This type of rutting is called as structural rutting, because this problem is more related to structural than materials. Weakening of the subgrade can also be resulted due to entering of moisture, which can further cause weakening of the subgrade. In structural rutting, the permanent deformation mainly accumulated in the subgrade. Figure 2.4(b) shows rutting due to weak subgrade.

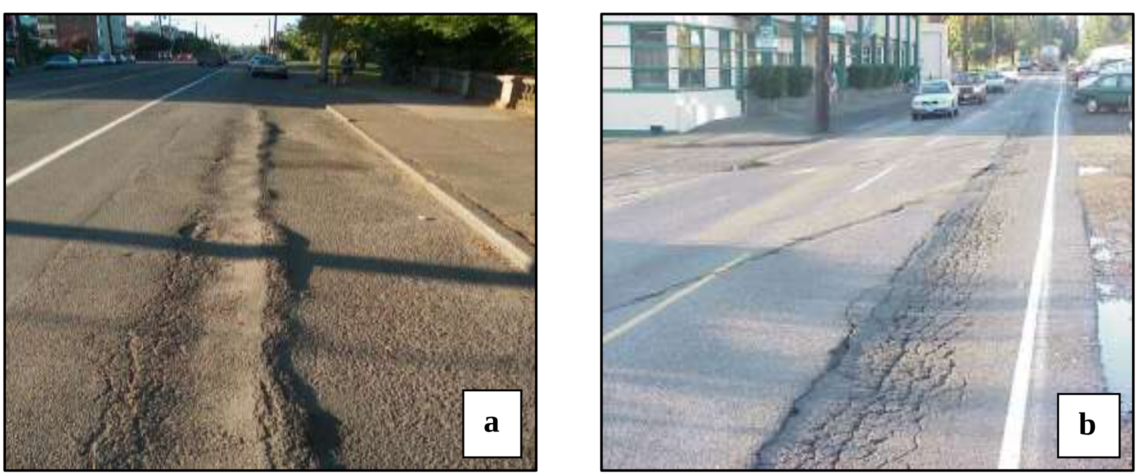


Figure 2.4: (a) Instability Rutting (b) Structural Rutting

2.5.2 Research Findings on Rutting Behavior of Asphalt Mixes

Saleh (2016) added RAP by various proportions, by mass of WMA from 0 to 70% to investigate the performance of WMA as compared to control HMA. Using binder with penetration grade 80/100, and two different WMA additives were used, including a rejuvenator and a chemical WMA additive. Tests were conducted on the viscosity of binder and mechanical performance of mixes such as fatigue cracking, rutting resistance and moisture resistance. The viscosity of the binder was decreased by addition of the two additives. Mixes having chemical additive showed better performance than other mixes in terms of moisture resistance. The performance of WMA mixes was significantly enhanced by increasing RAP content in term of rutting resistance. WMA having 0% RAP had a reduced number of cycles to reach maximum rut depth as compared to HMA. All WMA mixes with RAP indicated substantially improved rutting resistance than that of HMA.

Bower et al. (2016), Doyle et al. (2014), Copeland et al. (2010), Kvasnak et al. (2010a) (2010b), Xiao et al. (2010), Middleton and Forfylow (2009), Wielinski et al. (2009), carried out different research and illustrated that the studies on rutting are mostly established on laboratory prepared compacted specimens at the same air void levels, and compacted mixes in the fields may have different characteristics than that of laboratory compacted mixes.

Tesfaye (2014), and Abraham (2014) revealed that the prime mechanism which causes rutting is the shear deformation for the larger part of the lifetime of the pavement.

Doyle and Howard (2013) inspected the resistance of WMA mixes to rutting with the addition of high RAP percentages with conventional method and also with loaded wheel tracking, and observe that the resistance to rutting of WMA mixes increases by increasing RAP content. It seems that as compared to HMA the rutting performance of WMA is inconsistent, which are due to the discrepancy in the method of testing flow number, HWTD, Accelerated Pavement Analyser, etc., composition (with RAP or without RAP), test condition (wet or dry) and types of WMA.

Mogawer et al. (2012) illustrated that by using WMA technologies with the introduction of high RAP content the rutting resistance of such mixes may be badly affected, because the reduced production temperature could result in reduced stiffness.

Al-Qadi et al., (2012) carried out a study on RAP have shown that the physical property of HMA changes by mixing RAP. Stiffness of RAP binder is high and its result in increasing modulus of HMA. Due to higher stiffness of RAP binder the low temperature cracking and fatigue behavior of mix will also affect.

Hurley and Prowell, (2005a and 2005b) detected that Aspha-min and sasobit mixes with PG 64-22 binder and produced at temperatures considerably lower than that of the corresponding control HMA mixes with PG 58-28, had approximately the same level of air void. From this study we can conclude that the lubricating action of Aspha-min and sasobit dropped the production temperature by nearly one asphalt grade. They recommended to increase one grade to counter the affinity for higher rutting. According to them more research is required to confirm this judgement. One upper grade than that normally used in HMA should not be used randomly with WMA. Because compaction in laboratory of WMA along with HMA need to simulate the density that will eventually be attained in the field. 125 gyrations of the superpave gyratory compactor is standard laboratory procedure for HMA and have confirmed to be adequate for WMA mixes.

Hurley and Prowell (2006a) also observed that Aspha-Min, Evotherm and Sasobit did not increase potential of asphalt mixes toward rutting, as measured by the APA. Actually, the WMA additives increases resistance to rutting in some cases. However, rutting potential increases with lower production temperatures; they attributed this phenomenon to reduced binder aging. They stated no indication of different gain in strength with time (up to five days) for the two different WMA additives when compared to similar HMA mixes.

2.6 MOISTURE DAMAGE OF ASPHALT PAVEMENT

According to Ahmed, (2014) moisture damage is the result of moisture effect and can be defined as the loss of durability and strength of asphalt mixes. Moisture damage can occur in asphalt mixes if the fine aggregate and asphalt binder lack enough bond strength required for their bond integrity. Moisture damage is due to interaction of moisture with the adhesion between aggregate and binder in asphalt mix, which increase susceptible of asphalt mixture to moisture during cyclic loading.

Sullivan (2009) stated that moisture damage happens when moisture present in air voids adversely affects the durability and strength of the HMA. There are two different types of moisture damage: cohesive failure and adhesive failure. Cohesive failure is due to strength reduction of the binder due to moisture damage while adhesive failure occurs in between the aggregate and binder.

2.6.1 Findings on Moisture susceptibility of Asphalt Mix

Martin et al. (2014) proposed methods to estimate WMA susceptibility to moisture with the help of laboratory-mixed laboratory-compacted or plant-mixed laboratory-compacted samples, after examining various field projects in which they explored the moisture susceptibility of WMA technologies. The criteria used for evaluation include ITS and TSR of minimum 80%, resilient modulus, striping slope and stripping inflection point (SIP). They observed in most cases, that after ageing the resistance of WMA to rutting could be enhanced.

Zhao, et al. (2013) suggested that conventional measure of moisture susceptibility can be reinforced by the consideration of contact angle measurements and dynamic modulus results, which were proposed recently to be promising alternatives to assess moisture damage of asphalt mixes.

According to Washington State Department of Transportation, ITS is a very common performance test used for determination of moisture damage in the pavement industry. This test offers a consistent sign of the mix’s crack potential. Testing a mix with and without moisture conditioning can aid in measuring the moisture susceptibility of the mix.

According to Shrum (2010), reduced temperature used for compaction while producing WMA may increase the potential for moisture damage. The reduced temperatures can cause an insufficient aggregate drying, thus making it more susceptible to moisture damage due to trapped water in the coated aggregate. For WMA adequate moisture damage tests must be accomplished to make sure it will perform like HMA.

Mallick & El-Korchi, (2009) stated that in ITS test a specimen is diametrically loaded until failure; the mix having high strain at failure recommends that it will resist cracking. Also in 1998, Maine DOT accepted the superpave method of mix design. This method recommends considering the TSR of the moisture conditioned and unconditioned samples as the most appropriate measure of moisture damage.

Xiao, et al. (2009), explored the moisture damage of WMA containing moist aggregates. The moisture content was evaluated at 0 percent and 0.5 percent. Sasobit and Aspha-min were mixed as WMA additives in the study. Xiao conducted ITS, TSR, deformation, and toughness tests on the specimens. It was observed that WMA mixes altered ITS dry values or toughness. Also conditioned ITS did not differ between mixes. Deformation resistance did decrease with the added moisture content. For all mixes the addition of lime increased the deformation resistance.

Bhusal, et al.(2008) used the Hamburg wheel rut test to inspect the rutting potential and moisture damage of WMA mixes and compared it with that of control mixes. The study compared WMA with Sasobit, WMA with Aspha-min, and a control, and the addition of anti-stripping agents to all mixes. The specimens were loaded until either the 12 mm maximum rut depth value was reached or the maximum number of cycles i.e. 10,000, was reached. Using graph of rut depth versus number of passes for determination of stripping inflection point (SIP). Which describes the number of cycles at which the mix is badly affected by the moisture. The higher the SIP, the lower the asphalt mix is possible to strip or be affected by moisture. Bhusal also performed T283 on the specimens. Only the control mix with antistripping agents and WMA with sasobit and anti-stripping agents passed T283. However, the Hamburg wheel rut test showed WMA containing Sasobit and anti-stripping agent, WMA containing Sasobit, and WMA containing Aspha-min and anti-stripping agent to have the highest stripping inflection point respectively, indicating those would be the least susceptible to moisture damage.

2.7 SUMMARY

This chapter includes brief introduction on HMA, WMA pavement design methods and analysis with special concern about sasobit. It also includes the role of aggregate, binder and aggregate gradation in behavior of asphalt mixes. Over view on rut distress in flexible pavement, its types and factors affecting the pavements. Review of researches carried out on asphalt mix design including RAP and WMA, Laboratory evaluation of recycled asphalt pavements mixtures and their performance testing. Studies carried on Hamburg wheel tracker device and calculation of rutting susceptibility using HWTD and moisture damage using UTM for ITS test. Many testing techniques have been established over the years to examine moisture damage of an asphalt mixes.

Chapter 3

RESEARCH AND TESTING MEDOTHOLOGY

3.1 GENERAL

This chapter includes the methodology of planned research to achieve the objectives of study which are acquisition of required material, specimen preparation, testing and analyzing the importance of various factors. This study was carried out on different RAP prepared asphalt concrete specimens and control asphalt concrete specimen. In current chapter, in order to determine the OBC, the adopted Marshal Mix design procedure will be discussed in detail for varying percentages of RAP i.e. 0%(controlled sample), 15%, 25%, 35%, 50%. Based on OBC for different percentages of RAP the specimens for rutting on Hamburg Wheel Tracker test and moisture damage on UTM were prepared with the above mentioned percentages of RAP with further addition of sasobit at four different percentages i.e. 0%, 1%, 2%, 3% of OBC. NHA-B wearing course gradation and RAP gradation was used for preparation of these laboratory specimens, detail is presented in this chapter. The equipment used for testing, the laboratory tests that were to be conducted on the specimens and procedure adopted for preparation of test specimens, along with input parameters to be used during those tests will be discussed in this chapter.

3.2 RESEARCH METHODOLOGY

To achieve the objectives, RAP percentages and control sample were selected and then adding different percentages of Sasobit as mentioned above. Milled RAP material was collected from Islamabad-Lahore Motorway (M2) and brought to laboratory of National Institute of Transportation (NIT), NUST for testing and analysis of results using HWTD and UTM for rutting and moisture damage respectively. Specimens were prepared in laboratory under controlled conditions for wearing course mixtures. These specimens were prepared after finding out OBC in the laboratory. Afterwards, analysis of results was done and later conclusions and recommendations were made that will be described in next chapters. Figure 3.1, explains the planned methodology for this study.

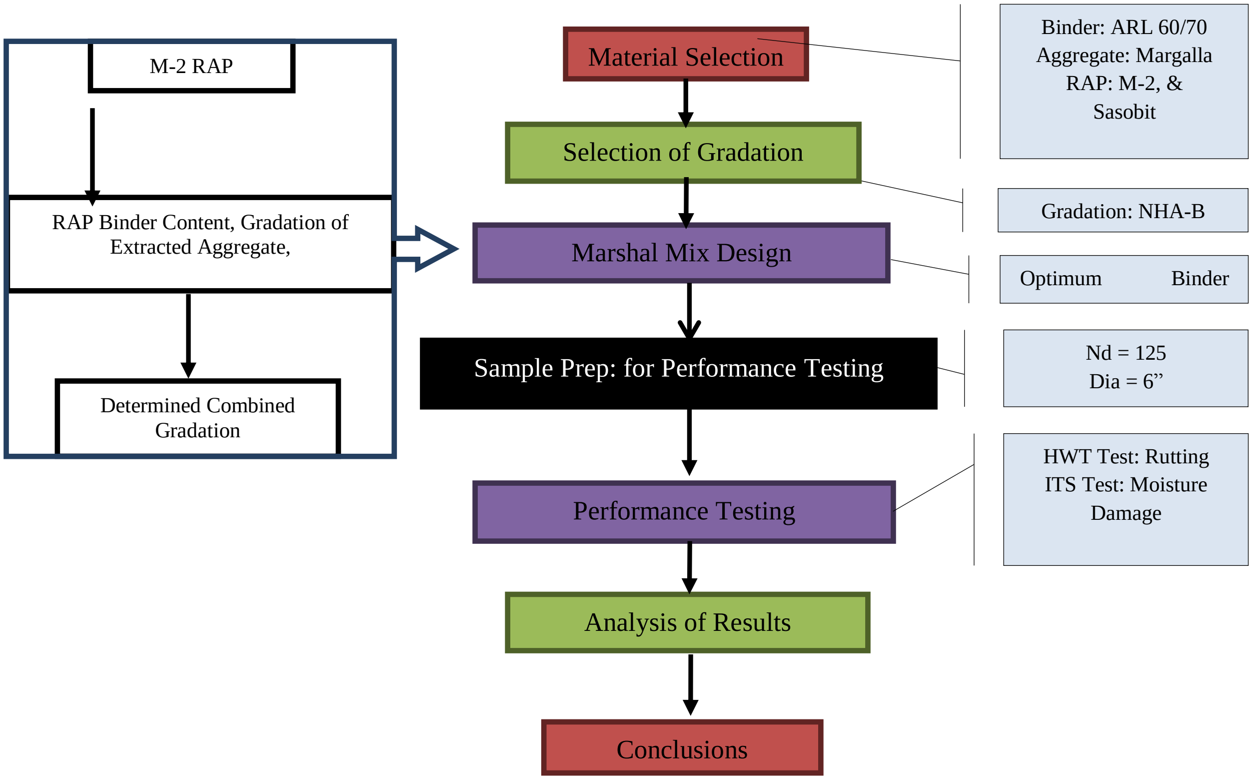


Figure 3.1: Research Methodology – Adopted

3.3 CHARACTERIZATION OF SELECTED MATERIALS

3.3.1 Materials Selection

In this research coarse and fine aggregates were brought from Margalla quarry and penetration grade of 60/70 bitumen was used, which was collected from Attock Refinery Limited (ARL) Rawalpindi. The purpose of selecting grade 60/70 is that it is typically used in practice in Pakistan and is appropriate for colder to moderate temperature regions. RAP material was collected from Islamabad-Lahore Motorway in the form of milled material.

The aggregate structure in the mix provide the main portion of the resistance to permanent deformation which is almost 95% and left over 5% is provided by the asphalt binder. To resist the repeated load applications, aggregates provide a strong stone skeleton. HMA properties are greatly affected by gradation, surface texture and shape of the aggregates. More shear strength is provided by angular and rough-textured aggregates as compared to rounded shaped aggregates having smooth-texture. According to the standards and specifications of ASTM and BS for material characterization, mandatory tests were performed on utilized aggregates and asphalt binder.

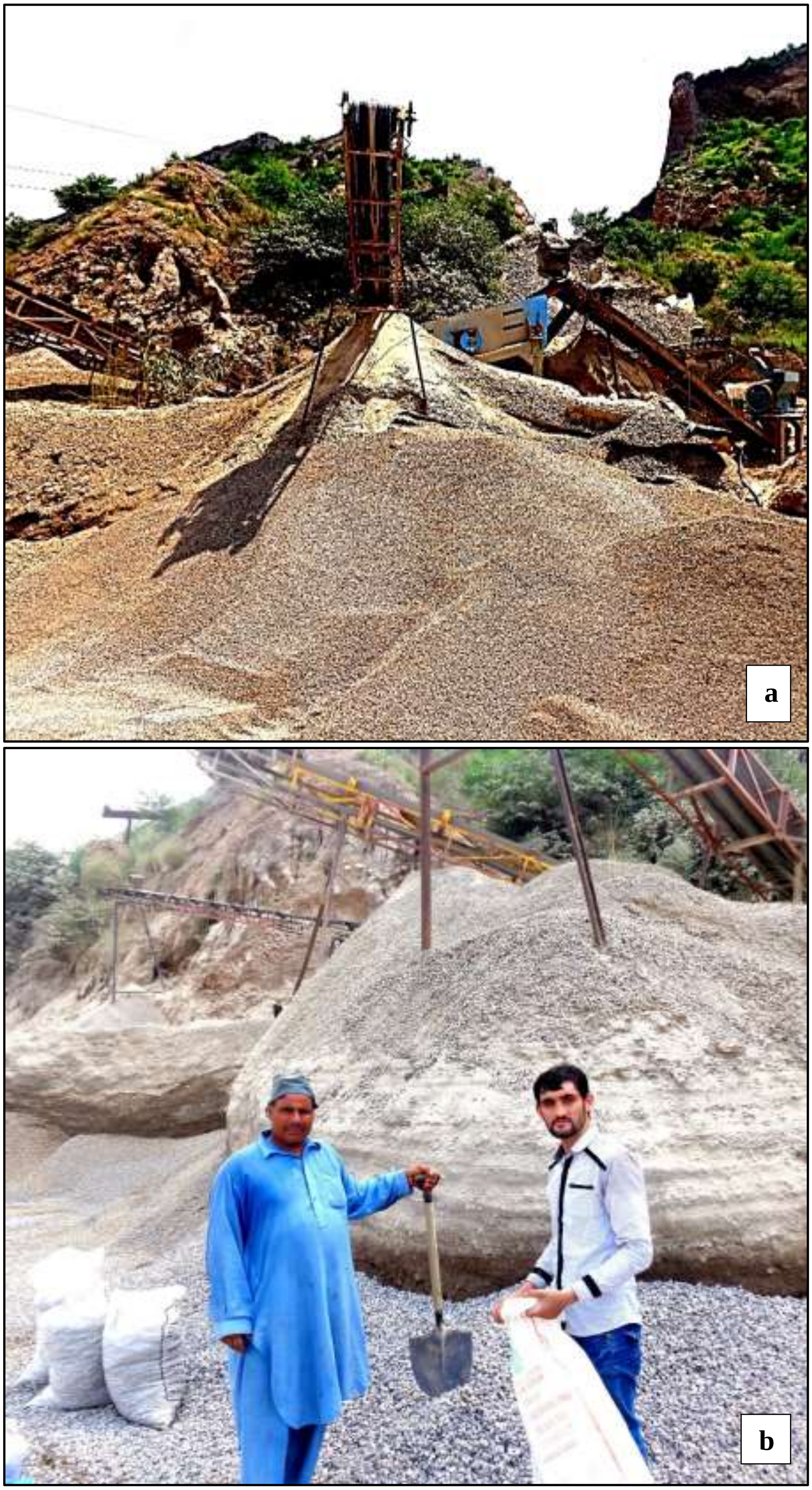


Figure 3.2: (a), (b): Margalla crush plant

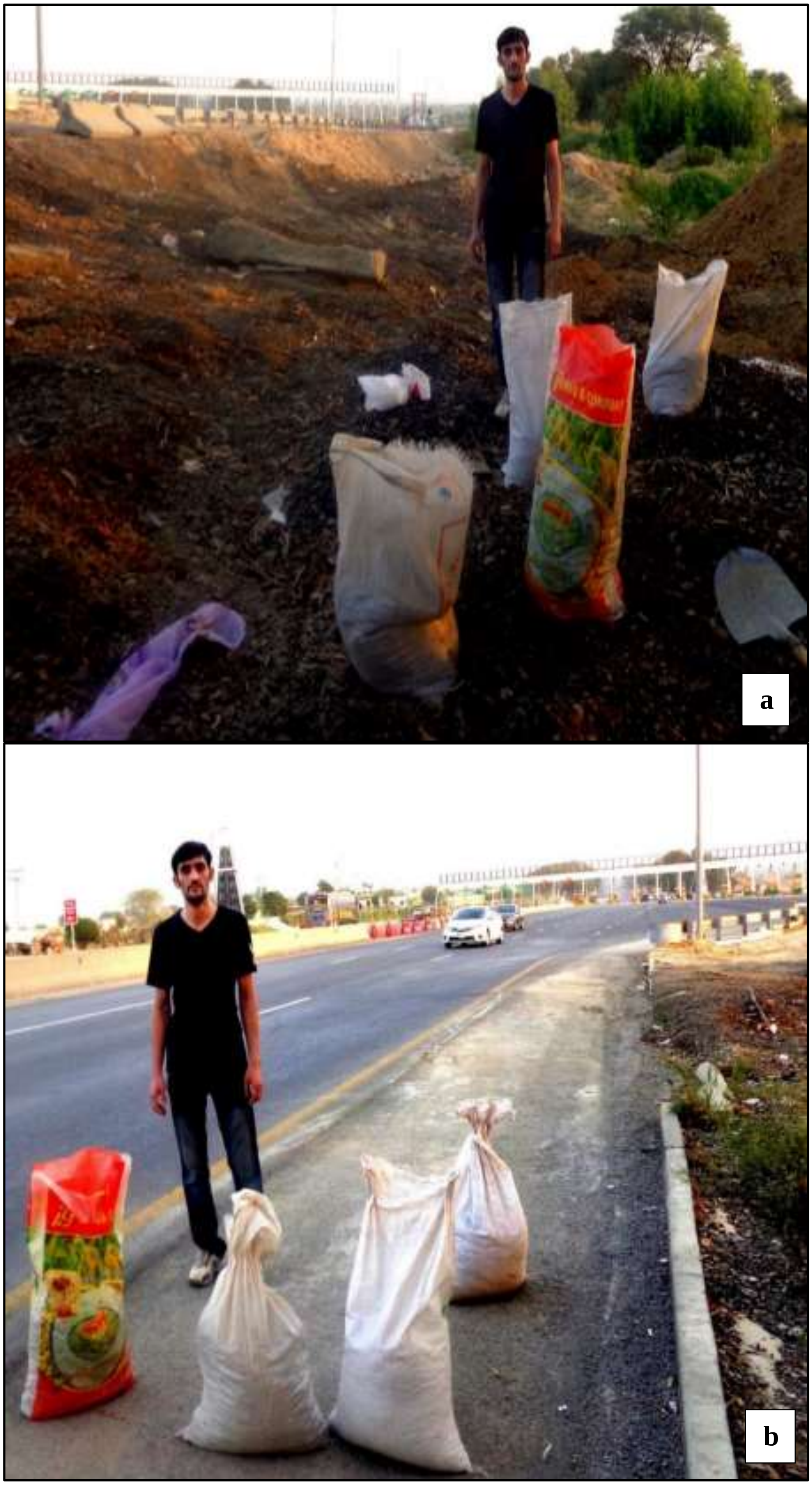


Figure 3.3: (a), (b): RAP Collection from M-2 (Motorway Toll plaza)

Sasobit is WMA additive utilized in the study. The product was in the form of prills as shown in Figure 3.4, and was imported through an authorized product distributor. Sasobit is generally added at the rates of 0.8 to 3 percent by the weight of the total (including RAP) binder. Sasobit can be both pre-blended with the binder or can be introduced directly in the mix bowl charged with the aggregates after the asphalt binder is added in appropriate amount, in this study samples were prepared with 0%, 1%, 2%, 3% sasobit of the OBC, and was added at the top of binder prior to mixing.

Figure 3.4: Sasobit Prills

3.3.2 Aggregate Testing

The aggregate skeleton of the mix is the central portion which offers resistance to permanent deformation and are expected to provide a strong skeleton for resisting repetitive loads. To find the aggregate fundamental properties, such as, gradation detailed and specific gravity laboratory tests of each stockpile was carried out. Tests performed in the laboratory include:

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

The tests mentioned above were carried out using three samples and then average was taken for further process.

3.3.2.1 Shape Test of Aggregate:

Strength and workability of asphalt mixture mostly depend on shape of particles. It also effects the effort required for compaction vital to achieve the necessary density. Therefore, through shape test the quantity of elongated and flat aggregate particles were determined. According to ASTM D4791, aggregate particles are categorized as flaky aggregate having smaller dimension less than 0.6 of their mean sieve size, while the aggregate particle will be called elongated with a length of more than 1.8 of their mean sieve size shown in Table 3.1.

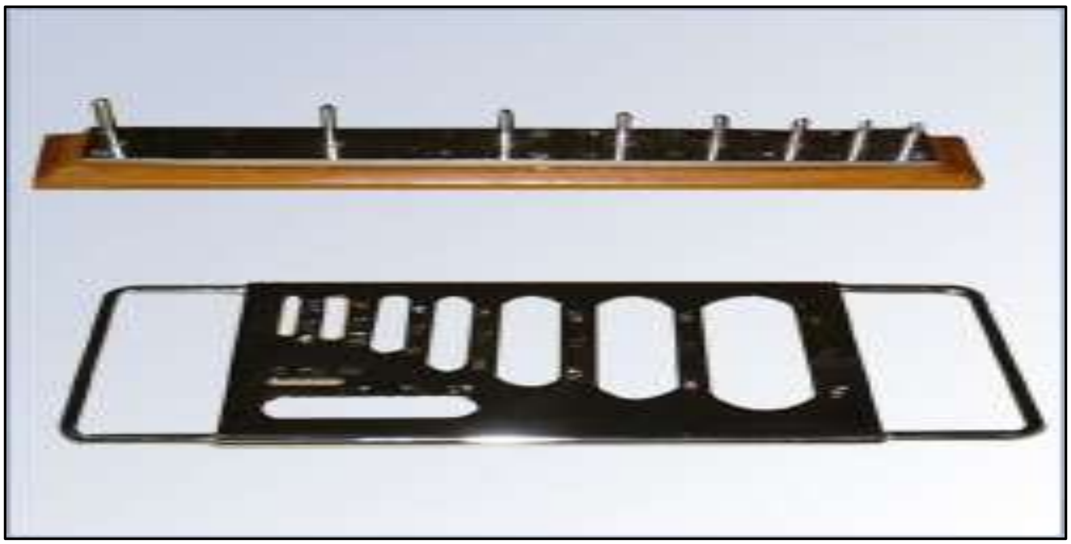


Figure 3.5: Shape test Apparatus

3.3.2.2 Specific Gravity of Aggregate:

Specific gravity represents the weight volume characteristics of aggregate material. Specific gravities of coarse aggregate, fine aggregate and Filler's were determined individually. By definition the aggregate that are retained on No. 4 sieve is coarse aggregate while fine aggregates are those passing No. 4 sieve.

- Specific Gravity of Coarse Aggregate

Specific gravity of coarse aggregate and water absorption was measured by the procedures and equipment stated in ASTM C 127. The specific gravity test for coarse aggregate determine weight of coarse aggregate under three different sample conditions i.e. Oven-dry having no water in sample, submerged in water or underwater and saturated surface-dry in which water fills the aggregate pores. The test was accomplished for both of the coarse graded stock piles i.e. 10-20 mm and 5-10 mm and results shown in Table 3.1.

Figure 3.6: Specific Gravity Test of Coarse Aggregate

Figure 3.7: Water Absorption Test of Coarse Aggregate

- Specific gravity of Fine Aggregate and Filler

Specific gravity of fine aggregate and water absorption were measured using the procedures and equipment stated in ASTM C 128. Specific gravity test was carried out on fine aggregate to determine the value of bulk, SSD and apparent specific gravities with the result shown in Table 3.1.

Figure 3.8 (a) & (b): Specific Gravity Test of Fine Aggregate (Filler)

3.3.2.3 Impact Value Test

Resistance of an aggregate to a sudden shock is measured by aggregate impact value. The apparatus required for measuring impact value included impact testing machine, tamping rod and sieves of sizes 1/2”, 3/8” and #8 (2.36mm.) Around 350g of aggregate passing through 1/2” sieve and retaining on 3/8” sieve was taken and filled in the mould of Impact Testing Machine in three layers, tamping each layer 25 times. The sample was transferred into the larger mould of the machine and 15 blows from a height of 38 cm were given with the hammer weighing 13.5 to 14 kg. The resulting aggregate was removed and passed through sieve #8. The impact value was measured by the percentage of aggregate passing through 2.36mm sieve.

Figure 3.9: Crushing Value Test Apparatus

3.3.2.4 Crushing Value Test

To achieve a pavement with higher quality and strength, it is necessary for the aggregates to have enough strength to sustain traffic loads. The apparatus used for this test was steel cylinder having open ends, base plate, plunger with a piston diameter of 150 mm and a hole provided across it, so that a rod could be inserted for lifting it, cylindrical measure, balance, tamping rod, and a compressive testing machine. Aggregates were passed through a set of sieves and that passing through ½" and retaining on 3/8" were selected. Sample of aggregate was washed, oven dried and weighed (W1) and then added into that cylindrical measure in three layers, each layer being tamped 25 times. The sample was shifted into the steel cylinder with base plate in three layers and the plunger was inserted. It was then placed in compressing testing machine and load was applied at a uniform rate of 4 tons/minute until the total load was 40 tons. Crushed aggregate was then removed from the steel cylinder and passed through 2.36mm sieve. The material that passed through this sieve was collected and weighed (W2). Crushing value of aggregate was calculated by = W2/W1 x 100

Figure 3.10 (a) & (b): Impact Value Test of Aggregate

3.3.2.5 Los Angeles Abrasion Test

This test determines hardness of road aggregate. Aggregate must be hard enough to resist wear due to heavy traffic loads. The apparatus used for this test included Los Angeles Abrasion machine, balance, set of sieves and steel balls. Testing methodology or grading B was adopted for this procedure. 2500 g of aggregate retained on ½" and 3/8" sieves each, which is a total of 5000g (W1) of aggregate along with 11 steel balls or charges were placed in the Los Angeles abrasion machine. The machine was rotated at a speed of 30 to 33 rpm for 500 revolutions. After that, the material was sieved through 1.7mm sieve. Weight of sample passing through it (W2) was noted down. The abrasion value was found out by = $W2/W1 \times 100$

So for the preparation of Asphalt mixtures, it is necessary to check the suitability of aggregates in the light of ASTM and BS standards and specifications for material characterization. These tests were performed on aggregate of Margalla quarry, Table 3.1 show the tests performed on the aggregates,

Figure 3.11: Los Angeles Abrasion Machine

Table 3.1: Laboratory Test Results of Aggregate

Test Description	Specification Refrence		Result	Limits
Elongation Index (EI)	ASTM D 4791		3.578 %	$\leq$ 15 %
Flakiness Index (FI)	ASTM D4791		12.9 %	$\leq$ 15 %
Aggregate Absorption	Fine	ASTM C 127	2.45 %	$\leq$ 3 %
	Coarse		0.73 %	$\leq$ 3 %
Impact Value	BS 812		17 %	$\leq$ 30 %
Los Angles Abrasion	ASTM C131		22	$\leq$ 45 %
Specific Gravity	Fine Agg	ASTM C 128	2.618	-
	Coarse Agg	ASTM C127	2.632	-

3.3.3 Determination of Asphalt Content in RAP

Three batches of re-graded RAP of approximately 1500 grams were burnt and the asphalt content were determined in accordance with ASTM D 6307 – 98: (Standard Test Method for Asphalt Content of Hot-Mix Asphalt by Ignition Method). It was found that 4.46% of the total re-graded mass of RAP was aged-binder (AB).

Figure 3.12: (a), (b) & (c): Determination of Asphalt content in RAP by Carbolite

3.3.4 Asphalt Binder Testing

According to Asphalt Institute MS-4 manual, for construction and engineering purposes, consistency, safety and purity are the three properties of binder which are essential to be considered. Consistency of asphalt binder changes with change in temperature. Therefore, standard temperature is obligatory for comparing consistencies of asphalt binder. Consistency of bitumen binder is commonly find out through penetration test or a viscosity test (Asphalt Institute MS-4, 2003). Some other tests like softening point test and ductility test of binder provides additional info and confidence about consistency. So for characterizing the asphalt binder in laboratory following tests were carried out.

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

3.3.4.1 Penetration Test

Penetration of asphaltic materials can be find out through penetration test. The penetration test comprises containers having specimen and needles. Softer binder gives greater values of penetration. According to AASHTO T 49-03 temperature used was 25°C, load of 100 grams, while time for the test equal 5 seconds, until unless the situations are not explicitly stated. Using two ARL 60/70 specimens, five values from each specimen were taken after performing penetration tests. All values obtained fulfilled the required criteria of penetration test as per specifications. Penetration test result is presented in Table 3.2.

3.3.4.2 Softening Point Test

Bitumen is a material with visco-elastic property, but as the temperature go higher it progressively becomes softer and its viscosity reduces. The temperature at which sample of bitumen of standard size cannot uphold the weight of 3.5 gm steel ball is called the softening point of that bitumen. Thus softening point of bitumen is the average temperature at which the two disks of bitumen soften adequate to allow the steel balls to fall a distance of 25 mm. For softening point determination of asphalt as per AASHTO-T-53 specifications ring and ball apparatus was used. Table 3.2 shows the results of softening point test.

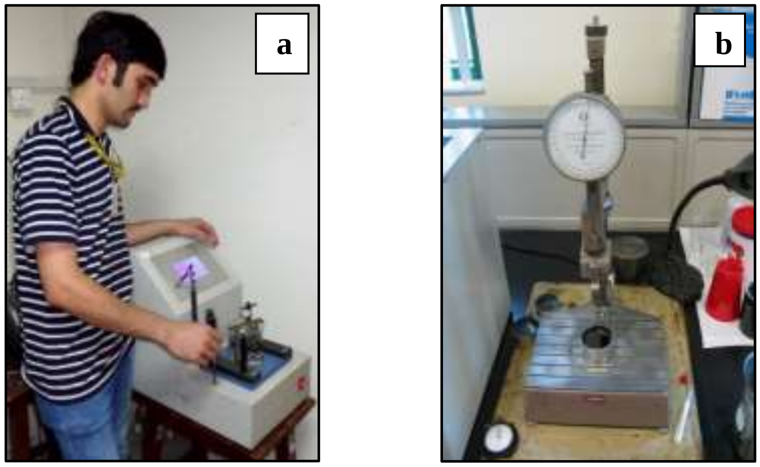


Figure 3.13: (a) Softening Point and (b) Penetration Tests of Bitumen

3.3.4.3 Ductility Test

Ductility is a significant property of bitumen and an essential factor to depict the performance of HMA mixture. Ductility shows the behavior of bitumen with the temperature changes. By definition it can be clarified as the “distance to which a specimen of binder lengthens without breaking when its two ends are pulled away from each other at a certain speed i.e. 5 cm/min and at a specific temperature of 25 ± 0.5 °C (AASHTO T 51-00). Table 3.2 shows the standard conditions and results obtained for ductility tests for bitumen. All specimens had seen satisfying the minimum 100cm ductility criteria.

Figure 3.14: Ductility test of Bitumen

3.3.4.4 Flash and Fire Point Test of Bitumen

Flash and Fire point test was conducted as per D3143/D3143M-13 standards.

Figure 3.15: Flash and Fire Point Test of Bitumen

3.3.4.5 Rotational Viscosity Test of Bitumen

Rotational Viscometer (RV) is used for determination of asphalt binders' viscosity at increased temperature range. we can conduct RV at different temperatures, but since production temperatures are similar, irrespective of the environmental conditions, the test for superpave performance grade asphalt binder description is always carried out at 135°C and 160°C.

To determine the viscosity of asphalt binder using RV apparatus as per AASHTO-T-316 and ASTM D 4402, Brookfield RV apparatus was used. First of all, heating of sample chamber, the spindle, and viscometer environmental chamber (Thermosel) to 135°C and 160°C. Then heating bitumen to make it fluid enough to pour. Stir the sample, being careful to avoid entrap air bubbles. Pour proper quantity of bitumen into sample chamber. Sample size varies with equipment manufacturer and selected spindle. Inserting sample chamber into temperature controller unit of RV and lower spindle no 27 into sample carefully. Bring specimen to the chosen test temperature of 135°C and 160°C within approximately thirty minutes and permit it to equilibrate at test temperature for ten minutes. Rotate spindle at twenty revolutions per minute, making sure that the percent torque as designated by the RV display remains between 2 and 98 percent. From RV display, take three viscosity readings as the sample has reached temperature and equilibrated, permitting one minute between each reading. Average of the three readings will report viscosity.

Figure 3.16: Rotational Viscometer

So for asphalt mixes preparation, it is also compulsory to check the suitability of bitumen as well, in the light of ASTM standards and specifications for material characterization. The above mentioned tests were carried out in laboratory to characterize the asphalt binder (ARL 60/70). Table 3.2 shows the tests performed on bitumen

Table 3.2: Laboratory Tests Performed on Virgin Bitumen

S No.	Test Description	Specification	Result
1	Penetration Test @ 25 (°C)	ASTM 5	64
2	Flash Point (°C)	ASTM D 92	268
3	Fire Point (°C)	ASTM D 92	293
4	Specific gravity	ASTM D 70	1.03
5	Softening Point (°C)	ASTM D36-06	48.2
6	Viscosity Test (Pa.sec)	ASTM D4402	0.2625
7	Ductility Test (cm)	ASTM D113-99	104

3.4 GRADATION SELECTION

Aggregate gradation used was NHA class B according to NHA (1998) specifications for dense graded surface course mixtures. The nominal maximum aggregate size selected for class B wearing coarse gradation was 19 mm according to Marshal Mix Design (MS2). The selected gradation is shown in Table 3.3 and Figure 3.17 shows gradation which is plotted with percentage passing verses sieve sizes.

Table 3.3: NHA Class-B Gradation Selected for Testing

S.NO	Sieve Size mm	NHA Specification Range (% Passing)	Our Selection	Retained (%)
1	19	100	100	0.00
2	12.5	75-90	82.5	17.50
3	9.5	60-80	70	12.50
4	4.75	40-60	50	20.00
5	2.38	20-40	30	20.00
6	1.18	5-15	10.00	20.00
7	0.075	3-8	5.5	4.50
8	Pan	…	…	5.50

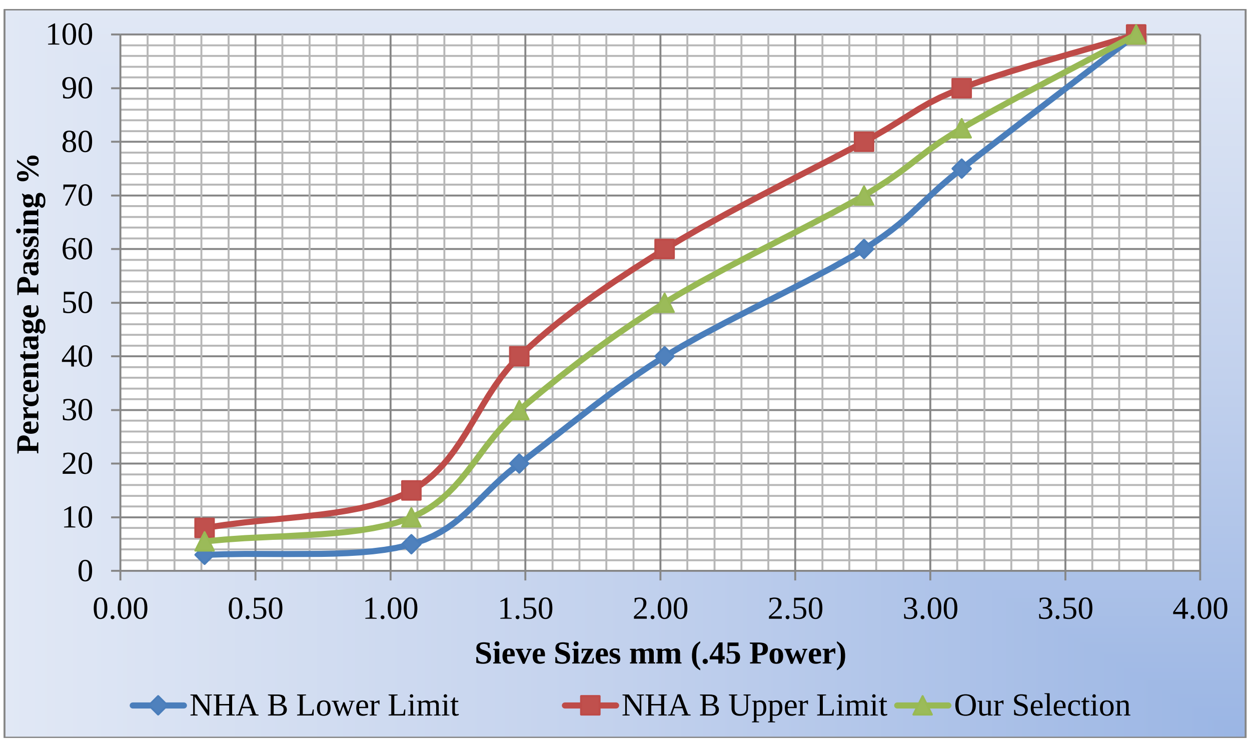


Figure 3.17: Class-B Gradation plot with NHA Specified limit

3.4.1 Gradation for varying proportions of RAP

As the main objectives of this research was to investigate the effect of different proportion of RAP and sasobit in the mix on permanent deformation and moisture damage of asphalt mix, so for this purpose the amount of RAP was varied by 0%, 15%, 25%, 35%, and 50% in asphalt mix, stability and flow values and volumetric were calculated using Marshall Mix design procedure. Therefore, five different RAP percentages and corresponding aggregate on different sieves were found which are shown by Table 3.4, Table 3.5 and Figure 3.18 shows gradation which is plotted with percentage passing verses sieve sizes.

Table 3.4: RAP gradation

SIEVE DIA (mm)	RAP (% Retained)
19	0.00%
12.5	7.02%
9.5	11.15%
4.75	20%
2.38	18%
1.18	31%
0.075	10.25%
Pan	2.70%

Table 3.5: Weight of Aggregate as per Gradation

SIEVE DIA mm	% Passing						
	NHA B Lower Limit	NHA B Upper Limit	Our Selection	15% RAP	25% RAP	35% RAP	50% RAP
19	100	100	100	100	100	100	100
12.5	75	90	82.5	85.22	85.95	86.523	87.39
9.5	60	80	70	69.03	69.725	70.138	70.779
4.75	40	60	50	50.2	50.818	51	51.43
2.38	20	40	30	32.54	33.765	34.559	35.379
1.18	5	15	10.00	10.908	12.8285	13.647	14.052
0.075	3	8	5.5	5.03	5.32	5.53	6.341

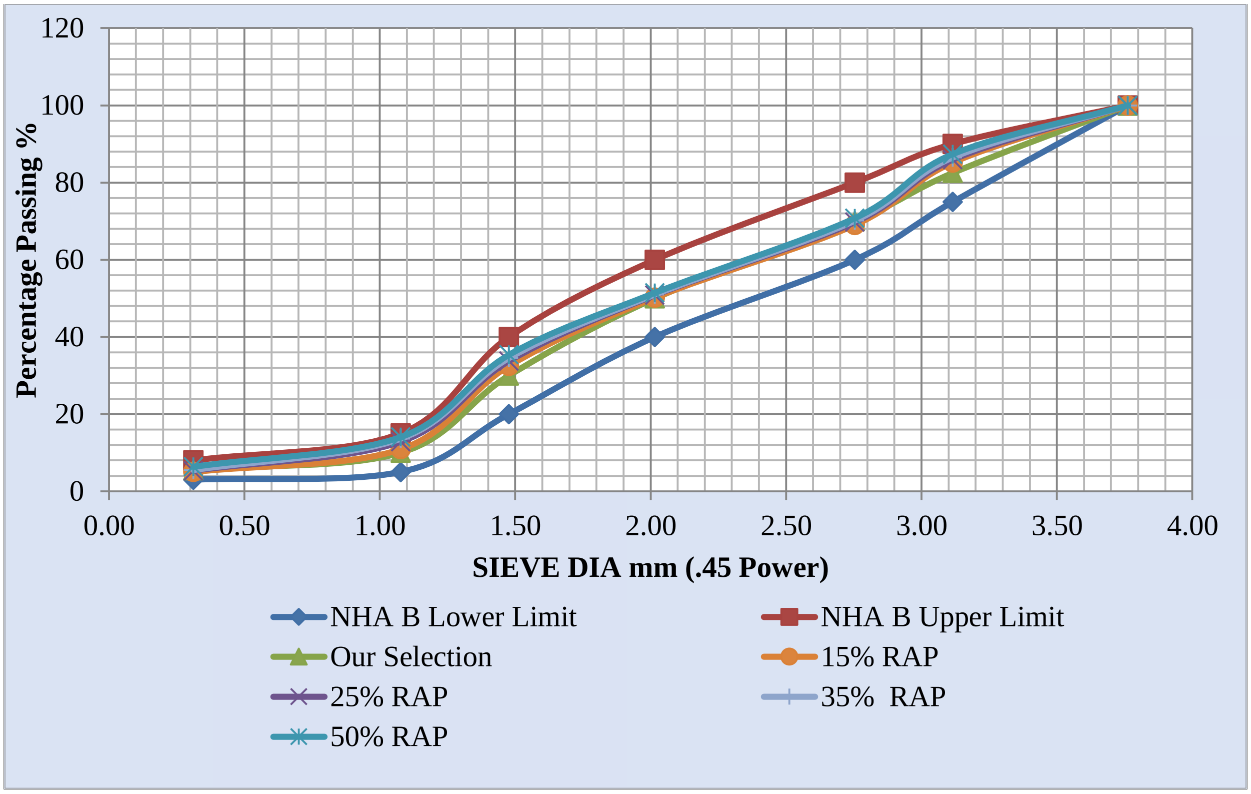


Figure 3.18: Gradation plot of RAP Percentages with Specified limit of NHA Class B

3.5 ASPHALT MIXTURES PREPARATION

As stated earlier, there are four categories of mixtures one is controlled asphalt mixture the second one containing some percentage of RAP only, the third one with some percentage of sasobit only and the last one with different percentage combination of RAP and sasobit. Laboratory prepared mixtures were designed through the determination of OBC using Marshal Mix design procedure. Afterwards, samples were compacted to their OBC at designed air voids. The procedure of preparation of laboratory prepared mixes is described in the following heading.

3.5.1 Preparation of Bituminous Mixes for Marshall Mix Design

The bituminous mixes prepared for the determination of OBC according to ASTM D 6926, standard practice for the preparation of bituminous specimens using Marshall Apparatus. As there were Five different gradations with respect to proportions of RAP, the OBC for each type of gradation were determined by revising the Marshall Mix design procedure thrice. The volumetric properties, stability and flow were measured, verified in light of Marshall Mix design criterion and finally OBC were determined. Marshall Mix design was carried out as follows:

3.5.2 Preparation of Aggregates and Bitumen for Mix Design

After sieve analysis the aggregates were dried to constant weight at 105℃ to 110℃. The amount of aggregates needed for the preparation of compacted 4 inches' diameter sample by Marshall Mix design method (ASTM D6926) should be 1200 gm. The amount of asphalt cement requisite for each specimen was taken as the percentage of total weight of mix obtained from Equation 3.2:

$$M_T = M_A + M_B \qquad (3.1)$$

$$M_B = X/100(M_T) \qquad (3.2)$$

Where,

M_T = Mass of the Total mix

M_A = Mass of the Aggregate

M_B = Mass of the Bitumen

X = Percentage of Bitumen

Figure 3.19: (a), (b) & (c): Preparation of Aggregates and Bitumen for Mix

3.5.3 Mixing of Aggregates and Asphalt Cement

The ASTM D6926 recommends the mechanical mixer for the proper mixing of bitumen and aggregates. The dried, heated aggregates and heated bitumen were transferred immediately into the mechanical mixing machine after removing from the oven. Figure 3.4 showing the schematic diagram of mechanical mixing machine. The range of mixing temperature was 160℃ and 165℃ that correspond to the temperature during manufacturing of bituminous mixes in

Pakistan (NHA Specifications). Moreover, this mixing temperature corresponds to the binder viscosity range of 0.22 - 0.45 Pa.sec as specified by Superpave mix design (SP-2).

3.5.4 Mixture Conditioning After Mixing

The ASTM D6926 recommends that bituminous mixes should conditioned for about two hours before compaction. So each bituminous mix obtained after mixing from mixing machine was placed in a metal container as shown in Figure 3.5

Figure 3.20: Asphalt Mixing and Conditioning

3.5.5 Compaction of Specimens

After conditioning each mix was compacted at 135℃ using Marshall Compactor. The mould assembly consists of a mould cylinder, base plate and extension collar. The mould cylinder has height of approximately 3-inch and internal diameter of 4-inch. The extension of collar and base plate are designed to be exchangeable with either end of mould. The mix was placed in the mould with spatula. While before packing of mould, it was cleaned and was paced in the oven at 135℃ and a piece of filter paper, equals to mould diameter was placed at the bottom of mould. When an entire batch was placed to the mould and spaded evenly. A filter paper piece was placed over it.

In this research, the adopted designed criterion was heavily trafficked pavement or designs design criteria of ESALs (millions) ≥ 30, for dense graded wearing courses. Therefore 75 blows on each end were applied to simulate the heavy traffic. For compaction (application of blows), the mould assembly was placed into the mould holder on the compaction pedestal. The hammer was properly positioned over mould assembly and 75 blows were delivered mechanically to the specimens. After blows completion on one side, the mould assembly was removed from the holder, specimen was inverted, and then mould was reassembled and same number of compaction blows on the reverse face were delivered to the specimen.

Figure 3.21: Marshall Compactor

3.5.6 Extraction of Specimens from Mold

The mould assembly was disassembled after compaction, and for few minutes the sample was allowed to cool. Then the specimen was removed from the mould by extraction jack. Prepared specimens were cooled down to room temperature on flat surface.

3.5.7 Number of Specimens for Each Job Mix Formula

For each asphalt cement and aggregates combination three specimens were prepared. As there were five types of gradations with respect to 0%, 15%, 25%, 35%, 50% RAP, 15 specimens for each type were prepared and the summation of 75 specimens. Specimens were prepared at five different binder contents (3.5, 4.0, 4.5, 5.0 and 5.5%). The reason five trial blends were the selection of the mix that performs optimal at minimum bitumen content at 4% air voids.

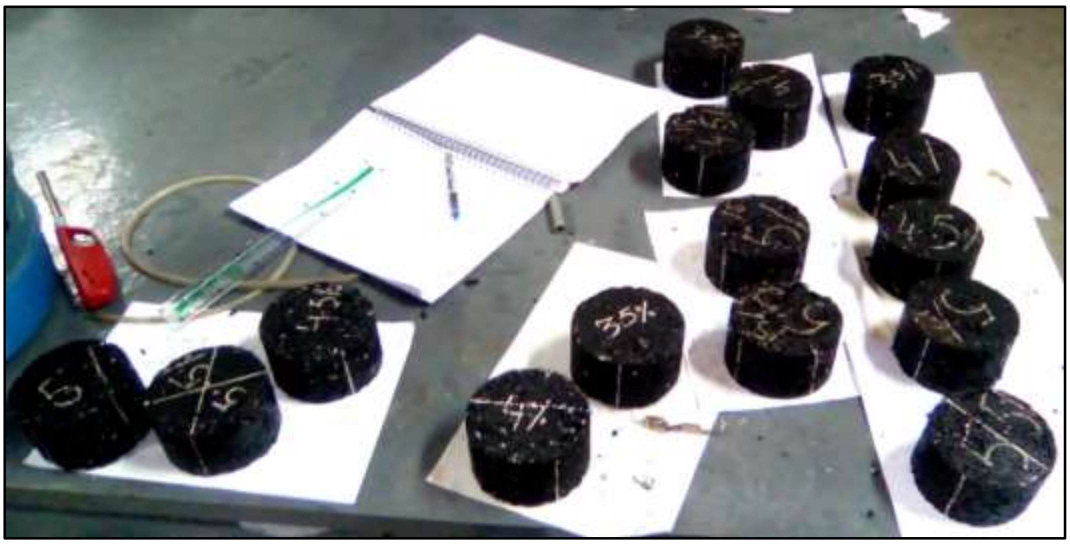


Figure 3.22: Marshal Samples

3.6 DETERMINATION OF VOLUMETRIC, STABILITY AND FLOW

The volumetric properties of the mixes, including; Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA), Air Voids (Va), and unit weight were calculated by their respective formulas after the determination of theoretical maximum specific gravity (Gmm), and bulk specific gravity (Gmb). The Marshall Mix design criterion is shown Table 3.3. Gmm and Gmb of bituminous paving mixtures were determined in accordance with ASTM D2041 and ASTM D2726. After the determination of Gmb the samples were kept in water bath for 1 hour at 60℃ and then tested for stability and flow using Marshall Test equipment as shown in Figure 3.26.

Figure 3.23: Gmb Calculation for Marshal Sample

Figure 3.24: Marshal Samples Placed in Water Bath

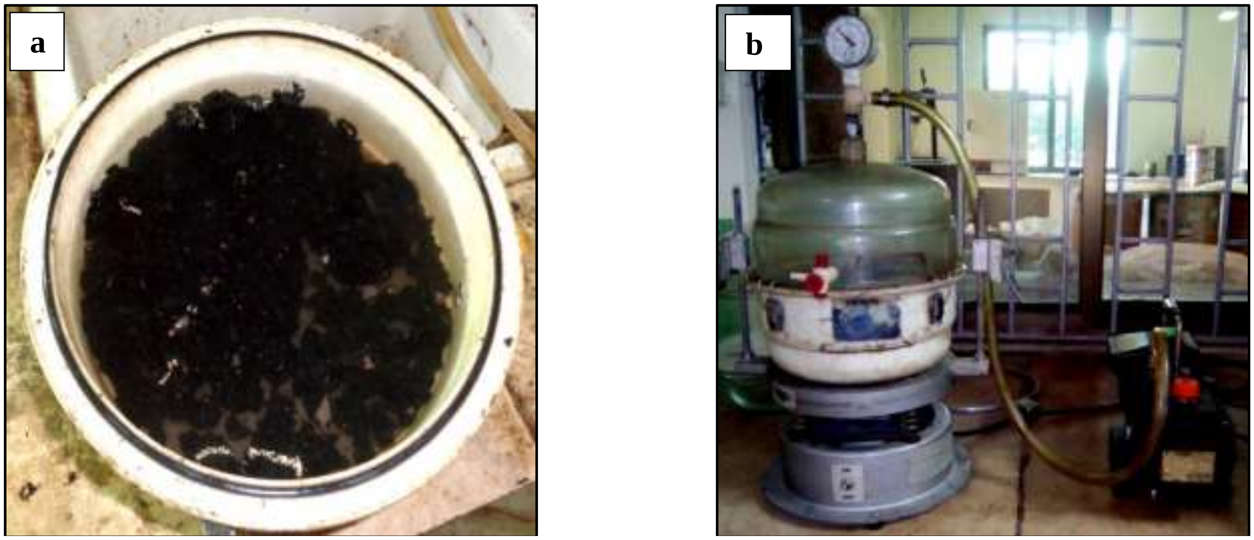


Figure 3.25: Gmm Calculation for Asphalt Mix

The samples were loaded at a constant deformation rate of 5 mm/minute until failure occurs. The total maximum load in KN was taken as Marshall Stability. The total deformation that occurs at maximum load was recorded as flow number value in mm. According to Marshall Mix design criteria (MS-2) the stability of specimen for heavy trafficked wearing course should not be less than 8.006 KN and the flow number is in between 2 to 3.5. The specimen was tested immediately after removing from the water bath.

Figure 3.26: Marshal Stability and Flow Testing Equipment

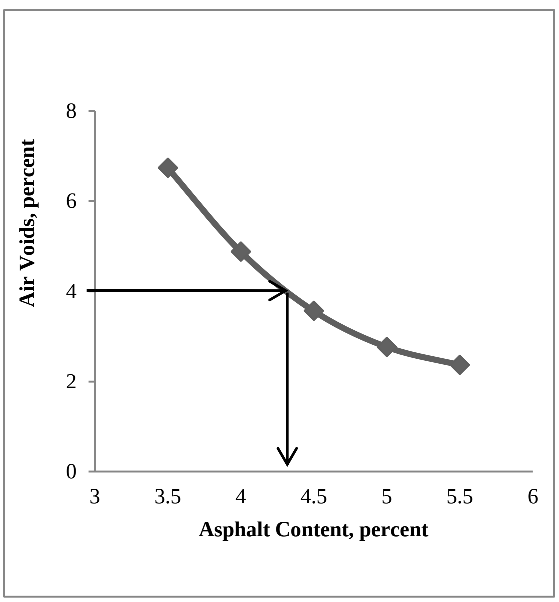
3.6.1 Volumetric Properties of Mix Having 0% RAP

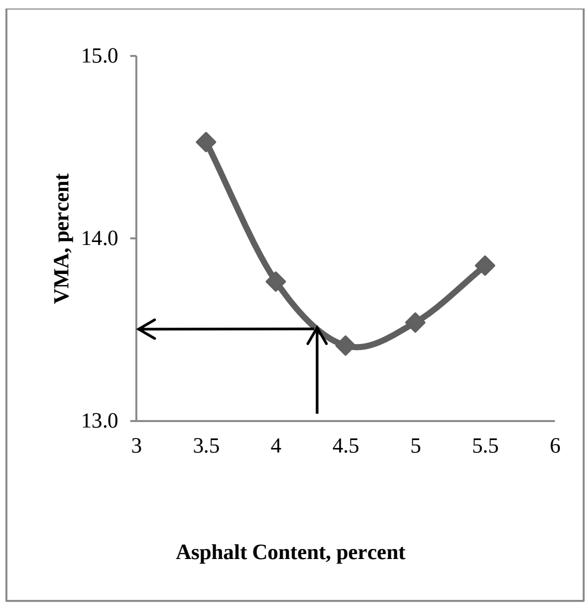
The volumetric properties, stability and flow correspond to the mix which has 0% of RAP are as shown below in Table 3.6

Table 3.6: Volumetric properties of mix having 0% RAP

% AC	G_{mb}	G_{mm}	Unit wt (mg/cm^{3})	Va (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
3.5	2.325	2.493	2.325	6.739	14.528	53.614	10.135	2.145
4	2.358	2.479	2.359	4.881	13.764	64.538	12.006	2.469
4.5	2.380	2.468	2.380	3.566	13.413	73.416	12.296	2.908
5	2.389	2.457	2.389	2.768	13.540	79.560	11.147	3.472
5.5	2.393	2.451	2.393	2.366	13.851	82.916	9.517	4.319

For the determination of OBC of mix having 0% RAP, the graphs between asphalt contents and volumetric properties, stability and flow were plotted according to MS-2 manual as shown in Figure 3.27





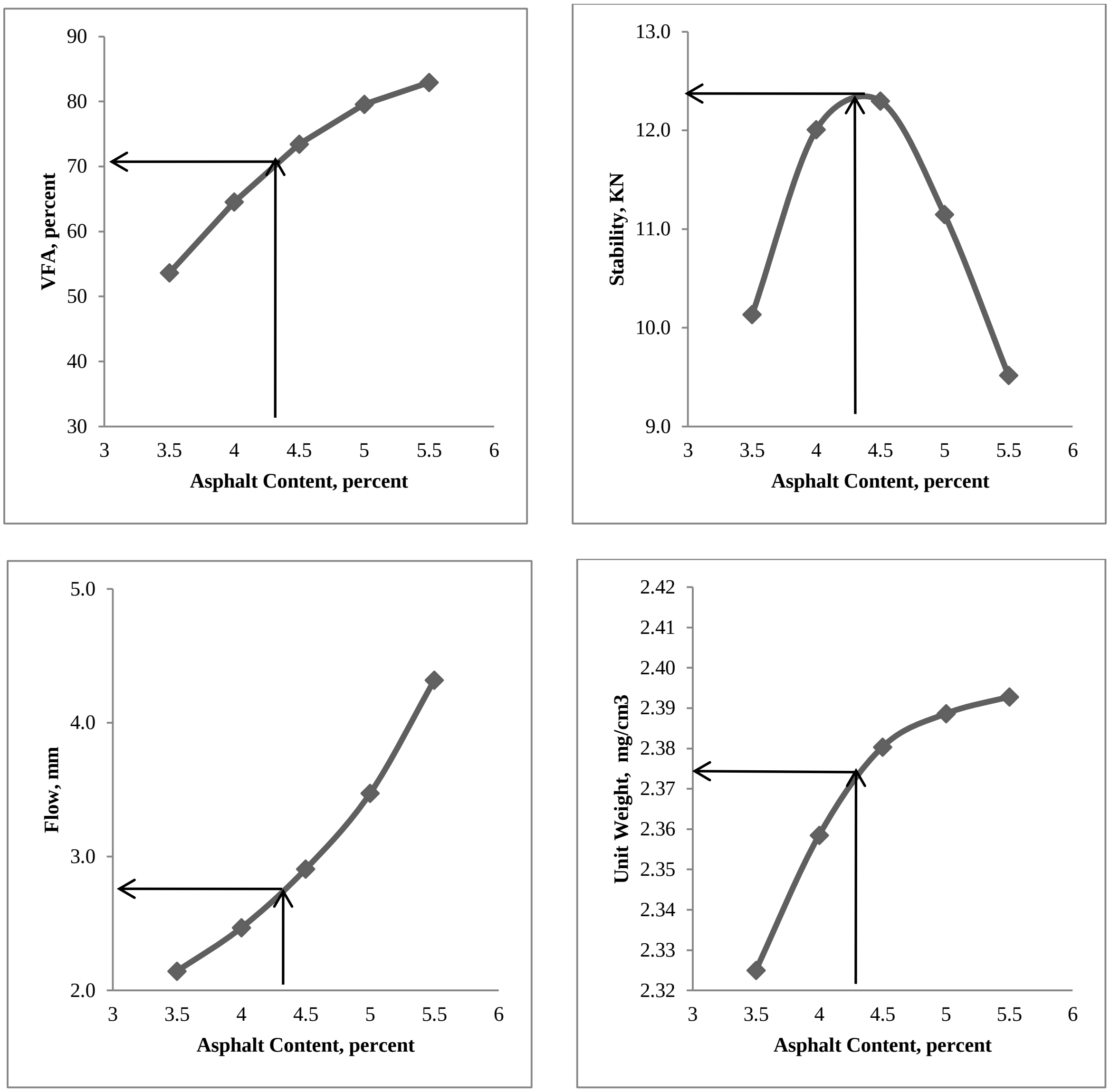


Figure 3.27: Graphs of Volumetric properties of mix having 0% RAP

The asphalt contents at 4% air voids are called as OBC. The mix with 0% RAP has OBC of 4.31%. The values of volumetric properties, stability and flow according to OBC were then found out from the graphs. Table 3.7 shows the job mix formula of mixture which having 0% RAP. It is clear from the table that all of the volumetric properties, stability and flow meeting the criteria. The VMA at 4% design air voids should not be less than 13% and in this case its value was 13.493%. VFA should be in between 65-75, its calculated value lies in this range which was 70.04%. The stability value according to criteria should not be less than 8.006KN and in this case it was 12.324 KN. The measured value of flow number was 2.724 mm which lie in the range of criteria.

Table 3.7: Job Mix Formula for mix having 0% RAP

Parameters	Measured Value	Criteria	Remarks
Optimum Asphalt Contents (%)	4.31	NA	-------
VMA (%)	13.493	13	Pass
VFA (%)	70.04	65-75	Pass
Stability (KN)	12.324	8.006	Pass
Flow (mm)	2.724	2.0-3.5	Pass

3.6.2 Volumetric Properties of Mix Having 15% RAP

The volumetric properties, stability and flow correspond to the mix which has 15% of RAP are as shown below in Table 3.8

Table 3.8: Volumetric properties of mix having 15% RAP

% AC	G_{mb}	G_{mm}	Unit wt (mg/cm^3)	Va (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
3.5	2.321	2.494	2.321	6.937	14.674	52.729	10.275	2.003
4	2.354	2.477	2.354	4.966	13.909	64.300	12.068	2.451
4.5	2.378	2.467	2.378	3.608	13.485	73.246	12.329	2.896
5	2.384	2.455	2.384	2.892	13.720	78.921	11.424	3.221
5.5	2.389	2.450	2.389	2.490	13.994	82.209	9.792	3.946

For the determination of OBC of mix having 15% RAP, the graphs between asphalt contents and volumetric properties, stability and flow were plotted according to MS-2 manual as shown in Figure 3.28

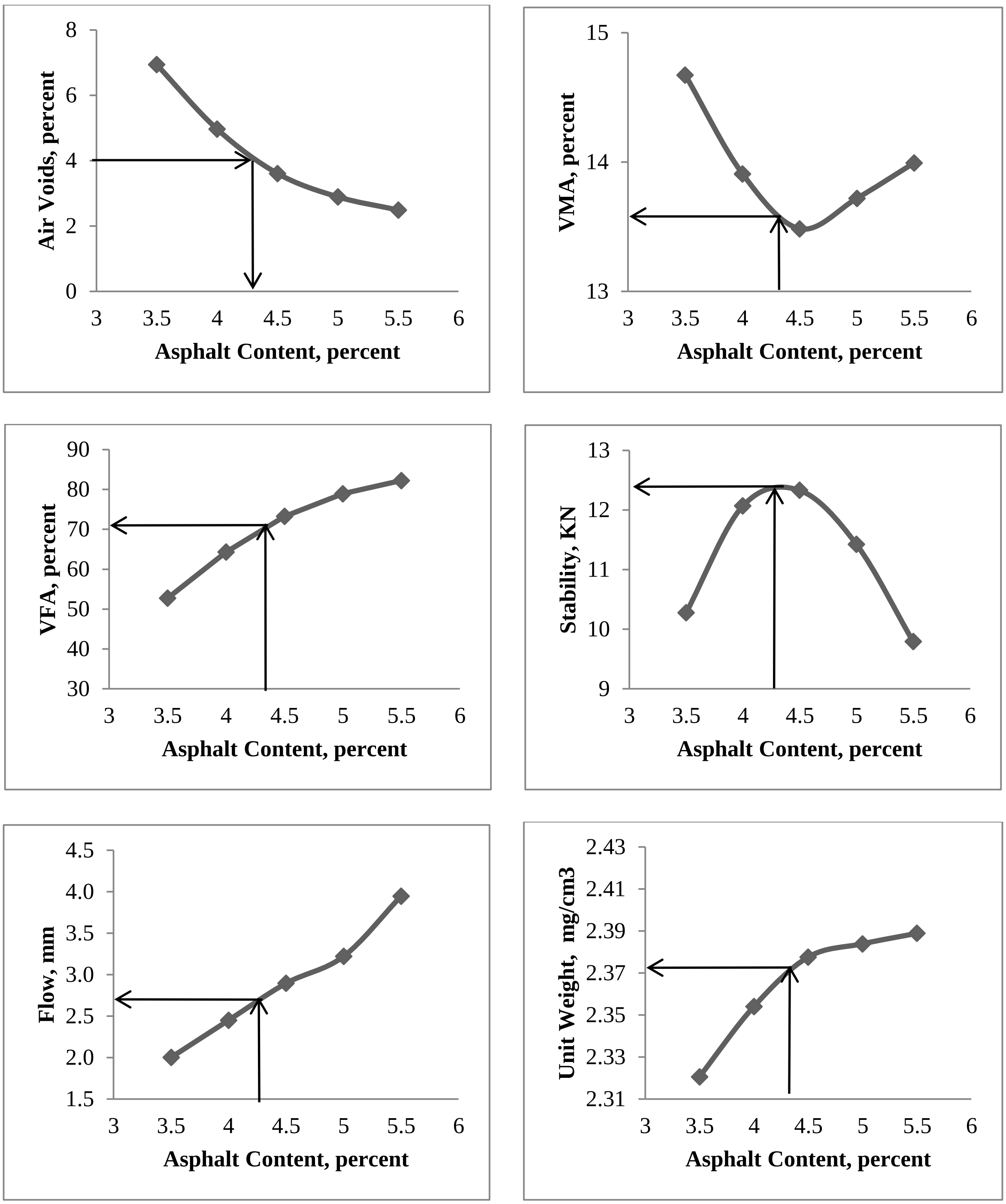


Figure 3.28: Graphs of Volumetric properties of mix having 15% RAP

The mix with 15% RAP has OBC of 4.33%. The values of volumetric properties, stability and flow according to OBC were then found out from the graphs. Table 3.9 shows the job mix formula of mixture which having 15% RAP. It is clear from the table that all of the volumetric properties, stability and flow meeting the criteria. The VMA at 4% design air voids should not be less than 13% and in this case its value was 13.568%. VFA should be in between 65-75, its calculated value lies in this range which was 70.19%. The stability value according to criteria should not be less than 8.006KN and in this case it was 12.37 KN. The measured value of flow number was 2.754 mm which lie in the range of criteria.

Table 3.9: Job Mix Formula for mix having 15% RAP

Parameters	Measured Value	Criteria	Remarks
Optimum Asphalt Contents (%)	4.33	NA	-------
VMA (%)	13.568	13	Pass
VFA (%)	70.19	65-75	Pass
Stability (KN)	12.37	8.006	Pass
Flow (mm)	2.754	2.0-3.5	Pass

3.6.3 Volumetric Properties of Mix Having 25% RAP

The volumetric properties, stability and flow correspond to the mix which has 25% of RAP are as shown below in Table 3.10

Table 3.10: Volumetric properties of mix having 25% RAP

% AC	G_{mb}	G_{mm}	Unit wt (mg/cm$^{3)}$	Va (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
3.5	2.329	2.490	2.329	6.466	14.377	55.027	10.753	2.193
4	2.350	2.472	2.350	4.935	14.053	64.880	12.46	2.69
4.5	2.365	2.458	2.365	3.784	13.955	72.887	12.97	2.99
5	2.378	2.455	2.378	3.136	13.935	77.492	11.43	3.27
5.5	2.385	2.453	2.385	2.772	14.136	80.389	10.63	3.83

For the determination of OBC of mix having 25% RAP, the graphs between asphalt contents and volumetric properties, stability and flow were plotted according to MS-2 manual as shown in Figure 3.29

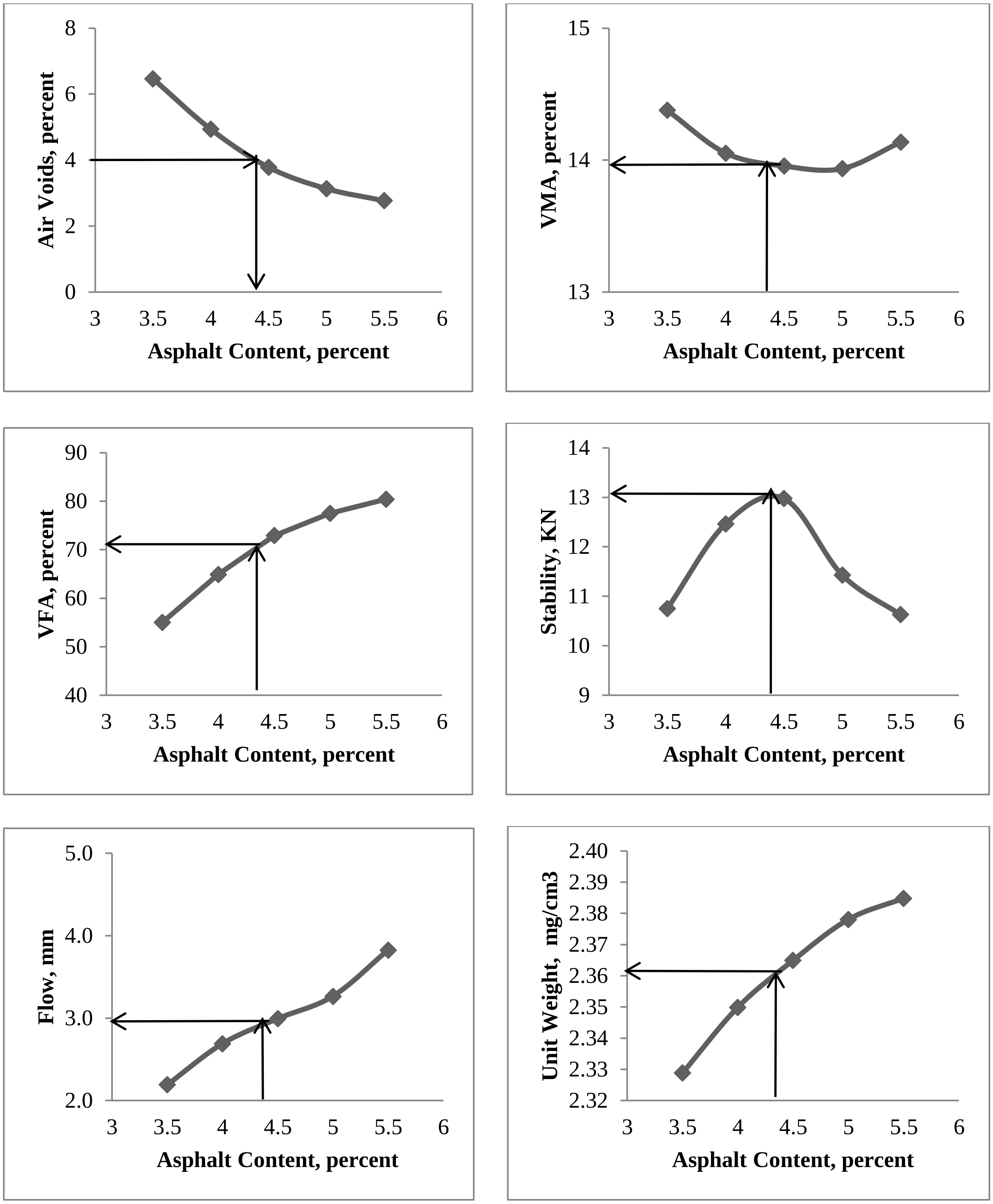


Figure 3.29: Graphs of Volumetric properties of mix having 25% RAP

The mix with 25% of RAP has OBC of 4.39%. The values of volumetric properties, stability and flow according to OBC were then found out from the graphs. Table 3.11 shows the job mix formula of mixture which having 25% RAP. It is clear from the table that all of the volumetric properties, stability and flow meeting the criteria. The VMA at 4% design air voids should not be less than 13% and in this case its value was 13.967%. VFA should be in between 65-75, its calculated value lies in this range which was 71.1%. The stability value according to criteria should not be less than 8.006KN and in this case it was 13.022 KN. The measured value of flow number was 2.933 mm which lie in the range of criteria.

Table 3.11: Job Mix Formula for mix having 25% RAP

Parameters	Measured Value	Criteria	Remarks
Optimum Asphalt Contents (%)	4.39	NA	-------
VMA (%)	13.967	13	Pass
VFA (%)	71.1	65-75	Pass
Stability (KN)	13.022	8.006	Pass
Flow (mm)	2.933	2.0-3.5	Pass

3.6.4 Volumetric Properties of Mix Having 35% RAP

The volumetric properties, stability and flow correspond to the mix which has 35% of RAP are as shown below in Table 3.12.

Table 3.12: Volumetric properties of mix having 35% RAP

% AC	G_{mb}	G_{mm}	Unit wt (mg/cm^{3})	Va (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
3.5	2.330	2.498	2.330	6.725	14.340	53.099	10.922	2.059
4	2.363	2.483	2.363	4.833	13.576	64.403	12.76	2.52
4.5	2.373	2.472	2.373	4.005	13.663	70.688	13.12	2.90
5	2.383	2.453	2.383	2.854	13.753	79.251	11.95	3.20
5.5	2.391	2.443	2.391	2.129	13.919	84.708	10.71	3.64

For the determination of OBC of mix having 35% RAP, the graphs between asphalt contents and volumetric properties, stability and flow were plotted according to MS-2 manual as shown in Figure 3.30

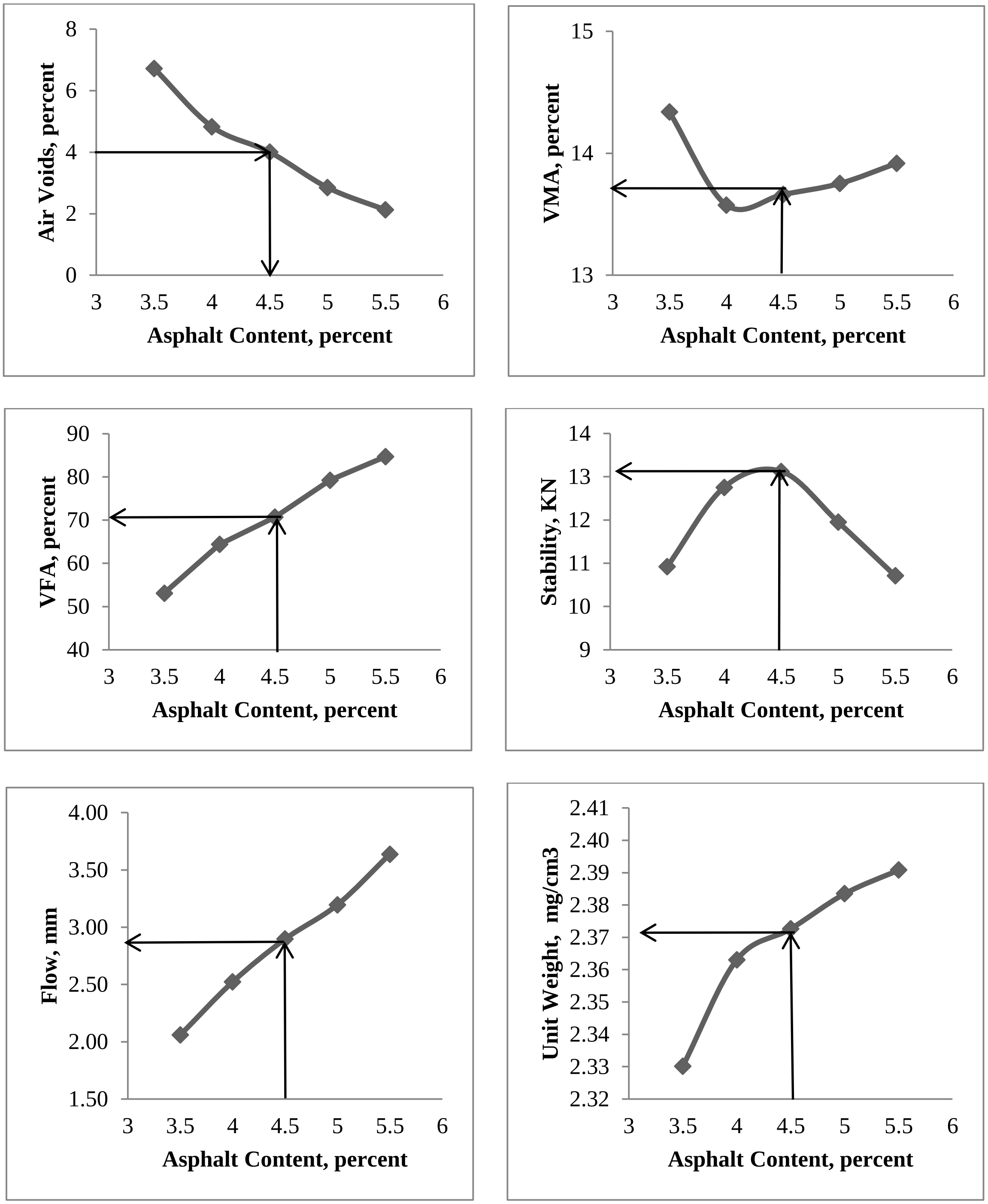


Figure 3.30: Graphs of Volumetric properties of mix having 35% RAP

The mix with 35% RAP has OBC of 4.50%. The values of volumetric properties, stability and flow according to OBC were then found out from the graphs. Table 3.13 shows the job mix formula of mixture which having 35% RAP. It is clear from the table that all of the volumetric properties, stability and flow meeting the criteria. The VMA at 4% design air voids should not be less than 13% and in this case its value was 13.661%. VFA should be in between 65-75, its calculated value lies in this range which was 70.7%. The stability value according to criteria should not be less than 8.006KN and in this case it was 13.124 KN. The measured value of flow number was 2.897 mm which lie in the range of criteria.

Table 3.13: Job Mix Formula for mix having 35% RAP

Parameters	Measured Value	Criteria	Remarks
Optimum Asphalt Contents (%)	4.50	NA	-------
VMA (%)	13.661	13	Pass
VFA (%)	70.7	65-75	Pass
Stability (KN)	13.124	8.006	Pass
Flow (mm)	2.897	2.0-3.5	Pass

3.6.5 Volumetric Properties of Mix Having 50% RAP

The volumetric properties, stability and flow correspond to the mix which has 50% of RAP are as shown below in Table 3.14

Table 3.14: Volumetric properties of mix having 50% RAP

% AC	G_{mb}	G_{mm}	Unit wt (mg/cm^{3})	Va (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
3.5	2.332	2.491	2.332	6.383	14.264	55.251	11.410	1.962
4	2.349	2.473	2.349	5.014	14.087	64.405	12.91	2.362
4.5	2.369	2.471	2.369	4.128	13.806	70.102	13.30	2.816
5	2.381	2.465	2.381	3.408	13.823	75.348	12.22	3.035
5.5	2.393	2.453	2.393	2.446	13.845	82.333	10.73	3.270

For the determination of OBC of mix having 50% RAP, the graphs between asphalt contents and volumetric properties, stability and flow were plotted according to MS-2 manual as shown in Figure 3.31

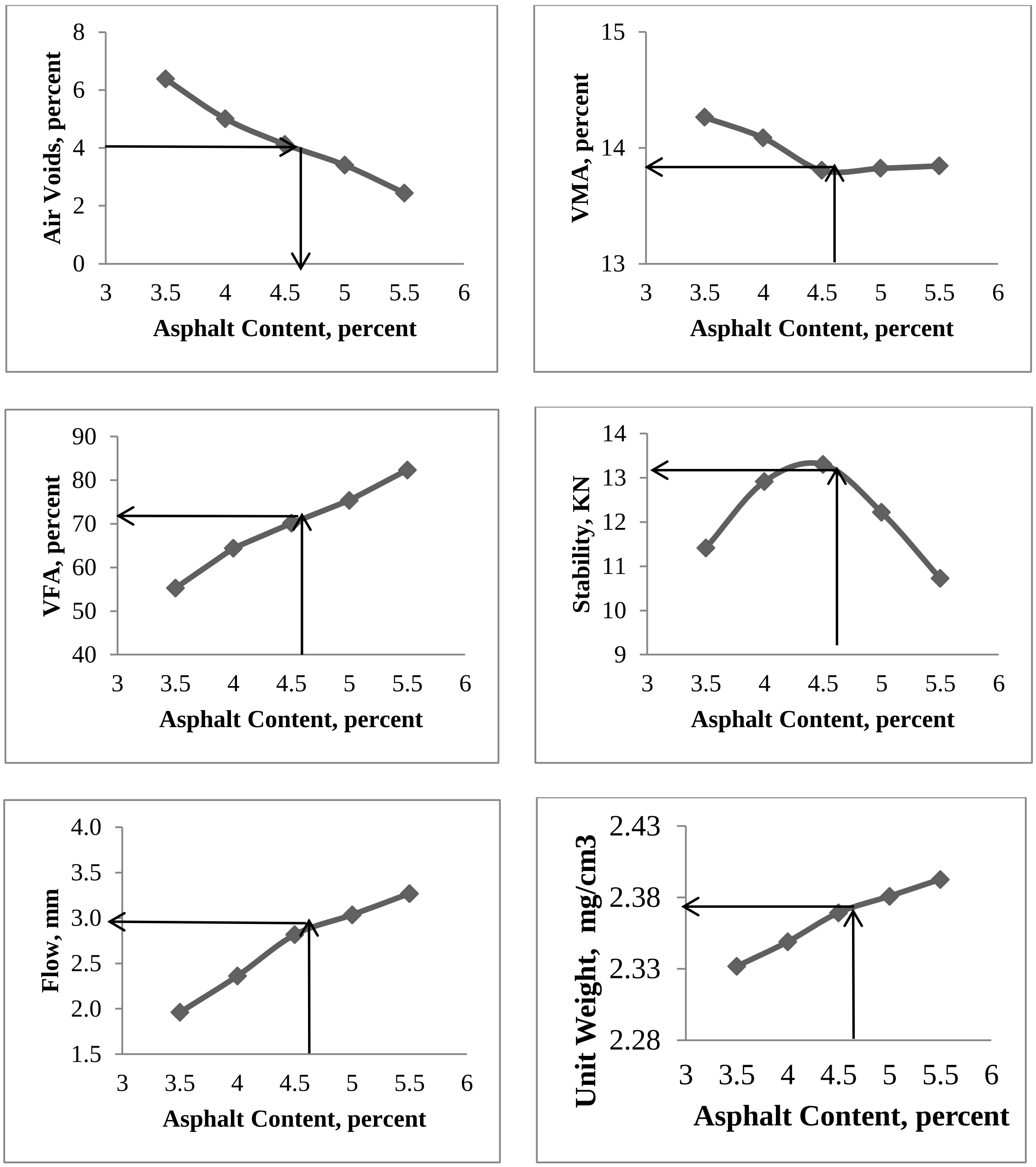


Figure 3.31: Graphs for Volumetric properties of mix having 50% RAP

The mix with 50% RAP has OBC of 4.59%. The values of volumetric properties, stability and flow according to OBC were then found out from the graphs. Table 3.15 shows the job mix formula of mixture which having 35% RAP. It is clear from the table that all of the volumetric properties, stability and flow meeting the criteria. The VMA at 4% design air voids should not be less than 13% and in this case its value was 13.79%. VFA should be in between 65-75, its calculated value lies in this range which was 71.07%. The stability value according to criteria should not be less than 8.006KN and in this case it was 13.22 KN. The measured value of flow number was 2.87 mm which lie in the range of criteria.

Table 3.15: Job Mix Formula for mix having 50% RAP

Parameters	Measured Value	Criteria	Remarks
Optimum Asphalt Contents (%)	4.59	NA	-------
VMA (%)	13.79	13	Pass
VFA (%)	71.07	65-75	Pass
Stability (KN)	13.22	8.006	Pass
Flow (mm)	2.87	2.0-3.5	Pass

After determination of above mentioned tests and performing analysis, separate graphical plots for all values were drawn as tabulated in Table 3.16 and shown in Figure 3.32

Table 3.16: Volumetric for Different Percentages of RAP

% RAP	OBC at 4% A.V	VMA, %	VFA, %	Stability, KN	Flow, mm	Unit Weight, mg/cm3
0	4.31	13.493	70.04	12.324	2.727	2.374
15	4.33	13.568	70.19	12.37	2.754	2.372
25	4.39	13.967	71.1	13.022	2.933	2.363
35	4.5	13.661	70.7	13.124	2.897	2.373
50	4.59	13.79	71.07	13.22	2.87	2.372

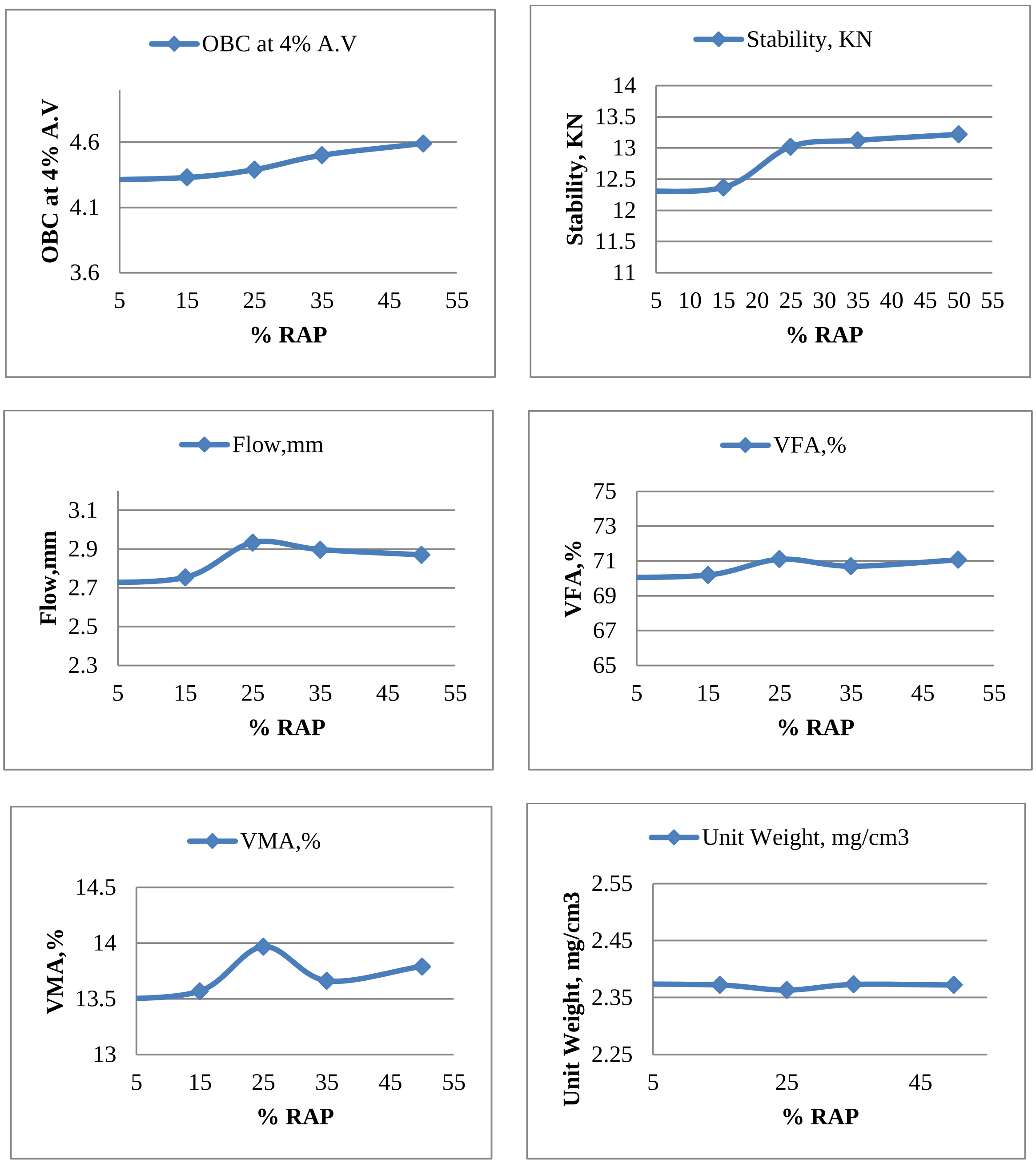


Figure 3.32: Plots between RAP percentages Vs Volumetric

3.7 SAMPLE PREPARATION FOR PERFORMANCE TESTS

For wheel tracker tests and checking moisture damage via UTM, Superpave mix design was used to prepare specimens. After sieving, the aggregates were heated to constant weight at

105°C to 110°C. Mixing temperature of 160±5^{o}C and compaction temperature of 135^{o}C were used for HMA while using 125±5^{o}C and 100^{o}C mixing and compaction temperature for WMA respectively, as general manufacturing temperature range for WMA is 93°C to 135°C (200-274^{o}F). The required quantity of aggregates for preparing 6-inch diameter gyratory compacted specimens was 5000gm. Compaction of specimens was done by providing 125 gyrations. 3 x replicates were prepared for every RAP percentage with further addition of 0%, 1%, 2%, and 3% sasobit using ARL 60/70 grade bitumen. Saw cutter was utilized for each specimen to obtain a standard sample of 1.5-inch height and 6-inch diameter for wheel tracker test. Core cutting and Saw cutting of specimens, for conducting tests are shown in Figure 3.34(a) and (b)respectively. During core cutting 4 in diameter sample was extracted for moisture damage on UTM as NHA grade B don't have a size greater than 1 inch and then by saw cutter further reducing it to samples of height 63±2.5 mm.

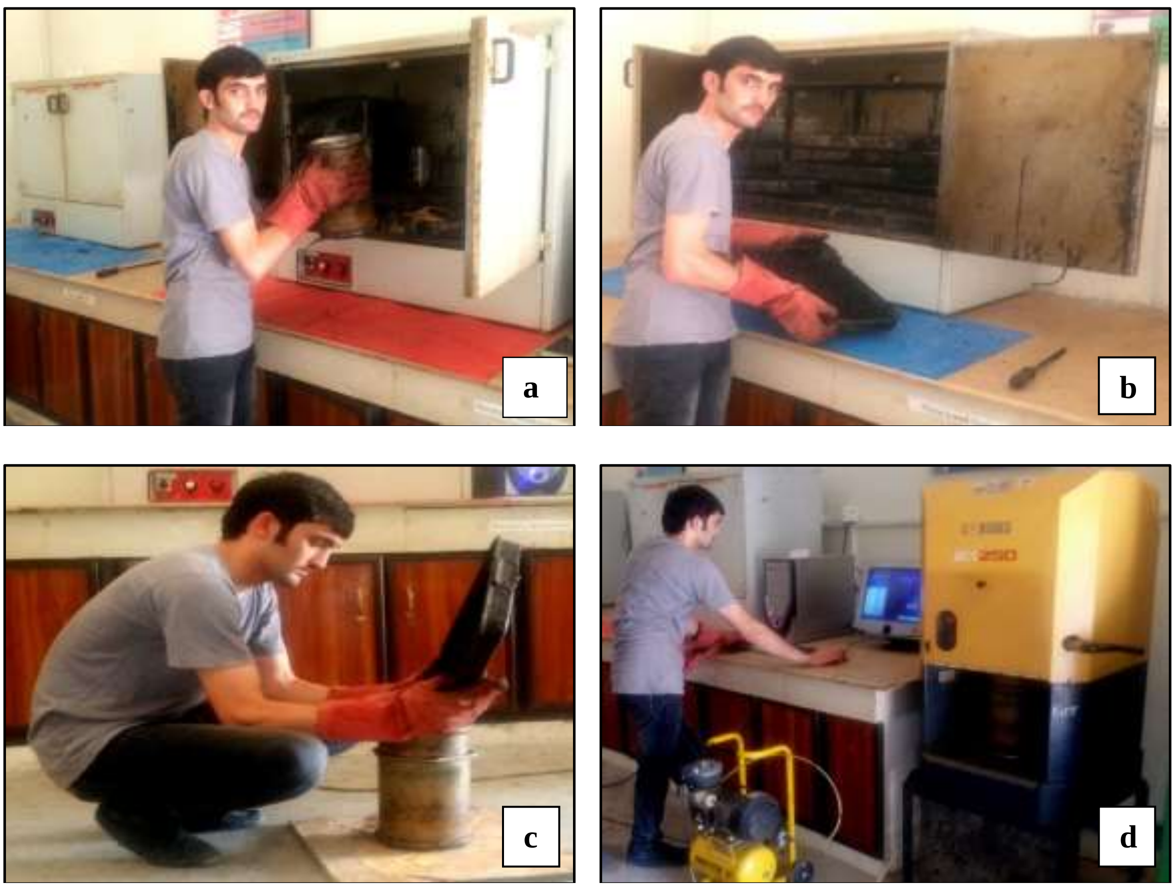


Figure 3.33 (a), (b), (c), & (d): Gyratory Sample Preparation

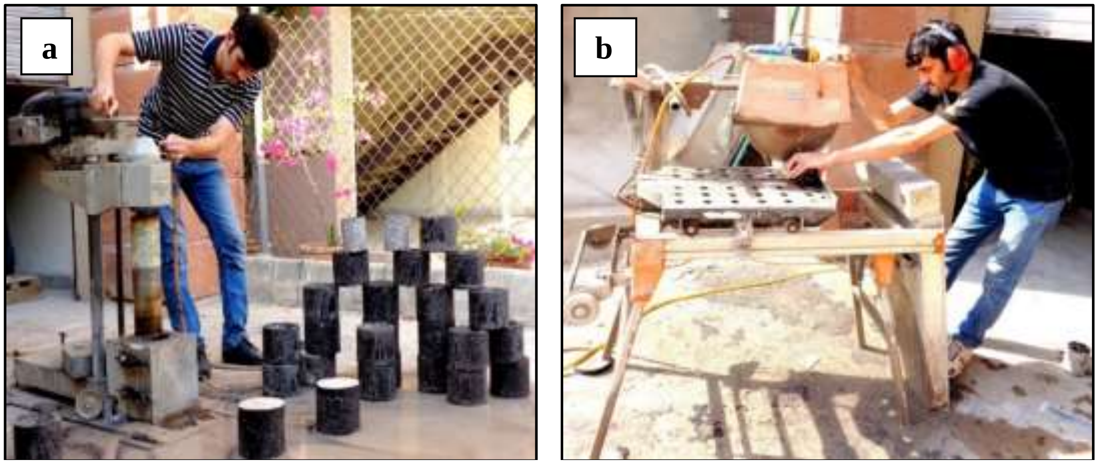


Figure 3.34: (a) Core Cutting, (b) Saw Cutting

3.8 INVESTIGATION OF SAMPLE POTENTIAL FOR RUTTING

Rutting is among the most common pavement permanent deformations which is the result of cyclic traffic loads and is the accumulation of slight pavement materials deformations in the form of longitudinal depressions along the wheel paths of the pavement. For the investigation of rutting propensity, the specimens were tested to determine their resistance to permanent deformation using Hamburg wheel tracker. The specimen is submerged in hot water, the steel wheel rolls across the specimen surface and thus the device measures the effects of moisture damage and rutting. HWT is an electrically powered device, capable of moving a 203.2mm diameter, 47-mm wide steel wheel over a test specimen. The load on the steel wheel is 158±1.0 lb, and the average contact stress produced by the contact of wheel is app: 0.73 MPa with a contact area around 970 mm^2. Just like the influence of rear tire of a double-axle is produced by the contact pressure of steel wheel. With increase in rut depth the contact area increases as result of which the contact stresses become variable. The steel wheel moves over the specimen in forward and backward direction. The steel wheel of HWTD must complete approximately 60 passes on the sample per minute. The highest speed of the wheel over the specimen is nearly 1 ft./sec, which is achieved at the center of the sample. With the help of HWTD rutting test can be carried out on dry, wet and air modes. In this research wet mode was used to determine the susceptibility of asphalt mixtures to rutting. These three modes can be utilized by adjusting the

HWTD at anticipated test conditions. Figure 3.35 shows the PMW wheel-tracking device used for conducting rutting tests. Before conducting the test, the sample were saw cut from the top and bottom surface so that two 1.5-inch thick specimens could be obtained. These specimens were cut according to the silicon mold of the wheel tracker tray.

Figure 3.35: PMW Wheel-Tracking Device

After insertion of specimen in the mold, extra spaces were adjusted with pieces of wood so that the movement of wheel does not make the sample move. The steel tray with the sample placed in it was kept under the wheel and fixed. The wheel tracker device was switched on. Then the sample details were entered in the software. The speed of the wheel was adjusted to 60 ppm (passes per minute). The number of passes were fixed to 10,000 as specified for determination of rutting potential of asphalt mixes having bitumen of 58 grade (ARL 60/70). Wheel tracker was used by selecting wet mode for determination of moisture damage at 45°C temperature of water. Finally, the test was run and wheel started moving to and fro on the mounted specimen. The number of passes were shown on the LCD of the system attached with machine. One complete to and fro movement of the wheel was taken as 2 passes. The LVDT (Linear Variable Differential Transformer) measures the impression of rut in millimeters of unit at the same time with the motion of wheel. The machine automatically stopped when required number of passes were achieved. Results were saved for further use.

3.9 MOISTURE SUSCEPTIBILITY TESTING

The moisture susceptibility test was carried out in accordance with ASTM D 6931-07, (Resistance of Compacted Hot-Mix Asphalt to Moisture Induced Damage). Three specimens per mix were tested unconditioned. These unconditioned specimens were placed in a water bath at 25±1°C (77±1.8°F) one hour prior to testing. Another set of three specimens per mix were tested conditioned. Conditioning of samples were carried out according to ALDOT-361 i.e. specimens were saturated and then placed in a 60±1°C (140±1.8°F) water bath for 24 hours followed by one hour in a water bath at 25±1°C (77±1.8°F). Both unconditioned and conditioned specimens were loaded diametrically at a rate of 50 mm/minute. For each specimen the tensile strength was then calculated using specimen dimensions and failure load. The tensile strength ratios were then calculated by dividing the average conditioned tensile strength by the average unconditioned tensile strength. The acceptable value for tensile strength ratio employed was 80% (minimum).

Figure 3.36: ITS Testing using UTM

The tensile strength of each subset was determined by Equation 3.3

$$St = \frac{2000P}{\pi Dt} \tag{3.3}$$

Where:

St = Tensile strength, kPa

P = Maximum load, N

t = Specimen height before tensile test, mm

D = Specimen diameter, mm

The TSR indicate the potential for moisture damage which is the ratio of the tensile strength of the conditioned subset to that of the unconditioned subset. The TSR for each mixture is calculated by Equation 3.4.

$$TSR = \left[\frac{S2}{S1}\right] \tag{3.4}$$

Where:

S1 = Average tensile strength of dry subset, and

S2 = Average tensile strength of conditioned subset.

3.10 SUMMARY

This chapter explains the laboratory characterization of aggregates and bitumen for the preparation of bituminous paving mixes. Those materials that satisfied the standard specifications were used for bituminous mix preparation. The volumetric properties of bituminous mix have been calculated and OBC were determined. The testing procedure adopted for the permanent deformation testing of bituminous mix specimens has been explained.

Chapter 4

RESULTS AND ANALYSIS

4.1 INTRODUCTION

In Pakistan the most common type of distress found on HMA pavements is rutting and it mainly occurs due to higher temperatures coupled with heavier axle loads. Therefore, employing the Hamburg Wheel tracker tests, are technically as well as practically reasonable as to investigate rutting susceptibility. Along with rutting, moisture also acts as a destructive agent which results in earlier collapse of pavement and by checking moisture damage via UTM is the easiest method.

This study is based upon utilizing different percentages of RAP content with incorporation of increasing sasobit content from 0% to 3% with 1% increment in order to have WMA mixtures, to see the effect of RAP and sasobit content on rutting propensity and moisture susceptibility of WMA mixtures. RAP used in this study was taken from Lahore Islamabad Motorway (M-2) and control samples were prepared in laboratory after calculation of OBC using the aggregate source of Margalla with NHA Class B gradation.

In Literature Review, rutting susceptibility and moisture damage have already been explained in detail while in Chapter 3 (Research and Testing Methodology), procedures and test parameters adopted for tests have been explained. In this chapter, the detailed analysis of data obtained from experimental testing, along with detailed test results has been included. The analysis of obtained results was done by spreadsheet program, Microsoft Excel 2016.

4.2 PERMANENT DEFORMATION (WHEEL TRACKER RESULTS)

Permanent deformation was evaluated by comparing the control specimen's resistance to rutting, with different RAP percentages modified asphalt mixtures and with addition of different percentages of sasobit. Gyratory compacted specimens were prepared for control samples and samples containing 15%, 25%, 35% and 50% RAP with further addition of 1%, 2%, and 3% sasobit of OBC making WMA, by using NHA class B wearing course.

Wheel tracker tests were conducted on specimens prepared for rutting under wet condition. For wheel tracker test a total of 60 samples were prepared with varying percentages of RAP and sasobit as mentioned above, these samples were saw cut for wheel tracker to check its rutting potential. All the controlled specimens showed good resistance to rutting, whereas the specimens with 0% and 15% RAP shows higher resistance to rutting at 2% sasobit and at 3% percent sasobit these samples have less rut resistance than that of samples having 2% sasobit. But samples with higher percentages of RAP that is 25%, 35% and 50% showed higher rut resistance at 3% sasobit. All of the specimens passed the wheel tracker test criteria of 12.5 mm.

Figure 4.1: HWT Tested Sample

Table 4.1: HWTD Tests Results

Specification	Codes	Avg: RUT Depth in mm	% Increase in RUT Potential w.r.t each incremental % RAP	% Increase in RUT Potential w.r.t 0 % RAP
0% RAP, 0% SASOBIT	R0S0	4.455	0.00	0.00
0% RAP, 1% SASOBIT	R0S1	4.410	1.01	1.01
0% RAP, 2% SASOBIT	R0S2	4.383	1.62	1.62
0% RAP, 3% SASOBIT	R0S3	4.420	0.79	0.79
15% RAP, 0% SASOBIT	R15S0	3.690	0.00	17.17
15% RAP, 1% SASOBIT	R15S1	3.545	3.93	20.43
15% RAP, 2% SASOBIT	R15S2	2.855	22.63	35.91
15% RAP, 3% SASOBIT	R15S3	2.965	19.65	33.45
25% RAP, 0% SASOBIT	R25S0	2.820	0.00	36.70
25% RAP, 1% SASOBIT	R25S1	2.680	4.96	39.84
25% RAP, 2% SASOBIT	R25S2	2.615	7.27	41.30
25% RAP, 3% SASOBIT	R25S3	2.405	14.72	46.02
35% RAP, 0% SASOBIT	R35S0	2.130	0.00	52.19
35% RAP, 1% SASOBIT	R35S1	1.940	8.92	56.45
35% RAP, 2% SASOBIT	R35S2	1.845	13.38	58.59
35% RAP, 3% SASOBIT	R35S3	1.655	22.30	62.85
50% RAP, 0% SASOBIT	R50S0	1.530	0.00	65.66
50% RAP, 1% SASOBIT	R50S1	1.410	7.84	68.35
50% RAP, 2% SASOBIT	R50S2	1.060	30.72	76.21
50% RAP, 3% SASOBIT	R50S3	0.850	44.44	80.92

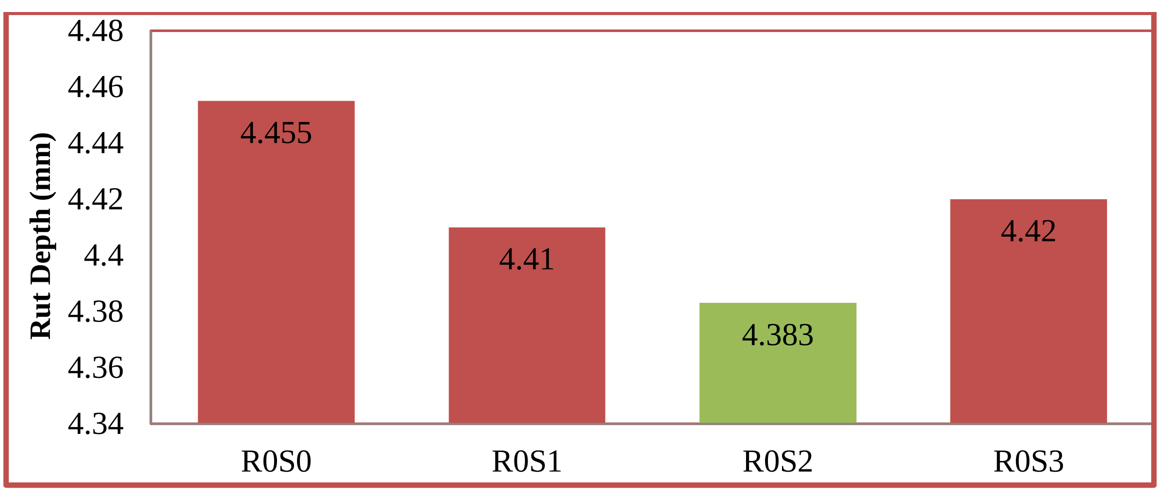


Figure 4.2: Average Rut Depth for 0% RAP with increasing Sasobit from 0% to 3%

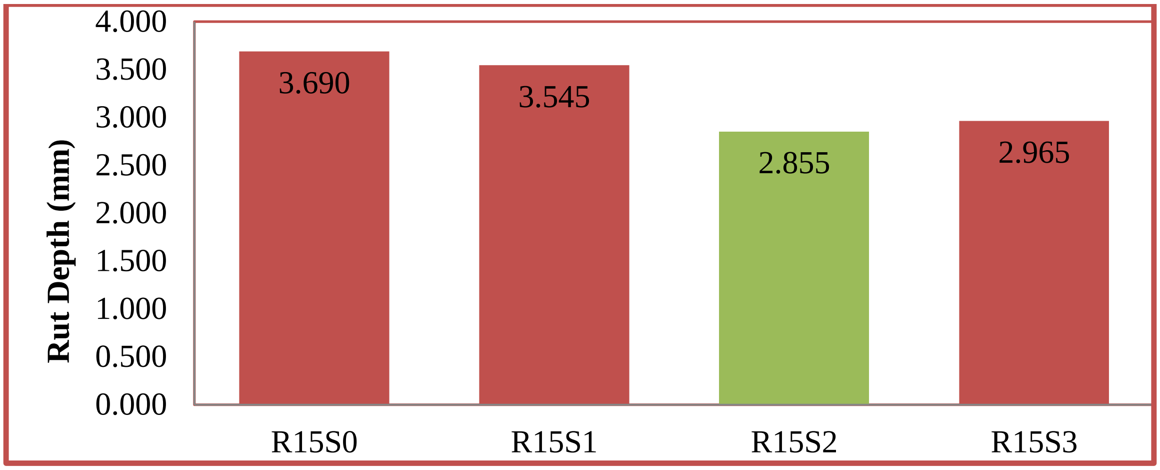


Figure 4.3: Average Rut Depth for 15% RAP with increasing Sasobit from 0% to 3%

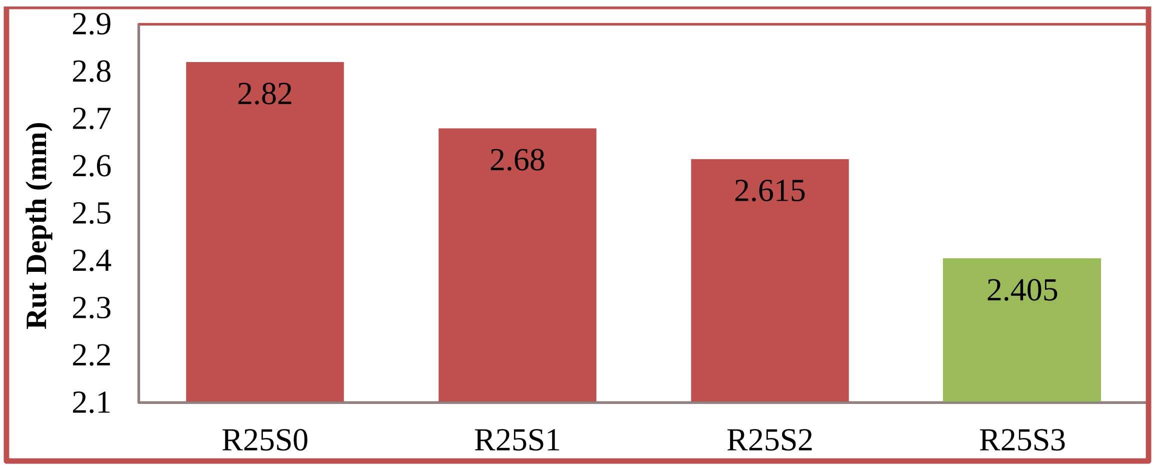


Figure 4.4: Average Rut Depth for 25% RAP with increasing Sasobit from 0% to 3%

Figure 4.5: Average Rut Depth for 35% RAP with increasing Sasobit from 0% to 3%

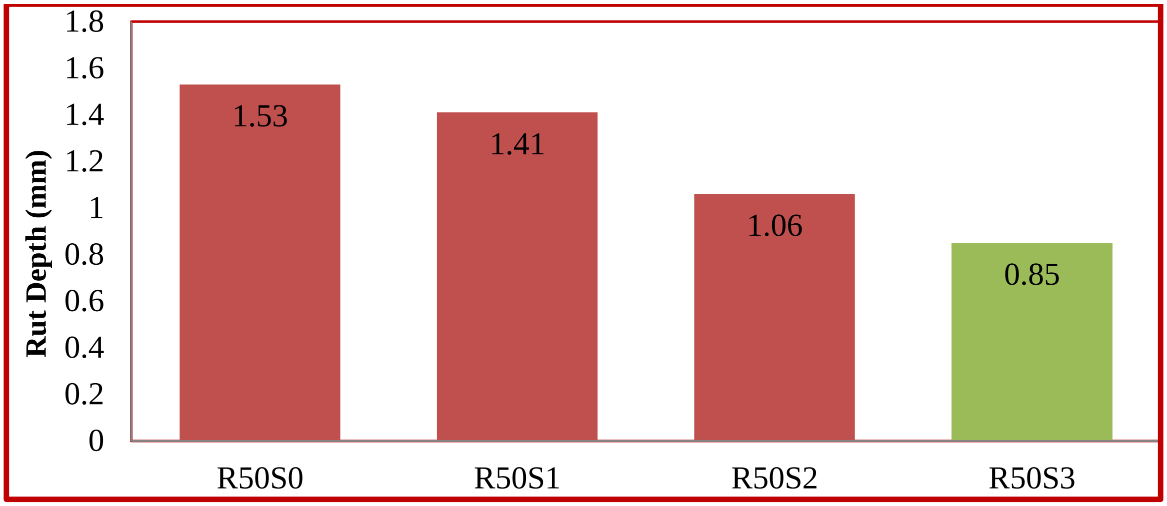


Figure 4.6: Average Rut Depth for 50% RAP with increasing Sasobit from 0% to 3%

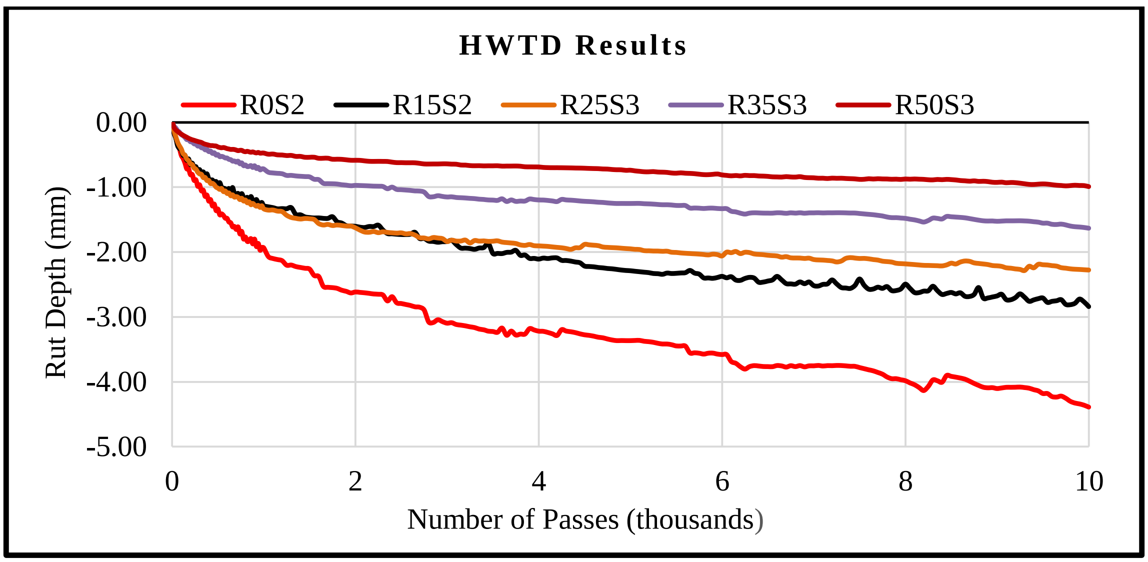


Figure 4.7: Rut Depth for RAP Content with Best percentage of Sasobit

4.3 MOISTURE DAMAGE (ITS TEST RESULTS)

After completion of mix design, moisture susceptibility test was carried out on the mixtures according to ASTM D 6931-07 (Resistance of compacted hot-mix asphalt to moisture induced damage). While conditioning of samples were carried out through ALDOT 361. A total of 120 gyratory samples at 4% air voids were prepared and tested for ITS test from which cores of 4 inches' diameter samples were extracted using core cutter for moisture damage testing on UTM by further reducing to a height of 63±2.5 mm through saw cutter (60 samples were tested unconditioned and 60 samples were tested after condoning). For each combination of RAP and sasobit, six samples were prepared in the gyratory compactor at 4% air voids. Three of the samples were tested un-conditioned, while the remaining three specimens were subject to a 60^{o}C warm-water soaking cycle for 24 hours following one-hour conditioning at 25^{o}C before being tested for ITS. No freeze-thaw conditioning cycles were performed on the conditioned specimens. The raw conditioned and unconditioned strength values for the 20 mixes are shown in Table 4.2. The results show that as the percentage of RAP increases the strength also increases.

Tables 4.2 summarize the moisture sensitivity results and Figures 4.9 to 4.18 shows trends of ITS test results along with TSR. Superpave criteria require a minimum TSR of 80%. The TSRs for the 20 mixes calculated were all above 80 percent except for 3% sasobit and 50% RAP which was 78.9%, also TSR for 2% sasobit and 50% RAP was too close to the lower limit of 80% i.e. 82.72%. Along with this the TSRs for 3% sasobit with 35% RAP and 0%, 1% and 2% sasobit with 50% RAP were less than 90 percent all other mixes give TSRs of higher than 90 percent.

Also ITS values show that all the conditioned samples give reduced strength value than that of unconditioned, showing that sasobit increase the moisture susceptibility of asphalt mixes.

Also there was very minute difference in TSR values when sasobit content increases from 0% to 3% for each of the mentioned RAP percentage except for higher RAP content of 35% and 50%.

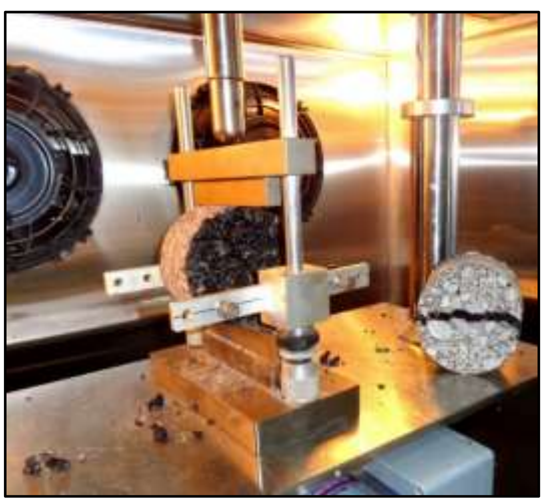


Figure 4.8: UTM Tested Sample

Table 4.2: ITS Tests Results

Specification	Codes	Average Un- Conditioned Strength, S1(kPa)	Average Conditioned Strength, S2 (kPa)	TSR=S2/S1 (%)
0% RAP, 0% SASOBIT	R0S0	777.85	777.5	99.96
0% RAP, 1% SASOBIT	R0S1	779.35	777.35	99.74
0% RAP, 2% SASOBIT	R0S2	780.2	776.3	99.50
0% RAP, 3% SASOBIT	R0S3	781.3	774.15	99.08
15% RAP, 0% SASOBIT	R15S0	783.05	770.55	98.40
15% RAP, 1% SASOBIT	R15S1	785.15	768.7	97.90
15% RAP, 2% SASOBIT	R15S2	787.9	767.2	97.37
15% RAP, 3% SASOBIT	R15S3	789.25	766.45	97.11
25% RAP, 0% SASOBIT	R25S0	791.8	764.7	96.58
25% RAP, 1% SASOBIT	R25S1	794.15	763.65	96.16
25% RAP, 2% SASOBIT	R25S2	796.75	763.3	95.80
25% RAP, 3% SASOBIT	R25S3	802.45	761.7	94.92
35% RAP, 0% SASOBIT	R35S0	806.85	759.1	94.08
35% RAP, 1% SASOBIT	R35S1	817.2	757.35	92.68
35% RAP, 2% SASOBIT	R35S2	820.75	748.4	91.18
35% RAP, 3% SASOBIT	R35S3	828.2	739.15	89.25
50% RAP, 0% SASOBIT	R50S0	835.1	730.85	87.52
50% RAP, 1% SASOBIT	R50S1	842.3	715.6	84.96
50% RAP, 2% SASOBIT	R50S2	858.7	710.3	82.72
50% RAP, 3% SASOBIT	R50S3	877.6	692.45	78.90

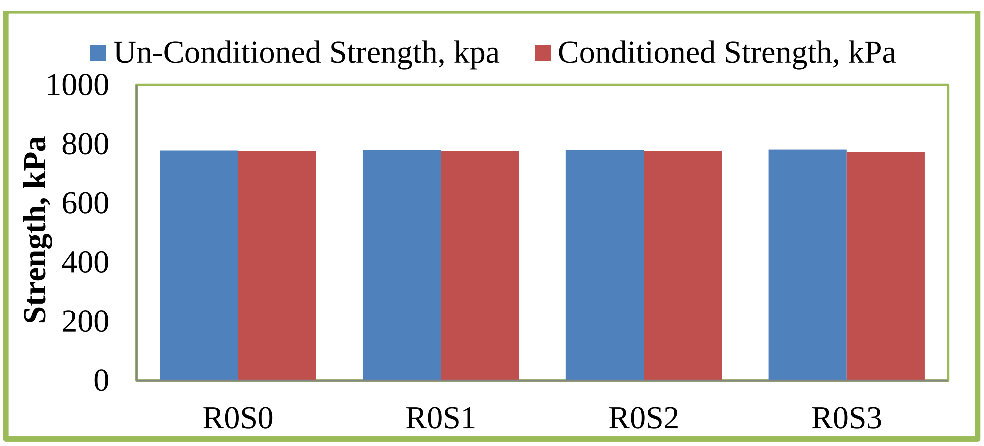


Figure 4.9: ITS for 0% RAP and sasobit from 0% to 3%

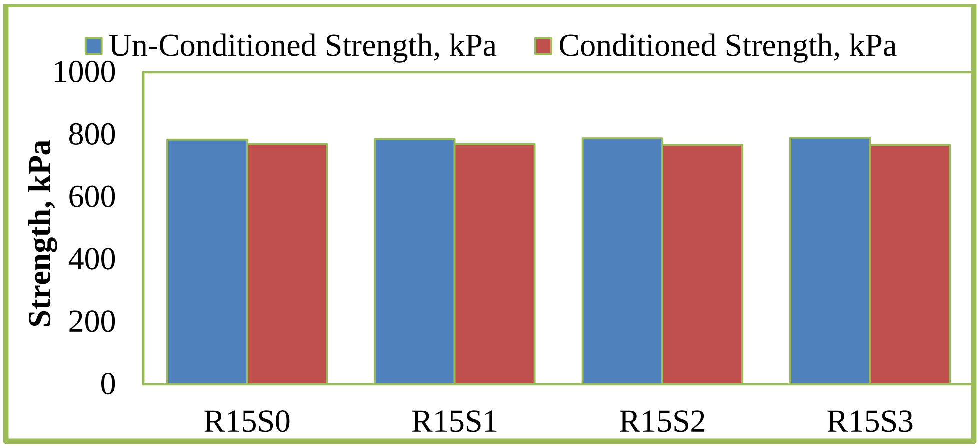


Figure 4.10: ITS for 15% RAP and sasobit from 0% to 3%

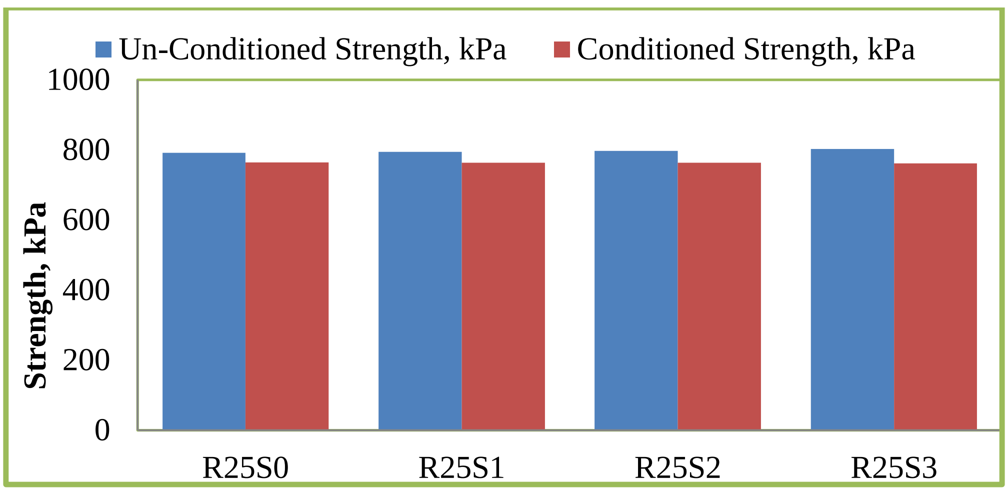


Figure 4.11: ITS for 25% RAP and sasobit from 0% to 3%

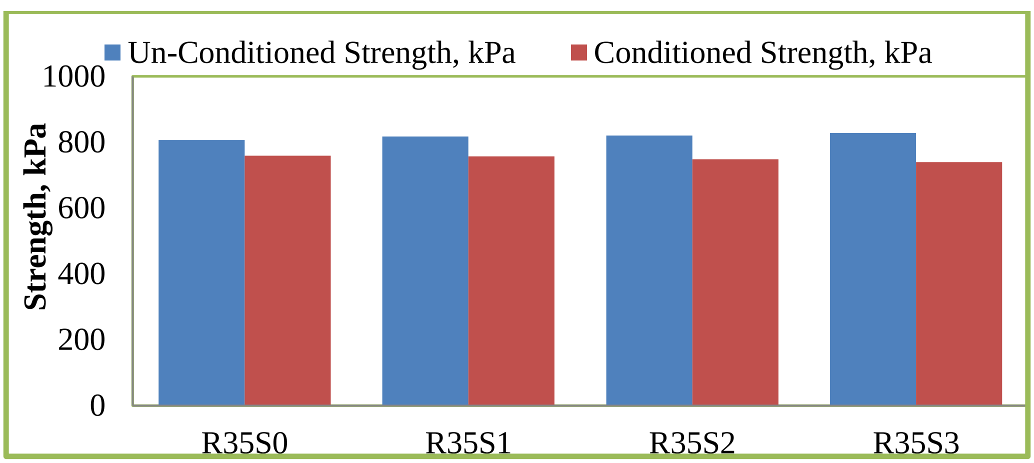


Figure 4.12: ITS for 35% RAP and sasobit from 0% to 3%

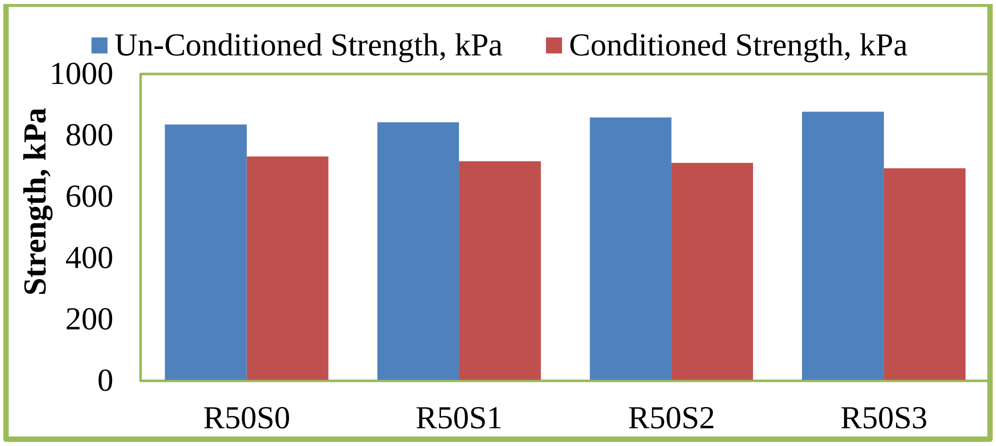


Figure 4.13: ITS with 50% RAP and sasobit from 0% to 3%

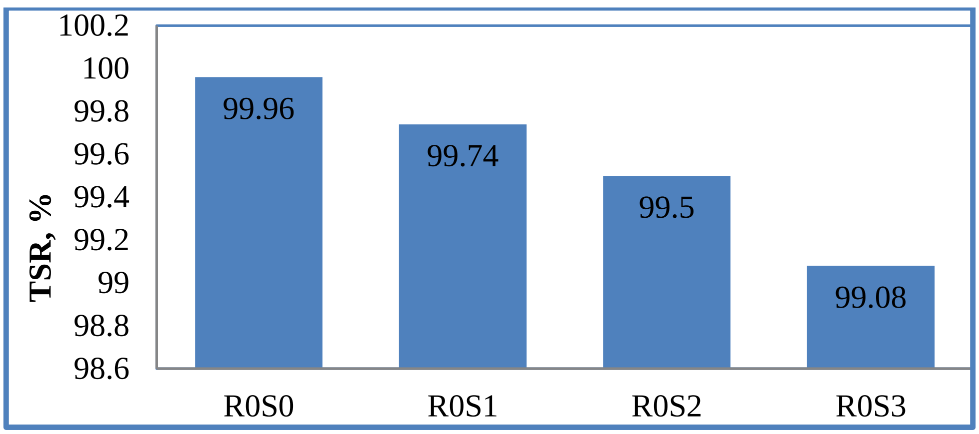


Figure 4.14: TSR for 0% RAP and sasobit from 0% to 3%

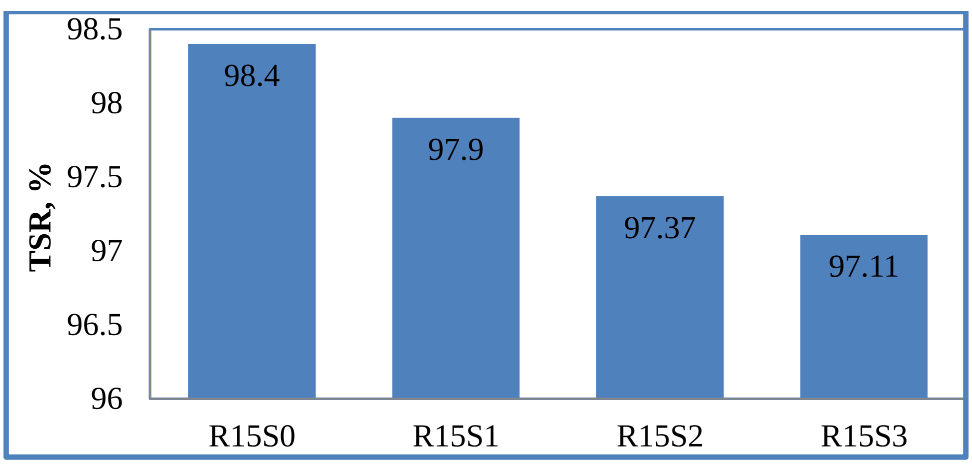


Figure 4.15: TSR for 15% RAP and sasobit from 0% to 3%

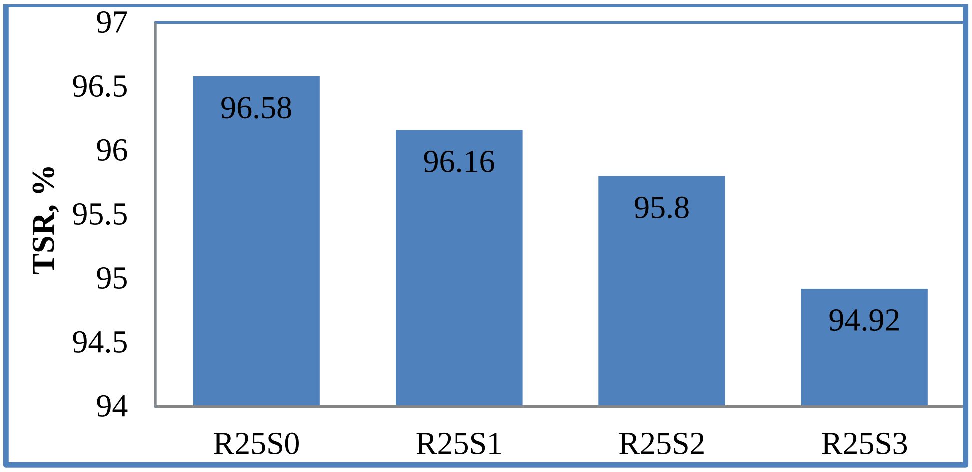


Figure 4.16: TSR for 25% RAP and sasobit from 0% to 3%

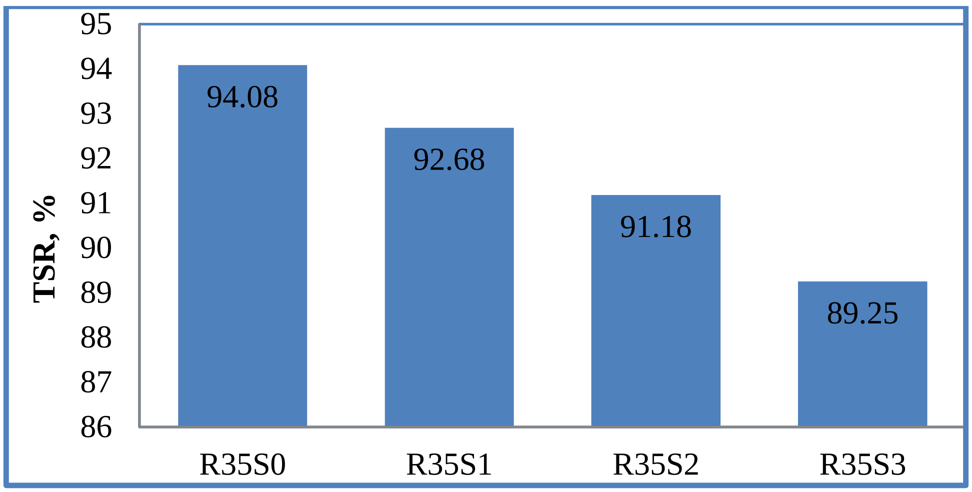


Figure 4.17: TSR for 35% RAP and sasobit from 0% to 3%

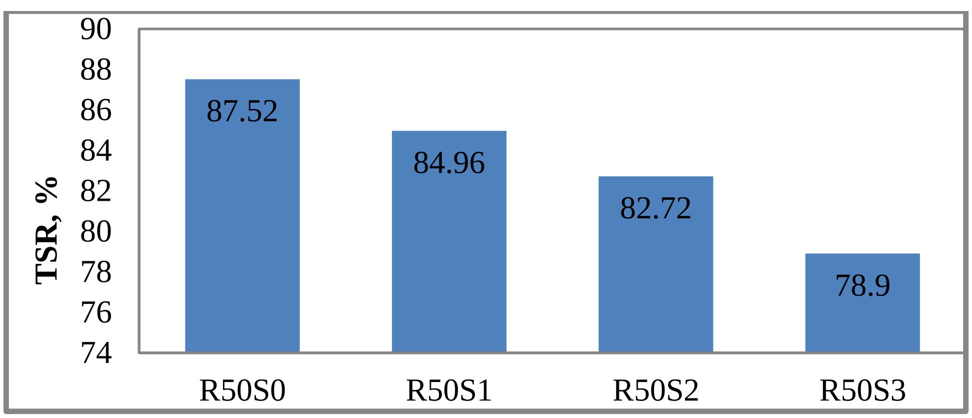


Figure 4.18: TSR for 50% RAP and sasobit from 0% to 3%

4.4 SUMMARY

In this chapter the detailed analysis of the results obtained after laboratory testing has been discussed. The results obtained from the HWTD and UTM are discussed in reference of increase in RUT potential, ITS values and TSRs. The data analysis carried out was presented in the form of tables and graphs. The results of wheel tracker test, ITS test for controlled specimens and specimen containing different percentages of RAP in addition of sasobit were presented in the form of bar charts. Comparison of results for each percentage of RAP, while increasing sasobit is done and discussed in detail, which showed that any combination of RAP and sasobit has greater resistance to rutting as compared to the controlled specimens, while ITS values for every combination of sasobit and RAP percentages is somewhat lower than that of unconditioned samples.

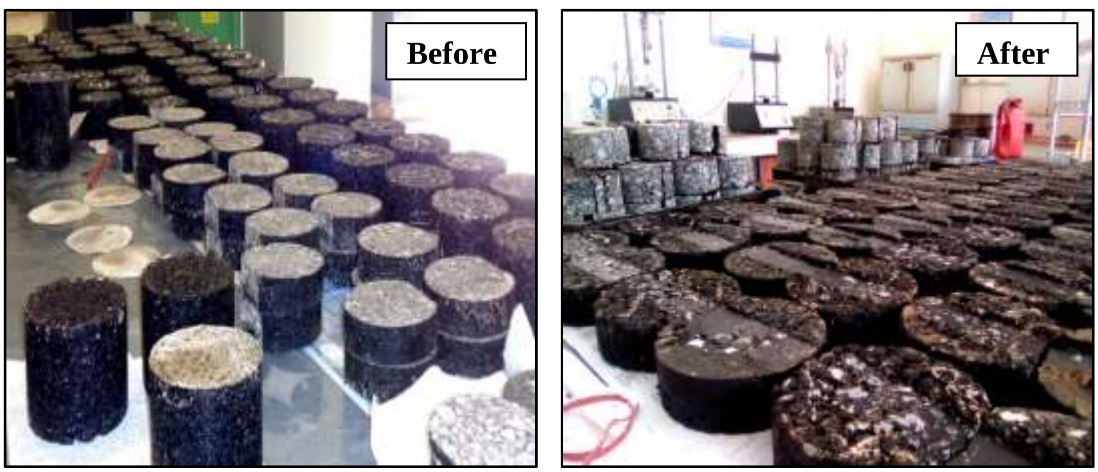


Figure 4.19: Gyratory Samples Before and After Tests

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

This research work primarily determines the effectiveness of asphalt mixes with RAP and increasing percentages of sasobit from 0% to 3%. Rutting and moisture damage are one of the severe problems witnessed in flexible pavements. Hamburg wheel tracker is one of the test equipment used for long term performance evaluation of asphalt mixes along with this ITS test is the simplest and easiest option to find the moisture damage of asphalt mixes. NHA Class-B wearing course gradation, bitumen from Attock Refinery Limited having 60/70 penetration grade and Aggregate material acquired from Margalla were used for testing in this research. RAP material was brought from Lahore Islamabad Motorway (M-2) for testing in Laboratory and WMA additive, Sasobit was arranged through a distributer. Marshal Mix design procedure was used to determine the OBC for NHA Class-B gradation and then for different percentages of RAP. The specimens were prepared using optimum percentage of bitumen for control mix and each percentage of RAP by changing sasobit content from 0% to 3% of OBC in Superpave Gyratory Compactor (SGC). The parameters selected for checking rutting susceptibility and moisture damage were wet conditions in Hamburg Wheel Tracker Device and temperature of 45ºC as specified in HWTD manual for 58 grade bitumen and rutting criteria and TSRs for checking moisture damage respectively. The key findings for HWTD testing, UTM testing and analysis of experimental results are concluded as under.

5.2 CONCLUSIONS

The conclusions drawn after analysis of tests conducted, as described in previous chapter are listed as under;

1. Using RAP in the mix design will help in conserving the natural resources, reducing the HMA price and also improves the performance of the mixes.
2. The rutting potential of HMA mixes containing RAP increases by increasing RAP content.

3. Rut potential of controlled asphalt mixes and asphalt mixes containing RAP increases by increasing sasobit content as compared to controlled mixes and mixes containing RAP only.

4. The rut potential also increased due to decreased production temperature and this may be associated more to the reduced binder aging.

5. Asphalt mixes having low percentages of RAP i.e. up to 15% give best rut potential at 2% sasobit and then decreased unlike for mixes with higher percentages of RAP i.e. above 15% for which rut potential increases linearly up to 3% sasobit. which may be due to increased workability and viscosity.

6. The ITS for mixes with either sasobit alone or both sasobit and RAP were slightly higher, as compared to the control mixes. which may be due to the formation of lattice structure.

7. The ITS for mixes with sasobit plus RAP were slightly higher, as compared to mix containing RAP only.

8. The resistance against moisture damage of asphalt mixes containing RAP or sasobit or both is lower than that of control mixes. And this may be contributed to the lower mixing and compaction temperatures for WMA as compared to HMA, and potential for moisture damage increases due to incomplete drying of aggregate in the resultant asphalt mix using WMA technology. The moisture damage may be due to water trapped in the coated aggregate.

9. For all percentages of RAP, TSRs decreases with increasing percentage of sasobit, and the difference increases with the increase in percentage of RAP.

10. For any percentage of RAP and sasobit the TSR values are above the minimum range of 80% except for 50% RAP and 3% sasobit which is 78.90%, and for 2% sasobit and 50% RAP which is 82.72% i.e. too close to the lower limit.

5.3 CONTRIBUTION TO THE STATE OF ART

Both HMA and WMA containing RAP met the required volumetric and showed improvement in rutting resistance, and have adequate resistant to moisture, so the trial sections can be laid in ongoing projects in Pakistan after carrying out the other performance tests.

5.4 RECOMMENDATIONS

Based on the results of the study the recommendations are as follow:

1. Since WMA technology is comparatively new, especially for Pakistan, there are still several aspects about this technology that must be evaluated in great detail before it is implemented. While earlier studies and this study have addressed several aspects of WMA binders and mixes, there are still several unknown parameters. It is recommended that the following topics be investigated to add on to the findings of this research.
2. Only two of the performance tests is carried out in this study i.e. the rutting susceptibility and moisture damage using HWTD and UTM respectively, other performance tests like dynamic modulus, creep test and fatigue analysis etc. should also be carried out to completely characterize the behavior of RAP containing mix with optimum sasobit.
3. Evaluating the performance of WMA containing recycled pavement material and rejuvenating agents and different aggregate gradations to evaluate the mix performance.
4. It is suggested for evaluating the performance of HMA and WMA with RAP content and suitable additive like sasobit, trail section be constructed after extensive testing to verify that RAP blends that suits the climate condition of country and to the adverse traffic loadings.
5. Life cycle cost analysis of WMA pavements versus HMA pavements.
6. Moisture sensitivity test should be carried out at field production temperatures. If test results determined are not favorable, an anti-striping agent should be added to the mix to increase the resistance to moisture.

On the basis of results of this research, it is recommended that HMA mixes containing RAP content and WMA containing RAP content with additives can be designed to meets the required volumetric and desired performance criteria that can perform equal to or better than the mixes produced with virgin aggregate, and as far as rutting potential and moisture susceptibility is concern it is recommended to use 3% sasobit and 30-40% RAP for best rutting potential and adequate resistance to moisture damage. Further it is recommended that It’s a better option to use 2% sasobit with control mixes and mixes containing low percentages of RAP i.e. up to 15%, while for higher percentages of RAP better option is to use 3% sasobit.

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APPENDICES

APPENDIX I: MARSHALL MIX DESIGN REPORTS

APPENDIX I

Marshall Test Report

Project: **FAZAL HAQ (MS THESIS)** Trial Mix: Controlled Sample (**0% RAP**)

Aggregate Source: Margalla Bitumen: ARL 60/70

Date:02/08/2016

				Mass, grams of compacted Specimen					Mass, grams of loose Mix								Stability, (KN)		
% AC by wt. of mix, Spec. No.	Spec. Height in. (mm)	Dimeter in cm	Volume in cm3 V=πr2h	In Air (A)	In Water (C)	Sat. Surface Dry (B)	B-C	Bulk S.G. Specimen (Gmb) Gmb =A/(B-C)	Dry Weight (a)	Calibration Weight = wt: of Pycnometer+ Glass Lid + Water (b)	wt: of Sample + Water + Pycnometer and Lid (c)	Max. S.G. (loose Mix) (Gmm) =a/b-(c-a)	Unit Wt. (mg/cm3)	% Air Voids	% VMA	% VFA	Measured	Adjusted	Flow, mm
3.5-A	64.75	10.16	524.95	1186.00	690.00	1198.50	508.50	2.332	1185.00	6762.00	7471.48	2.492	2.332	6.407	14.258	55.066	10.301	9.889	1.950
3.5-B	60.25	10.16	488.47	1106.70	649.50	1126.20	476.70	2.322	1104.00	6762.00	7423.10	2.493	2.322	6.863	14.654	53.165	9.901	10.792	2.275
3.5-C	65.25	10.16	529.00	1169.10	686.91	1190.60	503.69	2.321	1162.00	6762.00	7458.15	2.494	2.321	6.947	14.673	52.652	10.129	9.724	2.209
Average	63.42	10.16	514.14	1153.93	675.47	1171.77	496.30	2.325	1144.50	6762.00	7450.91	2.493	2.325	6.739	14.528	53.614	10.110	10.135	2.145
4.0-A	65.00	10.16	526.98	1194.70	695.10	1200.50	505.40	2.364	1192.00	6762.00	7473.90	2.483	2.364	4.791	13.550	64.644	12.538	12.037	2.197
4.0-B	62.50	10.16	506.71	1178.90	694.10	1193.90	499.80	2.359	1146.00	6762.00	7445.83	2.480	2.359	4.875	13.737	64.515	11.898	12.374	2.454
4.0-C	65.00	10.16	526.98	1178.10	693.10	1193.80	500.70	2.353	1178.00	6762.00	7464.23	2.476	2.353	4.971	13.951	64.368	12.091	11.607	2.756
Average	64.17	10.16	520.22	1183.90	694.10	1196.07	501.97	2.359	1172.00	6762.00	7461.32	2.479	2.359	4.879	13.746	64.509	12.176	12.006	2.469
4.5-A	63.75	10.16	516.84	1172.20	689.00	1179.60	490.60	2.389	1169.00	6762.00	7459.34	2.478	2.389	3.597	13.074	72.485	12.853	12.853	2.854
4.5-B	63.00	10.16	510.76	1178.20	688.90	1180.80	491.90	2.395	1176.00	6762.00	7463.95	2.481	2.395	3.449	12.860	73.185	11.939	11.939	2.909
4.5-C	64.50	10.16	522.92	1189.60	698.10	1202.90	504.80	2.357	1189.00	6762.00	7464.87	2.446	2.357	3.650	14.265	74.414	12.601	12.097	2.960
Average	63.75	10.16	516.84	1180.00	692.00	1187.77	495.77	2.380	1178.00	6762.00	7462.72	2.468	2.380	3.565	13.400	73.361	12.464	12.296	2.908
5.0-A	63.50	10.16	514.81	1189.10	698.80	1194.90	496.10	2.397	1185.00	6762.00	7466.47	2.466	2.397	2.803	13.255	78.851	10.903	10.903	3.659
5.0-B	61.50	10.16	498.60	1172.60	685.50	1178.20	492.70	2.380	1164.00	6762.00	7451.00	2.451	2.380	2.880	13.869	79.232	11.300	11.752	3.229
5.0-C	64.00	10.16	518.87	1181.10	694.30	1188.70	494.40	2.389	1180.00	6762.00	7461.00	2.453	2.389	2.620	13.543	80.656	10.787	10.787	3.528
Average	63.00	10.16	510.76	1180.93	692.87	1187.27	494.40	2.389	1176.33	6762.00	7459.49	2.457	2.389	2.768	13.555	79.582	10.997	11.147	3.472
5.5-A	60.00	10.16	486.44	1163.50	681.30	1167.00	485.70	2.396	1159.00	6762.00	7448.50	2.453	2.396	2.340	13.762	82.996	9.058	9.873	4.366
5.5-B	60.00	10.16	486.44	1161.50	679.70	1165.90	486.20	2.389	1159.00	6762.00	7446.45	2.442	2.389	2.186	13.998	84.387	8.163	8.898	4.145
5.5-C	62.75	10.16	508.73	1149.80	675.50	1155.80	480.30	2.394	1140.00	6762.00	7438.00	2.457	2.394	2.563	13.819	81.451	9.404	9.780	4.446
Average	60.92	10.16	493.87	1158.27	678.83	1162.90	484.07	2.393	1152.67	6762.00	7444.32	2.451	2.393	2.363	12.594	81.238	8.875	9.517	4.319

APPENDIX I

Worksheet for Volumetric Analysis of Compacted Paving Mixture

(Analysis by Weight of Total Mixture)

Project: FAZAL HAQ (MS THESIS)

Sample: Controlled sample (**0% RAP**) Date:03/08/2016

Identification: Margalla Aggregate & ARL 60/70 Bitumen.

Composition of Paving Mixture

	Specific Gravity, G			Mix Composition, % by Wt. of Total Mix, P					
			Bulk		Mix or Trial Number				
					1	2	3	4	5
1. Coarse Aggregate	G1		2.632	P1	48.250	48.000	47.750	47.500	47.250
2. Fine Aggregate	G2		2.618	P2	48.250	48.000	47.750	47.500	47.250
3. Mineral Filler	G3		…….	P3	5.308	5.280	5.253	5.225	5.198
4. Total Aggregate	Gs	---	2.625	Ps	96.50	96.00	95.50	95.00	94.50
5. Asphalt Cement	Gb	1.03	-----	Pb	3.50	4.00	4.50	5.00	5.50
6. Bulk Sp. Gr. (Gsb), total aggregate					2.625	2.625	2.625	2.625	2.625
7. Max. Sp. Gr. (Gmm), paving mix					2.493	2.479	2.468	2.457	2.451
8. Bulk Sp. Gr. (Gmb), compacted mix					2.325	2.358	2.380	2.389	2.393
9. Effective Sp. Gr. (Gse), total aggregate					2.628	2.633	2.642	2.650	2.665
10. Absorbed Asphalt (Pba), % by wt. total agg.					0.051	0.125	0.250	0.374	0.589
CALCULATIONS									
11. Effective Asphalt content (Pbe)					3.451	3.880	4.262	4.645	4.943
12. Voids in Mineral Aggregate, VMA (percent of bulk vol.)					14.528	13.764	13.413	13.540	13.851
13. Air Voids (Va)					6.739	4.881	3.566	2.768	2.366
14. Voids Filled with Aggregate, VFA					53.614	64.538	73.416	79.560	82.916
15.Dust to Asphalt ratio, DA					1.248	1.103	0.998	0.910	0.849

APPENDIX I

Marshall Test Report

Project: **FAZAL HAQ (MS THESIS)** Trial Mix: **15% RAP**

Aggregate Source: Margalla Bitumen: ARL 60/70

Date:05/08/2016

				Mass, grams of compacted Specimen					Mass, grams of loose Mix								Stability, (KN)		
% AC by wt. of mix, Spec. No.	Spec. Height in. (mm)	Dimeter in cm	Volume in cm3 V=πr2h	In Air (A)	In Water (C)	Sat. Surface Dry (B)	B-C	Bulk S.G. Specimen (Gmb) Gmb =A/(B-C)	Dry Weight (a)	Calibration Weight = wt: of Pycnometer+ Glass Lid + Water (b)	wt: of Sample + Water + Pycnometer and Lid (c)	Max. S.G. (loose Mix) (Gmm) =a/b-(c-a)	Unit Wt. (mg/cm3)	% Air Voids	% VMA	% VFA	Measured	Adjusted	Flow mm
3.5-A	64.00	10.16	518.87	1193.60	686.80	1206.70	519.90	2.296	1207.00	6762.00	7479.80	2.467	2.296	6.950	15.601	55.454	10.730	10.301	2.008
3.5-B	64.50	10.16	522.92	1177.50	687.10	1194.70	507.60	2.320	1172.20	6762.00	7464.00	2.493	2.320	6.949	14.722	52.797	10.047	10.951	1.800
3.5-C	64.75	10.16	524.95	1171.50	692.20	1191.50	499.30	2.346	1167.00	6762.00	7466.00	2.521	2.346	6.913	13.746	49.712	9.973	9.574	2.200
Average	64.42	10.16	522.25	1180.87	688.70	1197.63	508.93	2.321	1189.60	6762.00	7469.93	2.494	2.321	6.937	14.690	52.655	10.250	10.275	2.003
4.0-A	63.75	10.16	516.84	1190.00	690.40	1196.20	505.80	2.353	1191.00	6762.00	7474.10	2.487	2.353	5.398	13.958	61.328	12.104	11.620	2.357
4.0-B	63.25	10.16	512.79	1193.80	697.10	1200.10	503.00	2.373	1187.00	6762.00	7469.07	2.473	2.373	4.040	13.203	69.401	12.673	13.180	2.689
4.0-C	65.00	10.16	526.98	1192.80	696.00	1206.60	510.60	2.336	1191.00	6762.00	7471.00	2.471	2.336	5.459	14.566	62.526	11.880	11.405	2.306
Average	64.00	10.16	518.87	1192.20	694.50	1200.97	506.47	2.354	1189.67	6762.00	7471.39	2.477	2.354	4.965	13.909	64.419	12.219	12.068	2.451
4.5-A	61.00	10.16	494.55	1178.30	688.90	1178.80	489.90	2.405	1172.00	6762.00	7466.00	2.504	2.405	3.957	12.497	68.338	12.597	12.597	2.998
4.5-B	63.75	10.16	516.84	1204.60	694.50	1205.10	510.60	2.359	1201.00	6762.00	7474.00	2.456	2.359	3.943	14.171	72.173	12.780	12.780	2.893
4.5-C	63.50	10.16	514.81	1166.70	679.90	1172.50	492.60	2.368	1160.00	6762.00	7447.00	2.442	2.368	3.016	13.833	78.198	12.094	11.610	2.798
Average	62.75	10.16	508.73	1183.20	687.77	1185.47	497.70	2.378	1177.67	6762.00	7462.33	2.467	2.378	3.639	13.500	72.903	12.490	12.329	2.896
5.0-A	62.50	10.16	506.71	1184.60	686.30	1186.00	499.70	2.371	1179.00	6762.00	7458.30	2.443	2.371	2.943	14.206	79.282	11.871	11.871	3.438
5.0-B	63.00	10.16	510.76	1191.00	698.50	1191.90	493.40	2.414	1187.00	6762.00	7470.20	2.479	2.414	2.632	12.641	79.179	10.910	11.346	2.984
5.0-C	64.25	10.16	520.89	1182.20	683.80	1183.20	499.40	2.367	1172.00	6762.00	7454.50	2.444	2.367	3.149	14.328	78.022	11.056	11.056	3.240
Average	63.25	10.16	512.79	1185.93	689.53	1187.03	497.50	2.384	1179.33	6762.00	7461.00	2.455	2.384	2.907	13.725	78.821	11.279	11.424	3.221
5.5-A	60.00	10.16	486.44	1158.00	676.94	1161.80	484.86	2.388	1152.00	6762.00	7444.00	2.451	2.388	2.560	14.021	81.742	9.610	10.475	3.890
5.5-B	61.50	10.16	498.60	1190.40	695.58	1193.00	497.42	2.393	1181.00	6762.00	7460.90	2.450	2.393	2.308	13.847	83.328	9.373	10.217	3.901
5.5-C	62.50	10.16	506.71	1163.50	681.90	1169.70	487.80	2.385	1161.00	6762.00	7449.00	2.449	2.385	2.620	14.133	81.463	8.350	8.684	4.048
Average	61.33	10.16	497.25	1170.63	684.81	1174.83	490.03	2.389	1164.67	6762.00	7451.30	2.450	2.389	2.496	14.000	82.171	9.111	9.792	3.946

APPENDIX I

Worksheet for Volumetric Analysis of Compacted Paving Mixture

(Analysis by Weight of Total Mixture)

Project: FAZAL HAQ (MS THESIS)

Sample: **15% RAP** Date:08/08/2016

Identification: Margalla Aggregate &ARL 60/70 Bitumen.

Composition of Paving Mixture										
		Specific Gravity, G			Mix Composition, % by Wt. of Total Mix, P					
				Bulk		Mix or Trial Number				
						1	2	3	4	5
1. Coarse Aggregate		G1		2.632	P1	48.057	47.808	47.559	47.310	47.061
2. Fine Aggregate		G2		2.618	P2	48.443	48.192	47.941	47.690	47.439
3. Mineral Filler		G3		…….	P3	4.854	4.829	4.804	4.779	4.753
4. Total Aggregate		Gs	---	2.625	Ps	96.50	96.00	95.50	95.00	94.50
5. Asphalt Cement		Gb	1.03	-----	Pb	3.50	4.00	4.50	5.00	5.50
6. Bulk Sp. Gr. (Gsb), total aggregate						2.625	2.625	2.625	2.625	2.625
7. Max. Sp. Gr. (Gmm), paving mix						2.494	2.477	2.467	2.455	2.450
8. Bulk Sp. Gr. (Gmb), compacted mix						2.321	2.354	2.378	2.384	2.389
9. Effective Sp. Gr. (Gse), total aggregate						2.630	2.631	2.641	2.648	2.664
10. Absorbed Asphalt (Pba), % by wt. total agg.						0.069	0.090	0.232	0.339	0.571
CALCULATIONS										
11. Effective Asphalt content (Pbe)					3.434		3.913	4.278	4.678	4.960
12. Voids in Mineral Aggregate, VMA (percent of bulk vol.)					14.674		13.909	13.485	13.720	13.994
13. Air Voids (Va)					6.937		4.966	3.608	2.892	2.490
14. Voids Filled with Aggregate, VFA					52.729		64.300	73.246	78.921	82.209
15.Dust to Asphalt ratio, DA					1.122		0.978	0.889	0.808	0.757

APPENDIX I

Marshall Test Report

Project: **FAZAL HAQ (MS THESIS)** Trial Mix: **25 % RAP**

Aggregate Source: Margalla, ,Bitumen:ARL 60/70

Date: 12/08/2016

				Mass, grams of compacted Specimen					Mass, grams of loose Mix								Stability, (KN)		
% AC by wt. of mix, Spec. No.	Spec. Height in. (mm)	Dimeter in cm	Volume in cm3 V=πr2h	In Air (A)	In Water (C)	Sat. Surface Dry in Air (B)	B-C	Bulk S.G. Specimen (Gmb) Gmb =A/(B-C)	Dry Weight (a)	Calibration Weight = wt: of Pycnometer+ Glass Lid + Water (b)	wt: of Sample + Water + Pycnometer and Lid (c)	Max. S.G. (loose Mix) (Gmm) =a/b-(c-a)	Unit Wt., pcf (Mg/cm3)	% Air Voids	% VMA	% VFA	Measured	Adjusted	Flow mm
3.5-A	65.25	10.16	529.00	1176.10	688.60	1195.60	507.00	2.320	1186.00	6762.00	7471.90	2.491	2.320	6.879	14.723	53.279	10.900	10.464	2.010
3.5-B	65.13	10.16	527.99	1178.50	692.10	1198.15	506.05	2.329	1176.50	6762.00	7465.99	2.490	2.329	6.468	14.387	55.087	10.515	10.753	2.193
3.5-C	65.00	10.16	526.98	1180.90	695.60	1200.70	505.10	2.338	1167.00	6762.00	7460.08	2.489	2.338	6.057	14.052	56.896	10.130	11.042	2.376
Average	65.13	10.16	527.99	1178.50	692.10	1198.15	506.05	2.329	1176.50	6762.00	7465.99	2.490	2.329	6.468	14.387	55.087	10.515	10.753	2.193
4.0-A	63.50	10.16	514.81	1146.50	663.60	1152.80	489.20	2.344	1129.00	6762.00	7435.13	2.477	2.344	5.369	14.290	62.431	12.713	12.204	2.632
4.0-B	63.38	10.16	513.80	1158.75	675.40	1168.50	493.10	2.350	1148.50	6762.00	7445.87	2.472	2.350	4.936	14.062	64.94	12.47	12.46	2.69
4.0-C	63.25	10.16	512.79	1171.00	687.20	1184.20	497.00	2.356	1168.00	6762.00	7456.60	2.467	2.356	4.504	13.833	67.441	12.232	12.721	2.750
Average	63.38	10.16	513.80	1158.75	675.40	1168.50	493.10	2.350	1148.50	6762.00	7445.87	2.472	2.350	4.936	14.062	64.94	12.47	12.46	2.69
4.5-A	62.75	10.16	508.73	1183.65	688.95	1189.45	500.50	2.365	1177.00	6762.00	7460.15	2.458	2.365	3.784	13.961	72.89	12.97	12.97	2.99
4.5-B	63.00	10.16	510.76	1186.10	690.10	1191.80	501.70	2.364	1179.00	6762.00	7460.79	2.455	2.364	3.707	13.990	73.501	12.938	12.938	3.002
4.5-C	62.50	10.16	506.71	1181.20	687.80	1187.10	499.30	2.366	1175.00	6762.00	7459.50	2.461	2.366	3.861	13.933	72.286	13.010	13.010	2.986
Average	62.75	10.16	508.73	1183.65	688.95	1189.45	500.50	2.365	1177.00	6762.00	7460.15	2.458	2.365	3.784	13.961	72.89	12.97	12.97	2.99
5.0-A	62.75	10.16	508.73	1181.50	690.90	1187.00	496.10	2.382	1175.00	6762.00	7457.00	2.448	2.382	2.710	13.810	80.375	11.387	11.387	3.230
5.0-B	62.13	10.16	503.67	1177.85	687.85	1183.15	495.30	2.378	1174.00	6762.00	7457.80	2.455	2.378	3.136	13.937	77.53	11.21	11.43	3.27
5.0-C	61.50	10.16	498.60	1174.20	684.80	1179.30	494.50	2.375	1173.00	6762.00	7458.60	2.462	2.375	3.562	14.065	74.677	11.032	11.473	3.301
Average	62.13	10.16	503.67	1177.85	687.85	1183.15	495.30	2.378	1174.00	6762.00	7457.80	2.455	2.378	3.136	13.937	77.53	11.21	11.43	3.27
5.5-A	61.75	10.16	500.63	1181.10	690.00	1184.80	494.80	2.387	1170.00	6762.00	7455.90	2.457	2.387	2.866	14.067	79.623	9.603	10.467	3.761
5.5-B	61.75	10.16	500.63	1182.15	690.60	1186.30	495.70	2.385	1175.00	6762.00	7457.95	2.453	2.385	2.772	14.147	80.40	9.75	10.63	3.83
5.5-C	61.75	10.16	500.63	1183.20	691.20	1187.80	496.60	2.383	1180.00	6762.00	7460.00	2.448	2.383	2.677	14.226	81.184	9.901	10.792	3.891
Average	61.75	10.16	500.63	1182.15	690.60	1186.30	495.70	2.385	1175.00	6762.00	7457.95	2.453	2.385	2.772	14.147	80.40	9.75	10.63	3.83

APPENDIX I

Worksheet for Volumetric Analysis of Compacted Paving Mixture

(Analysis by Weight of Total Mixture)

Project: FAZAL HAQ (MS THESIS)

Sample: **25% RAP** Date: 15/08/2016

Identification: Margalla Aggregate &ARL 60/70 Bitumen.

Composition of Paving Mixture											
		Specific Gravity, G			Mix Composition, % by Wt. of Total Mix, P						
				Bulk		Mix or Trial Number					
						1	2	3	4	5	
1. Coarse Aggregate		G1		2.632	P1	47.461	47.215	46.969	46.723	46.477	
2. Fine Aggregate		G2		2.618	P2	49.039	48.785	48.531	48.277	48.023	
3. Mineral Filler		G3		…….	P3	5.134	5.107	5.081	5.054	5.027	
4. Total Aggregate		G4	---	2.625	Ps	96.50	96.00	95.50	95.00	94.50	
5. Asphalt Cement		G5	1.03	-----	Pb	3.50	4.00	4.50	5.00	5.50	
6. Bulk Sp. Gr. (Gsb), total aggregate						2.625	2.625	2.625	2.625	2.625	
7. Max. Sp. Gr. (Gmm), paving mix						2.490	2.472	2.458	2.455	2.453	
8. Bulk Sp. Gr. (Gmb), compacted mix						2.329	2.350	2.365	2.378	2.385	
9. Effective Sp. Gr. (Gse), total aggregate						2.625	2.625	2.630	2.648	2.667	
10. Absorbed Asphalt (Pba), % by wt. total agg.						0.001	0.004	0.074	0.340	0.627	
CALCULATIONS											
11. Effective Asphalt content (Pbe)						3.499	3.996	4.430	4.677	4.908	
12. Voids in Mineral Aggregate, VMA (percent of bulk vol.)						14.377	14.053	13.955	13.935	14.136	
13. Air Voids (Va)						6.466	4.935	3.784	3.136	2.772	
14. Voids Filled with Aggregate, VFA						55.027	64.880	72.887	77.492	80.389	
15.Dust to Asphalt ratio, DA						1.181	1.028	0.921	0.867	0.821	

APPENDIX I

Marshall Test Report

Project: **FAZAL HAQ (MS THESIS)** Trial Mix: **35% RAP**

Aggregate Source: Margalla, ,Bitumen:ARL 60/70

Date:20/08/2016

				Mass, grams of compacted Specimen					Mass, grams of loose Mix								Stability, (KN)		
% AC by wt. of mix, Spec. No.	Spec. Height in. (mm)	Dimeter in cm	Volume in cm3 V=πr2h	In Air (A)	In Water (C)	Sat. Surface Dry in Air (B)	B-C	Bulk S.G. Specimen (Gmb) Gmb =A/(B-C)	Dry Weight (a)	Calibration Weight = wt: of Pycnometer+ Glass Lid + Water (b)	wt: of Sample + Water + Pycnometer and Lid (c)	Max. S.G. (loose Mix) (Gmm) =a/b-(c-a)	Unit Wt., pcf (Mg/cm3)	% Air Voids	% VMA	% VFA	Measured	Adjusted	Flow mm
3.5-A	65.50	10.16	531.03	1187.90	693.60	1201.20	507.60	2.340	1179.40	6762.00	7468.00	2.491	2.340	6.065	13.969	56.578	10.980	10.541	1.921
3.5-B	65.00	10.16	526.98	1179.50	691.70	1200.10	508.40	2.320	1187.60	6762.00	7475.51	2.505	2.320	7.385	14.712	49.804	10.370	11.303	2.197
3.5-C	65.25	10.16	529.00	1183.70	692.65	1200.65	508.00	2.330	1183.50	6762.00	7471.76	2.498	2.330	6.725	14.340	53.191	10.675	10.922	2.059
Average	65.25	10.16	529.00	1183.70	692.65	1200.65	508.00	2.330	1183.50	6762.00	7471.76	2.498	2.330	6.725	14.340	53.191	10.675	10.922	2.059
4.0-A	65.00	10.16	526.98	1174.60	691.40	1196.90	505.50	2.324	1173.80	6762.00	7455.16	2.442	2.324	4.853	15.021	67.692	12.847	12.333	2.430
4.0-B	64.88	10.16	525.96	1175.05	695.15	1192.55	497.40	2.363	1175.25	6762.00	7463.82	2.483	2.363	4.833	13.581	64.03	12.760	12.76	2.52
4.0-C	64.75	10.16	524.95	1175.50	698.90	1188.20	489.30	2.402	1176.70	6762.00	7472.47	2.524	2.402	4.812	12.140	60.363	12.672	13.179	2.614
Average	64.88	10.16	525.96	1175.05	695.15	1192.55	497.40	2.363	1175.25	6762.00	7463.82	2.483	2.363	4.833	13.581	64.03	12.760	12.76	2.52
4.5-A	63.13	10.16	511.77	1180.60	687.95	1185.60	497.65	2.373	1172.45	6762.00	7460.08	2.472	2.373	4.009	13.682	70.73	13.124	13.12	2.90
4.5-B	63.00	10.16	510.76	1175.60	681.80	1173.00	491.20	2.393	1171.40	6762.00	7462.15	2.486	2.393	3.717	12.929	71.246	13.250	13.250	2.983
4.5-C	63.25	10.16	512.79	1185.60	694.10	1198.20	504.10	2.352	1173.50	6762.00	7458.00	2.458	2.352	4.300	14.435	70.211	12.997	12.997	2.809
Average	63.13	10.16	511.77	1180.60	687.95	1185.60	497.65	2.373	1172.45	6762.00	7460.08	2.472	2.373	4.009	13.682	70.73	13.124	13.12	2.90
5.0-A	64.00	10.16	518.87	1205.40	699.00	1205.20	506.20	2.381	1197.90	6762.00	7470.64	2.448	2.381	2.741	13.821	80.165	11.870	11.870	3.105
5.0-B	63.75	10.16	516.84	1197.45	694.00	1196.40	502.40	2.383	1183.95	6762.00	7463.38	2.453	2.383	2.854	13.741	79.23	11.720	11.95	3.20
5.0-C	63.50	10.16	514.81	1189.50	689.00	1187.60	498.60	2.386	1170.00	6762.00	7456.12	2.459	2.386	2.966	13.661	78.288	11.569	12.032	3.286
Average	63.75	10.16	516.84	1197.45	694.00	1196.40	502.40	2.383	1183.95	6762.00	7463.38	2.453	2.383	2.854	13.741	79.23	11.720	11.95	3.20
5.5-A	63.25	10.16	512.79	1178.80	689.00	1183.80	494.80	2.382	1167.60	6762.00	7449.31	2.431	2.382	2.001	14.234	85.940	9.447	10.297	3.682
5.5-B	63.13	10.16	511.77	1177.30	689.20	1179.90	490.70	2.399	1157.20	6762.00	7447.76	2.455	2.399	2.256	13.628	83.444	10.208	11.127	3.591
5.5-C	63.19	10.16	512.28	1178.05	689.10	1181.85	492.75	2.391	1162.40	6762.00	7448.54	2.443	2.391	2.129	13.931	84.69	9.828	10.71	3.64
Average	63.19	10.16	512.28	1178.05	689.10	1181.85	492.75	2.391	1162.40	6762.00	7448.54	2.443	2.391	2.129	13.931	84.69	9.828	10.71	3.64

APPENDIX I

Worksheet for Volumetric Analysis of Compacted Paving Mixture

(Analysis by Weight of Total Mixture)

Project: FAZAL HAQ (MS THESIS)

Sample: **35% RAP** Date: 20/08/2016

Identification: Margalla Aggregate &ARL 60/70 Bitumen.

Composition of Paving Mixture

		Specific Gravity, G			Mix Composition, % by Wt. of Total Mix, P					
				Bulk		Mix or Trial Number				
						1	2	3	4	5
1. Coarse Aggregate		G1		2.632	P1	47.285	47.040	46.795	46.550	46.305
2. Fine Aggregate		G2		2.618	P2	49.215	48.960	48.705	48.450	48.195
3. Mineral Filler		G3		…….	P3	5.336	5.309	5.281	5.254	5.226
4. Total Aggregate		G4	---	2.625	Ps	96.50	96.00	95.50	95.00	94.50
5. Asphalt Cement		G5	1.03	-----	Pb	3.50	4.00	4.50	5.00	5.50
6. Bulk Sp. Gr. (Gsb), total aggregate						2.625	2.625	2.625	2.625	2.625
7. Max. Sp. Gr. (Gmm), paving mix						2.498	2.483	2.472	2.453	2.443
8. Bulk Sp. Gr. (Gmb), compacted mix						2.330	2.363	2.373	2.383	2.391
9. Effective Sp. Gr. (Gse), total aggregate						2.634	2.638	2.647	2.645	2.655
10. Absorbed Asphalt (Pba), % by wt. total agg.						0.139	0.197	0.322	0.304	0.445
CALCULATIONS										
11. Effective Asphalt content (Pbe)					3.366		3.811	4.192	4.711	5.079
12. Voids in Mineral Aggregate, VMA (percent of bulk vol.)					14.340		13.576	13.663	13.753	13.919
13. Air Voids (Va)					6.725		4.833	4.005	2.854	2.129
14. Voids Filled with Aggregate, VFA					53.099		64.403	70.688	79.251	84.708
15.Dust to Asphalt ratio, DA					1.288		1.131	1.021	0.903	0.832

APPENDIX I

Marshall Test Report

Project: **FAZAL HAQ (MS THESIS)** Trial Mix: **50 % RAP**

Aggregate Source: Margalla, Bitumen:ARL 60/70

Date:21/08/2016

				Mass, grams of compacted Specimen					Mass, grams of loose Mix								Stability, (KN)		
% AC by wt. of mix, Spec. No.	Spec. Height in. (mm)	Dimeter in cm	Volume in cm3 V=πr2h	In Air (A)	In Water (C)	Sat. Surface Dry in Air (B)	B-C	Bulk S.G. Specimen (Gmb) Gmb =A/(B-C)	Dry Weight (a)	Calibration Weight = wt: of Pycnometer+ Glass Lid + Water (b)	wt: of Sample + Water + Pycnometer and Lid (c)	Max. S.G. (loose Mix) (Gmm) =a/b-(c-a)	Unit Wt., pcf (Mg/cm3)	% Air Voids	% VMA	% VFA	Measured	Adjusted	Flow mm
3.5-A	66.50	10.16	539.13	1189.70	693.50	1204.00	510.50	2.330	1183.00	6762.00	7470.00	2.491	2.330	6.427	14.328	55.143	11.301	10.849	1.830
3.5-B	67.13	10.16	544.20	1193.05	695.00	1206.65	511.65	2.332	1190.00	6762.00	7474.24	2.491	2.332	6.384	14.280	55.291	11.142	11.410	1.962
3.5-C	67.75	10.16	549.27	1196.40	696.50	1209.30	512.80	2.333	1197.00	6762.00	7478.48	2.491	2.333	6.342	14.232	55.439	10.982	11.970	2.093
Average	67.13	10.16	544.20	1193.05	695.00	1206.65	511.65	2.332	1190.00	6762.000	7474.24	2.491	2.332	6.384	14.280	55.291	11.142	11.410	1.962
4.0-A	65.25	10.16	529.00	1192.80	688.70	1198.30	509.60	2.341	1181.00	6762.00	7466.00	2.476	2.341	5.462	14.399	62.067	12.956	12.438	2.263
4.0-B	65.38	10.16	530.02	1193.85	691.90	1200.15	508.25	2.349	1180.50	6762.00	7465.14	2.473	2.349	5.013	14.10	64.48	12.915	12.91	2.362
4.0-C	65.50	10.16	531.02	1194.90	695.10	1202.00	506.90	2.357	1180.00	6762.00	7464.27	2.470	2.357	4.565	13.791	66.903	12.873	13.388	2.460
Average	65.38	10.16	530.02	1193.85	691.90	1200.15	508.25	2.349	1180.50	6762.00	7465.14	2.473	2.349	5.013	14.10	64.48	12.915	12.91	2.362
4.5-A	64.50	10.16	522.92	1184.20	688.90	1190.00	501.10	2.363	1190.30	6762.00	7471.79	2.477	2.363	4.600	14.024	67.198	13.406	13.406	2.840
4.5-B	65.13	10.16	527.99	1193.45	694.35	1198.05	503.70	2.369	1186.90	6762.00	7468.65	2.471	2.369	4.128	13.80	70.13	13.304	13.30	2.816
4.5-C	65.75	10.16	533.05	1202.70	699.80	1206.10	506.30	2.375	1183.50	6762.00	7465.50	2.466	2.375	3.657	13.578	73.071	13.201	13.201	2.792
Average	65.13	10.16	527.99	1193.45	694.35	1198.05	503.70	2.369	1186.90	6762.00	7468.65	2.471	2.369	4.128	13.80	70.13	13.304	13.30	2.816
5.0-A	62.50	10.16	506.77	1180.90	687.90	1183.10	495.20	2.385	1186.00	6762.00	7466.00	2.461	2.385	3.084	13.697	77.483	12.030	12.030	3.050
5.0-B	62.88	10.16	509.75	1183.75	689.40	1186.60	497.20	2.381	1182.00	6762.00	7464.45	2.465	2.381	3.407	13.84	75.40	11.982	12.22	3.035
5.0-C	63.25	10.16	512.78	1186.60	690.90	1190.10	499.20	2.377	1178.00	6762.00	7462.90	2.469	2.377	3.729	13.975	73.314	11.934	12.411	3.020
Average	62.88	10.16	509.75	1183.75	689.40	1186.60	497.20	2.381	1182.00	6762.00	7464.45	2.465	2.381	3.407	13.84	75.40	11.982	12.22	3.035
5.5-A	65.00	10.16	526.97	1196.00	698.70	1198.00	499.30	2.395	1200.90	6762.00	7474.00	2.456	2.395	2.482	13.767	81.969	9.702	10.575	3.291
5.5-B	63.38	10.16	513.80	1187.50	692.95	1189.25	496.30	2.393	1195.55	6762.00	7470.10	2.453	2.393	2.444	13.86	82.37	9.841	10.73	3.270
5.5-C	61.75	10.16	500.62	1179.00	687.20	1180.50	493.30	2.390	1190.20	6762.00	7466.19	2.449	2.390	2.405	13.959	82.772	9.980	10.878	3.249
Average	63.38	10.16	513.80	1187.50	692.95	1189.25	496.30	2.393	1195.55	6762.00	7470.10	2.453	2.393	2.444	13.86	82.37	9.841	10.73	3.270

APPENDIX I

Worksheet for Volumetric Analysis of Compacted Paving Mixture

(Analysis by Weight of Total Mixture)

Project: **FAZAL HAQ (MS THESIS**)

Sample: **50% RAP** Date: 23/08/2016

Identification: Margalla Aggregate &ARL 60/70 Bitumen.

Composition of Paving Mixture

		Specific Gravity, G			Mix Composition, % by Wt. of Total Mix, P					
				Bulk		Mix or Trial Number				
						1	2	3	4	5
1. Coarse Aggregate		G1		2.632	P1	46.870	46.627	46.384	46.142	45.899
2. Fine Aggregate		G2		2.618	P2	49.630	49.373	49.116	48.859	48.601
3. Mineral Filler		G3		…….	P3	6.119	6.087	6.056	6.024	5.992
4. Total Aggregate		G4	---	2.625	Ps	96.50	96.00	95.50	95.00	94.50
5. Asphalt Cement		G5	1.03	-----	Pb	3.50	4.00	4.50	5.00	5.50
6. Bulk Sp. Gr. (Gsb), total aggregate						2.625	2.625	2.625	2.625	2.625
7. Max. Sp. Gr. (Gmm), paving mix						2.491	2.473	2.471	2.465	2.453
8. Bulk Sp. Gr. (Gmb), compacted mix						2.332	2.349	2.369	2.381	2.393
9. Effective Sp. Gr. (Gse), total aggregate						2.626	2.626	2.645	2.660	2.667
10. Absorbed Asphalt (Pba), % by wt. total agg.						0.020	0.023	0.306	0.520	0.628
CALCULATIONS										
11. Effective Asphalt content (Pbe)						3.481	3.978	4.208	4.506	4.906
12. Voids in Mineral Aggregate, VMA (percent of bulk vol.)						14.264	14.087	13.806	13.823	13.845
13. Air Voids (Va)						6.383	5.014	4.128	3.408	2.446
14. Voids Filled with Aggregate, VFA						55.251	64.405	70.102	75.348	82.333
15.Dust to Asphalt ratio, DA						1.471	1.279	1.201	1.115	1.018

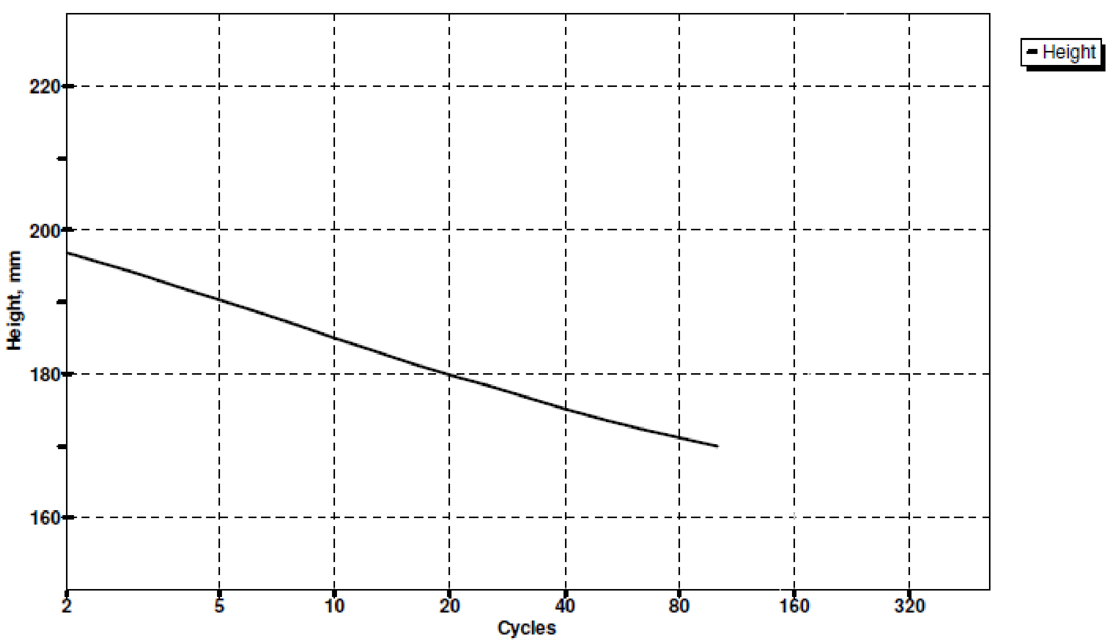
APPENDIX II: GYRATORY COMPACTOR SAMPLE RESULTS

APPENDIX II

INTENSIVE COMPACTION TESTING / ICT-150
PRINTED 02.01.2017 FROM FILE 10.txt

20.09.2016		SAMPLE WEIGHT	5000 g
12:20		PRESSURE IN SAMPLE	600 kPa
TEST-ID	2	GYRATORY ANGLE	22.00 mrad
SAMPLE CODE	10	GYRATORY SPEED	26.1 rpm

CYCL	HEIGHT mm	DENSITY kg/m3	SHEAR kN/m2
4	192.0	1474	
5	190.3	1487	
6	188.9	1498	
8	186.7	1516	
10	185.0	1530	
12	183.6	1541	
16	181.5	1559	
20	179.9	1573	
25	178.4	1586	
32	176.7	1602	
40	175.2	1615	
50	173.7	1629	
64	172.3	1643	
80	171.1	1654	
100	169.9	1665	
125	168.9	1675	

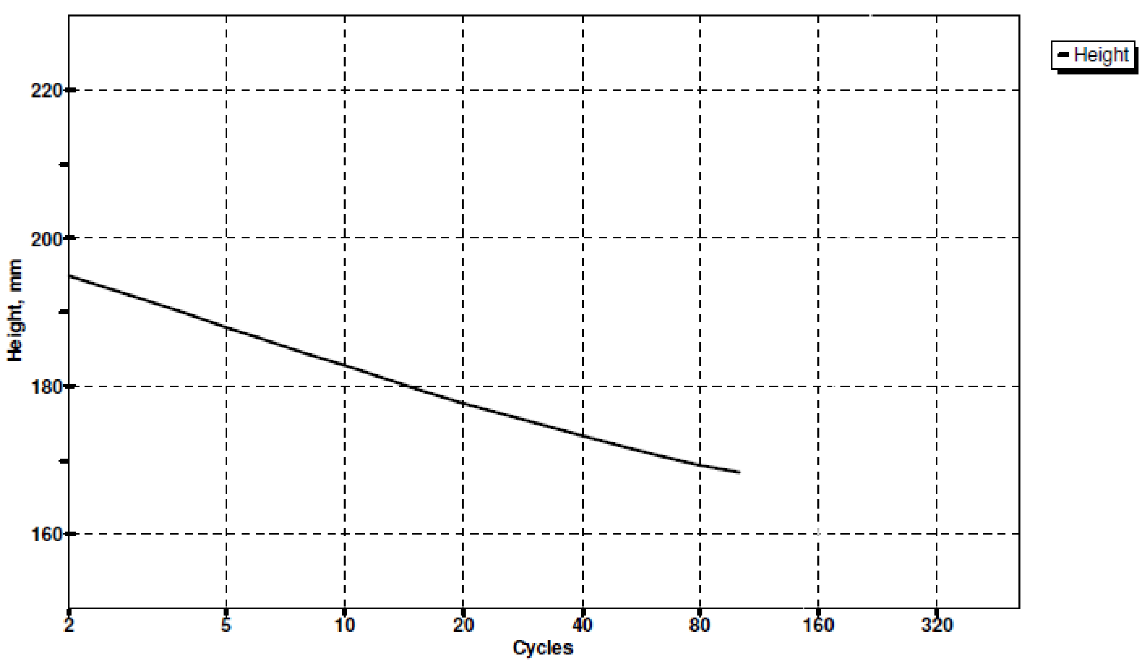


APPENDIX II

INTENSIVE COMPACTION TESTING / ICT-150
PRINTED 02.01.2017 FROM FILE Copy of 51.txt

04.10.2016		SAMPLE WEIGHT	5000 g
12:28		PRESSURE IN SAMPLE	600 kPa
TEST-ID	51	GYRATORY ANGLE	22.00 mrad
SAMPLE CODE	51	GYRATORY SPEED	26.1 rpm

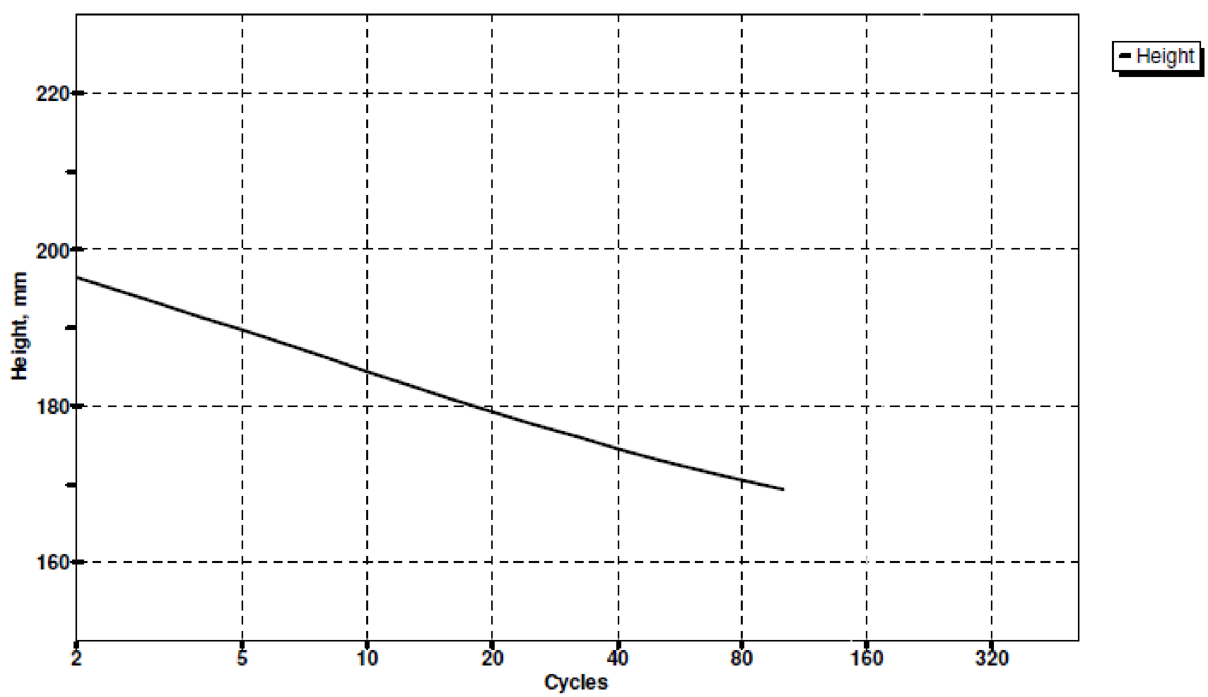
CYCL	HEIGHT mm	DENSITY kg/m3	SHEAR kN/m2
4	189.7	1492	
5	188.0	1505	
6	186.6	1516	
8	184.4	1534	
10	182.7	1549	
12	181.4	1560	
16	179.3	1578	
20	177.7	1592	
25	176.2	1606	
32	174.6	1621	
40	173.3	1633	
50	172.0	1645	
64	170.6	1659	
80	169.4	1671	
100	168.3	1681	
125	167.3	1691	



INTENSIVE COMPACTION TESTING / ICT-150
PRINTED 02.01.2017 FROM FILE 80.txt

14.10.2016		SAMPLE WEIGHT	5000 g
12:48		PRESSURE IN SAMPLE	600 kPa
TEST-ID	4	GYRATORY ANGLE	22.00 mrad
SAMPLE CODE	80	GYRATORY SPEED	26.1 rpm

CYCL	HEIGHT mm	DENSITY kg/m3	SHEAR kN/m2
4	191.4	1479	
5	189.7	1492	
6	188.3	1503	
8	186.1	1520	
10	184.4	1534	
12	183.1	1546	
16	180.9	1564	
20	179.3	1578	
25	177.8	1592	
32	176.1	1607	
40	174.6	1621	
50	173.2	1634	
64	171.8	1647	
80	170.6	1659	
100	169.4	1670	
125	168.4	1680	



APPENDIX III: WHEEL TRACKER TEST RESULT

WheelTracker Report

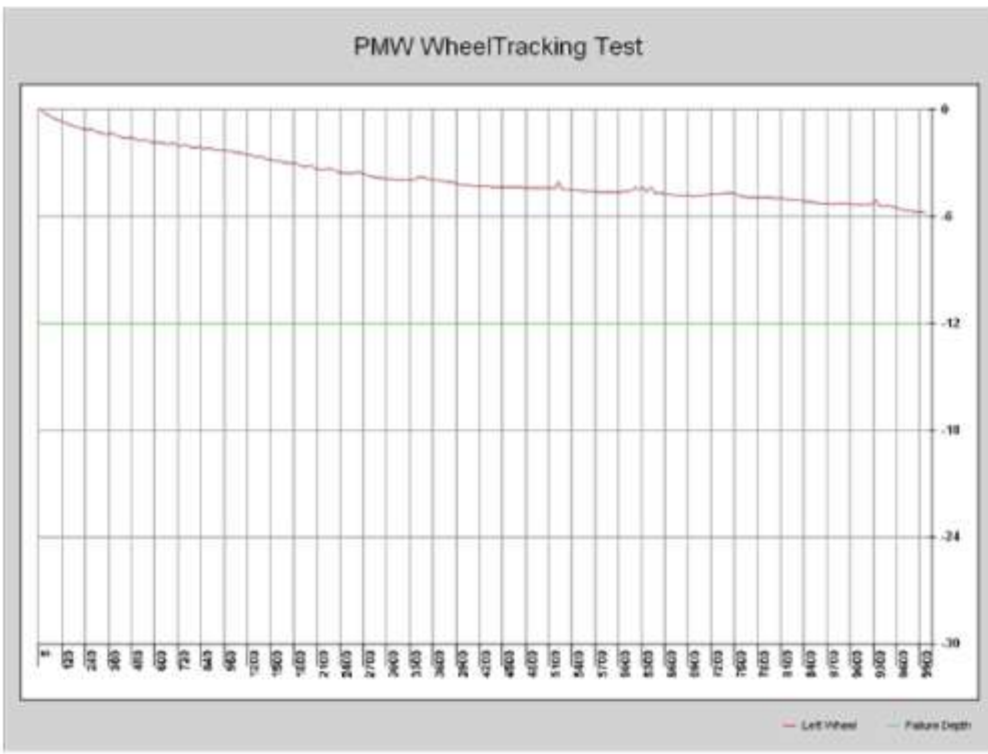
Project Name:	MS THESIS	Date:	29-SEP-2016
Project Number:	1	Date Sampled:	29-SEP-2016
Job Number:	1	Lab Number:	(RAP-0%,SASOBIT-0%))
Project Engineer:	FAZAL HAQ	Mix Type:	HMA
Submitted By:	FAZAL HAQ	Asphalt Grade:	ARL60/70
Temperature:	45	Pit Source:	LAB PREPARED
Comments:	Comments		

Left

Max Impression: -5.78 mm

Pass #: 9950 / Pt: 9

Fail Depth: 12.5mm PASSED



CC:

APPENDIX III

Pass #	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	Avg
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	-0.1473	-0.1372	-0.1270	-0.1626	-0.1727	-0.1880	-0.1778	-0.2235	-0.1981	-0.1524	-0.1676	-0.1686
40	-0.2591	-0.2692	-0.2591	-0.2997	-0.3048	-0.3353	-0.3251	-0.3658	-0.3454	-0.2743	-0.3048	-0.3039
60	-0.3353	-0.3658	-0.3404	-0.3912	-0.4064	-0.4572	-0.4267	-0.4623	-0.4572	-0.3658	-0.4064	-0.4013
80	-0.4064	-0.4470	-0.4115	-0.4775	-0.5080	-0.5639	-0.5182	-0.5537	-0.5537	-0.4470	-0.5436	-0.4937
100	-0.4572	-0.5029	-0.4724	-0.5486	-0.5842	-0.6350	-0.5842	-0.6350	-0.6452	-0.5080	-0.6401	-0.5648
120	-0.4978	-0.5537	-0.5232	-0.6045	-0.6655	-0.6960	-0.6401	-0.7163	-0.7264	-0.5690	-0.6604	-0.6230
140	-0.5436	-0.6452	-0.5740	-0.6604	-0.7264	-0.7468	-0.7010	-0.7874	-0.8026	-0.8382	-0.7366	-0.7057
160	-0.5944	-0.6909	-0.6248	-0.7010	-0.7976	-0.8026	-0.7620	-0.8585	-0.8941	-0.8636	-0.8026	-0.7629
180	-0.6452	-0.7315	-0.6858	-0.7518	-0.8636	-0.8433	-0.8280	-0.9246	-0.9703	-0.8839	-0.8839	-0.8193
200	-0.6909	-0.7620	-0.7112	-0.7976	-0.9195	-0.9144	-0.9093	-0.8992	-1.0516	-0.8890	-0.9601	-0.8641
220	-0.6350	-0.7976	-0.7468	-0.8128	-0.8585	-0.9652	-0.9550	-0.9652	-1.1125	-0.8992	-1.0363	-0.8895
240	-0.6706	-0.8331	-0.7823	-0.8585	-0.9093	-1.0211	-0.9957	-1.0363	-1.1684	-0.9144	-1.1024	-0.9356
260	-0.7163	-0.8636	-0.8179	-0.9195	-0.9652	-1.0566	-1.0414	-1.1074	-1.1024	-0.9296	-1.1633	-0.9712
280	-0.7671	-0.8890	-0.8484	-0.9550	-1.0211	-1.0922	-1.0871	-1.1836	-1.1887	-0.9449	-1.1989	-1.0160
300	-0.8128	-0.9398	-0.8890	-0.9957	-1.0770	-1.1176	-1.1430	-1.2446	-1.2700	-1.2446	-1.1227	-1.0779
320	-0.8585	-0.9703	-0.9296	-1.0312	-1.1379	-1.1481	-1.2040	-1.3056	-1.3513	-1.2090	-1.2090	-1.1231
340	-0.9042	-0.9957	-0.9500	-1.0617	-1.0770	-1.1836	-1.2040	-1.3665	-1.4224	-1.1633	-1.2954	-1.1476
360	-0.8128	-1.0109	-0.9601	-1.0566	-1.1176	-1.2243	-1.2395	-1.3411	-1.3360	-1.1328	-1.3665	-1.1453
380	-0.8636	-1.0211	-0.9754	-1.0973	-1.1684	-1.2395	-1.2852	-1.3970	-1.4122	-1.1125	-1.3970	-1.1790
400	-0.9144	-1.0566	-1.0109	-1.1278	-1.2344	-1.2649	-1.3462	-1.4681	-1.5088	-1.1227	-1.2802	-1.2123
420	-0.9601	-1.0770	-1.0363	-1.1532	-1.2802	-1.2802	-1.3056	-1.5138	-1.5799	-1.3208	-1.3818	-1.2626
440	-0.8534	-1.0973	-1.0465	-1.1227	-1.2090	-1.3259	-1.3513	-1.4732	-1.6205	-1.2598	-1.4732	-1.2575
460	-0.9093	-1.1074	-1.0566	-1.1735	-1.2649	-1.3513	-1.4021	-1.5392	-1.5494	-1.2192	-1.5138	-1.2806
480	-0.9652	-1.1278	-1.0820	-1.2141	-1.3208	-1.3614	-1.4580	-1.6053	-1.6459	-1.2090	-1.3462	-1.3033
500	-1.0211	-1.1532	-1.1227	-1.2497	-1.3818	-1.3868	-1.5291	-1.6612	-1.7323	-1.4478	-1.4630	-1.3771
520	-0.9042	-1.1735	-1.1176	-1.1989	-1.3005	-1.4173	-1.4478	-1.6002	-1.7628	-1.3513	-1.5646	-1.3490
540	-0.9601	-1.1786	-1.1176	-1.2497	-1.3513	-1.4427	-1.5037	-1.6764	-1.6916	-1.2954	-1.6154	-1.3711
560	-1.0262	-1.1989	-1.1481	-1.2954	-1.4072	-1.4580	-1.5748	-1.7424	-1.7882	-1.2852	-1.4326	-1.3961
580	-1.0820	-1.2243	-1.1836	-1.3259	-1.4681	-1.4834	-1.6510	-1.7983	-1.8644	-1.5138	-1.5596	-1.4686
600	-0.9652	-1.2344	-1.1735	-1.2751	-1.3818	-1.5088	-1.5596	-1.7323	-1.8644	-1.3919	-1.6612	-1.4316
620	-1.0262	-1.2294	-1.1786	-1.3259	-1.4376	-1.5240	-1.6256	-1.8085	-1.8440	-1.3513	-1.6866	-1.4580
640	-1.0922	-1.2598	-1.2141	-1.3665	-1.4986	-1.5392	-1.6967	-1.8644	-1.9202	-1.6612	-1.5443	-1.5143
660	-0.9652	-1.2751	-1.2141	-1.2852	-1.4122	-1.5494	-1.6053	-1.7831	-1.9710	-1.5088	-1.6713	-1.4764
680	-1.0363	-1.2751	-1.2090	-1.3513	-1.4630	-1.5748	-1.6662	-1.8644	-1.8898	-1.4173	-1.7424	-1.4991
700	-1.1074	-1.2954	-1.2395	-1.3970	-1.5342	-1.6002	-1.7526	-1.9406	-1.9863	-1.3919	-1.5443	-1.5263
720	-1.1684	-1.3106	-1.2649	-1.4376	-1.5900	-1.5850	-1.6561	-2.0015	-2.0574	-1.6256	-1.6815	-1.5799
740	-1.0363	-1.3208	-1.2548	-1.3818	-1.5037	-1.6358	-1.7272	-1.9253	-1.9609	-1.5037	-1.7882	-1.5489
760	-1.1125	-1.3208	-1.2700	-1.4326	-1.5596	-1.6561	-1.7983	-2.0015	-2.0422	-1.4427	-1.8034	-1.5854
780	-1.1786	-1.3513	-1.3157	-1.4783	-1.6205	-1.6866	-1.8796	-2.0625	-2.1285	-1.7526	-1.6713	-1.6478
800	-1.0465	-1.3614	-1.2954	-1.3970	-1.5291	-1.6764	-1.7729	-1.9710	-2.1387	-1.5850	-1.8085	-1.5984
820	-1.1176	-1.3564	-1.3005	-1.4630	-1.5799	-1.7069	-1.8390	-2.0523	-2.0930	-1.5037	-1.8593	-1.6247
840	-1.1938	-1.3767	-1.3310	-1.5037	-1.6459	-1.7374	-1.9304	-2.1234	-2.1844	-1.8644	-1.6866	-1.6889

860	-1.2598	-1.3919	-1.3310	-1.4173	-1.5545	-1.7069	-1.8136	-2.0218	-2.2149	-1.6612	-1.8288	-1.6547
880	-1.1328	-1.3868	-1.3259	-1.4884	-1.6053	-1.7475	-1.8999	-2.1133	-2.1590	-1.5494	-1.9101	-1.6653
900	-1.2192	-1.4072	-1.3564	-1.5392	-1.6866	-1.7882	-1.9914	-2.1996	-2.2606	-1.9355	-1.7323	-1.7378
920	-1.3005	-1.4275	-1.3665	-1.4529	-1.5951	-1.7577	-1.8745	-2.0930	-2.2860	-1.6967	-1.8948	-1.7041
940	-1.1684	-1.4122	-1.3564	-1.5291	-1.6510	-1.8034	-1.9761	-2.1895	-2.2403	-1.5799	-1.9558	-1.7147
960	-1.2649	-1.4427	-1.3970	-1.5799	-1.7424	-1.8440	-2.0726	-2.2758	-2.3419	-1.8999	-1.8186	-1.7891
980	-1.1278	-1.4478	-1.3767	-1.5088	-1.6408	-1.8085	-1.9507	-2.1844	-2.3063	-1.6662	-1.9660	-1.7258
1000	-1.2294	-1.4326	-1.3970	-1.5900	-1.7170	-1.8542	-2.0625	-2.2911	-2.3470	-1.5900	-1.7577	-1.7517
1050	-1.3462	-1.4834	-1.4275	-1.5240	-1.6764	-1.8390	-1.9812	-2.2250	-2.4282	-1.7882	-1.9863	-1.7914
1100	-1.2497	-1.4783	-1.4427	-1.6510	-1.7729	-1.9304	-2.1438	-2.3876	-2.4486	-1.6612	-1.8186	-1.8168
1150	-1.3868	-1.5240	-1.4681	-1.5748	-1.7323	-1.9101	-2.0625	-2.3216	-2.5298	-1.8390	-2.0676	-1.8560
1200	-1.2903	-1.5138	-1.4834	-1.7018	-1.8339	-2.0015	-2.2454	-2.4994	-2.5603	-1.7120	-1.8948	-1.8851
1250	-1.1887	-1.5596	-1.4986	-1.6307	-1.7932	-1.9761	-2.1488	-2.4333	-2.6060	-1.8745	-2.1387	-1.8953
1300	-1.3462	-1.5697	-1.5342	-1.7678	-1.9050	-2.0777	-2.3520	-2.6111	-2.6822	-2.2809	-1.9863	-2.0103
1350	-1.2344	-1.5951	-1.5240	-1.6916	-1.8440	-2.0472	-2.2555	-2.5552	-2.6314	-1.8796	-2.2098	-1.9516
1400	-1.3970	-1.6053	-1.5748	-1.8136	-1.9812	-2.1590	-2.4689	-2.7229	-2.7889	-2.2454	-2.0828	-2.0763
1450	-1.3005	-1.6104	-1.5494	-1.7628	-1.9152	-2.1336	-2.3825	-2.6822	-2.7584	-1.8796	-2.2809	-2.0232
1500	-1.2141	-1.6358	-1.5748	-1.6916	-1.9050	-2.0980	-2.3114	-2.6314	-2.8346	-2.0574	-2.2403	-2.0177
1550	-1.4173	-1.6358	-1.6104	-1.8745	-2.0422	-2.2504	-2.5806	-2.8448	-2.9108	-2.3774	-2.1234	-2.1516
1600	-1.3360	-1.6459	-1.5799	-1.8186	-1.9863	-2.2250	-2.5095	-2.8296	-2.8854	-1.9355	-2.3470	-2.0999
1650	-1.5240	-1.6662	-1.6053	-1.7424	-1.9609	-2.1793	-2.4333	-2.7838	-2.9362	-2.0980	-2.3165	-2.1133
1700	-1.4630	-1.6764	-1.6510	-1.9304	-2.1336	-2.3724	-2.7280	-2.9870	-3.0378	-2.3673	-2.2250	-2.2338
1750	-1.3868	-1.6713	-1.6205	-1.8898	-2.0676	-2.3266	-2.6568	-2.9769	-3.0328	-1.9761	-2.4028	-2.1826
1800	-1.3056	-1.6967	-1.6358	-1.8136	-2.0320	-2.2911	-2.5806	-2.9413	-3.0277	-2.0980	-2.4181	-2.1673
1850	-1.5240	-1.7069	-1.6612	-1.9964	-2.0117	-2.4892	-2.5146	-3.1242	-3.1344	-2.2962	-2.3520	-2.2555
1900	-1.4580	-1.7018	-1.6662	-1.9660	-2.1692	-2.4536	-2.8296	-3.1344	-3.1902	-2.6162	-2.2403	-2.3114
1950	-1.3919	-1.7170	-1.6510	-1.9101	-2.1234	-2.4181	-2.7686	-3.1242	-3.1801	-2.0625	-2.5044	-2.2592
2000	-1.3259	-1.7323	-1.6713	-1.8491	-2.0980	-2.3774	-2.7076	-3.0988	-3.1242	-2.1844	-2.5095	-2.2435
2050	-1.5545	-1.7424	-1.6967	-2.0676	-2.3266	-2.3216	-3.0480	-3.2918	-3.2817	-2.3673	-2.4435	-2.3765
2100	-1.5037	-1.7424	-1.7170	-2.0371	-2.2606	-2.5705	-2.9870	-3.2868	-3.3477	-2.6162	-2.3520	-2.4019
2150	-1.4529	-1.7424	-1.7018	-1.9964	-2.2250	-2.5451	-2.9413	-3.2918	-3.3680	-2.1285	-2.2809	-2.3340
2200	-1.3919	-1.7577	-1.7018	-1.9456	-2.1895	-2.5044	-2.8804	-3.2715	-3.3579	-2.1946	-2.6010	-2.3451
2250	-1.3411	-1.7729	-1.7170	-1.8898	-2.1641	-2.4536	-2.8194	-3.2309	-3.3122	-2.3114	-2.5756	-2.3262
2300	-1.5850	-1.7780	-1.7374	-2.1336	-2.4181	-2.4130	-2.7737	-3.4544	-3.4442	-2.4587	-2.5298	-2.4296
2350	-1.5545	-1.7729	-1.7780	-2.1133	-2.3774	-2.7127	-3.1547	-3.4696	-3.5204	-2.6416	-2.4740	-2.5063
2400	-1.5088	-1.7678	-1.7526	-2.0777	-2.3317	-2.6822	-3.1140	-3.4646	-3.5509	-2.8550	-2.3978	-2.5003
2450	-1.4732	-1.7831	-1.7475	-2.0523	-2.3063	-2.6568	-3.0785	-3.4595	-3.5712	-2.2352	-2.3520	-2.4287
2500	-1.4326	-1.7983	-1.7475	-2.0168	-2.2860	-2.6416	-3.0480	-3.4544	-3.5712	-2.2860	-2.7026	-2.4532
2550	-1.4021	-1.8136	-1.7526	-1.9812	-2.2657	-2.6162	-3.0175	-3.4442	-3.5814	-2.3470	-2.7026	-2.4476
2600	-1.3665	-1.8237	-1.7678	-1.9558	-2.2555	-2.5959	-2.9769	-3.4290	-3.4849	-2.4282	-2.6975	-2.4347
2650	-1.6358	-1.8237	-1.7780	-1.9202	-2.2403	-2.5654	-2.9566	-3.4138	-3.5966	-2.5095	-2.6568	-2.4633
2700	-1.6205	-1.8288	-1.8694	-2.2200	-2.5400	-2.9007	-2.9261	-3.6982	-3.6779	-2.6162	-2.6264	-2.5931
2750	-1.6002	-1.8288	-1.8491	-2.2098	-2.5146	-2.8804	-3.3833	-3.7084	-3.7389	-2.7280	-2.5959	-2.6398
2800	-1.5900	-1.8288	-1.8440	-2.1996	-2.5095	-2.8905	-3.3782	-3.7287	-3.7795	-2.7991	-2.5857	-2.6485

2850	-1.5748	-1.8237	-1.8339	-2.1895	-2.4892	-2.8804	-3.3680	-3.7287	-3.8151	-2.9159	-2.5552	-2.6522
2900	-1.5596	-1.8237	-1.8288	-2.1793	-2.4740	-2.8651	-3.3528	-3.7389	-3.8405	-3.0175	-2.5349	-2.6559
2950	-1.5443	-1.8237	-1.8288	-2.1641	-2.4638	-2.8651	-3.3528	-3.7541	-3.8659	-2.3774	-2.5248	-2.5968
3000	-1.5392	-1.8237	-1.8288	-2.1692	-2.4638	-2.8753	-3.3528	-3.7694	-3.8913	-2.3978	-2.5146	-2.6023
3050	-1.5291	-1.8593	-1.8288	-2.1590	-2.4587	-2.8651	-3.3528	-3.7694	-3.9014	-2.4282	-2.8499	-2.6365
3100	-1.5088	-1.8694	-1.8288	-2.1387	-2.4384	-2.8550	-3.3223	-3.7643	-3.9167	-2.4587	-2.8600	-2.6328
3150	-1.4986	-1.8796	-1.8339	-2.1234	-2.4333	-2.8397	-3.3172	-3.7694	-3.9218	-2.4841	-2.8702	-2.6337
3200	-1.4834	-1.8796	-1.8390	-2.1133	-2.4232	-2.8448	-3.3122	-3.7694	-3.9370	-2.5044	-2.8804	-2.6351
3250	-1.4834	-1.8948	-1.8440	-2.1082	-2.4282	-2.8397	-3.3172	-3.7897	-3.9522	-2.5298	-2.8854	-2.6430
3300	-1.4681	-1.8948	-1.8440	-2.0980	-2.4232	-2.8245	-3.2969	-3.7897	-3.9624	-2.5705	-2.8854	-2.6416
3350	-1.4478	-1.8999	-1.8542	-2.0726	-2.4079	-2.8042	-3.2715	-3.7744	-3.9624	-2.6162	-2.8854	-2.6361
3400	-1.4326	-1.9050	-1.8593	-2.0625	-2.4028	-2.7991	-3.2664	-3.7744	-3.7897	-2.6518	-2.8804	-2.6204
3450	-1.4275	-1.9101	-1.8694	-2.0574	-2.4028	-2.7940	-3.2664	-3.7795	-3.8252	-2.6721	-2.8854	-2.6264
3500	-1.4275	-1.9202	-1.8745	-2.0574	-2.4079	-2.7991	-3.2715	-3.7948	-3.8659	-2.6975	-2.8956	-2.6374
3550	-1.7221	-1.9202	-1.8847	-2.0472	-2.4028	-2.7788	-3.2563	-3.7897	-3.9268	-2.7432	-2.8804	-2.6684
3600	-1.7120	-1.9202	-1.8898	-2.0371	-2.3927	-2.7788	-3.2563	-3.7897	-3.9726	-2.7838	-2.8753	-2.6735
3650	-1.7120	-1.9253	-1.8999	-2.3825	-2.3978	-2.7686	-3.2563	-3.7948	-4.0030	-2.8143	-2.8702	-2.7113
3700	-1.7120	-1.9253	-1.9050	-2.0371	-2.3927	-2.7686	-3.2563	-4.1300	-4.0284	-2.8346	-2.8753	-2.7150
3750	-1.7120	-1.9304	-1.9101	-2.3876	-2.4028	-2.7686	-3.2664	-3.8100	-4.0538	-2.8499	-2.8804	-2.7247
3800	-1.7120	-1.9304	-1.9152	-2.0371	-2.7737	-2.7686	-3.2715	-3.8252	-4.0792	-2.8753	-2.8804	-2.7335
3850	-1.6967	-1.9253	-1.9202	-2.3825	-2.7483	-2.7432	-3.2461	-4.1605	-4.1351	-2.9464	-2.8550	-2.7963
3900	-1.6815	-1.9253	-1.9863	-2.3673	-2.7280	-3.2106	-3.7897	-4.1605	-4.1758	-3.0175	-2.8296	-2.8974
3950	-1.6713	-1.9253	-1.9761	-2.3622	-2.7076	-3.2004	-3.7744	-4.1605	-4.2062	-3.0785	-2.8245	-2.8988
4000	-1.6612	-1.9202	-1.9660	-2.3470	-2.6873	-3.1852	-3.7643	-4.1605	-4.2418	-3.1496	-2.7991	-2.8984
4050	-1.6510	-1.9152	-1.9609	-2.3368	-2.6721	-3.1750	-3.7490	-4.1605	-4.2570	-3.2258	-2.7788	-2.8984
4100	-1.6358	-1.9152	-1.9609	-2.3266	-2.6518	-3.1648	-3.7389	-4.1707	-4.2723	-3.2969	-2.7584	-2.8993
4150	-1.6256	-1.9152	-1.9558	-2.3165	-2.6365	-3.1496	-3.7236	-4.1707	-4.2926	-3.3731	-2.7432	-2.9002
4200	-1.6104	-1.9507	-1.9456	-2.3012	-2.6162	-3.1293	-3.6982	-4.1554	-4.2977	-2.6060	-2.7229	-2.8212
4250	-1.6053	-1.8999	-1.9507	-2.3012	-2.6162	-3.1344	-3.7033	-4.1656	-4.3129	-2.6213	-2.7229	-2.8212
4300	-1.5951	-1.8948	-1.9558	-2.3012	-2.6162	-3.1344	-3.7033	-4.1707	-4.3180	-2.6416	-2.7229	-2.8231
4350	-1.5951	-1.8999	-1.9558	-2.3012	-2.6111	-3.1293	-3.7033	-4.1758	-4.3231	-2.6467	-2.7229	-2.8240
4400	-1.6002	-1.9558	-1.9609	-2.3114	-2.6162	-3.1445	-3.7186	-4.1910	-4.3383	-2.6518	-2.7280	-2.8379
4450	-1.5900	-1.9660	-1.9609	-2.3012	-2.6060	-3.1344	-3.7084	-4.1859	-4.3485	-2.6670	-2.7229	-2.8356
4500	-1.5850	-1.9710	-1.9660	-2.2962	-2.6010	-3.1242	-3.6982	-4.1910	-4.3536	-2.6822	-2.7127	-2.8346
4550	-1.5596	-1.9812	-1.9660	-2.2758	-2.5806	-3.0937	-3.6678	-4.1758	-4.3485	-2.7229	-3.1039	-2.8614
4600	-1.5596	-1.9812	-1.9710	-2.2708	-2.5857	-3.0937	-3.6728	-4.1859	-4.3586	-2.7229	-3.1090	-2.8647
4650	-1.5596	-1.9812	-1.9710	-2.2758	-2.5857	-3.1039	-3.6830	-4.1910	-4.3688	-2.7280	-3.1191	-2.8697
4700	-1.5646	-1.9914	-1.9761	-2.2809	-2.5857	-3.1140	-3.6881	-4.2012	-4.3790	-2.7381	-3.1191	-2.8762
4750	-1.5646	-1.9964	-1.9863	-2.2860	-2.5908	-3.1140	-3.6932	-4.2113	-4.3891	-2.7483	-3.1242	-2.8822
4800	-1.5646	-1.9964	-1.9863	-2.2911	-2.5908	-3.1140	-3.6932	-4.2113	-4.3942	-2.7534	-3.1293	-2.8841
4850	-1.5748	-2.0015	-1.9914	-2.2962	-2.6010	-3.1191	-3.7084	-4.2266	-4.4094	-2.7584	-3.1344	-2.8928
4900	-1.5748	-1.9964	-1.9964	-2.3012	-2.6060	-3.1344	-3.7236	-4.2367	-4.4247	-2.7686	-3.1445	-2.9007
4950	-1.5596	-2.0015	-1.9964	-2.2911	-2.5908	-3.1140	-3.7033	-4.2316	-4.4196	-2.7889	-3.1496	-2.8951
5000	-1.5494	-2.0066	-1.9964	-2.2758	-2.5806	-3.0937	-3.6830	-4.2164	-4.4145	-2.7991	-3.1445	-2.8873

5050	-1.5443	-2.0015	-1.9964	-2.2708	-2.5806	-3.0937	-3.6830	-4.2164	-4.4247	-2.8194	-3.1496	-2.8891
5100	-1.5392	-2.0066	-2.0015	-2.2758	-2.5806	-3.0937	-3.6881	-4.2266	-4.4298	-2.8346	-3.1496	-2.8933
5150	-1.5392	-2.0066	-2.0117	-2.2758	-2.5806	-3.0886	-3.6830	-4.2266	-4.4399	-2.8448	-3.1547	-2.8956
5200	-1.5392	-2.0117	-2.0168	-2.2758	-2.5857	-3.0937	-3.6932	-4.2418	-4.0437	-2.8499	-3.1598	-2.8647
5250	-1.5494	-2.0168	-2.0168	-2.2911	-2.5959	-3.1140	-3.7084	-4.2570	-4.4602	-2.8448	-3.1750	-2.9118
5300	-1.5596	-2.0218	-2.0269	-2.3063	-2.6060	-3.1394	-3.7440	-4.2824	-4.4856	-2.8397	-3.1801	-2.9265
5350	-1.5697	-2.0218	-2.0269	-2.3114	-2.6111	-3.1496	-3.7592	-4.2926	-4.5009	-2.8397	-3.1902	-2.9339
5400	-1.5646	-2.0269	-2.0371	-2.3165	-2.6162	-3.1496	-3.7592	-4.2926	-4.5009	-2.8448	-3.1953	-2.9367
5450	-1.5900	-2.0269	-2.0422	-2.3470	-2.6365	-3.2004	-3.8049	-4.3231	-4.5263	-2.8194	-3.2004	-2.9561
5500	-1.6053	-2.0320	-2.0523	-2.3673	-2.6568	-3.2360	-3.8456	-4.3536	-4.5568	-2.8143	-3.2055	-2.9750
5550	-1.6205	-2.0371	-2.0625	-2.3876	-2.6721	-3.2614	-3.8710	-4.3739	-4.5720	-2.7991	-3.2106	-2.9880
5600	-1.6256	-2.0422	-2.0676	-2.3927	-2.6772	-3.2664	-3.8862	-4.3891	-4.5872	-2.7991	-2.8245	-2.9598
5650	-1.6408	-2.0472	-2.0777	-2.4181	-2.7026	-3.3020	-3.9319	-4.4196	-4.6076	-2.7940	-3.2207	-3.0147
5700	-1.6561	-2.0472	-2.0980	-2.4435	-2.7280	-3.3376	-3.9624	-4.4450	-4.6228	-2.7788	-2.8804	-3.0000
5750	-1.6713	-2.0472	-2.1082	-2.4587	-2.7483	-3.3680	-3.9980	-4.4653	-4.6279	-2.7737	-2.9058	-3.0157
5800	-1.6866	-1.9914	-2.1234	-2.4740	-2.7788	-3.4036	-4.0386	-4.4958	-4.6431	-3.5712	-2.9413	-3.1043
5850	-1.7069	-1.9964	-2.1387	-2.4841	-2.8042	-3.4392	-4.0691	-4.5212	-4.6431	-3.5103	-2.9718	-3.1168
5900	-1.7272	-2.0066	-2.1539	-2.4994	-2.8346	-3.4696	-4.1046	-4.5415	-4.6380	-3.4290	-3.0074	-3.1284
5950	-1.7595	-2.0389	-2.1863	-2.5317	-2.8670	-3.5020	-4.1370	-4.5739	-4.6704	-3.4613	-3.0397	-3.1607
6000	-1.7919	-2.0713	-2.2186	-2.5640	-2.8993	-3.5343	-4.1693	-4.6062	-4.7027	-3.4937	-3.0720	-3.1930
6050	-1.8242	-2.1036	-2.2509	-2.5964	-2.9317	-3.5667	-4.2017	-4.6385	-4.7351	-3.5260	-3.1044	-3.2254
6100	-1.8565	-2.1359	-2.2833	-2.6287	-2.9640	-3.5990	-4.2340	-4.6709	-4.7674	-3.5583	-3.1367	-3.2577
6150	-1.8889	-2.1683	-2.3156	-2.6610	-2.9963	-3.6313	-4.2663	-4.7032	-4.7997	-3.5907	-3.1690	-3.2900
6200	-1.9212	-2.2006	-2.3479	-2.6934	-3.0287	-3.6637	-4.2987	-4.7355	-4.8321	-3.6230	-3.2014	-3.3224
6250	-1.9536	-2.2330	-2.3803	-2.7257	-3.0610	-3.6960	-4.3310	-4.7679	-4.8644	-3.6554	-3.2337	-3.3547
6300	-1.9859	-2.2653	-2.4126	-2.7581	-3.0933	-3.7283	-4.3633	-4.8002	-4.8967	-3.6877	-3.2661	-3.3871
6350	-2.0182	-2.2976	-2.4450	-2.7904	-3.1257	-3.7607	-4.3957	-4.8326	-4.9291	-3.7200	-3.2984	-3.4194
6400	-2.0506	-2.3300	-2.4773	-2.8227	-3.1580	-3.7930	-4.4280	-4.8649	-4.9614	-3.7524	-3.3307	-3.4517
6450	-2.0829	-2.3623	-2.5096	-2.8551	-3.1903	-3.8253	-4.4603	-4.8972	-4.9937	-3.7847	-3.3631	-3.4841
6500	-2.1152	-2.3946	-2.5420	-2.8874	-3.2227	-3.8577	-4.4927	-4.9296	-5.0261	-3.8170	-3.3954	-3.5164
6550	-2.1476	-2.4270	-2.5743	-2.9197	-3.2550	-3.8900	-4.5250	-4.9619	-5.0584	-3.8494	-3.4277	-3.5487
6600	-2.1799	-2.4593	-2.6066	-2.9521	-3.2874	-3.9224	-4.5574	-4.9942	-5.0908	-3.8817	-3.4601	-3.5811
6650	-2.2123	-2.4917	-2.6390	-2.9844	-3.3197	-3.9547	-4.5897	-5.0266	-5.1231	-3.9141	-3.4924	-3.6134
6700	-2.2446	-2.5240	-2.6713	-3.0168	-3.3520	-3.9870	-4.6220	-5.0589	-5.1554	-3.9464	-3.5248	-3.6457
6750	-2.2769	-2.5563	-2.7037	-3.0491	-3.3844	-4.0194	-4.6544	-5.0913	-5.1878	-3.9787	-3.5571	-3.6781
6800	-2.3093	-2.5887	-2.7360	-3.0814	-3.4167	-4.0517	-4.6867	-5.1236	-5.2201	-4.0111	-3.5894	-3.7104
6850	-2.3416	-2.6210	-2.7683	-3.1138	-3.4490	-4.0840	-4.7190	-5.1559	-5.2524	-4.0434	-3.6218	-3.7428
6900	-2.3739	-2.6533	-2.8007	-3.1461	-3.4814	-4.1164	-4.7514	-5.1883	-5.2848	-4.0757	-3.6541	-3.7751
6950	-2.4063	-2.6857	-2.8330	-3.1784	-3.5137	-4.1487	-4.7837	-5.2206	-5.3171	-4.1081	-3.6864	-3.8074
7000	-2.4386	-2.7180	-2.8653	-3.2108	-3.5461	-4.1811	-4.8161	-5.2529	-5.3495	-4.1404	-3.7188	-3.8398
7050	-2.4710	-2.7504	-2.8977	-3.2431	-3.5784	-4.2134	-4.8484	-5.2853	-5.3818	-4.1728	-3.7511	-3.8721
7100	-2.5033	-2.7827	-2.9300	-3.2754	-3.6107	-4.2457	-4.8807	-5.3176	-5.4141	-4.2051	-3.7834	-3.9044
7150	-2.5356	-2.8150	-2.9623	-3.3078	-3.6431	-4.2781	-4.9131	-5.3499	-5.4465	-4.2374	-3.8158	-3.9368
7200	-2.5680	-2.8474	-2.9947	-3.3401	-3.6754	-4.3104	-4.9454	-5.3823	-5.4788	-4.2698	-3.8481	-3.9691

7250	-2.6003	-2.8797	-3.0270	-3.3725	-3.7077	-4.3427	-4.9777	-5.4146	-5.5111	-4.3021	-3.8805	-4.0015
7300	-2.6326	-2.9120	-3.0594	-3.4048	-3.7401	-4.3751	-5.0101	-5.4470	-5.5435	-4.3344	-3.9128	-4.0338
7350	-2.6650	-2.9444	-3.0917	-3.4371	-3.7724	-4.4074	-5.0424	-5.4793	-5.5758	-4.3668	-3.9451	-4.0661
7400	-2.6973	-2.9767	-3.1240	-3.4695	-3.8048	-4.4398	-5.0748	-5.5116	-5.6082	-4.3991	-3.9775	-4.0985
7450	-2.7296	-3.0090	-3.1564	-3.5018	-3.8371	-4.4721	-5.1071	-5.5440	-5.6405	-4.4314	-4.0098	-4.1308
7500	-2.7620	-3.0414	-3.1887	-3.5341	-3.8694	-4.5044	-5.1394	-5.5763	-5.6728	-4.4638	-4.0421	-4.1631
7550	-2.7943	-3.0737	-3.2210	-3.5665	-3.9018	-4.5368	-5.1718	-5.6086	-5.7052	-4.4961	-4.0745	-4.1955
7600	-2.8267	-3.1061	-3.2534	-3.5988	-3.9341	-4.5691	-5.2041	-5.6410	-5.7375	-4.5285	-4.1068	-4.2278
7650	-2.8590	-3.1384	-3.2857	-3.6312	-3.9664	-4.6014	-5.2364	-5.6733	-5.7698	-4.5608	-4.1392	-4.2602
7700	-2.8913	-3.1707	-3.3181	-3.6635	-3.9988	-4.6338	-5.2688	-5.7057	-5.8022	-4.5931	-4.1715	-4.2925
7750	-2.9237	-3.2031	-3.3504	-3.6958	-4.0311	-4.6661	-5.3011	-5.7380	-5.8345	-4.6255	-4.2038	-4.3248
7800	-2.9560	-3.2354	-3.3827	-3.7282	-4.0634	-4.6984	-5.3334	-5.7703	-5.8668	-4.6578	-4.2362	-4.3572
7850	-2.9883	-3.2677	-3.4151	-3.7605	-4.0958	-4.7308	-5.3658	-5.8027	-5.8992	-4.6901	-4.2685	-4.3895
7900	-3.0207	-3.3001	-3.4474	-3.7928	-4.1281	-4.7631	-5.3981	-5.8350	-5.9315	-4.7225	-4.3008	-4.4218
7950	-3.0530	-3.3324	-3.4797	-3.8252	-4.1605	-4.7955	-5.4305	-5.8673	-5.9639	-4.7548	-4.3332	-4.4542
8000	-3.0854	-3.3648	-3.5121	-3.8575	-4.1928	-4.8278	-5.4628	-5.8997	-5.9962	-4.7872	-4.3655	-4.4865
8050	-3.1177	-3.3971	-3.5444	-3.8899	-4.2251	-4.8601	-5.4951	-5.9320	-6.0285	-4.8195	-4.3979	-4.5189
8100	-3.1500	-3.4294	-3.5768	-3.9222	-4.2575	-4.8925	-5.5275	-5.9644	-6.0609	-4.8518	-4.4302	-4.5512
8150	-3.1824	-3.4618	-3.6091	-3.9545	-4.2898	-4.9248	-5.5598	-5.9967	-6.0932	-4.8842	-4.4625	-4.5835
8200	-3.2147	-3.4941	-3.6414	-3.9869	-4.3221	-4.9571	-5.5921	-6.0290	-6.1255	-4.9165	-4.4949	-4.6159
8250	-3.2470	-3.5264	-3.6738	-4.0192	-4.3545	-4.9895	-5.6245	-6.0614	-6.1579	-4.9488	-4.5272	-4.6482
8300	-3.2794	-3.5588	-3.7061	-4.0515	-4.3868	-5.0218	-5.6568	-6.0937	-6.1902	-4.9812	-4.5595	-4.6805
8350	-3.3117	-3.5911	-3.7384	-4.0839	-4.4192	-5.0542	-5.6892	-6.1260	-6.2226	-5.0135	-4.5919	-4.7129
8400	-3.3441	-3.6235	-3.7708	-4.1162	-4.4515	-5.0865	-5.7215	-6.1584	-6.2549	-5.0459	-4.6242	-4.7452
8450	-3.3764	-3.6558	-3.8031	-4.1486	-4.4838	-5.1188	-5.7538	-6.1907	-6.2872	-5.0782	-4.6566	-4.7775
8500	-3.4087	-3.6881	-3.8354	-4.1809	-4.5162	-5.1512	-5.7862	-6.2230	-6.3196	-5.1105	-4.6889	-4.8099
8550	-3.4411	-3.7205	-3.8678	-4.2132	-4.5485	-5.1835	-5.8185	-6.2554	-6.3519	-5.1429	-4.7212	-4.8422
8600	-3.4734	-3.7528	-3.9001	-4.2456	-4.5808	-5.2158	-5.8508	-6.2877	-6.3842	-5.1752	-4.7536	-4.8746
8650	-3.5057	-3.7851	-3.9325	-4.2779	-4.6132	-5.2482	-5.8832	-6.3201	-6.4166	-5.2075	-4.7859	-4.9069
8700	-3.5381	-3.8175	-3.9648	-4.3102	-4.6455	-5.2805	-5.9155	-6.3524	-6.4489	-5.2399	-4.8182	-4.9392
8750	-3.5704	-3.8498	-3.9971	-4.3426	-4.6779	-5.3129	-5.9479	-6.3847	-6.4813	-5.2722	-4.8506	-4.9716
8800	-3.6028	-3.8822	-4.0295	-4.3749	-4.7102	-5.3452	-5.9802	-6.4171	-6.5136	-5.3046	-4.8829	-5.0039
8850	-3.6351	-3.9145	-4.0618	-4.4072	-4.7425	-5.3775	-6.0125	-6.4494	-6.5459	-5.3369	-4.9152	-5.0362
8900	-3.6674	-3.9468	-4.0941	-4.4396	-4.7749	-5.4099	-6.0449	-6.4817	-6.5783	-5.3692	-4.9476	-5.0686
8950	-3.6998	-3.9792	-4.1265	-4.4719	-4.8072	-5.4422	-6.0772	-6.5141	-6.6106	-5.4016	-4.9799	-5.1009
9000	-3.7321	-4.0115	-4.1588	-4.5043	-4.8395	-5.4745	-6.1095	-6.5464	-6.6429	-5.4339	-5.0123	-5.1333
9050	-3.7644	-4.0438	-4.1912	-4.5366	-4.8719	-5.5069	-6.1419	-6.5788	-6.6753	-5.4662	-5.0446	-5.1656
9100	-3.7968	-4.0762	-4.2235	-4.5689	-4.9042	-5.5392	-6.1742	-6.6111	-6.7076	-5.4986	-5.0769	-5.1979
9150	-3.8291	-4.1085	-4.2558	-4.6013	-4.9366	-5.5716	-6.2066	-6.6434	-6.7400	-5.5309	-5.1093	-5.2303
9200	-3.8614	-4.1408	-4.2882	-4.6336	-4.9689	-5.6039	-6.2389	-6.6758	-6.7723	-5.5632	-5.1416	-5.2626
9250	-3.8938	-4.1732	-4.3205	-4.6659	-5.0012	-5.6362	-6.2712	-6.7081	-6.8046	-5.5956	-5.1739	-5.2949
9300	-3.9261	-4.2055	-4.3528	-4.6983	-5.0336	-5.6686	-6.3036	-6.7404	-6.8370	-5.6279	-5.2063	-5.3273
9350	-3.9585	-4.2379	-4.3852	-4.7306	-5.0659	-5.7009	-6.3359	-6.7728	-6.8693	-5.6603	-5.2386	-5.3596
9400	-3.9908	-4.2702	-4.4175	-4.7630	-5.0982	-5.7332	-6.3682	-6.8051	-6.9016	-5.6926	-5.2710	-5.3920

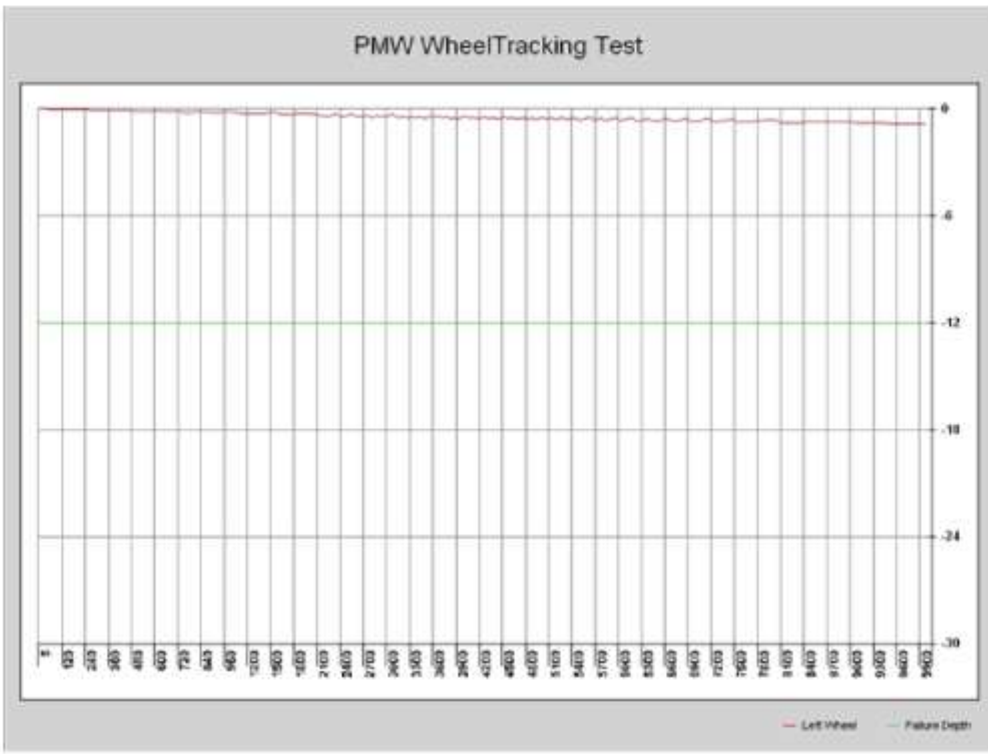
9450	-4.0231	-4.3025	-4.4499	-4.7953	-5.1306	-5.7656	-6.4006	-6.8375	-6.9340	-5.7249	-5.3033	-5.4243
9500	-4.0555	-4.3349	-4.4822	-4.8276	-5.1629	-5.7979	-6.4329	-6.8698	-6.9663	-5.7573	-5.3356	-5.4566
9550	-4.0878	-4.3672	-4.5145	-4.8600	-5.1952	-5.8302	-6.4652	-6.9021	-6.9986	-5.7896	-5.3680	-5.4890
9600	-4.1201	-4.3995	-4.5469	-4.8923	-5.2276	-5.8626	-6.4976	-6.9345	-7.0310	-5.8219	-5.4003	-5.4890
9650	-4.1525	-4.4319	-4.5792	-4.9246	-5.2599	-5.8949	-6.5299	-6.9668	-7.0633	-5.8543	-5.4326	-5.5213
9700	-4.1848	-4.4642	-4.6115	-4.9570	-5.2923	-5.9273	-6.5623	-6.9991	-7.0957	-5.8866	-5.4650	-5.5536
9750	-4.2172	-4.4966	-4.6439	-4.9893	-5.3246	-5.9596	-6.5946	-7.0315	-7.1280	-5.9190	-5.4973	-5.5860
9800	-4.2495	-4.5289	-4.6762	-5.0217	-5.3569	-5.9919	-6.6269	-7.0638	-7.1603	-5.9513	-5.5297	-5.6183
9850	-4.2818	-4.5612	-4.7086	-5.0540	-5.3893	-6.0243	-6.6593	-7.0962	-7.1927	-5.9836	-5.5620	-5.6507
9900	-4.3142	-4.5936	-4.7409	-5.0863	-5.4216	-6.0566	-6.6916	-7.1285	-7.2250	-6.0160	-5.5943	-5.6830
9950	-4.3465	-4.6259	-4.7732	-5.1187	-5.4539	-6.0889	-6.7239	-7.1608	-7.2573	-6.0483	-5.6267	-5.7153
10000	-4.3788	-4.6582	-4.8056	-5.1510	-5.4863	-6.1213	-6.9563	-7.3842	-7.2897	-6.0806	-5.6590	-5.7832

WheelTracker Report

Project Name:	MS THESIS	**Date:**	08,NOV,2016
Project Number:	39	**Date Sampled:**	08,NOV,2016
Job Number:	39	**Lab Number:**	50% RAP,3% SASOBIT
Project Engineer:	FAZAL HAQ	**Mix Type:**	WMA
Submitted By:	FAZAL HAQ	**Asphalt Grade:**	ARL60/70
Temperature:	45	**Pit Source:**	LAB PREPARED
Comments:	Comments		

Max Impression: Left: -0.85 mm
Pass #: 9600 / Pt: 9

Fail Depth: 12.5mm PASSED



CC:

Pass #	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	Avg
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0203	-0.0102	-0.0102	-0.0051	-0.0042
40	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0051	-0.0203	-0.0203	-0.0203	-0.0060
60	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0152	-0.0305	-0.0203	-0.0203	-0.0079
80	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0051	-0.0356	-0.0406	-0.0305	-0.0305	-0.0129
100	0.0000	0.0000	0.0000	0.0000	-0.0051	-0.0051	-0.0051	-0.0203	-0.0406	-0.0356	-0.0406	-0.0139
120	0.0000	0.0000	0.0000	0.0000	-0.0051	-0.0051	-0.0102	-0.0406	-0.0508	-0.0457	-0.0406	-0.0180
140	0.0000	0.0000	0.0000	0.0000	-0.0051	-0.0051	-0.0051	-0.0254	-0.0508	-0.0457	-0.0508	-0.0171
160	0.0000	0.0000	0.0000	0.0000	-0.0102	-0.0051	-0.0051	-0.0203	-0.0610	-0.0457	-0.0508	-0.0180
180	0.0000	0.0000	0.0000	-0.0051	-0.0102	-0.0051	-0.0051	-0.0508	-0.0660	-0.0559	-0.0508	-0.0226
200	0.0000	0.0000	0.0000	-0.0051	-0.0152	-0.0102	-0.0203	-0.0457	-0.0660	-0.0660	-0.0508	-0.0254
220	0.0000	0.0000	0.0000	-0.0051	-0.0203	-0.0102	-0.0152	-0.0406	-0.0660	-0.0559	-0.0660	-0.0254
240	0.0000	0.0000	0.0000	-0.0051	-0.0203	-0.0152	-0.0152	-0.0305	-0.0660	-0.0610	-0.0660	-0.0254
260	0.0000	-0.0051	-0.0051	-0.0102	-0.0254	-0.0203	-0.0203	-0.0305	-0.0914	-0.0711	-0.0711	-0.0319
280	0.0000	-0.0051	-0.0102	-0.0102	-0.0203	-0.0203	-0.0152	-0.0254	-0.0965	-0.0711	-0.0711	-0.0314
300	0.0000	-0.0051	-0.0102	-0.0203	-0.0254	-0.0203	-0.0203	-0.0762	-0.0965	-0.0762	-0.0711	-0.0383
320	0.0000	-0.0051	-0.0102	-0.0203	-0.0254	-0.0203	-0.0305	-0.0762	-0.1016	-0.0864	-0.0762	-0.0411
340	0.0000	-0.0051	-0.0152	-0.0203	-0.0254	-0.0203	-0.0305	-0.0762	-0.1067	-0.0914	-0.0813	-0.0429
360	0.0000	-0.0051	-0.0152	-0.0203	-0.0305	-0.0203	-0.0305	-0.0762	-0.1118	-0.0965	-0.0864	-0.0448
380	0.0000	-0.0102	-0.0152	-0.0203	-0.0356	-0.0203	-0.0305	-0.0762	-0.1118	-0.1016	-0.0914	-0.0466
400	0.0000	-0.0102	-0.0152	-0.0254	-0.0406	-0.0254	-0.0356	-0.0762	-0.1168	-0.1118	-0.0914	-0.0499
420	0.0000	-0.0102	-0.0203	-0.0305	-0.0406	-0.0254	-0.0356	-0.0762	-0.1219	-0.1168	-0.0914	-0.0517
440	0.0000	-0.0152	-0.0203	-0.0305	-0.0406	-0.0254	-0.0406	-0.0813	-0.1219	-0.1168	-0.0965	-0.0536
460	0.0000	-0.0152	-0.0203	-0.0356	-0.0406	-0.0254	-0.0406	-0.0864	-0.1270	-0.1168	-0.0965	-0.0550
480	0.0000	-0.0152	-0.0203	-0.0356	-0.0406	-0.0254	-0.0406	-0.0914	-0.1372	-0.1168	-0.1016	-0.0568
500	0.0000	-0.0152	-0.0254	-0.0356	-0.0406	-0.0305	-0.0457	-0.0965	-0.1422	-0.1219	-0.1067	-0.0600
520	0.0000	-0.0203	-0.0254	-0.0406	-0.0457	-0.0305	-0.0508	-0.1067	-0.1524	-0.1219	-0.1118	-0.0642
540	0.0000	-0.0203	-0.0254	-0.0457	-0.0457	-0.0457	-0.0508	-0.1168	-0.1626	-0.1219	-0.1118	-0.0679
560	0.0000	-0.0203	-0.0254	-0.0356	-0.0508	-0.0457	-0.0356	-0.0559	-0.1626	-0.1168	-0.1168	-0.0605
580	0.0000	-0.0203	-0.0254	-0.0356	-0.0508	-0.0406	-0.0406	-0.0660	-0.1676	-0.1168	-0.1219	-0.0623
600	-0.0051	-0.0254	-0.0305	-0.0406	-0.0559	-0.0457	-0.0406	-0.0711	-0.1219	-0.1168	-0.1219	-0.0614
620	-0.0102	-0.0305	-0.0305	-0.0406	-0.0610	-0.0406	-0.0406	-0.0762	-0.1372	-0.1168	-0.1270	-0.0647
640	-0.0102	-0.0305	-0.0356	-0.0457	-0.0610	-0.0406	-0.0457	-0.0914	-0.1422	-0.1219	-0.1372	-0.0693
660	-0.0102	-0.0356	-0.0356	-0.0457	-0.0660	-0.0406	-0.0508	-0.0965	-0.1524	-0.1219	-0.1372	-0.0720
680	-0.0152	-0.0203	-0.0356	-0.0508	-0.0660	-0.0406	-0.0508	-0.1067	-0.1676	-0.1270	-0.1372	-0.0744
700	-0.0152	-0.0203	-0.0356	-0.0559	-0.0660	-0.0406	-0.0559	-0.1168	-0.1778	-0.1676	-0.1372	-0.0808
720	-0.0152	-0.0254	-0.0406	-0.0610	-0.0660	-0.0406	-0.0660	-0.1270	-0.1930	-0.1575	-0.1422	-0.0850
740	-0.0152	-0.0305	-0.0457	-0.0610	-0.0610	-0.0457	-0.0711	-0.1422	-0.1981	-0.1575	-0.1422	-0.0882
760	-0.0203	-0.0356	-0.0406	-0.0457	-0.0711	-0.0610	-0.0508	-0.1524	-0.2134	-0.1473	-0.1473	-0.0896
780	-0.0102	-0.0356	-0.0406	-0.0508	-0.0762	-0.0559	-0.0508	-0.0914	-0.2184	-0.1473	-0.1473	-0.0841
800	-0.0152	-0.0356	-0.0406	-0.0559	-0.0762	-0.0559	-0.0508	-0.0965	-0.1626	-0.1422	-0.1524	-0.0804
820	-0.0152	-0.0406	-0.0457	-0.0610	-0.0762	-0.0559	-0.0559	-0.1067	-0.1676	-0.1422	-0.1626	-0.0845
840	-0.0152	-0.0406	-0.0457	-0.0610	-0.0762	-0.0508	-0.0660	-0.1168	-0.1880	-0.1473	-0.1626	-0.0882

860	-0.0152	-0.0457	-0.0457	-0.0711	-0.0762	-0.0508	-0.0660	-0.1270	-0.1981	-0.1473	-0.1626	-0.0914
880	-0.0203	-0.0305	-0.0508	-0.0711	-0.0762	-0.0508	-0.0762	-0.1422	-0.2134	-0.1524	-0.1676	-0.0956
900	-0.0203	-0.0356	-0.0559	-0.0762	-0.0762	-0.0508	-0.0762	-0.1524	-0.2286	-0.1880	-0.1676	-0.1025
920	-0.0203	-0.0356	-0.0457	-0.0762	-0.0762	-0.0762	-0.0914	-0.1676	-0.2388	-0.1829	-0.1676	-0.1071
940	-0.0203	-0.0406	-0.0508	-0.0610	-0.0864	-0.0711	-0.0559	-0.0965	-0.2489	-0.1727	-0.1727	-0.0979
960	-0.0152	-0.0457	-0.0508	-0.0660	-0.0914	-0.0660	-0.0610	-0.1118	-0.1727	-0.1676	-0.1778	-0.0933
980	-0.0203	-0.0457	-0.0559	-0.0711	-0.0914	-0.0660	-0.0660	-0.1219	-0.1930	-0.1676	-0.1778	-0.0979
1000	-0.0203	-0.0508	-0.0559	-0.0762	-0.0914	-0.0660	-0.0711	-0.1321	-0.2083	-0.1676	-0.1829	-0.1021
1050	-0.0203	-0.0508	-0.0610	-0.0762	-0.0965	-0.0660	-0.0711	-0.1219	-0.1981	-0.1727	-0.1880	-0.1021
1100	-0.0203	-0.0508	-0.0610	-0.0762	-0.0965	-0.0762	-0.0660	-0.1219	-0.2794	-0.1829	-0.1930	-0.1113
1150	-0.0254	-0.0457	-0.0610	-0.0762	-0.1016	-0.0813	-0.0660	-0.1168	-0.2896	-0.1981	-0.1981	-0.1145
1200	-0.0305	-0.0457	-0.0660	-0.0965	-0.0914	-0.0914	-0.1016	-0.1930	-0.2896	-0.2235	-0.2083	-0.1307
1250	-0.0305	-0.0457	-0.0711	-0.0965	-0.0965	-0.0711	-0.0965	-0.1778	-0.2794	-0.2438	-0.2184	-0.1298
1300	-0.0254	-0.0406	-0.0711	-0.0965	-0.1016	-0.0711	-0.0914	-0.1676	-0.2692	-0.1981	-0.2184	-0.1228
1350	-0.0305	-0.0711	-0.0762	-0.1016	-0.1168	-0.0762	-0.0914	-0.1676	-0.2642	-0.1981	-0.2235	-0.1288
1400	-0.0305	-0.0711	-0.0762	-0.1016	-0.1168	-0.0813	-0.0914	-0.1626	-0.2540	-0.2032	-0.2235	-0.1284
1450	-0.0305	-0.0660	-0.0813	-0.1016	-0.1219	-0.0914	-0.0914	-0.1626	-0.2489	-0.2032	-0.2286	-0.1298
1500	-0.0254	-0.0711	-0.0813	-0.1016	-0.1219	-0.0914	-0.0914	-0.1524	-0.2438	-0.2083	-0.2337	-0.1293
1550	-0.0254	-0.0660	-0.0813	-0.1016	-0.1270	-0.0914	-0.0914	-0.1524	-0.2388	-0.2184	-0.2388	-0.1302
1600	-0.0305	-0.0711	-0.0864	-0.1067	-0.1270	-0.0965	-0.0914	-0.1524	-0.3505	-0.2235	-0.2438	-0.1436
1650	-0.0305	-0.0711	-0.0864	-0.1067	-0.1321	-0.0965	-0.0914	-0.1524	-0.3607	-0.2286	-0.2489	-0.1459
1700	-0.0305	-0.0711	-0.0864	-0.1118	-0.1321	-0.0965	-0.0914	-0.1524	-0.3658	-0.2286	-0.2489	-0.1469
1750	-0.0305	-0.0711	-0.0864	-0.1118	-0.1372	-0.0965	-0.0914	-0.1626	-0.3759	-0.2286	-0.2540	-0.1496
1800	-0.0356	-0.0711	-0.0914	-0.1168	-0.1372	-0.1016	-0.0965	-0.1676	-0.2642	-0.2337	-0.2591	-0.1432
1850	-0.0356	-0.0762	-0.0914	-0.1168	-0.1372	-0.0965	-0.0965	-0.1676	-0.2743	-0.2337	-0.2591	-0.1441
1900	-0.0356	-0.0813	-0.0914	-0.1168	-0.1422	-0.0965	-0.1016	-0.1778	-0.2896	-0.2337	-0.2642	-0.1482
1950	-0.0356	-0.0813	-0.0965	-0.1270	-0.1422	-0.0965	-0.1067	-0.1930	-0.3099	-0.2388	-0.2642	-0.1538
2000	-0.0356	-0.0864	-0.1016	-0.1321	-0.1422	-0.0965	-0.1168	-0.2083	-0.3302	-0.2438	-0.2896	-0.1621
2050	-0.0406	-0.0914	-0.1118	-0.1372	-0.1372	-0.0965	-0.1219	-0.2235	-0.3607	-0.2540	-0.2896	-0.1695
2100	-0.0406	-0.0610	-0.1118	-0.1422	-0.1372	-0.0965	-0.1372	-0.2438	-0.3861	-0.3251	-0.2896	-0.1792
2150	-0.0457	-0.0711	-0.1168	-0.1473	-0.1270	-0.1016	-0.1473	-0.2692	-0.4166	-0.2997	-0.2896	-0.1847
2200	-0.0457	-0.0762	-0.1016	-0.1270	-0.1524	-0.1219	-0.1067	-0.1676	-0.4318	-0.2794	-0.2896	-0.1727
2250	-0.0356	-0.0864	-0.1067	-0.1321	-0.1524	-0.1168	-0.1118	-0.1930	-0.4318	-0.2642	-0.2896	-0.1746
2300	-0.0406	-0.0914	-0.1118	-0.1422	-0.1524	-0.1118	-0.1219	-0.2184	-0.3454	-0.2642	-0.2845	-0.1713
2350	-0.0457	-0.0610	-0.1168	-0.1473	-0.1473	-0.1118	-0.1321	-0.2438	-0.3861	-0.2692	-0.3099	-0.1792
2400	-0.0457	-0.0711	-0.1270	-0.1575	-0.1422	-0.1118	-0.1473	-0.2743	-0.4267	-0.3404	-0.3099	-0.1958
2450	-0.0457	-0.0813	-0.1118	-0.1372	-0.1626	-0.1270	-0.1168	-0.1727	-0.4572	-0.2946	-0.3048	-0.1829
2500	-0.0406	-0.0914	-0.1168	-0.1422	-0.1626	-0.1168	-0.1219	-0.2032	-0.3353	-0.2692	-0.2946	-0.1723
2550	-0.0457	-0.1016	-0.1219	-0.1575	-0.1524	-0.1168	-0.1372	-0.2489	-0.4013	-0.2794	-0.3200	-0.1893
2600	-0.0457	-0.0762	-0.1372	-0.1626	-0.1422	-0.1168	-0.1626	-0.2946	-0.4623	-0.3302	-0.3200	-0.2046
2650	-0.0457	-0.0914	-0.1168	-0.1473	-0.1727	-0.1321	-0.1219	-0.1981	-0.4775	-0.2946	-0.3099	-0.1917
2700	-0.0457	-0.1067	-0.1270	-0.1575	-0.1676	-0.1219	-0.1372	-0.2438	-0.3962	-0.2845	-0.2997	-0.1898
2750	-0.0508	-0.0711	-0.1372	-0.1626	-0.1473	-0.1168	-0.1626	-0.2946	-0.4623	-0.3556	-0.3302	-0.2083
2800	-0.0457	-0.0914	-0.1168	-0.1473	-0.1727	-0.1321	-0.1219	-0.2032	-0.4877	-0.2946	-0.3150	-0.1935

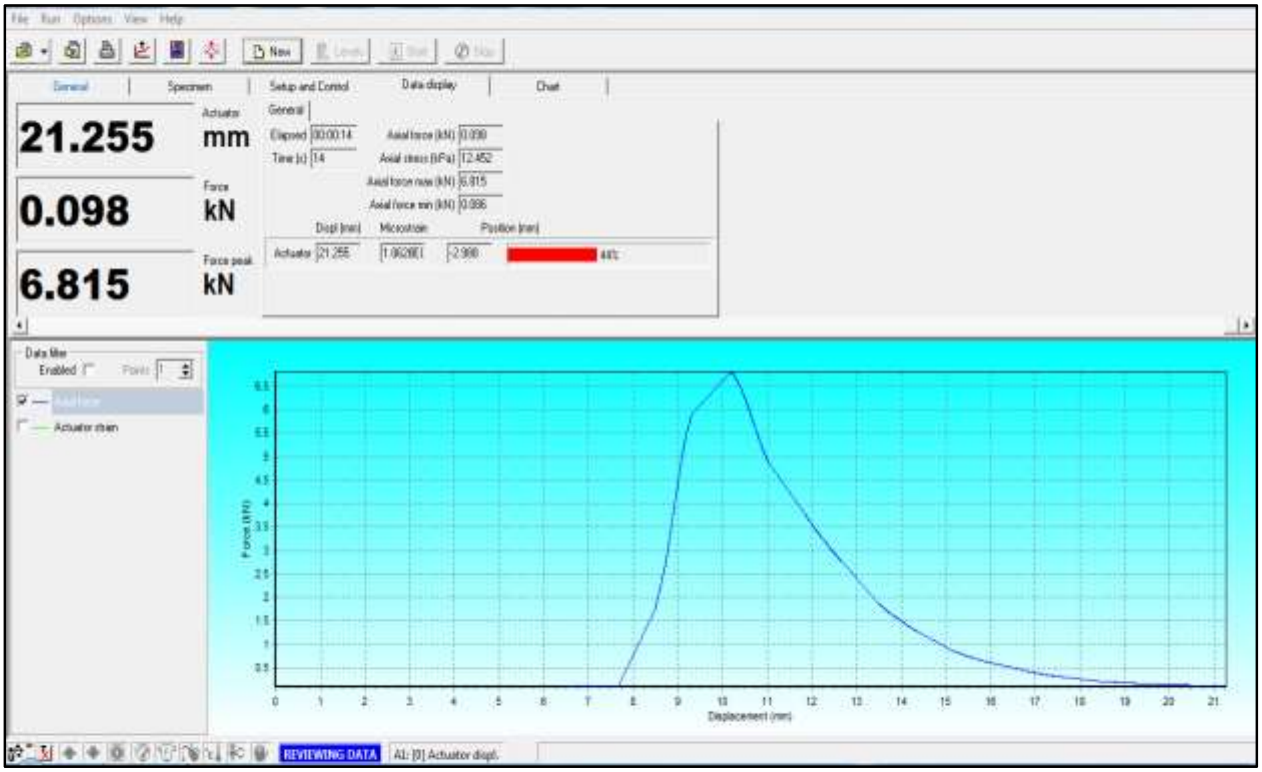
2850	-0.0457	-0.1118	-0.1321	-0.1626	-0.1676	-0.1219	-0.1473	-0.2642	-0.4216	-0.2946	-0.3454	-0.2014
2900	-0.0559	-0.0864	-0.1168	-0.1727	-0.1473	-0.1473	-0.1219	-0.3251	-0.4928	-0.3302	-0.3353	-0.2120
2950	-0.0457	-0.1067	-0.1321	-0.1626	-0.1727	-0.1270	-0.1372	-0.2388	-0.3861	-0.2946	-0.3150	-0.1926
3000	-0.0508	-0.0762	-0.1422	-0.1727	-0.1524	-0.1219	-0.1676	-0.3048	-0.4826	-0.3708	-0.3404	-0.2166
3050	-0.0457	-0.0965	-0.1270	-0.1575	-0.1778	-0.1321	-0.1321	-0.2184	-0.3658	-0.2997	-0.3200	-0.1884
3100	-0.0559	-0.0762	-0.1422	-0.1727	-0.1676	-0.1270	-0.1626	-0.2896	-0.4674	-0.4064	-0.3454	-0.2194
3150	-0.0457	-0.0965	-0.1270	-0.1626	-0.1880	-0.1372	-0.1321	-0.2134	-0.5182	-0.3099	-0.3353	-0.2060
3200	-0.0508	-0.0711	-0.1422	-0.1727	-0.1676	-0.1270	-0.1524	-0.2896	-0.4674	-0.3150	-0.3505	-0.2097
3250	-0.0457	-0.0914	-0.1321	-0.1626	-0.1880	-0.1422	-0.1321	-0.2083	-0.5232	-0.3150	-0.3353	-0.2069
3300	-0.0559	-0.1168	-0.1422	-0.1829	-0.1778	-0.1321	-0.1626	-0.2896	-0.4674	-0.3200	-0.3607	-0.2189
3350	-0.0610	-0.0965	-0.1321	-0.1626	-0.1880	-0.1473	-0.1372	-0.2184	-0.5283	-0.3200	-0.3404	-0.2120
3400	-0.0559	-0.0762	-0.1473	-0.1829	-0.1727	-0.1321	-0.1626	-0.2997	-0.4826	-0.3251	-0.3658	-0.2184
3450	-0.0508	-0.1067	-0.1372	-0.1676	-0.1930	-0.1473	-0.1372	-0.2235	-0.5334	-0.3150	-0.3454	-0.2143
3500	-0.0559	-0.0864	-0.1575	-0.1829	-0.1727	-0.1372	-0.1727	-0.3150	-0.4978	-0.4115	-0.3658	-0.2323
3550	-0.0508	-0.1067	-0.1372	-0.1727	-0.1930	-0.1473	-0.1422	-0.2438	-0.3912	-0.3150	-0.3454	-0.2041
3600	-0.0610	-0.0864	-0.1575	-0.1880	-0.1676	-0.1321	-0.1778	-0.3251	-0.5182	-0.3962	-0.3658	-0.2341
3650	-0.0508	-0.1118	-0.1422	-0.1727	-0.1930	-0.1422	-0.1473	-0.2540	-0.4166	-0.3150	-0.3404	-0.2078
3700	-0.0610	-0.0914	-0.1626	-0.1880	-0.1626	-0.1372	-0.1372	-0.1930	-0.5385	-0.3708	-0.3658	-0.2189
3750	-0.0559	-0.1168	-0.1473	-0.1829	-0.1880	-0.1372	-0.1524	-0.2743	-0.4470	-0.3251	-0.3404	-0.2152
3800	-0.0610	-0.0965	-0.1372	-0.1930	-0.1981	-0.1626	-0.1372	-0.2134	-0.5486	-0.3505	-0.3607	-0.2235
3850	-0.0559	-0.1168	-0.1473	-0.1880	-0.1880	-0.1372	-0.1626	-0.2997	-0.4877	-0.3353	-0.3759	-0.2268
3900	-0.0508	-0.1067	-0.1422	-0.1727	-0.1981	-0.1524	-0.1422	-0.2235	-0.5588	-0.3404	-0.3607	-0.2226
3950	-0.0610	-0.0813	-0.1575	-0.1930	-0.1778	-0.1372	-0.1727	-0.3200	-0.5182	-0.3454	-0.3759	-0.2309
4000	-0.0508	-0.1118	-0.1422	-0.1829	-0.1981	-0.1473	-0.1473	-0.2489	-0.4166	-0.3251	-0.3505	-0.2111
4050	-0.0610	-0.0914	-0.1321	-0.1981	-0.1676	-0.1372	-0.1930	-0.3607	-0.5588	-0.3861	-0.3708	-0.2415
4100	-0.0559	-0.1168	-0.1473	-0.1880	-0.1930	-0.1422	-0.1626	-0.2845	-0.4724	-0.3353	-0.3454	-0.2221
4150	-0.0508	-0.1016	-0.1422	-0.1727	-0.2032	-0.1626	-0.1422	-0.2184	-0.5690	-0.3505	-0.3658	-0.2254
4200	-0.0610	-0.0864	-0.1626	-0.1981	-0.1880	-0.1422	-0.1727	-0.3200	-0.5283	-0.4470	-0.3861	-0.2448
4250	-0.0559	-0.1168	-0.1473	-0.1880	-0.2032	-0.1524	-0.1473	-0.2489	-0.4267	-0.3404	-0.3607	-0.2171
4300	-0.0610	-0.0914	-0.1372	-0.1981	-0.1727	-0.1727	-0.1372	-0.3658	-0.5690	-0.3962	-0.3810	-0.2438
4350	-0.0610	-0.1270	-0.1575	-0.1930	-0.2032	-0.1473	-0.1626	-0.2896	-0.4877	-0.3404	-0.3505	-0.2291
4400	-0.0559	-0.1118	-0.1473	-0.1880	-0.2134	-0.1626	-0.1473	-0.2286	-0.5842	-0.3556	-0.3759	-0.2337
4450	-0.0660	-0.0914	-0.1727	-0.2083	-0.1930	-0.1473	-0.1880	-0.3404	-0.5486	-0.4521	-0.3962	-0.2549
4500	-0.0610	-0.1219	-0.1575	-0.1981	-0.2134	-0.1524	-0.1524	-0.2692	-0.4521	-0.3454	-0.3658	-0.2263
4550	-0.0711	-0.1016	-0.1473	-0.2134	-0.1778	-0.1473	-0.1473	-0.3912	-0.5893	-0.3962	-0.3912	-0.2522
4600	-0.0660	-0.1321	-0.1676	-0.2083	-0.2032	-0.1473	-0.1727	-0.3150	-0.5232	-0.3556	-0.4064	-0.2452
4650	-0.0610	-0.1168	-0.1575	-0.1981	-0.2184	-0.1626	-0.1524	-0.2540	-0.5893	-0.3556	-0.3759	-0.2401
4700	-0.0711	-0.1016	-0.1829	-0.2134	-0.1880	-0.1473	-0.2032	-0.3759	-0.5893	-0.4216	-0.4013	-0.2632
4750	-0.0660	-0.1321	-0.1676	-0.2083	-0.2184	-0.1524	-0.1676	-0.2997	-0.4928	-0.3556	-0.3708	-0.2392
4800	-0.0711	-0.1118	-0.1575	-0.2184	-0.2235	-0.1778	-0.1524	-0.2235	-0.6147	-0.3962	-0.3962	-0.2494
4850	-0.0660	-0.1422	-0.1727	-0.2134	-0.2134	-0.1524	-0.1778	-0.3200	-0.5334	-0.3708	-0.4166	-0.2526
4900	-0.0610	-0.1168	-0.1626	-0.1981	-0.2286	-0.1778	-0.1524	-0.2438	-0.6198	-0.3810	-0.3962	-0.2489
4950	-0.0711	-0.0914	-0.1829	-0.2184	-0.2134	-0.1524	-0.1880	-0.3454	-0.5690	-0.3810	-0.4216	-0.2577
5000	-0.0610	-0.1321	-0.1676	-0.2083	-0.2286	-0.1676	-0.1626	-0.2692	-0.4572	-0.3708	-0.3912	-0.2378

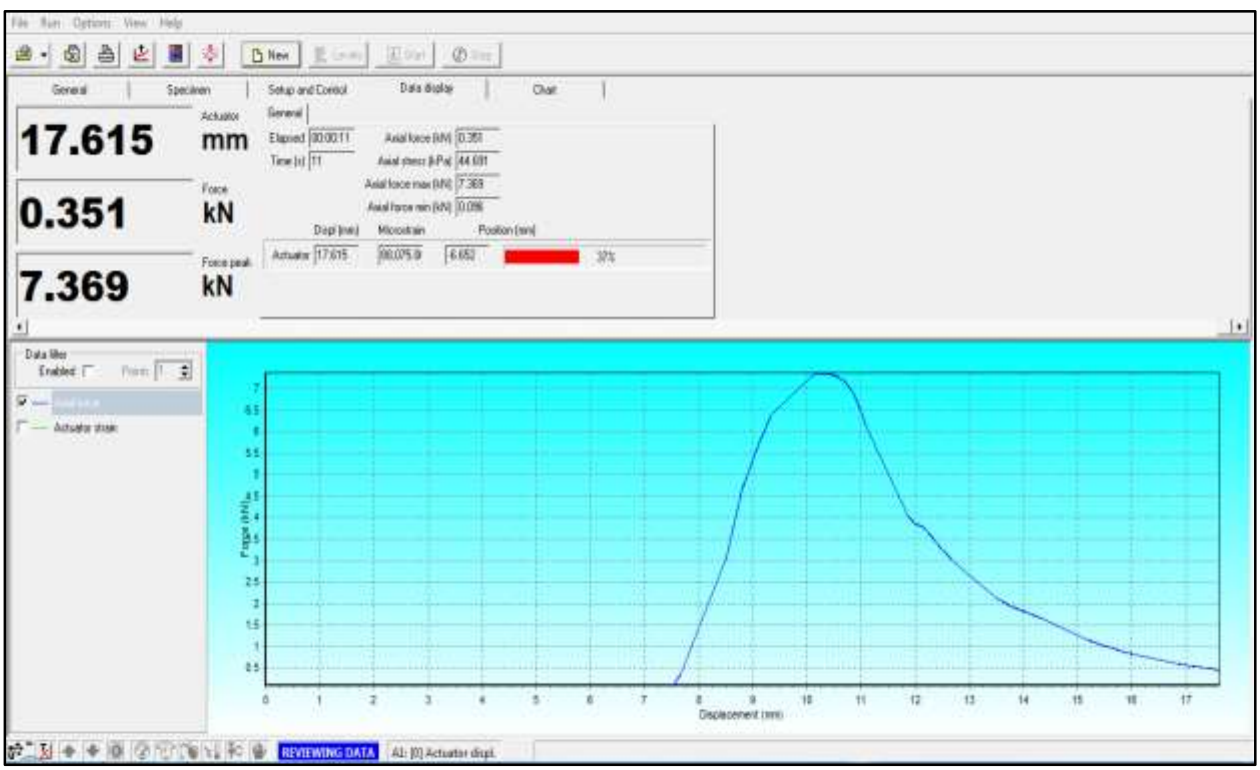
5050	-0.0711	-0.1067	-0.1880	-0.2235	-0.1981	-0.1524	-0.2083	-0.3861	-0.6096	-0.4420	-0.4166	-0.2729
5100	-0.0711	-0.1422	-0.1727	-0.2184	-0.2235	-0.1626	-0.1727	-0.3099	-0.5131	-0.3708	-0.3810	-0.2489
5150	-0.0813	-0.1168	-0.1626	-0.2337	-0.2388	-0.1626	-0.1626	-0.2438	-0.6350	-0.3962	-0.4064	-0.2582
5200	-0.0711	-0.0965	-0.1880	-0.2286	-0.2184	-0.1626	-0.1930	-0.3607	-0.5842	-0.4978	-0.4267	-0.2752
5250	-0.0660	-0.1321	-0.1727	-0.2184	-0.2337	-0.1676	-0.1676	-0.2946	-0.4978	-0.3759	-0.3912	-0.2471
5300	-0.0610	-0.1168	-0.1626	-0.2388	-0.2438	-0.1930	-0.1626	-0.2438	-0.6401	-0.4064	-0.4166	-0.2623
5350	-0.0711	-0.1016	-0.1930	-0.2337	-0.2184	-0.1626	-0.1981	-0.3708	-0.5994	-0.4928	-0.4369	-0.2799
5400	-0.0711	-0.1372	-0.1829	-0.2235	-0.2388	-0.1676	-0.1727	-0.2997	-0.5131	-0.3810	-0.3962	-0.2531
5450	-0.0813	-0.1219	-0.1676	-0.2134	-0.2438	-0.1930	-0.1626	-0.2489	-0.6452	-0.4064	-0.4166	-0.2637
5500	-0.0813	-0.1118	-0.2032	-0.2388	-0.2184	-0.1676	-0.2134	-0.3912	-0.6248	-0.4877	-0.4369	-0.2886
5550	-0.0711	-0.1473	-0.1880	-0.2337	-0.2388	-0.1676	-0.1880	-0.3251	-0.5486	-0.3912	-0.3912	-0.2628
5600	-0.0711	-0.1321	-0.1829	-0.2184	-0.2489	-0.1880	-0.1676	-0.2743	-0.4724	-0.3962	-0.4166	-0.2517
5650	-0.0864	-0.1168	-0.2134	-0.2438	-0.2032	-0.1676	-0.2286	-0.4267	-0.6553	-0.4420	-0.4369	-0.2928
5700	-0.0762	-0.1067	-0.1981	-0.2438	-0.2286	-0.1676	-0.1981	-0.3658	-0.6045	-0.4115	-0.4521	-0.2776
5750	-0.0711	-0.1422	-0.1880	-0.2337	-0.2489	-0.1778	-0.1778	-0.3048	-0.5232	-0.3962	-0.4064	-0.2609
5800	-0.0864	-0.1321	-0.1727	-0.2184	-0.2489	-0.1981	-0.1676	-0.2540	-0.6655	-0.4166	-0.4267	-0.2715
5850	-0.0864	-0.1168	-0.2134	-0.2489	-0.2235	-0.1676	-0.2184	-0.4064	-0.6452	-0.4826	-0.4470	-0.2960
5900	-0.0813	-0.1575	-0.1981	-0.2438	-0.2438	-0.1778	-0.1930	-0.3454	-0.5842	-0.4115	-0.4623	-0.2817
5950	-0.0711	-0.1422	-0.1880	-0.2388	-0.2540	-0.1880	-0.1778	-0.2946	-0.5131	-0.4013	-0.4216	-0.2628
6000	-0.0914	-0.1321	-0.1829	-0.2235	-0.2083	-0.2083	-0.1727	-0.2489	-0.6807	-0.4420	-0.4420	-0.2757
6050	-0.0864	-0.1168	-0.2134	-0.2540	-0.2286	-0.1727	-0.2184	-0.4064	-0.6502	-0.5080	-0.4623	-0.3016
6100	-0.0813	-0.1575	-0.1981	-0.2438	-0.2438	-0.1778	-0.1930	-0.3556	-0.5944	-0.4166	-0.4064	-0.2789
6150	-0.0762	-0.1473	-0.1930	-0.2438	-0.2591	-0.1930	-0.1880	-0.3099	-0.5334	-0.4064	-0.4267	-0.2706
6200	-0.0914	-0.1321	-0.1829	-0.2337	-0.2642	-0.2083	-0.1778	-0.2692	-0.6909	-0.4267	-0.4420	-0.2836
6250	-0.0864	-0.1219	-0.1727	-0.2591	-0.2235	-0.1778	-0.2388	-0.4420	-0.6807	-0.4826	-0.4623	-0.3043
6300	-0.0864	-0.1118	-0.2134	-0.2591	-0.2438	-0.1778	-0.2083	-0.3861	-0.6401	-0.5537	-0.4724	-0.3048
6350	-0.0813	-0.1575	-0.1981	-0.2489	-0.2591	-0.1880	-0.1930	-0.3404	-0.5740	-0.4166	-0.4216	-0.2799
6400	-0.0762	-0.1422	-0.1930	-0.2438	-0.2692	-0.2032	-0.1880	-0.2997	-0.6858	-0.4216	-0.4369	-0.2873
6450	-0.0914	-0.1321	-0.1880	-0.2388	-0.2184	-0.2184	-0.1778	-0.2642	-0.7010	-0.4521	-0.4572	-0.2854
6500	-0.0864	-0.1168	-0.2184	-0.2642	-0.2388	-0.1778	-0.2286	-0.4267	-0.6858	-0.5131	-0.4724	-0.3117
6550	-0.0864	-0.1626	-0.2134	-0.2591	-0.2540	-0.1880	-0.2083	-0.3759	-0.6350	-0.4420	-0.4877	-0.3011
6600	-0.0864	-0.1575	-0.2032	-0.2540	-0.2692	-0.1930	-0.1930	-0.3353	-0.5740	-0.4267	-0.4369	-0.2845
6650	-0.0762	-0.1422	-0.1930	-0.2438	-0.2743	-0.2083	-0.1880	-0.2946	-0.7061	-0.4318	-0.4521	-0.2919
6700	-0.0914	-0.1321	-0.2388	-0.2692	-0.2743	-0.1880	-0.1880	-0.4775	-0.7112	-0.4674	-0.4674	-0.3187
6750	-0.0864	-0.1168	-0.2235	-0.2692	-0.2438	-0.1880	-0.2286	-0.4267	-0.6858	-0.5283	-0.4877	-0.3168
6800	-0.0864	-0.1676	-0.2134	-0.2642	-0.2591	-0.1880	-0.2083	-0.3861	-0.6401	-0.4420	-0.4928	-0.3043
6850	-0.0813	-0.1575	-0.2083	-0.2591	-0.2692	-0.1981	-0.1981	-0.3404	-0.5842	-0.4267	-0.4369	-0.2873
6900	-0.0762	-0.1422	-0.1981	-0.2489	-0.2794	-0.2134	-0.1880	-0.2997	-0.7112	-0.4420	-0.4521	-0.2956
6950	-0.0914	-0.1321	-0.1880	-0.2743	-0.2235	-0.2235	-0.2642	-0.4928	-0.7214	-0.4724	-0.4724	-0.3233
7000	-0.0914	-0.1219	-0.2286	-0.2743	-0.2438	-0.1880	-0.2388	-0.4420	-0.6960	-0.5334	-0.4877	-0.3223
7050	-0.0864	-0.1727	-0.2184	-0.2692	-0.2591	-0.1930	-0.2184	-0.3962	-0.6604	-0.4521	-0.4978	-0.3113
7100	-0.0864	-0.1626	-0.2134	-0.2591	-0.2692	-0.1981	-0.2032	-0.3505	-0.5994	-0.4369	-0.4369	-0.2923
7150	-0.0813	-0.1473	-0.1981	-0.2540	-0.2794	-0.2032	-0.1930	-0.3150	-0.5486	-0.4369	-0.4521	-0.2826
7200	-0.0914	-0.1422	-0.1930	-0.2438	-0.2794	-0.2184	-0.1880	-0.2794	-0.7264	-0.4521	-0.4674	-0.2983

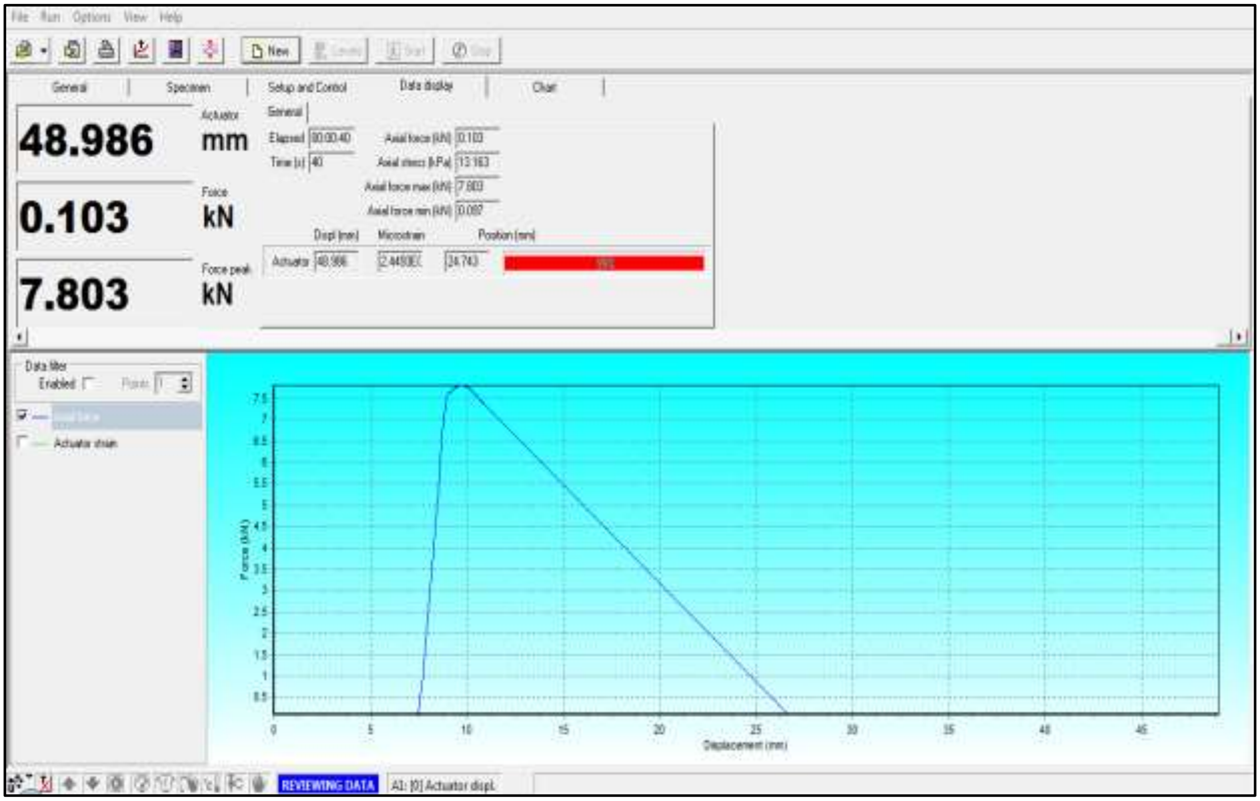
7250	-0.0914	-0.1321	-0.1880	-0.2794	-0.2337	-0.1880	-0.1880	-0.4826	-0.7264	-0.4928	-0.4826	-0.3168
7300	-0.0914	-0.1168	-0.2337	-0.2743	-0.2489	-0.1880	-0.2286	-0.4369	-0.7010	-0.5537	-0.4978	-0.3247
7350	-0.0864	-0.1727	-0.2184	-0.2692	-0.2642	-0.1930	-0.2184	-0.3912	-0.6604	-0.4521	-0.5131	-0.3127
7400	-0.0864	-0.1626	-0.2134	-0.2642	-0.2743	-0.1981	-0.2032	-0.3556	-0.6147	-0.4420	-0.4470	-0.2965
7450	-0.0864	-0.1575	-0.2134	-0.2642	-0.2845	-0.2083	-0.1930	-0.3251	-0.5740	-0.4420	-0.4623	-0.2919
7500	-0.0813	-0.1473	-0.2083	-0.2591	-0.2896	-0.2184	-0.1930	-0.3099	-0.7315	-0.4521	-0.4724	-0.3057
7550	-0.1016	-0.1422	-0.1981	-0.2845	-0.2896	-0.2235	-0.1930	-0.2896	-0.7468	-0.4674	-0.4826	-0.3108
7600	-0.1016	-0.1422	-0.1981	-0.2896	-0.2438	-0.2438	-0.2692	-0.5131	-0.7518	-0.4928	-0.4928	-0.3399
7650	-0.0965	-0.1372	-0.2489	-0.2946	-0.2489	-0.1930	-0.2591	-0.4877	-0.7468	-0.5232	-0.5080	-0.3404
7700	-0.0965	-0.1321	-0.2438	-0.2946	-0.2642	-0.1930	-0.2438	-0.4623	-0.7315	-0.5639	-0.5182	-0.3404
7750	-0.0965	-0.1270	-0.2438	-0.2896	-0.2743	-0.1981	-0.2337	-0.4369	-0.7112	-0.5994	-0.5283	-0.3399
7800	-0.0914	-0.1829	-0.2388	-0.2896	-0.2794	-0.2032	-0.2235	-0.4115	-0.6858	-0.4775	-0.5334	-0.3288
7850	-0.0914	-0.1727	-0.2337	-0.2845	-0.2896	-0.2083	-0.2184	-0.3912	-0.6706	-0.4724	-0.4623	-0.3177
7900	-0.0914	-0.1727	-0.2286	-0.2845	-0.2946	-0.2134	-0.2134	-0.3708	-0.6502	-0.4674	-0.4674	-0.3140
7950	-0.0914	-0.1676	-0.2235	-0.2845	-0.2997	-0.2184	-0.2083	-0.3556	-0.6248	-0.4674	-0.4775	-0.3108
8000	-0.0914	-0.1626	-0.2235	-0.2845	-0.3048	-0.2235	-0.2083	-0.3404	-0.6045	-0.4674	-0.4877	-0.3090
8050	-0.0914	-0.1626	-0.2184	-0.2845	-0.3099	-0.2286	-0.2032	-0.3251	-0.7671	-0.4775	-0.4978	-0.3242
8100	-0.1118	-0.1575	-0.2184	-0.2794	-0.3150	-0.2388	-0.2032	-0.3150	-0.7823	-0.4877	-0.5029	-0.3284
8150	-0.1118	-0.1575	-0.2134	-0.3099	-0.3150	-0.2489	-0.2032	-0.5690	-0.7874	-0.5029	-0.5131	-0.3574
8200	-0.1118	-0.1473	-0.2134	-0.3099	-0.3150	-0.2032	-0.2032	-0.5486	-0.7925	-0.5232	-0.5232	-0.3538
8250	-0.1067	-0.1473	-0.2134	-0.3099	-0.2642	-0.2642	-0.2743	-0.5334	-0.7925	-0.5385	-0.5334	-0.3616
8300	-0.1067	-0.1422	-0.2692	-0.3099	-0.2692	-0.2032	-0.2642	-0.5131	-0.7874	-0.5690	-0.5385	-0.3611
8350	-0.1067	-0.1422	-0.2642	-0.3099	-0.2743	-0.2083	-0.2642	-0.4978	-0.7823	-0.5893	-0.5486	-0.3625
8400	-0.1067	-0.1372	-0.2591	-0.3099	-0.2845	-0.2083	-0.2489	-0.4826	-0.7722	-0.5283	-0.5486	-0.3533
8450	-0.1222	-0.1527	-0.2746	-0.3254	-0.3000	-0.2238	-0.2644	-0.4981	-0.7877	-0.5438	-0.5642	-0.3688
8500	-0.1377	-0.1682	-0.2901	-0.3409	-0.3155	-0.2393	-0.2800	-0.5137	-0.8032	-0.5594	-0.5797	-0.3843
8550	-0.1533	-0.1837	-0.3057	-0.3565	-0.3311	-0.2549	-0.2955	-0.5292	-0.8187	-0.5749	-0.5952	-0.3999
8600	-0.1688	-0.1993	-0.3212	-0.3720	-0.3466	-0.2704	-0.3110	-0.5447	-0.8343	-0.5904	-0.6107	-0.4154
8650	-0.1843	-0.2148	-0.3367	-0.3875	-0.3621	-0.2859	-0.3266	-0.5602	-0.8498	-0.6060	-0.6263	-0.4309
8700	-0.1998	-0.2303	-0.3522	-0.4030	-0.3776	-0.3014	-0.3421	-0.5758	-0.8653	-0.6215	-0.6418	-0.4464
8750	-0.2154	-0.2458	-0.3678	-0.4186	-0.3932	-0.3170	-0.3576	-0.5913	-0.8808	-0.6370	-0.6573	-0.4620
8800	-0.2309	-0.2614	-0.3833	-0.4341	-0.4087	-0.3325	-0.3731	-0.6068	-0.8964	-0.6525	-0.6729	-0.4775
8850	-0.2464	-0.2769	-0.3988	-0.4496	-0.4242	-0.3480	-0.3887	-0.6223	-0.9119	-0.6681	-0.6884	-0.4930
8900	-0.2619	-0.2924	-0.4143	-0.4651	-0.4397	-0.3635	-0.4042	-0.6379	-0.9274	-0.6836	-0.7039	-0.5086
8950	-0.2775	-0.3080	-0.4299	-0.4807	-0.4553	-0.3791	-0.4197	-0.6534	-0.9430	-0.6991	-0.7194	-0.5241
9000	-0.2930	-0.3235	-0.4454	-0.4962	-0.4708	-0.3946	-0.4352	-0.6689	-0.9585	-0.7146	-0.7350	-0.5396
9050	-0.3085	-0.3390	-0.4609	-0.5117	-0.4863	-0.4101	-0.4508	-0.6844	-0.9740	-0.7302	-0.7505	-0.5551
9100	-0.3240	-0.3545	-0.4764	-0.5272	-0.5018	-0.4256	-0.4663	-0.7000	-0.9895	-0.7457	-0.7660	-0.5707
9150	-0.3396	-0.3701	-0.4920	-0.5428	-0.5174	-0.4412	-0.4818	-0.7155	-1.0051	-0.7612	-0.7815	-0.5862
9200	-0.3551	-0.3856	-0.5075	-0.5583	-0.5329	-0.4567	-0.4973	-0.7310	-1.0206	-0.7767	-0.7971	-0.6017
9250	-0.3706	-0.4011	-0.5230	-0.5738	-0.5484	-0.4722	-0.5129	-0.7465	-1.0361	-0.7923	-0.8126	-0.6172
9300	-0.3862	-0.4166	-0.5386	-0.5894	-0.5640	-0.4878	-0.5284	-0.7621	-1.0516	-0.8078	-0.8281	-0.6328
9350	-0.4017	-0.4322	-0.5541	-0.6049	-0.5795	-0.5033	-0.5439	-0.7776	-1.0672	-0.8233	-0.8436	-0.6483
9400	-0.4172	-0.4477	-0.5696	-0.6204	-0.5950	-0.5188	-0.5594	-0.7931	-1.0827	-0.8388	-0.8592	-0.6638

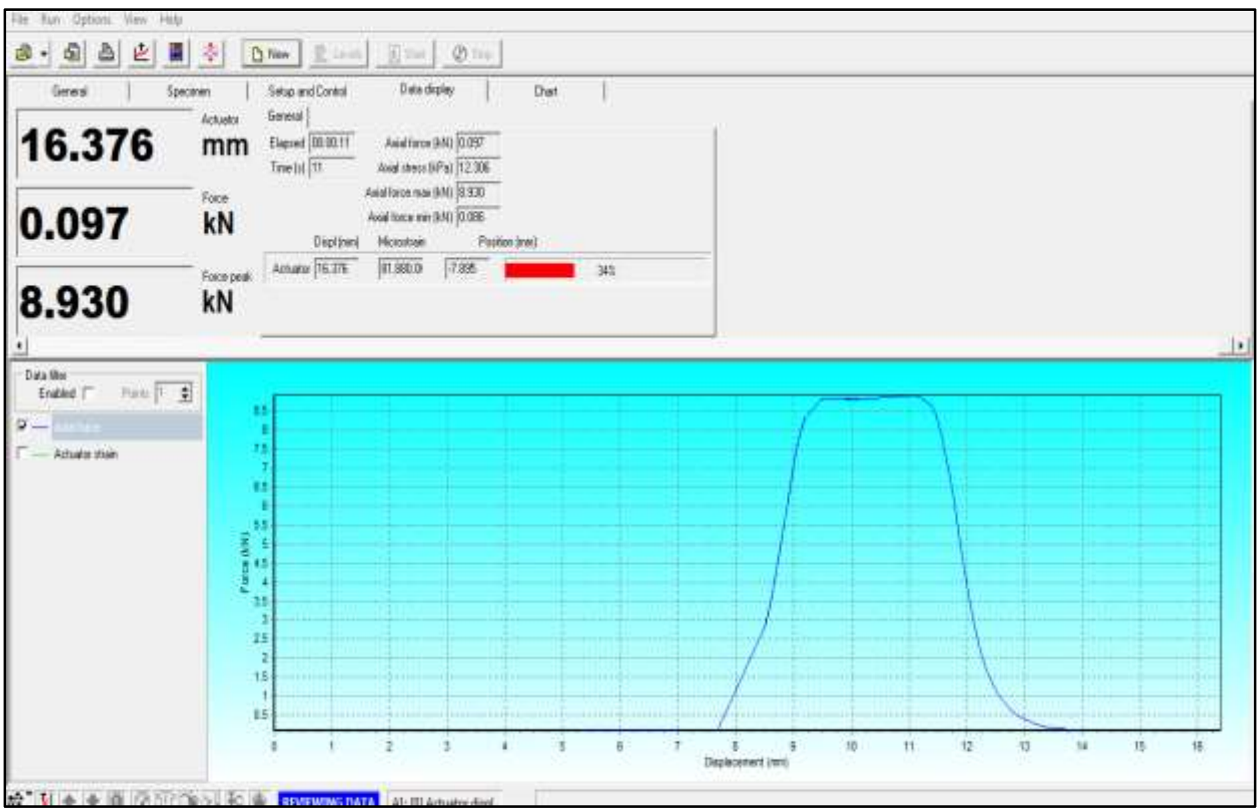
9450	-0.4327	-0.4632	-0.5851	-0.6359	-0.6105	-0.5343	-0.5750	-0.8087	-1.0982	-0.8544	-0.8747	-0.6793
9500	-0.4483	-0.4787	-0.6007	-0.6515	-0.6261	-0.5499	-0.5905	-0.8242	-1.1137	-0.8699	-0.8902	-0.6949
9550	-0.4638	-0.4943	-0.6162	-0.6670	-0.6416	-0.5654	-0.6060	-0.8397	-1.1293	-0.8854	-0.9057	-0.7104
9600	-0.4793	-0.5098	-0.6317	-0.6825	-0.6571	-0.5809	-0.6216	-0.8552	-1.1448	-0.9010	-0.9213	-0.7259
9650	-0.4948	-0.5253	-0.6472	-0.6980	-0.6726	-0.5964	-0.6371	-0.8708	-1.1603	-0.9165	-0.9368	-0.7415
9700	-0.5104	-0.5408	-0.6628	-0.7136	-0.6882	-0.6120	-0.6526	-0.8863	-1.1758	-0.9320	-0.9523	-0.7570
9750	-0.5259	-0.5564	-0.6783	-0.7291	-0.7037	-0.6275	-0.6681	-0.9018	-1.1914	-0.9475	-0.9679	-0.7725
9800	-0.5414	-0.5719	-0.6938	-0.7446	-0.7192	-0.6430	-0.6837	-0.9173	-1.2069	-0.9631	-0.9834	-0.7880
9850	-0.5569	-0.5874	-0.7093	-0.7601	-0.7347	-0.6585	-0.6992	-0.9329	-1.2224	-0.9786	-0.9989	-0.8036
9900	-0.5725	-0.6030	-0.7249	-0.7757	-0.7503	-0.6741	-0.7147	-0.9484	-1.2380	-0.9941	-1.0144	-0.8191
9950	-0.5880	-0.6185	-0.7404	-0.7912	-0.7658	-0.6896	-0.7302	-0.9639	-1.2535	-1.0096	-1.0300	-0.8346
10000	-0.6035	-0.6340	-0.7559	-0.8067	-0.7813	-0.7051	-0.7458	-0.9794	-1.2690	-1.0252	-1.0455	-0.8501

APPENDIX IV: ITS TEST RESULT


21.255
mm
0.098
kN
6.815
kN
REVIEWING DATA
Displacement (mm)


17.615
mm
0.351
kN
7.369
kN
REVIEWING DATA
Displacement (mm)


48.986
mm
0.103
kN
7.803
kN
Displacement (mm)
REVIEWING DATA


16.376
mm
0.097
kN
8.930
kN
Displacement (mm)
REVIEWING DATA