Addis Ababa University
Addis Ababa Institute of Technology
School of Civil and Environmental Engineering

STUDY ON BEHAVIOR OF MODIFIED ASPHALT MIXES CONTAINING WASTE POLYVINYL CHLORIDE AT HIGH TEMPERATURE AND HEAVY TRAFFIC CONDITION (SUPER-PAVE PERFORMANCE BASED TEST METHOD)

A Thesis Submitted to The School of Civil and Environmental Engineering Addis Ababa University in Partial Fulfillment for The Requirement of Degree of Master of Science

Submitted by

Beza Taye

Advisor: **Dr.Ephrem Taddesse**

June 2020

Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

STUDY ON BEHAVIOR OF MODIFIED ASPHALT MIXES CONTAINING WASTE POLYVINYL CHLORIDE AT HIGH TEMPERATURE AND HEAVY TRAFFIC CONDITION (SUPER-PAVE PERFORMANCE BASED TEST METHOD)

A Thesis Submitted to The School of Civil and Environmental Engineering, Addis Ababa University in Partial Fulfillment for The Requirement of Degree of Master of Science

Submitted by

Beza Taye

Approved by Board of examiners

Dr.Ephrem Taddesse Advisor	______________________ Signature
Internal Examiner	______________________ Signature
Internal Examiner	______________________ Signature
Internal Examiner	______________________ Signature

Undertaking

I, the undersigned, declare that this dissertation work, to the best of my knowledge and belief, is my original work, it has not been presented for a degree in this or any other universities and all sources of material for this dissertation has been fully acknowledged

Beza Taye
Candidate

Signature

Date of submission

This is to certify the above declaration made by the candidate is correct to the best of my knowledge

Dr. Ephrem Taddesse

Signature

Acknowledgment

First and for most I would like to thank the almighty GOD for what he has done for me in all regards. Secondly, I would like to thank my thesis advisor Dr. Ephrem Taddesse and Co-Advisor Tewodros Nigatu for their support & constructive suggestions for the completion of my research.

My sincere thanks also goes to Modjo – Hawasa Lot 1 and Lot 2 road project laboratory staff and AAIT highway laboratory staff for their willingness for assisting me in laboratory works. I would like to thank Ethiopian Roads Authority for crafting education opportunities for students along different places in our country and I am greatful to be one of the opportunist.

I am extremely grateful to my family, brother, sisters, my mother in low, friends and work collogues for their prayer, endless love and support throughout my research works. My special thanks goes to my fiance for his sincerity, invaluable guidance and motivation to complete this thesis successfully.

Abstract

At some route corridors, especially at import and export corridors, there exists a considerable movement of heavy trucks, higher tire pressures and high temperature which instigates a significant increase of dynamic loads and failures on the bituminous road pavements. Due to this, currently, high budgets are allocated for the construction of rigid pavements at some corridors which intern is affecting the financial dealings of the government since there are also other alternatives for enhancing the performance of flexible pavement with reduced cost. One alternative to improve the performance of asphalt pavements in hot climates and under heavy traffic is to use bitumen modifiers to enhance its rheological property. Hence, in this research waste thermoplastic polymer (waste polyvinyl Chloride (PVC)) modifiers were used with varied content and percentage by weight of the bitumen (i.e. 8%, 10%, 12 & 14% by weight of the bitumen) and the performance of the modified bitumen and the asphalt mix were evaluated through experimental studies based on Super-pave test method (specific tests selected for targeted performance indicater tests). As a result, unlike the pure bitumen which has a temperature resistance of up to 64^{o}c and accommodating a maximum traffic level up to 10 Million ESAL, at the same temperature, it was able to increase the resisteance of the traffic level up to three times (i.e. 30 Million) by adding 14% PVC to the bitumen. Furthermore, with the same composition the modified bitumen was able to resist a standard traffic level up to 10million ESAL at increased temperature level up to 70^{o}c. Additionally, based on performance tests, by adding 14% waste PVC, the permanent deformation (rut depth) at the end of the design life of the asphalt mix was able to reduce by 35% relative to the pure/non – modified mix and the modified mix was able to have a better resistance to moisture-induced damages and lesser reduction in strength after it was conditioned in water.

Table of content

List of Figures

List of Tables

List of Symbols and Abbreviations

PVC	Polyvinile chloride
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Material
Va	air void
G_{mm}	theoretical Specific gravity
MSCR	Multiple stress recovery
PG	performance grade
RTFO	Rolling Thin Film Oven
SHRP	Strategic Highway Research Program
SUPER-PAVE	Superior Performance Pavement
DSR	Dynamic Shear Rheometer
GTP	Growth and transformation plan
RSDP	road sector development program
GOE	Government of Ethiopia
MEPDG	Mechanistic–Empirical Pavement Design Guide
εo	Initial Strain at the beginning of the Creep Portion of each Cycle
εc	Strain at the end of the Creep Portion of each Cycle
εr	the strain value at the of the recovery portion
Jnr	residual strain (Non recoverable creep compliance)
G*	Complex Shear Modulus
δ	Phase angle

1 Introduction

1.1 Background

The communal consequence of traffic loading and temprature is very critical on the functional as well as on the structural performance of flexible pavements, and it shall be carefully considered through the design and material selection of the pavement. Temperature variations within a pavement structure Contribute to the occurrence of distresses in different ways cause possible failure of pavement structures. More than rigid pavements, flexible pavements, which are widely used, are more subjected to large temperature range/variation due to temperature susceptible behavior of bitumen in asphalt concrete mix. And to this regard, during the past three years, the road industry in Ethiopia is introducing rigid pavement construction in hot semi-arid corridors where large number of heavy axle traffic are anticipated like most of Afar region (i.e. construction of Dichoto-Galafi-Elidar-Belho road project and Afdera-Irebti junction-Ertale junction- Ahmedela road projects are amongst). In this case, even if it is significant to bring new and different design and construction techniques in the road construction commerce, on the other hand, it is apparent to ruminate the cost riding quality and safety aspects on both type of pavements which in this case the initial construction cost and the riding quality for rigid pavement is comparatively tough relative to the flexible pavements. To counter these shortcomings, the common pavement materials shall be modified to enhance high-temperature performance/response of this flexiable pavements like using modified binders in asphalt mixes and this could enable flexible pavement to withstand the combined effect of both hot climate and large number of heavy axle traffic.

The basis of this research is to study the performance/enactment of flexiable pavements at high temperature and traffic loading through using Bitumen modifiers particularly by using non-biodegradable material like waste thermoplastic polymers (waste polyvinyl Chloride (PVC)) that has been used previously as either part of cable and service ducting, drainage pipe, pipe and fittings, and sewerage system by considering the undesirable impact on the environment. Here, the concern is to study waste PVC pipes performing as bitumen modifier by varring the content of the PVC for pavement applications. And further, the preeminent way to yield this benefit is that to use analytical and experimental methodologies that potentially improve the mix design methods that imply a direct relationship between laboratory analysis and field performance after construction i.e. Super-pave Mix Design method for HMA. The different properties of individual mixture materials aggregates (coarse, fine & filler), bitumen, PVC modified bitumen and different mixes made of this materials are evaluated through different material quality and performance tests; and for the modified and unmodified bituminous mixture, comparisons have been made with one another based on the performance test results and the proposed mix design outcomes.

1.2 Statement of the problem

For hot temperature areas, the most important performance requirement for asphalt mixture is resistance to rutting and resistance to bleeding of asphalt binder. And bitumen has a prodigious influence on this performance requirement and it is very necessary to know how the composition of bitumen affects the physical reactivity of the bitumen itself and the physical property of the asphalt mixture. For flexible pavements, High Temperature causes colossal damage to the pavement majorly due variation of asphalt binder property (rheology) with temprature, therefore, expected extreme tempratures and the damage/effect thereof should be primary consideration and to address this deficiency modifying the bitumen physical property to achieve the required performance can be satisfactorily achieved through bitumen modifiers. In this regard, the previous asphalt binder characterization and grading system(i.e. the empirical system) did not directly account temperature effects and on the other hand, Super-pave asphalt binder performance gardening system corrects this deficiency by grading asphalt binder based on its performance in relation to temperature. In advantage, the Super-pave mix design is advanced to address/consider specific mix design issues with Hveem and Marshal mix design methods such as traffic loading, environmental condition and better simulation with the actual field compaction (gyratory) which in this case more suitable for studying the effect of traffic condition and temprature on the modified and unmodified mix conditions.

1.3 Research questions

The following questions are answered by this research:

- Is waste PVC bitumen modifier compatible with bitumen, and in what conditions?
- What is the effect of Waste PVC bitumen modifier in altering the properties of bitumen, and the overall asphalt mix performance?

- What is the reliable content of modifier to satisfactorily enhance the property of bitumen?

1.4 Objectives of the research

1.4.1 General objectives

The general objective of this research is to study performance of bitumen and bitumenous mixture at high temperature by adding a modifier (i.e. thermoplastic polymer/waste PVC) to the 40/50 bitumen.

1.4.2 Specific objectives

- To check the compatibility of waste polyvinyle chloride with Bitumen,
- To study the performance behavior (ability for rut resistance) of the modified bitumen by varying the modifier content,
- To define the appropriate content of the modifier by weight of bitumen,
- To compare the modified mix with the conventional one through Super-pave mix design.
- To evaluate the performance of the two different mixes using performance tests.

1.5 Scope and Limitation of the Research

The limitations and assumptions of the research are: -

- The experimental tests for this research were limited to the available testing equipment in Addis Ababa University, and test machines which were available at the laboratory of the Modjo – Hawasa expressway project. In this regard, rotational viscometer and indirect tensile test machines (with Super-pave mold) were not available at so many laboratories. Therefore, as a replacement of the rotational viscometer, the compaction and mixing temperature was determined based on the original/pure binder's viscosity.
- The research does not include economic implications (cost analysis) evaluation of the outputs of the research.
- The research is conducted for only one penetration grade bitumen (40/50) and all results of the tests and the overall conclusions are pertinent for similar grade and source of bitumen.

1.6 Significance of the research

This research will make a contribution to waste materials to be recycled and used as a modifier for bitumen mixture which enhances the performance of the mixture in later use in pavement works. Furthermore, it contributes to minimizing environmental damage by adding value to the plastic (non-degradable) waste management problems.

1.7 Outline and organization of the research

Here **Section one** provides the introduction, statement of the problem, objective and significance of the research. **Section 2** comprises literature survey of past experimental investigations on interrelated matters focusing on the study area and significant parameters. **Section 3** sights the methodology for experimental tests and major process of the tests conducted. **Section 4** discusses the results obtained from the experimental studies. **Section 5** determines the conclusion and recommendation of the research.

2 Literature review

This chapter delivers a background of the study area and related subjects and identifies the connection of others works in the context of their contribution to the subject matter and tries to put the topic within the context of existing literature by specifying a case for why further study is required. Thus, further review will be made on the historical background of Super-pave mix design analysis, system components, bitumen modifiers, the relevancy of bitumen modification and performance of pavement in relation to traffic loading and temperature.

2.1 Introduction

Ethiopia's road network has been improving each year. As of the end of Fiscal year 2017/18, Ethiopia had 126,773 kilometers (78,773 miles) of all-weather roads – about 37% of the required road network in the country. In 2017 and 2018, the Ethiopian Goverment invested about 33.1 billion Ethiopian birr in road construction. The Federal roads authority has plans to build a total road stretch of about 10,000 KMs at a cost of 41 billion during the past year (2019). In the previous 15 ysears, the Government of Ethiopia has been robustly engaged in construction of new roads targeting expantion of the existing road network through Road Sector Development Program (RSDP). Throughout the the second Growth ransformation Plan period which covers from 2015/16 to 2019/20, the Government of Ethiopia planned expansion of the the road network of the country to 220,000 kilometers. (Ethiopia road and railway, 2019)

Accordingly, it is understood that our country is assigning large budget for road construction and in order to get (Byram, et al., 2012) well benefits from the invested costs, Proper designed, constructed and maintained Hot Mix Asphalt (HMA) are required for giving many years of satisfactory service in return. However, like all pavements, HMA pavements can be damaged by certain conditions. Different researches and investigations have indicated some of the main reasons behind the failures in road constructions. The common forms of pavement distresses comprises distortion, cracking, skidding hazards, disintegration and surface treatment distress. For these failures, the typical causes include traffic loading (extreme/unexpected traffic and heavy loading), influence of climate or environment, pavement drainage problem, individual material quality deficiencies and workmanship problem. Therefore, climate conditions and traffic load are some of the significant effects of the deterioration and early failure of roads.

2.2 Effect of temperature and Traffic loading on pavement performance

Climate change has a huge effect on the deterioration rates of flexible pavements and pavement service lives. Many studies have indicated that temperature is the supreme significant environmental factor in road construction. For the asphalt mixture, Proper design of a pavement includes consideration of climatic factor. Unless otherwise, distresses caused by the environment are inevitable. The Selection of asphalt binder is strictly related to the surrounding temprature conditions in order to fulfil the pavement functional and structural requirements. To this effect, some recent reserches proved that temperature is the most dominant factor for flexiable pavemnts and the discovery of Byram et al is amongest. (Byram, et al., 2012)

This study is basically conducted to examine the sensitivity of climatic inputs of an American pavement analysis tool, the Mechanistic–Empirical Pavement Design Guide (MEPDG).

Pavement temperature is considered to have an effect on rutting of asphalt, thermal cracking, and age hardening. Because of the viscoelastic nature of bituminous binders, temperature plays an important part in rutting and stiffness performance of asphalt pavement. Enlarged rutting of asphalt is anticipated under higher tempratures, mainly while large and slow traffic volume is experianced. (WillwayT, et al., 2008)

Flexible pavements are more prone to age hardening under increased pavement temperature. Among the undesirable influences on road surface, age hardening is amongst because this can condense the capability of the pavement to flex under traffic. Due to this effect, the surface becomes brittle and vulnerable to cracking. (Ishai, 1987)

In addition to the impact of temperature on the road, as illustrated above; traffic load has a significant influence. Examining the effect of traffic loading on pavement is important since it is an input for the road design and construction process particularly for technical reason (i.e. bituminous mixture & pavement design and for administration which is regulation of total loads of vehicles and regulation of legal axle).

Traffic on a pavement is categorized through a large number of different vehicle types, and traffic loads are considered in pavement design by means of truck factors to change the damage they put on the pavement to the anticipated damage that would be applied through standard axle. The truck factors to change trucks into standard axles or the load equivalent factors to change axles in to standard axles are well-defined by considering the average loads for each axle. This procedure comprises vehicles travling with axle loads beyond the legal limit. This vehicles/axles cause significant damage to pavementsm which intern increases the rehabilitation and construction cost of roads.

Important investigations and recommendations were done by AASHTO road tests which gives the interact information on the effects of axle loads on pavements. Afterwards other essential research has been performed.

The basic behaviors of pavement depends on the combined characteristics of individual pavement materials and thickness, the construction quality, the environmental and climatic condition, and compliant of the subgrade (presence of ground water and bearing capacity of the subgrade material). However, it is the traffic (i.e. frequency, load intensity of the axle and tire configuration) which is principally accountable for pavement damage because of the applied loads by tires of vehicles. In this regared, the critical factor causing failures in pavement resulting rutting and fatigue cracking and at the end demanding pavement rehabilitation at early stage of the road design period is heavy traffic. (JorgeC, 2013)

In a process of investigating the influence of traffic loads on performance of pavement, Timm et al. has recommended models to characterized the distribution of traffic which can be applied to study the influence of the overloaded traffic on pavement performance. (TimmD, et al., 2005)

Currently, in our country, routes serving as main import-export corridors are experiencing hot temperatures and are serving large number of heavy axle traffic and due to this, they are undergoing difficulty withstanding the traffic loading adequately. And now, due to these reasons, rigid pavements are currently introduced to the construction industry. However, from the comparative studies made by Milind V. Mohod & Dr.K.N.Kadam, on rigid and flexible pavements, the disadvantages of rigid pavement when compared with flexible were Higher initial cost of construction; and if not properly constructed tends to be more troublesome for reconstruction or repair and the rough riding quality of rigid pavement than flexible are amongst. (MilindV, et al., 2016)

Thus, even though many advantages will be gained through using rigid pavements like less lifetime cost, durability and ability to accommodate the traffic at difficult external conditions, the initial investment cost is the main factor to be considered to satisfy and address the increasing demand of road and transportation infrastructure. (MilindV, et al., 2016)

This demand for better roads and services required researchers to explore cost effective engineering products in order to satisfy the increasing demand that would economize the construction as well as increase durability like those modifiers which improve the temperature susceptibility and viscosity characteristics of bitumen. Money studies have been conducted on enhancing high temperature performance of flexible pavements and have proposed many types of bitumen modifiers based on experimental studies.

Therefore, Especial attention is needed for the roads constructed in hot weather condition regions and areas of the country. In the same way, the growth in the development of the area, which in consequence will have an enormous contribution for traffic growth, shall be considered on the stage of design. Accordingly, the type of modifiers and the relevance of the same will be discussed on the next section of the chapter.

2.3 Bitumen Modifiers

Bitumen is composed principally of high molecular weight hydrocarbons, having adhesive properties, derived from petroleum either by natural or refinery processes and substantially soluble in carbon disulphide. (Akhber Yousefi ,2002), bitumen in pure form may not be suitable for heavy traffic and high temperature condition. Modern roads and present traffic, therefore forced engineers to modify bitumen to improve its performance during service life. The modified binders are more stable under heavy loads, braking and accelerating forces and shows increased resistance to permanent deformation in hot weather.

There are 3 categories of bitumen modifier, based on the physical changes they make on the overall properties of bitumen, they are categorized as physical, chemical and other type of modification. Among the modification types the research focuses on physical modification.

The type of physical modifiers is indicated in the table below: -

Table 2-1 The type of physical modifier and additive used in the material (Read and Whiteoak, 2003)

TYPE OF MODIFIER	TYPE OF ADDITIVE
(1) Thermoplastic Elastomers	• Styrene – butadiene – styrene (SBS) • Styrene – butadiene – rubber (SBR) • Styrene – isoprene – styrene (SIS) • Styrene – ethylene – butadiene – styrene (SEBS) • Ethylene – propylene – diene terpolymer (EPDM) • Isobutene – isoprene copolymer (IIR) • Natural rubber • Crumb tyre rubber • Polybutadine (PBD) • Polyisoprene
(2) Thermoplastic Polymer	• Ethylene vinyl acetate (EVA) • Ethylene methyl acrylate (EMA) • Ethylene butyl acrylate (EBA) • Atactic polypropylene (APP) • Polyethylene (PE) • Polypropylene (PP) • Polyvinyl Chloride (PVC) • Polystyrene (PS)
(3) Thermosetting Polymers	• Epoxy Resin • Polyurethane Resin • Acrylic Resin • Phenolic resin

Bitumen can be modified using polymers either using physical modification by adding thermoplastic elastomers, thermoplastic polymers & thermosetting polymers or by using a chemical agent as additive like Organo- metallic compounds, Sulphur, hydrated lime & other chemical additives. (Read & Whiteoak, 2003)

However, most modifiers besides being costly are not easily available and since better alternatives with reduced cost are needed, further studies made by Usman G. and Waqass Arshade T. have familiarize the use of Waste polymers like (polyvinyl Chloride (PVC) materials that considers both reduced cost of construction and protected environment from waste plastic in regard to availability and non-degradability of waste plastic materials has been introduced through experimental study. And based on experimental tests they have proved that Waste PVC pipe can be successfully used as modifier with bitumen, and the addition of waste PVC has increased the softening point and decreased the penetration value which will prove beneficial in hot climate areas and also helpful to overcome the bleeding problems and the stability and % air voids of the bituminous mixes were also improved and this intern enables to withstand larger stresses imposed on it by moving wheel loads without sustaining substantial permanent deformation. (Ghani & Tanoli, 2015)

Furthermore, similar results were also obtained on researches made by Bale, Vasudevan and Mauskar on waste plastic modified bitumen with the added content of PVC within the range of 4-8% by weight of bitumen content. (BaleA.S, 2011), (MauskarJ.M, 2008)

The above mentioned researches showed that The performance characteristic of the bituminous mix made up of these modified binder (PVC) were enhanced based on prevailing conditions on each studies but many of the researchers conduct their studies by considering the effects of varying percentage of modifiers with in small range and does not provide the more reliable percentage content of modifier. plus, recent studies made here in Ethiopia using other bitumen modifiers used a marshal mix deign method for the mix design which is an empirical system that did not directly account temperature, traffic and actual performance of the mix and this research focus on this gaps.

This research also considers utilizing waste plastic materials (PVC) for pavement works. Therefore, it is important to review the practices of plastic waste management in our country. Currently, economic development and people’s changing patterns of consumption and production have led to a drastic increase in plastic wastes all over the world. Plastic waste disposal harms the environment and poses a threat to human health. Hence, there is a great desire to reduce plastic wastes. To reduce plastic wastes, education is of utmost importance as education can change people’s knowledge, attitude, and behaviors toward plastic waste management. In this regard, we have to use these surplus wastes to useful material input for engineering and other purposes.

2.3.1 Plastic Waste Management Practices

In developing countries, improper handling and disposal of solid wastes contribute to high level of mortality and morbidity even if produce less per capita solid waste (Me (martin_medina_martinez, 2013), because of cities and municipalities cannot cope up with the accelerated rate of waste production and composition in terms of technology, institutional arrangement and cost-effectiveness of solid waste management (Modak, 2010)

Due to these, improper municipal solid waste disposal and management causes all types of pollution, i.e. air, soil and water pollution (Alam and Ahamade, 2013). This indicated that human health and ecosystem service is threatened by an improper solid waste management system. Even though the overall goal of urban solid waste management is to collect, treat and dispose of solid waste generated by all urban dwellers, 30%–60% of all the urban solid wastes are uncollected, and less than 50% of the population is served (Monoyoncho, 2013). As a result, inefficient municipal solid waste management systems increase disease transmission, contaminate ground and surface water, create greenhouse gas emissions, damage ecosystem services, discourages tourism and other business activities (Alam and Ahamade, 2013).

Taking into account all the mentioned problems, this research also tried to consider waste material (waste PVC) to be used as bitumen modifier which decreases the biodiversity impact of plastic wastes. The following pictures illustrate solid/plastic waste disposal practices in Ethiopia.


Figure 2-1 solid/plastic waste disposal practices around Koshe Addis Ababa Ethiopia

2.3.2 The role of bitumen modifiers in bitumen and bituminous mixture

Bitumen plays a significant role and is responsible for the visco-elastic behavior of asphalts, and this is important in determining many aspects of road performance, particularly resistance to deformation and cracking. In general, the proportion of any induced strain in asphalt that is attributable to viscous flow (i.e. non-recoverable flow) increases with both the loading time and the temperature. One of the prime roles of many bitumen modifiers is to increase the resistance of the asphalt to deformation at high road temperatures without adversely affecting the properties of the bitumen or asphalt at other temperatures. This is achieved by one of the two following methods, both of which result in a reduction in the permanent strain. The first approach is to stiffen the bitumen so that the total visco-elastic response of the asphalt is reduced. The second approach is to increase the elastic component of the bitumen, thereby reducing the viscous component. Increasing the stiffness of the bitumen is also likely to increase the dynamic stiffness of the asphalt. This will improve the load spreading capability of the material, increase the structural strength and lengthen the expected service life of the pavement. Alternatively, it may be possible to achieve the same structural strength but with a thinner layer. Increasing the elastic component of the bitumen will improve the flexibility of the asphalt. This is important where high tensile strains are induced. In the 1970s, the development of PMBs (Jiqing et al., 2014; Taylor and Airey, 2008; Yetkin, 2007) and the use of additives for bitumen by controlled industrial The Shell Bitumen Handbook150.

Furthermore, the addition/modification of bitumen through modifiers requires advanced level test methods in order to evaluate the effects of the modifier on the bitumen by considering the external factors (temperature and traffic loading) as basic input. The research paper also takes in to account the advanced test methods for the evaluation of the modifications made on the bitumen and bituminous mixture. The next section also explains the basics of the test methods utilized in this research.

2.4 Super-pave test methods

A variety of asphalt mix design methods are practiced all over the world such as Asphalt Institute Triaxial, Marshall, Hubbard field, Super-pave, and Hveem mix design methods. Out of these three are most widely practiced: Marshall; Super-pave; and Hveem mix design methods (H.U.Bahia, 1993). The primary problem of the Marshall Design method is that the asphalt mixes are designed based on empirical laboratory procedures, without simulating the actual field conditions. This makes it difficult to accurately predict how a particular mix will perform in the field. (Roberts, et al., 1991). The Super-pave mix design method was developed to fill this need. To design a proper asphalt mix, this method is based on performance-related criteria which allow a direct relationship to be drawn between the lab and field performance of the asphalt mix.

Super-pave stands for Superior Performing Asphalt Pavements. Super-pave was initially developed by the Strategic Highway Research Program (SHRP) (1987-1993) and it continues to improve. This method was mainly developed to improve previous HMA design methods. Some of the primary goals of this method are: better incorporation of traffic and climatic conditions, better asphalt binder and aggregate evaluation and selection and better volumetric approaches to mix design. ((SP-2), 1996)

the temperature conditions under which specified binder properties must be achieved are vastly different, recognizing the deficiencies in the existing system, state highway agencies decided to fund a research program to develop a new system for specifying paving asphalt also and the following features comprises the developed system: -

- it is called a “binder “specification because it is intended for modified as well as unmodified asphalts,
- a unique feature of the Super-pave specification is that the specified criteria remain constant, but the temperature at which the criteria must be achieved changes for the various grades.
- The Super-pave test measures physical properties that can be related directly to field performance by engineering principles.
- The Super-pave binder tests are also conducted at temperatures that are encountered by in-service pavements.

  The following table depicts Super-pave binder test equipment and their purpose.

Table 2-2 Super-pave Binder Test Equipment

Super-pave Binder Test Equipment		
Equipment		**Purpose**
Dynamic Shear Rheometer (DSR)	Amplitude Sweep Test	Measures binders stiffness and elasticity properties at high and intermediate temperatures
	Frequency Sweep Test	
	PG Determination Test	
	Multiple Stress Creep & Recovery Test	
Rotational Viscometer (RV)		Measures binder viscosity at high temperature
Bending Beam Rheometer		Measures low-temperature stiffness and failure properties

The Super-pave mix design process starts with aggregate evaluation. Aggregate characteristics are identified as either source properties or consensus properties. Source properties are defined by the purchasing agency. Consensus aggregate properties were defined by the Super-pave researches to ensure mixes made with the aggregate have good performance characteristics. The researcher envisioned that all agencies using Super-pave would adopt these specifications without modification for local conditions. (McLeod & N.W, 1956)

A study in India by Swami et al. was conducted to ascertain and evaluate how well Super-pave designed mixtures performed compared to conventional Marshall mix with respect to permanent deformation (rutting) using local materials in Malaysia. The study results showed that the Super-pave gyratory compactor (SGC) is capable of achieving lower air void contents than that could be achieved by the mechanical Marshall hammer compactor. Also they found that Super-pave mixes have less asphalt binder contents than the Marshall mixes. (B.L.Swami, et al., 2004)

The presence of modifiers and the effects thereof is also more identifiable through Super-pave test methods since it accounts for the effect of variation of different external factors on the properties of bitumen. Considering this, the Super-pave test methods are selected for this research.

3 Research methods and materials

3.1 Introduction

The research methodology applied for this study is experimental. As it is stated before, the main objective of this study is to investigate the behavior of modified asphalt mixes containing waste polyvinyl chloride at high temperature and heavy traffic condition that is based on the super-pave performance test method. Therefore, it is necessary to conduct all the necessary experimental tests required in order to arrive at a reasonable conclusion point. The tests are conducted on a virgin binder and on the bitumen treated with a waste polyvinyl chloride modifier. Therefore, the research design describes the types of materials to be tested, sample preparation, types of tests and purpose of the test and related matters.

3.2 Experimental Program Test Method

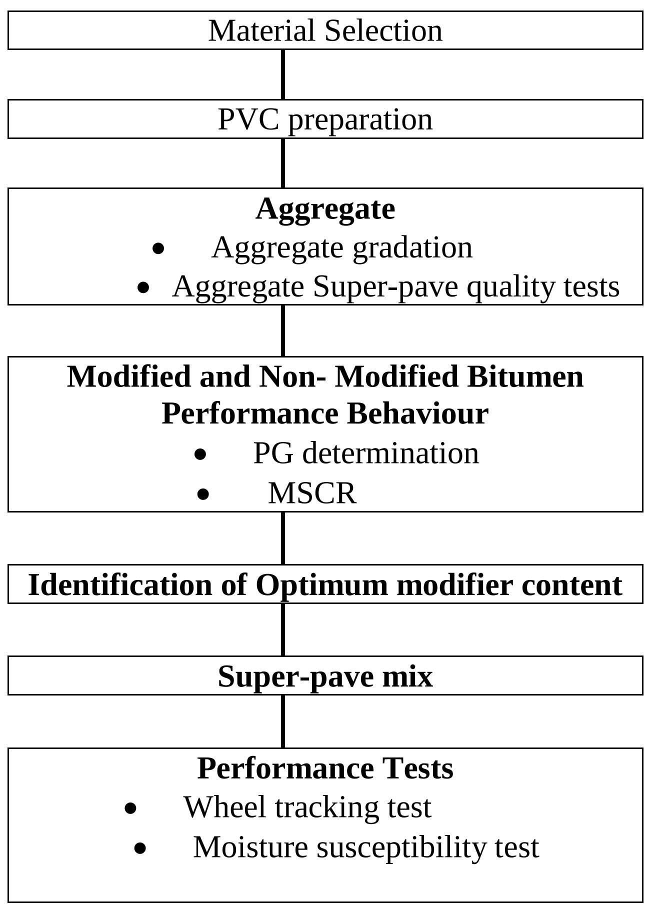


Figure 3-1 Experimental Program

3.3 Materials

Materials required for the research work are as follows:

- Bitumen
- Waste PVC material as modifier
- Aggregates

3.3.1 Bitumen

Super-pave uses its own asphalt binder selection process which is tied to Super-pave asphalt binder performance grading system that is considering the anticipated pavement temperature extremes in the area of intended use. For this study, a penetration grade of 40/50 is used, which is one of the most commonly used bitumen type for hot weather environment in Ethiopia.

3.3.2 Waste PVC material as modifier

By considering the undesirable impact on the environment, a thermoplastic polymer (waste polyvinyl Chloride (PVC)) that has been used previously as plastic partition board and drainage pipe were selected for the modification purpose. The collected PVC was subjected to shredding through shredding machines at plastic factories. Then the shredded pieces were further sieved to get a particle size less than 0.25 millimeter since as per MS4 7th edition, a particulate matter that has a particle size greater than 0.25 millimeter may interfere with the consistency response of tests at high temperature while testing through DSR machine.

However, the PVC powder was not compatible with the bitumen, while mixing, it was noted that all the PVC powder try to stick together rather than dispersing through the bitumen. Further, the distinct powder was unable to melt with in the PVC melting temperature which is suggested to be between 160^{o}c up to 260^{o}c. Nevertheless, within the melting temperature of the PVC it was able to get a PVC burned powder which can be easily pulverized into small pieces. Then, the pulverized pieces were again sieved to get a particle size less than 0.25 millimeter and finally, the compatibility of the bitumen and the burned PVC powder within the range of melting temperature of the PVC were achieved. The following pictures describe the process to prepare a compatible PVC powder modifier for the bitumen.

(a) (b) (c)

Figure 3-2 material preparation of PVC material (a) Pulverized PVC (b) Burning Furness (c) Burned powder

Figure 3-3 bitumen mixed with PVC powder

3.3.3 Aggregates

Aggregates are also major compositions of the asphalt mix, coarse aggregates, fine aggregates and filler (dust) that have been used to conduct the experimental tests for this research.

Figure 3-4 Aggregate used for the asphalt mix

Under the Super-pave system, there are two types of aggregate properties: source properties and Consensus Properties. Those properties must be met at various levels depending on the traffic level and position within the pavement. These properties are requirements for quality of aggregate used in HMA.

3.3.3.1 Consensus properties for aggregate

- coarse aggregate angularity
- fine aggregate angularity
- flat or elongated particles
- clay content

Coarse Aggregate Angularity

This property confirms a high degree of aggregate rutting resistance & internal friction and recommends how much percent of the coarse aggregate has Fractured Face based on traffic level and position within the pavement. The details of the procedure and recommended values are stated under ASTM D 5821.

Table 3-1 Requirements for coarse aggregate angularity

Traffic, million ESALs	Depth from Surface	
	≤ 100 mm	> 100 mm
< 0.3	55	50
0.3 to < 3	75	50
3 to < 10	85/80	60
10 to < 30	95/90	80/75
≥ 30	100/100	100/100
Shoulder	50	50

Fine Aggregate Angularity

This property is distinct as the percentage air void in loosely compacted aggregate sizes smaller than 2.36mm. A higher void content means more fractured faces and confirms a high degree of rutting resistance and fine aggregate internal friction. As per AASHTO T 304 test method, the output results are recommended to have fine aggregate angularity as indicated in the table below based on traffic level and position within the pavement.

Table 3-2 Requirements for fine aggregate angularity

Traffic, million ESALs	Depth from Surface	
	≤ 100 mm	> 100 mm
< 0.3	42	42
0.3 to < 3	42 (45*)	42
3 to < 10	45	42
10 to < 30	45	42
≥ 30	45	45
Shoulder	40	40

Flat and Elongated Particles

Normally, those aggregates which have greater maximum to minimum dimension ratio than five are not recommended for the aggregate structure. Elongated particles are unwanted because they have an affinity to break under traffic and during construction. The test procedure used is illustrated under ASTM D-4791.

Table 3-3 : Requirements for Flat and Elongated Particles for HMA

Traffic, million ESALs	Maximum, Percent
All Traffic Levels	10
Note: Criteria are presented as maximum percent by mass of flat and elongated particles.	

Clay Content (Sand Equivalent)

Clay content (Sand Equivalent) is the percent by volume of clay material which is contained in the aggregate fraction. The sand equivalent value is computed as a ratio of the sand to clay height readings expressed as a percentage.

Table 3.4: Clay Content (Sand Equivalent) Criteria

Traffic, million ESALs	Sand Equivalent minimum, percent
< 0.3	40
0.3 to < 3	40
3 to < 10	45
10 to < 30	45
≥ 30	50
Shoulder	40

3.3.3.2 Source Properties

The source properties are:

- toughness
- soundness

Toughness

Toughness is the resistance of coarse aggregates to abrasion and degradation and is measured by the Los Angeles abrasion test (AASHTO T 96 or ASTM C131). This test estimates the mechanical degradation of aggregates during handling, construction, and in-service. It is performed by subjecting the coarse aggregate, usually larger than 2.36 mm, to impact and grinding by steel spheres. The test result is percent loss, which is the mass percentage of coarse material lost during the test as a result of the mechanical degradation. The percentage loss is recommended to be less than 35 percent.

Soundness

Soundness is the percent loss of materials from an aggregate blend during the sodium sulfate soundness test. The procedure is stated in AASHTO T 104 or ASTM C88. This test estimates the resistance of aggregate to weathering while in service. It can be performed on both coarse and fine aggregate. The test is performed by alternately exposing an aggregate sample to repeated immersions in saturated solutions of sodium or magnesium sulfate each followed by oven drying. One immersion and drying is considered one soundness cycle. During the drying phase, salts precipitate in the permeable void space of the aggregate. Upon re-immersion, the salt rehydrates and exerts expansive forces that simulate the expansive forces of freezing water. The test result is total percent loss over various sieve intervals for a required number of cycles. Maximum loss values range from approximately 10 to 20 percent for five cycles.

Aggregate Gradation

aggregate structure (design blend) consists of determining the aggregate stockpile proportions and corresponding combined gradations of the mix design. The design aggregate structure, when blended at the optimum asphalt binder content, should yield acceptable volumetric properties based on the established criteria.

For this specific study, a nominal size of 19mm has been selected considering heavy traffic (i.e. Design ESALs (million) > 30) and the following figures and charts depicts the template and chart prepared as a requirement based on MS4.

Table 3-4 Gradation control points (Asphalt Institute Manual, MS_4)

19mm nominal size					Sieve Size mm power of 0.45
Sieve Size	Control Points		Restricted Zone		
	Lower	upper	Lower	upper	
25	100	100			4.3
19	90	100			3.8
12.5		90			3.1
9.5					2.8
4.75					2.0
2.36	23	49	34.6	34.6	1.5
1.18			22.3	28.3	1.1
0.6			16.7	20.7	0.8
0.3			13.7	13.7	0.6
0.15					0.4
0.075	2	8			0.3

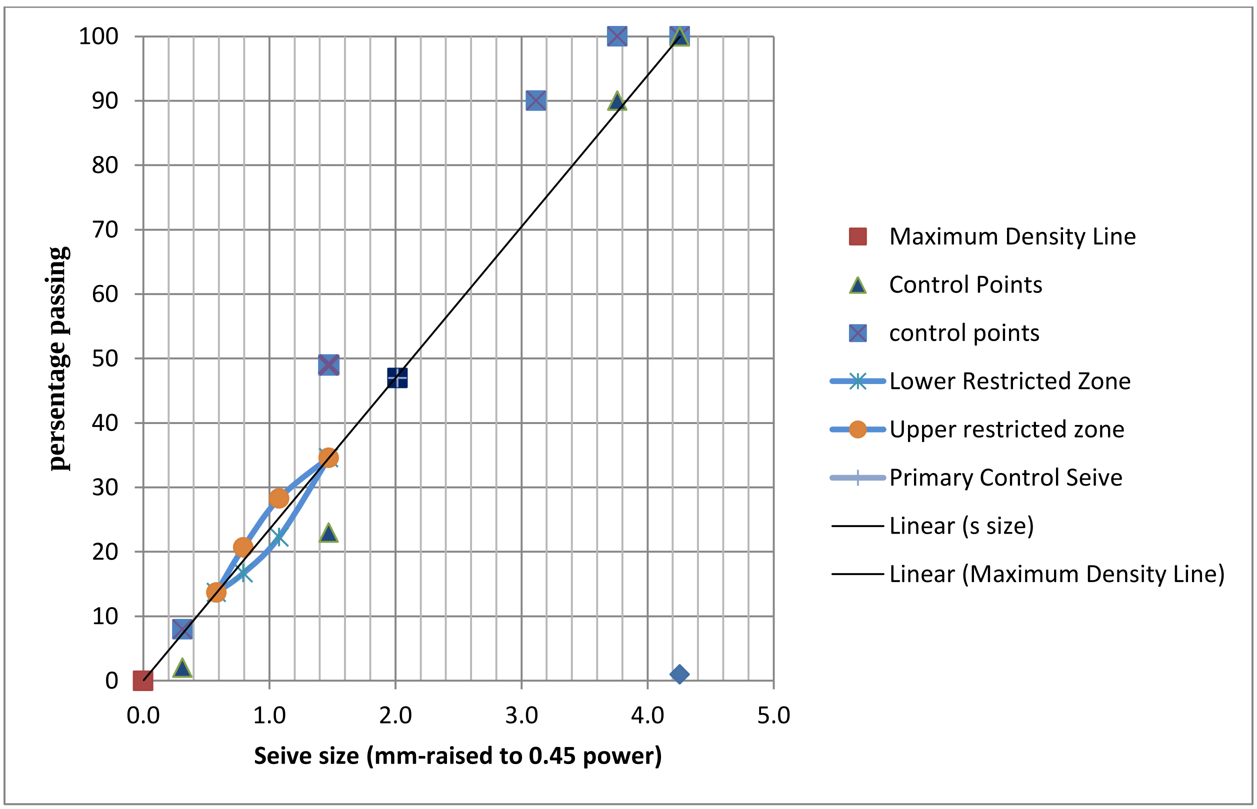


Figure 3-5 grading chart including control and restricted points

3.4 Bitumen Tests

3.4.1 Conventional Tests

The following conventional tests of bitumen have been conducted.

3.4.1.1 Penetration Test

Penetration test measures the consistency (hardness or softness) of asphalt binder. The standard test method for penetration of bituminous materials is described under ASTM D5 or AASHTO T 49. The penetration is determined by measuring the distance in tenths of millimeter that a standard needle vertically penetrates a sample of the material under a specified load at a specified temperature within a specific period of time. In normal condition, 100g of loading at a temperature of 25°C and 5sec of testing time is common. Higher values of penetration indicate softer consistency and the lower the value the harder the bitumen is. Here the penetration test is conducts in order to confirm the supplier data.

3.4.1.2 Kinematic viscosity

It is the ratio of - absolute (or dynamic) viscosity to density - a quantity in which no force is involved (gravitational force). Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with the fluid mass density. On which absolute viscosity - coefficient of absolute viscosity - is a measure of internal resistance. It is the tangential force per unit area required to move one horizontal plane with respect to another plane - at a unit velocity - when maintaining a unit distance apart in the fluid. Here, viscosity test was conducted in order to estimate the compaction and mixing temperature of the mix.

3.4.1.3 Specific gravity (as an input for the asphalt mix design)

The specific gravity of bitumen is the ratio of the mass of a given volume of bitumen to the mass of an equal volume water at a similar temperature. The specific gravity of bitumen is an input for the mix design process.

3.4.2 Conditioning test

A. RTFO (Rotational Thin Film Oven test)

The basic RTFO procedure is conducted with unaged asphalt binder samples in cylindrical glass bottles and these bottles are placed in a rotating carriage within an oven. The carriage rotates within the oven while the 325°F (163°C) temperature ages the samples for 85 minutes. RTFO aged sample simulates the reaction of the bitumen with oxygen while mixing and placing of the asphalt mix by considering the short term aging of the bitumen due to the same scenario.

Figure 3-6 RTFO test Machine

3.4.3 Asphalt SUPER-PAVE Tests

Super-pave binder tests are used to quantify the asphalt performance at different stage of the pavement life. It used to study the bitumen property at its original state, after mixing and placing of the asphalt layer (short term aging effect) and after its service/design life (long term aging effect) considering different external factors. In this research, before beginning of tests for the bitumen, test specimens (bitumen and PVC powder) were prepared accordingly the bitumen was heated at 165^{o}c first and based on related researches (i.e. research done by (Ambika Behl, 2012) and (Shirish N. Nemade, 2013)), the mixing temperature for blending bitumen and PVC was considered between 160^{o}c and 165^{o}c, (this temperature is also with in the range of pvc melting temperature which is also used to crack the pvc in to powder form), and the frequency of the stirrer Machine (i.e. 2000rpm using electronic stirrer machine). The mixing time was considered to be 40 minutes.

Figure 3-7 Electronic Stiring Machine

Table 3-5 proportions for Mixing/Blending of Waste PVC Material with Bitumen

1	0%-PVC
2	8%-PVC
3	10%-PVC
4	12%-PVC
5	14%-PVC

Figure 3-8 prepared samples with different asphalt and PVC proportion

3.4.3.1 Dynamic Shear Rheometer (DSR) Tests

The rheological behavior of asphalt depends on both temperature and loading time. And a supreme test for asphalt should consider both factors. In this regard, the Dynamic Shear Rheometer (DSR) test machine has a competency of considering both effects in the test procedure. The DSR is used to characterize the viscous and elastic behavior of asphalt binders. It measures the viscous and elastic properties of a thin asphalt binder sample sandwiched between an oscillating and a fixed plate. Operational details of the DSR can be found in AASHTO T 315.

Figure 3-9 DSR test machine

In this research, among the DSR tests, only PG determination and Multiple stress recovery tests were conducted for original and aged binder respectively.

A. PG Determination Test

PG determination test is one of DSR tests which is conducted at high temperature in order to categorize the bitumen, based on its temperature resistance considering PG factors. The basic target here is to determine the complex shear (G*) modulus and phase angle (δ) of asphalt binders. The apparatus consists of a dynamic shear rheometer (DSR), a temperature controller, and a computer that is used to control the rheometer and acquire data. The test is performed on unaged binders and binders that have been aged in a rolling thin film oven. However, in this research considering updated versions of the DSR tests and considering better correlation with the actual performance of HMA on fields, MSCR test better simulates the effect of temperature and traffic loading. Therefor, here PG determination test is conducted in order to identify testing temperatures for MSCR test and for minimizing several trials for later tests. And the tests are conducted for only unaged binder. Super-pave specification defines and places requirements on a rutting factor, G*/sin δ which represents a measure of high-temperature stiffness; and to minimize the rutting effect of the asphalt G*/sin δ should be minimum of 1Kpa for unaged binder.

B. Multiple stress creep and Recovery Test

The Multiple Stress Creep Recovery (MSCR) test is the newest upgrading to the Super-pave PG Asphalt Binder specification. The requirement/procedure is listed under AASHTO T350 and AASHTO M332. MSCR provides a new high-temperature binder specification that more accurately indicates the rutting performance of the asphalt binder. It avoids the need to conduct tests such as elastic recovery and phase angle designed specifically to indicate polymer modification of asphalt binders. A single MSCR test can provide information on both the performance and formulation of the asphalt binder. The MSCR test results allow binder formulators to use a more economical use of polymers to improve performance.

MSCR test uses the Dynamic Shear Rheometer to measure the nonrecoverable creep compliance (Jnr) and percent recovery (R3.2). The asphalt binder sample is sandwiched between the DSR's parallel plates and is sheared for one second and allowed to recover without loading for nine seconds. J (compliance) is inversely related to the complex modulus. The lower the Jnr value the stiffer the binder. The permanent strain measured directly relates to rutting. The calculated Jnr is unrecoverable strain/ applied stress. The R3.2 which gives us information about binder modification is recoverable strain/unrecoverable strain x 100%. Recovery tells us how readily the sample will return to its original form.

3.5 Asphalt Mix Design using the Super-pave method

3.5.1 Determining the Optimum Binder Content

Based on the test results from the bitumen test (i.e. PG determination test and MSCR test), one optimum content of PVC is selected and for comparison purpose one modified and non - modified mixes (at optimum content of PVC) are prepared as per the following procedures. By utilizing the selected aggregate gradations initially, the optimum binder content was predicted and samples were prepared accordingly. Design bitumen content is determined giving air void content of 4% at design gyration and insuring the specification values for Voids in mineral aggregates (VMA), Voids Filled with Asphalt (VFA) and Specific gravity.

Primarily, the actual traffic load for 20 years regardless of actual roadway design life and the number of gyration is selected according to the table below;

Table 3-6 A number of gyration for Ninitial, Ndesign, Nmax (SP-2, third edition)

20-yr Traffic Loading	Number of Gyrations		
(10^6 ESALs)	$N_{initial}$	N_{design}	N_{max}
<0.3	6	50	75
0.3 to 3	7	75	115
3 to 30	8	100	160
≥ 30	9	125	205

The traffic load is selected for ESALs > 30 for 20-year traffic loading and Ndesign is selected as 125. When the gyration number is selected specimens with three different binder contents (5.2%, 5.3%, and 5.4%) is prepared. For modified binder (5.8%, 6% and 6.2%). All of them have been compacted with the Ndesign gyration numbers. After the compaction, the air void contents, VMA contents, VFA contents and specific gravity values are calculated according to the following equations;

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100 \tag{3.1}$$

$$G_{mb} = \frac{W_d}{W_{SSD} - W_{Sub}} \tag{3.2}$$

$$G_{mm} = \frac{W_{agg} + W_b}{V_{eff} + V_b} \tag{3.3}$$

$$V_{eff} = V_{agg} - V_{BA} \tag{3.4}$$

Where; Va is the air void (%),

G_{mm} is the theoretical Specific gravity ($g\ cm3/$),

wD is the dry weight (g),

$WSSD$ is the saturated surface dry weight (g),

$Wsub$ is the weight submerged in water (g),

$Wagg$ is the weight of aggregate (g),

Wb is the weight of binder= (g),

V_{eff} is the effective volume of aggregate (cm3),

V is the volume of binder (cm3),

V_{agg} is the volume of aggregate (cm3),

V_{BA} is the volume of absorbed asphalt (cm3),

When the air voids are calculated the corresponding VMA and VFA values are calculated with the following equations;

$$V_{MA} = 100 - \left[\frac{G_{mb} \times P_s}{G_{sb}} \right] \qquad (3.5)$$

$$V_{FA} = V_{MA} - P_a \qquad (3.6)$$

Where; VMA is the voids in mineral aggregate (%),

Ps is the aggregate content by weight of mix (%),

Gsb is the bulk specific gravity of the aggregate ($g\ cm$3),

VFA is the voids filled with asphalt (%),

Pa percent of the air voids (%),

Accordingly, the design mix is selected considering the mix at the optimum bitumen content that satisfies all volumetric properties requirements and compaction characteristics.

The following figures illustrate the test machines used for the mix design preparation and sample preparations for the mix.

Figure 3-10 vacuum pump machine (used to suck the air in the asphalt mixture)

Figure 3-11 Gyratory compaction machine

Figure 3-12 Super-pave Compacted Samples

3.6 Performance tests

As part of the study, after proper mixes with the required proportion of aggregate and bitumen is identifies further performance evaluation of the two types of mixes were conducted through wheel-track and moisture susceptibility tests. Here the wheel track test for both modified and non-modified samples is conducted at 64^0c for comparison purposes.

3.6.1 Moisture Susceptibility

AASHTO T283 (2011) test procedure is used to obtain the Indirect Tensile (IDT) strength. Here for moisture susceptibility test the method of compaction and the over all procedure is adopted based on marshall test method due to the reason that the molds avialble at the laboratory for this particular test was marshal moulds. Accordingly, the mixtures are compacted with 400 blows for each side. Compacted specimens are prepared to be further conditioned in water at 60oc for 24 hours to simulate the water damage on the mix and other untreated samples as a control to verify the percentage difference/ratio on the tensile strength of test specimens. Typical TSR values are expected to lie in between the range from 70% to 90%. The following figures show the test machines for the indirect tensile strength and sample socking water bath which was used for conditioning the samples.

Figure 3-13 Indirect Tensile strength test machine

Figure 3-14 water bath for conditioning samples for moisture susceptibility test

3.6.2 Wheel Tracking Test

The wheel track is used to evaluate the rutting performance of asphalt mixture. Before beginning the test, samples were prepared using a slab compactor machine with 25 number of passes considering the initial compaction of asphalt after placing. Then the compacted specimen is subjected to wheel tracking test for 6hrs and 20,000 number of passes (i.e. the number of pass simulates heavy traffic condition which exceeds 30million ESAL) with controlling the temperature at 64oc. The following figures show the wheel track machines and specimens (including after tests are conducted).


Figure 3-15 Wheel truck test machine

Figure 3-16 Specimen compactor for Wheel track

Figure 3-17 wheel truck specimen after test

4 Result and Discussion

This part of the research signifies the study results in light of the conducted laboratory tests and interprets and describes how the results fit with the prevailing knowledge, what new comprehensions they contribute and insights confirmation and challenges with the prevailing theories.

4.1 Analysis and Interpretation of Asphalt Test Results

Almost all tests conducted here are based on super pave test methods except penetration and viscosity for the original binder (i.e. in order to confirm the penetration grades of the bitumen and for the purpose of determining mixing and compaction temperature) and moisture susceptibility test for the asphalt mixes for both modified and non- modified was conducted using Marshall test machine (i.e. Marshall test machine is used here due to the difficulty of using Super-pave gyratory compacter mold at the laboratory for moisture susceptibility test).

4.1.1 Conventional Tests for Asphalt

Conventional Tests for asphalt binder undergoes rigorous methods that do not have a common generic asphalt binder selection and evaluation procedure; each specifying entity uses empirical methods and have poor relation with the performance of asphalt on the actual conditions.

Here, penetration test was conducted to confirm the supplier data and Kinematics viscosity test was conducted for the purpose of determining compaction and mixing temperature for later use of the Asphalt mix procedures. Results of conventional tests conducted on the binder are given in the table 4-1 below: -

Table 4-1 penetration and kinematic viscosity specific gravity test result

Description of test	Test Method	Composition	Test Result
Penetration value AC 40/50 at 25^{o} c	AASHTO T49	Non modified bitumen	44
Kinematics Viscosity at 135 ^{o} c Cst (for non modified bitumen)	AASHTO T201	Non modified bitumen	400
Kinematics Viscosity at 160 ^{o} c Cst (for non modified bitumen)	AASHTO T201	Non modified bitumen	190
Specific gravity at 25^{o}c	AASHTO T228	Non modified bitumen	1.026
Specific gravity at 25^{o}c	AASHTO T228	modified bitumen	1.041

As depicted in the table above the penetration value is 44 which confirms that the penetration grade of the original asphalt is 40/50; and the fluid's internal resistance to flow under gravitational force at different tempratures is also presented with Cst (square millimeter per second).

4.1.2 Super pave tests for Asphalt

The basis for conducting Super-pave tests for the asphalt in this research is basically to study the material property under different (i.e. high) temperature and to determine the optimum content of modifier that brings satisfactory test results for later use in the mix design. And this research only focuses on high pavement temperature since the study is basically for high temperature and heavy traffic performance of asphalt mix.

As preliminary, prior to the beginning of tests, the first preparation work was mixing the PVC powder with the bitumen; as mentioned in chapter three, the PVC is first prepared in a powder form with a particle size of less 0.25 millimeter. Then, the powder was added percentage by weight of the bitumen and thoroughly mixed with the bitumen until a uniform mixture is developed the percent compositions mentioned under table 3.5 are decided through PG determination tests, after many trials, by considering those results that show significant changes in the output results. Further, the initial trials for determining the amount of PVC to be added to the bitumen were based on previously conducted researches. However, it was difficult to attain similar percentages since most of the researches were done by melting the PVC with chemicals or by using the unprocessed or the virgin PVC powder as a bitumen modifier.

4.1.2.1 Performance grade determination

In the case of performance grade determination using DSR, as the shear stress, (τ) is applied to the test samples, it measures the response (shear strain) of the asphalt. The relationship between the applied stress and the resulting strain provides information necessary to calculate the complex shear modulus (G*) and phase angle (δ /delta). Here the strain (input) was 12% and this being an input for the test the samples were conditioned for 10 minutes and the test was conducted at different Temperatures with 6^{o}c increments until the sample fails to satisfy the required resistance for the provided temperature (i.e until $G^*/\sin\delta$ becomes less than 1Kpa) . The following table shows the test results of all binders (both modified and non-modified) including the exact temperature at which the requisite factor goes beyond the required limit.

Table 4-2 PG determination test results of modified and unmodified original binder

40/50 binder and modifier composition	Trials	Temperature (°C)	Phase Angle (°)	Complex Modulus (KPa)	Elastic Modulus (KPa)	Viscous Modulus (KPa)	G*/sin δ	Pass Fail Temp	Avg. Pass Fail Temp
100% - bitumen 0% - PVC	1	58.1	88.9	2.92	0.06	2.92	3.63	65.7	65.73
		64.09	89.28	1.22	0.02	1.22	1.26		
		70.05	89.25	0.55	0.01	0.55	0.57		
	2	58.02	89.04	2.87	0.05	2.87	3.27	65.8	
		64.09	89.47	1.26	0.01	1.26	1.26		
		69.96	89.4	0.56	0.01	0.56	0.57		
	3	58.04	89.02	2.89	0.05	2.89	3.32	65.7	
		64.09	89.24	1.23	0.02	1.29	1.29		
		70.05	89.35	0.55	0.01	0.55	0.56		
92% - bitumen 8% - PVC	1	58.01	88.9	4.32	0.08	4.32	5.37	68.5	68
		63.95	89.28	1.85	0.02	1.85	1.91		
		69.95	89.26	0.82	0.01	0.82	0.85		
	2	58.06	88.72	3.84	0.09	3.84	5.6	68.1	
		64.07	88.9	1.69	0.03	1.69	2.1		
		69.98	88.81	0.78	0.02	0.79	1.05		
	3	58.04	88.72	3.46	0.08	3.46	5.04	67.4	
		64.1	88.91	1.5	0.03	1.5	1.85		
		70.02	88.73	0.71	0.02	0.71	1.03		
90% - bitumen 10% - PVC	1	58.06	88.3	4.33	0.15	4.33	13.15	69	68.87
		64.02	88.72	1.93	0.05	1.93	2.81		
		69.98	88.34	0.88	0.03	0.88	2.4		
	2	58.03	88.41	4.59	0.13	4.58	10.64	68.9	
		63.93	88.76	1.96	0.04	1.96	2.75		
		69.9	88.75	0.87	0.02	0.87	1.23		
	3	57.91	88.46	4.3	0.12	4.3	9.05	68.7	
		64.09	88.83	1.84	0.04	1.84	2.42		
		70.03	88.88	0.84	0.02	0.84	1.06		
88% - bitumen 12% - PVC	1	58.06	88.71	5.09	0.11	5.09	7.5	69.3	69.33
		63.97	89.26	2.11	0.03	2.11	2.19		
		69.99	89.4	0.91	0.01	0.91	0.92		
	2	57.96	88.55	4.71	0.12	4.71	8.52	69	
		63.94	89.01	1.98	0.03	1.98	2.29		
		69.99	89.15	0.87	0.01	0.87	0.94		
	3	58.1	88.58	4.78	0.12	4.78	8.28	69.7	
		63.95	89.1	2.11	0.03	2.11	2.32		
		70.1	89.25	0.95	0.01	0.94	0.98		

86% - bitumen 14% - PVC	1	57.98	88.7	5.86	0.13	5.86	8.74	70.3	70.27
		64.08	89.22	2.42	0.03	2.42	2.54		
		70.1	89.46	1.03	0.01	1.03	1.03		
		76.04	89.23	0.48	0.01	0.48	0.5		
	2	58.1	88.77	5.54	0.12	5.54	7.69	70.4	
		64.01	89.22	2.34	0.03	2.34	2.46		
		70.01	89.3	1	0.01	0.99	1.03		
		76.07	89.42	0.45	0.01	0.43	0.46		
		57.97	88.75	5.7	0.13	5.72	8.06	70.1	
		64.02	89.24	2.37	0.03	2.37	2.48		
		70.09	89.36	1.01	0.01	1	1.02		
		76.01	89.33	0.46	0.01	0.44	0.47		

N.B, minimum of 3 trials have been conducted for the conducted tests

Based on the results, the complex shear modulus (G*) is the ratio of the total shear stress to the total shear strain and the time lag between the applied stress and the resulting strain is related to the phase angle (δ /delta). For perfectly elastic material an applied load causes an immediate response; thus the time lag or phase angle is zero, meanwhile a viscous material has a relatively larger time lag between load and response. Before the formation of the MSCR test, Super-pave specification defines and places requirements on a rutting factor, G*/sin δ which represents a measure of high-temperature stiffness or rutting resistance; and to minimize the rutting effect of the asphalt G*/sin δ should be minimum of 1Kpa for the original binder.

Accordingly, as presented on the table above, all compositions of binders except the 14% modifier & 86% binder composition, failed the minimum criteria of AASHTO M-320 (i.e. G*/sin δ > 1Kpa) between 64oC and 70 oC and the latest fails to satisfy after 70oc. And this indicates the used 14% modifier has better resistance under higher temperatures relative to the others.

As a result, based on the average pass-fail temperature (i.e., for every three trials), and the corresponding rutting factor (G*/sin δ) the equivalent PG grade is determined as follows:- (here the PG graids are disiginated as “PG HH – LL”, HH stands for the high temperature at which the samples deem to comply the rutting factor /limit to the maximum and LL stands for the low temperature; however, since the research focuses on high temperature performance this area has not been included/studied in this circumstance).

Table 4-3 equivalent PG grade for the binder

binder Type	composition	Avg. Pass Fail Temp	G*/sin δ > 1Kpa	PG Determination
40/50	0% - PVC 100% - bitumen	65.73	1.26	PG 64 – LL
			1.26	PG 64 – LL
			1.29	PG 64 – LL
	8% - PVC 92% - bitumen	68	1.91	PG 64 – LL
			2.1	PG 64 – LL
			1.85	PG 64 – LL
	10% - PVC 90% - bitumen	68.87	2.81	PG 64 – LL
			2.75	PG 64 – LL
			2.42	PG 64 – LL
	12% - PVC 88% - bitumen	69.33	2.19	PG 64 – LL
			2.29	PG 64 – LL
			2.32	PG 64 – LL
	14% - PVC 86% - bitumen	70.27	1.03	PG 70 – LL
			1.03	PG 70 – LL
			1.02	PG 70 – LL

N.B, minimum of 3 trials have been conducted for the executed tests and the study gives emphases on for only high temperature

Accordingly, all binders (0%, 8%, 10%, 12%) compositions are categorized as PG 64 and 14% modified binder categorized as PG 70. Note that the drade classification is further strengthen/ confirmed through MSCR test since PG is less correlated (is indicator of) rutting performance.

4.1.2.2 Multiple Stress Creep Recovery

Principally, in rating binders for rutting resistance, the PG rutting parameter (G*/sinδ) was found to have poor correlations with field rutting. It was found to be deficient in indicating the rutting performance of some binders on previous studies, particularly polymer-modified binders. As a consequence, this has become the reason for the development of the improved test method (i.e. Multiple Stress Creep Recovery (MSCR) test) which has a better correlation with rutting performance. The determination of PG temperature minimizes the number of tests for too many temperature levels. Therefore, based on the determined PG grade of each binder, the MSCR test was conducted at a temperature of the corresponding PG grade and at the immediate preceding and succeeding grades with number of three trials for every sample. The temperature level for each sample are depicted in the table below: -

Table 4-4 Testing Temperature for MSCR test

binder Type	composition	Equivalent PG	Testing Temperature			
40/50	0% - PVC 100% - bitumen	PG 64	58	64	70	-
	8% - PVC 92% - bitumen	PG 64	58	64	70	-
	10% - PVC 90% - bitumen	PG 64	58	64	70	-
	12% - PVC 88% - bitumen	PG 64	58	64	70	-
	14% - PVC 86% - bitumen	PG 70	58	64	70	76

After the samples are prepared based on the above compositions, the samples were exposed for aging using RTFO (rolling thin film oven) aging machine, all samples were exposed for 85 minutes under 163oc with an application of external air pressure. The samples have been checked for percent mass/weight loss before and after aging condition and it was confirmed that all samples are in the range of 0.05 to 0.5 percent.

Subsequently, based on the computation illustrated under chapter three for MSCR test, all output data are computed using similar procedures and for purpose of demonstration among the three trials for a sample, one trial test which is conducted at 58oc for pure bitumen is presented in table 4-6 below.

Table 4-5 computation of MSCR test data for 0.1Kpa stress level for pure bitumen at a temperature of 58^{o}c

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}
0.1 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	ε_r	$\varepsilon_r(0.1,N)=(\varepsilon_c-\varepsilon_r)/\varepsilon_1*100$	$\varepsilon_{10}=\varepsilon_r-\varepsilon_o$	$J_{nr}(0.1,N)=\varepsilon_{10}/0.1kPa$
1	197.92613	218.72542	20.79929	217.52700	5.8	19.60087	1.96
2	217.79331	238.13986	20.34655	236.99470	5.6	19.20139	1.92
3	237.31428	257.79399	20.47971	256.59557	5.9	19.28129	1.93

4	256.91515	277.34160	20.42645	276.19644	5.6	19.28129	1.93
5	276.51602	296.96909	20.45308	295.69078	6.2	19.17476	1.92
6	295.98372	316.83628	20.85255	315.53133	6.3	19.54760	1.95
7	315.85091	336.49041	20.63950	335.21209	6.2	19.36118	1.94
8	335.53167	355.98474	20.45308	354.41348	7.7	18.88181	1.89
9	354.73306	375.18614	20.45308	373.69477	7.3	18.96171	1.90
10	374.01435	394.46742	20.45308	392.92279	7.6	18.90844	1.89
Temperature		**58°C**			**6.4**		**1.92**
						Avg	**1.9220**
						Min	**1.8882**
						Max	**1.9601**
					% Normalized Range		**3.7412**

Table 4-6 computation of MSCR test data for 3.2Kpa stress level for pure bitumen at a temperature of 58^{o}c

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	ε_r	$\varepsilon_r(3.2,N)=(\varepsilon_c-\varepsilon_r)/\varepsilon_1*100$	$\varepsilon_{10}=\varepsilon_r-\varepsilon_o$	$Jnr(3.2,N)=\varepsilon_{10}/3.2kPa$
1	404.02817	1073.25393	669.22576	1067.95418	0.8	663.926	2.07
2	1079.61883	1753.55840	673.93957	1751.05500	0.4	671.436	2.10
3	1762.13375	2439.77505	677.64130	2437.35160	0.4	675.218	2.11
4	2448.32382	3125.96518	677.64136	3121.89053	0.6	673.567	2.10
5	3133.26223	3811.46285	678.20062	3807.38820	0.6	674.126	2.11
6	3818.33379	4499.78347	681.44968	4495.44247	0.6	677.109	2.12
7	4506.97395	5191.53948	684.56553	5187.22515	0.6	680.251	2.13
8	5198.67674	5886.46475	687.78800	5882.15041	0.6	683.474	2.14
9	5893.14927	6581.92265	688.77338	6577.42183	0.7	684.273	2.14
10	6588.74026	7274.13143	685.39117	7269.60401	0.7	680.864	2.13
Temperature		**58°C**			**0.59**		**2.11**
						Avg	**2.1138**
						Min	**2.0748**
						Max	**2.1384**
					% Normalized Range		**3.0080**

Table 4-7 Jnr diff computation

Stress Cycle	Jnr diff=(Jnr3.2-Jnr,0.1)/Jnr0.1*100
1	5.851
2	9.275
3	9.435
4	9.168
5	9.865
6	8.247
7	9.796
8	13.117
9	12.772
10	12.526
Avg	10.005

Accordingly, all test data are computed with similar procedure and the computations for the remaining all samples are attached in the Appendix.

From the computation and analysis of test data two vital parameters i.e. Non Recoverable Creep Compliance (Jnr) and Percent Recovery are basically considered, and they are used for analyzing properties of a binder at high temperatures. Accordingly, Jnr is a measure of the amount of residual strain left in the binder specimen after repeated creep and recovery, relative to the applied stress magnitude. The %Recovery at 3.2 kPa is a measure of how much the sample returns to its previous shape after being repeatedly stretched and relaxed.

According to AASHTO M-332 there is a standard specification for PG grade asphalt based on Jnr 3.2 value and other parameters of MSCR test result as stated in the table below:-

Table 4-8 Standard Specification for PG Binder Using MSCR Test (AASHTO M-332)

Traffic Category	Traffic levels (ESALs)	Traffic Speed/Load rate(km/h)	Jnr diff	Jnr3.2 (kPa-1)
Standard "S"	<10 million	>70	max 75%	4
Heavy "H"	10>30 million	20-70 (slow)	max 75%	2
Very Heavy "V"	>30 million	< 20	max 75%	1
Extremely Heavy "E"	>30 million	< 20 (standing)	max 75%	0.5

As depicted in the table above, for example for specific temperature say 580c and with Jnr(Kpa-1) (τ=3.2) value of 1.987, the sample is categorized with a grade under PG58H-LL. (which means the sample has a maximum resistance of heavy traffic i.e. 10 – 30Million ESAL, with traffic speed of 20-70Km/hr at 58^{o}c.)

According to the requirements indicated above, test results of each sample are evaluated against the non-Recoverable Creep Compliance Jnr(Kpa-1) (τ=3.2) limits. Subsequently, the categorization of each binder based on the test results is summarized as shown in the table 4-10 below: -

Table 4-9 summary of test results of MSCR and grading of asphalt based on Jnr(Kpa-1) (τ=3.2)

binder Type	composition	Temprature (^{o}c)	trial	Jnr(Kpa-1)		Jnr diff	% Recovery	average Jnr(Kpa-1) (τ=3.2)	Grade
				τ=0.1	τ=3.2	(Kpa)	τ=3.2		
40/50	0% - modifier 100% - binder	58	1	1.92	2.11	10.0%	0.59	1.987	PG58H - LL
			2	1.82	1.95	7.13%	0.61		
			3	1.87	1.90	1.83%	0.58		
		64	1	2.99	3.29	10.1%	0.17	3.287	PG64S - LL
			2	2.98	3.38	13.1%	0.2		
			3	2.79	3.19	14.3%	0.19		
		70	1	10.74	11.26	4.8%	-0.45	11.235	-
			2	10.47	11.21	7.0%	-0.44		
40/50	8% - modifier 92% - binder	58	1	1.54	1.55	0.6%	1.14	1.637	PG58H- LL
			2	1.68	1.72	2.4%	1.43		
			3	1.61	1.64	1.9%	1.31		
		64	1	2.85	3.00	5.2%	0.28	3.145	PG64S - LL
			2	2.76	3.20	15.8%	0.29		
			3	2.99	3.24	8.4%	0.26		
		70	1	6.51	7.30	12.1%	-0.04	7.037	-
			2	6.44	6.92	7.5%	0.01		
			3	5.98	6.89	15.2%	0.02		
40/50	10% - modifier 90% - binder	58	1	1.16	1.20	2.9%	1.46	1.173	PG58H - LL
			2	1.09	1.15	5.8%	1.58		
			3	1.12	1.17	4.3%	1.52		
		64	1	2.75	3.05	11.1%	0.45	3.027	PG64S - LL
			2	2.82	3.00	6.4%	0.4		
			3	2.79	3.03	8.7%	0.42		
		70	1	6.48	7.03	8.5%	-0.12	7.013	-
			2	6.27	7.00	11.6%	-0.1		
			3	6.38	7.01	10.0%	-0.11		
40/50	12% - modifier 88% - binder	58	1	0.92	1.02	10.99%	1.78	1.100	PG58H - LL
			2	1.13	1.18	5.0%	1.25		

binder Type	composition	Temprature (°c)	trial	Jnr(Kpa-1)		Jnr diff	% Recovery	average Jnr(Kpa-1)	Grade
			3	1.02	1.10	7.7%	1.5		
		64	1	2.43	3.03	25.5%	0.54	2.830	PG64S - LL
			2	2.64	2.85	8.2%	0.58		
			3	2.45	2.61	6.4%	0.51		
		70	1	5.21	6.40	23.2%	-0.02	6.820	-
			2	6.7	7.24	8.1%	-0.14		
			3	5.95	6.82	14.6%	-0.08		
40/50	14% - modifier 86% - binder	58	1	0.69	0.72	4.8%	2.73	0.753	PG58V - LL
			2	0.77	0.79	2.0%	2.52		
			3	0.73	0.75	3.2%	2.62		
		64	1	1.73	1.85	7.2%	0.89	1.790	PG64H - LL
			2	1.42	1.59	12.1%	1.25		
			3	1.76	1.93	9.2%	0.85		
		70	1	3.82	4.00	4.9%	0.17	3.930	PG70S - LL
			2	3.46	3.79	9.5%	0.26		
			3	3.73	4.00	7.2%	0.21		
		76	1	8.65	9.22	6.6%	-0.28	8.515	-
			2	7.3	7.81	7.0%	-0.53		

As depicted in the above table the Jnr3.2 value decreases as the percentage of PVC modifier increases from 8% to 14% for all test temperatures. Plus, based on the result it is only possible to attain the required performance at 70oc on the modified bitumen at 14% PVC but only for Standard "S" traffic with ESAL of less10 million. Further, it can be noted that for all samples the Jnr diff is way less than 75%.In addition, the following figures illustrate the effect of variation of temperature on the total strain at different stress levels and the effect of addition of PVC at different present on the total strain at maximum stress level (3.2Kpa). (N.B the following data is sample selection for demonstration the remaining samples shares similar trained and are attached in the appendix part of the research paper.)

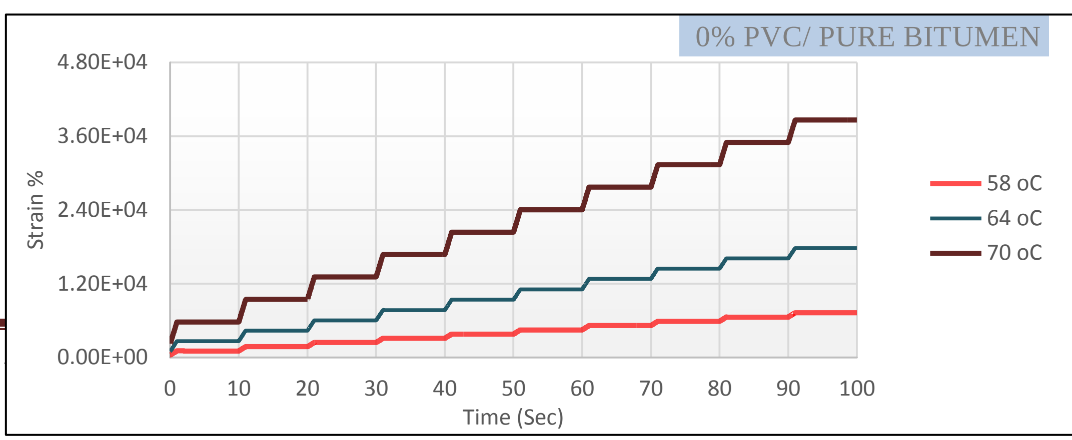


Figure 4-1 effect of variation of temperature on the total strain at stress level 3.2 kpa for pure bitumen

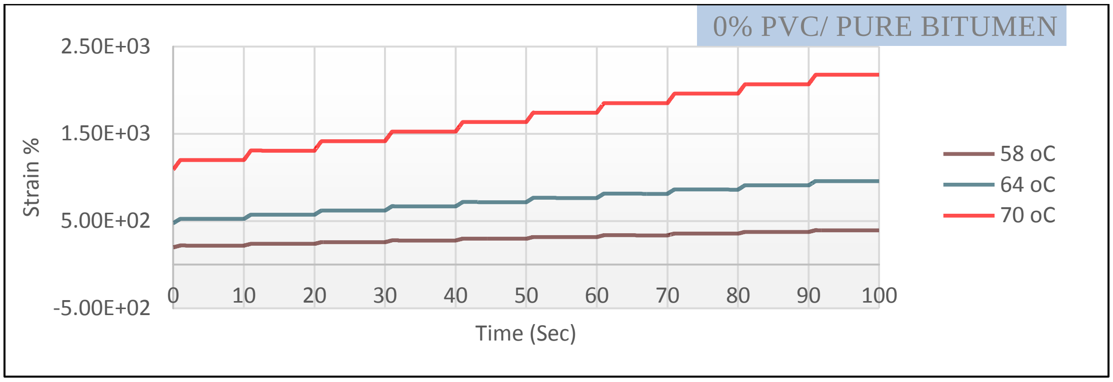


Figure 4-2 effect of variation of temperature on the total strain at stress level 0.1 kpa for pure bitumen

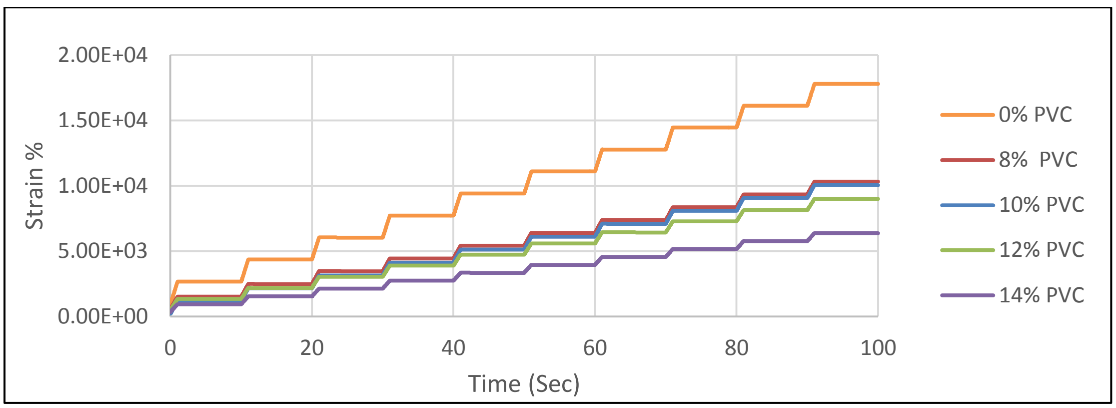


Figure 4-3 effect of modifier on the total strain at similar temperature (640c)

Finally, based on the asphalt test results shown in figure 4-3, it is noted that the modified bitumen with 14% PVC has better rut resistance than the remaining compositions. As a result, for further verification of the outputs of the asphalt test result two different mixes i.e. one with no modification of bitumen and the other with addition of 14% PVC by weight of bitumen will be prepared for performance tests of the mix.

4.2 Aggregate test results

Super-pave identifies aggregate consensus and source properties as critical to the overall performance of the mix. Criteria for the consensus properties are based on the anticipated traffic level and aggregate position within the pavement structure. Aggregates near the pavement surface are subjected to high traffic levels and require stringent consensus properties. The consensus properties include coarse aggregate angularity, fine aggregate angularity, flat and elongated particles, and clay content in fine aggregate. The summary of consensus test results of aggregates that have been used for the mix is presented below along with the requirements asphalting works as per Super-pave requirement is summarized in the tables 4-11 below:

Table 4-10 Super-pave Consensus Aggregate Requirements for Design ESALs (million) > 30 (source Table 4.2 MS-4)

Item No.	Consensus Aggregate Properties	Acceptance Criteria	Results of the test aggregate
1	Coarse aggregate angularity (%) Min.	100/100	100
2	Uncompacted void content of fine aggregate (%) Min.	45	50
3	Clay Content (Sand Equivalent) (%) Min.	50	86.9
5	Flat and Elongated (%) Max. (criterion based upon a 5:1 maximum to minimum ratio)	10	4

Source aggregate properties include the soundness, toughness of the aggregate, and the deleterious materials contained. These three properties of the source aggregate are determined using the Sodium or Magnesium Sulfate Soundness test (AASHTO T104 or ASTM C88), Los Angeles Abrasion test (AASHTO T96 or ASTM C131 or C535), and the Clay Lumps and Friable Particles test (AASHTO T112 or ASTM C142) respectively. Source aggregate properties closely relate to the quality of the parent rock.

Table 4-11 Recommended Source aggregate properties

Item No.	**Test performed**	**Acceptance Criteria**	**Result**
1	Toughness, Max. (%)	35%	16.4%
2	Soundness (Coarse aggregate) (%)	Max 10% when Na_2SO_4 is used and 20% when $MgSO_4$ is used.	4.9%
3	Soundness (Fine aggregate) (%)	Max 16% when Na_2SO_4 is used and 20% when $MgSO_4$ is used.	1.0%

As shown in the tables above, the selected aggregates to be used in the experiment are cohesion less and sound and it consists of hard, strong, durable pieces, free of coherent coating and conforms to the Super-pave specification.

4.2.1 Aggregate Gradation Analysis

Accordingly, the design aggregate structure is determined using Super-pave mix design method which includes developing of various blends of aggregate, when plotted on 0.45 power curve, that meet Super-pave specification criteria. The grading analysis of individual sized aggregate and combined aggregates are shown in the Table 4-13 below.

Table 4-12 Grading of Combined aggregates as per Asphalt Institute Manual, MS_4

Sieve size (mm)	0-3 mm	percentage proportion (30%)	3-6 mm	percentage proportion (18%)	6-13 mm	percentage proportion (24%)	13-20 mm	percentage proportion (26%)	filler	Percentage proportion (2%)	Combined	sieve size^0.45	Maximum density line	specification control points (lower)	specification control points (upper)
50	100	30	100	18	100	24	100	26							
25	100	30	100	18	100	24	100	26	100	2	100.00	4.26	100.00	100	100
19	100	30	100	18	100	24	100	26	100	2	100.00	3.76	88.38	90	100
12.5	100	30	100	18	100	24	34.5	8.97	100	2	82.97	3.12	73.20		90
9.5	100	30	100	18	90.5	21.72	3.2	0.832	100	2	72.55	2.75	64.70		
6.3	100	30	100	18	26.2	6.288	0.2	0.052	100	2	56.34	2.29	53.78		
4.75	100	30	95	17.1	1.6	0.384	0.2	0.052	100	2	49.54	2.02	47.36		
3.35	97.6	29.28	45	8.1	0.3	0.072	0.1	0.026	100	2	39.48	1.72	40.48		
2.36	91	27.3	19.9	3.582	0.1	0.024	0.1	0.026	100	2	32.93	1.47	34.57	23	49
1.18	65.5	19.65	1.4	0.252	0.1	0.024	0.1	0.026	100	2	21.95	1.08	25.31		
0.6	48.6	14.58	0.2	0.036	0.1	0.024	0.1	0.026	100	2	16.67	0.79	18.67		
0.3	30.5	9.15	0.1	0.018	0.1	0.024	0.1	0.026	100	2	11.22	0.58	13.67		
0.15	20	6	0.1	0.018	0.1	0.024	0.1	0.026	99.6	2	8.07	0.43	10.00		
0.075	10	3	0.1	0.018	0.1	0.024	0.1	0.026	99.3	2	5.07	0.31	7.32	2	8

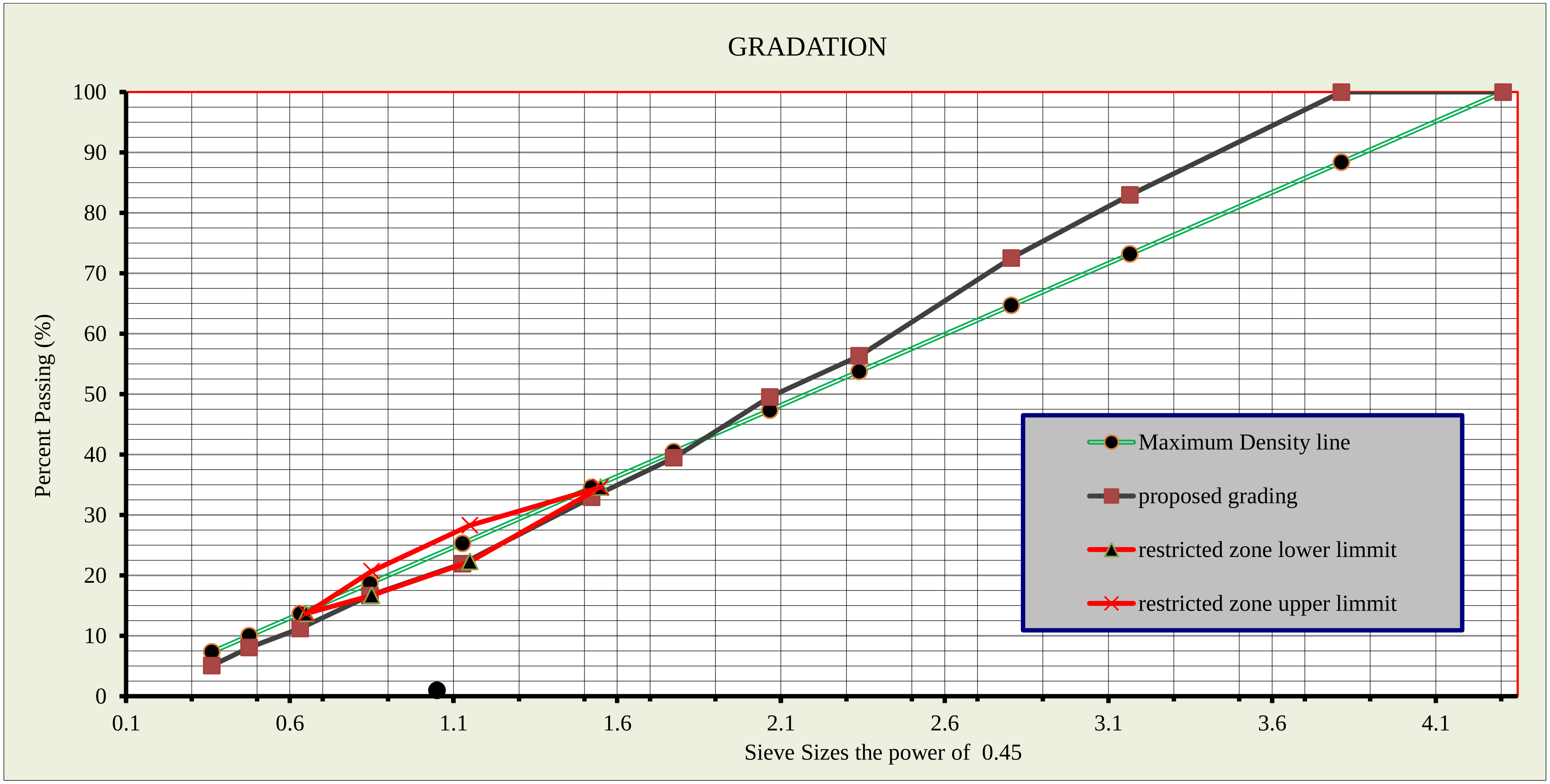


Figure 4-4 Combined grading

4.3 Asphalt mix design

The basics in asphalt mix design is to determine adequate proportion of aggregate and asphalt binder in a way that the desired bituminous mixture is achieved (i.e. a mix that resist deformation and cracking, able to serve its service life(durable), resist water damage, minimized cost and applicable for the actual condition).

Accordingly, AASHTO M -323 2014 suggests requirements based on traffic levels. For heavy traffic which has an equivalent standard axel load of more than 30 million, there are suggested criteria for volumetric and other parameters.

Table 4-13 Super-pave Criteria from AASHTO M -323 2014

Super-pave Method Mix Criteria	**Heavy Traffic**	
	Minimum	**Maximum**
Relative density @ $N_{initial}$ %		89
Relative density @ N_{design} %	=96	
Relative density @ N_{max} %		98
Percent Air Voids %	4	
Percent Voids Filled with Asphalt (VFA)	65	75
Percent VMA (For Nominal Maximum Particle Size of 19 mm and design air void of 4%)	13	
Dust binder ratio	0.6-1.2	
Number of cycle @ $N_{initial}$	9	
Number of cycle @ N_{design}	125	
Number of cycle @ N_{max}	205	

4.3.1 Mixing and Compaction Temperature

The mixing and compaction temperatures for the asphalt mixes being used are determined from temperature-viscosity graph (SP-2, 1995). The temperatures are those required to produce viscosities of 170±20 centistokes for mixing and 280±30 centistokes for compaction. Accordingly, In the mix preparation, based on the viscosity of the original binder, the temperature range 160 -170 ^{0}C is used for mixing and 142 -150 ^{0}C is used for compaction of test specimens and specifically for the pure bitumen the considered temperature was the middle range of compaction and mixing temperature and for the modified bitumen the upper limits of both compaction and mixing temperature were considered. Here the mixing and compaction temperature for the modified bitumen could not be directly determined/considered due to the following reasons:-

1, for modified bitumens, adopting “Temprature Viscosity Chart” results unrealistic high temperature and this has been proved through previos researchs,

2, the Rotetional Viscometer was another alternative to determine the tempratures; however the available equipment at this university is not operating well,

3, by taking in to aaccount the above to reasons and considering the PG of the non modified bitumen here it is presumed that more than 85% is the bitumen component which is the widely held composition and the test results on the bitumen specially the MSCR test result has shown that similar grade but different traffic class. Therefore, based on the determined compaction and mixing temperature of the non-modified bitumen the upper limits were considered for the modified one.

The following chart illustrates how the temperature range is selected:-

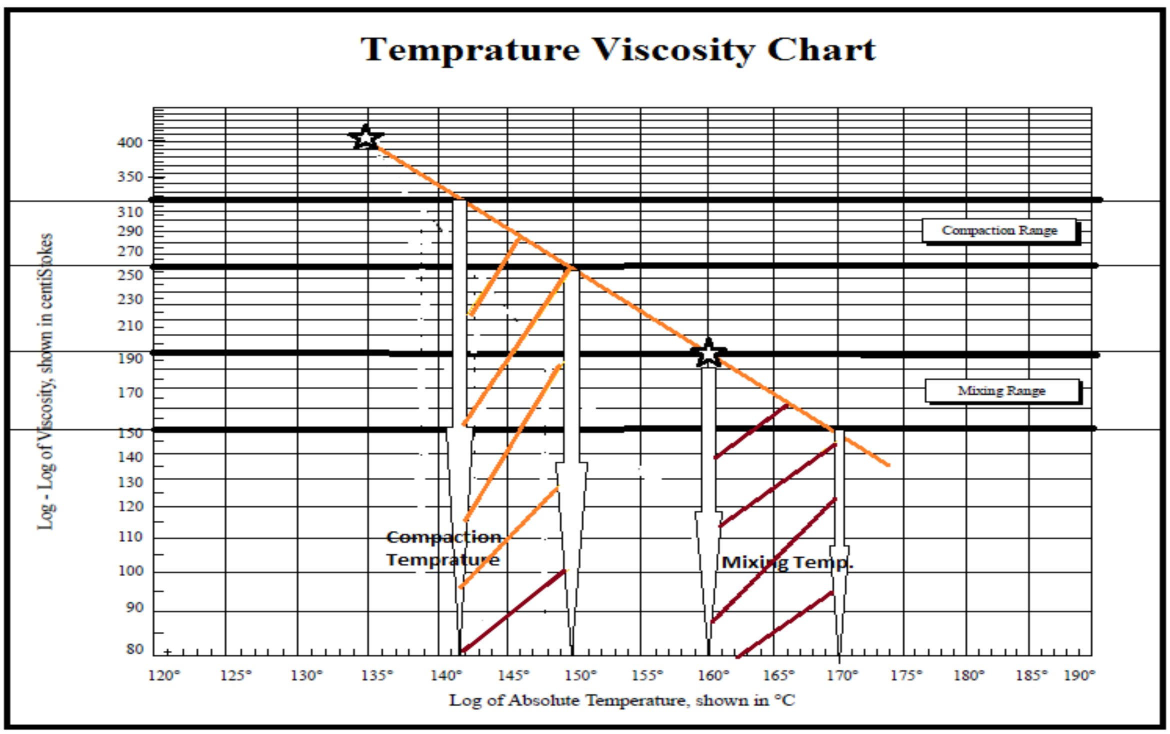


Figure 4-5 Temprature Viscosity Chart (ASTM D 2493)

4.3.2 Optimum Asphalt Binder Estimation

As per the Super-pave mix design method and based on the methodologies particularized under chapter three of the research paper, three asphalt binder contents have been considered for volumetric analyses for both modified (with 14% PVC) and non-modified mixes among which one is the first estimated binder content.

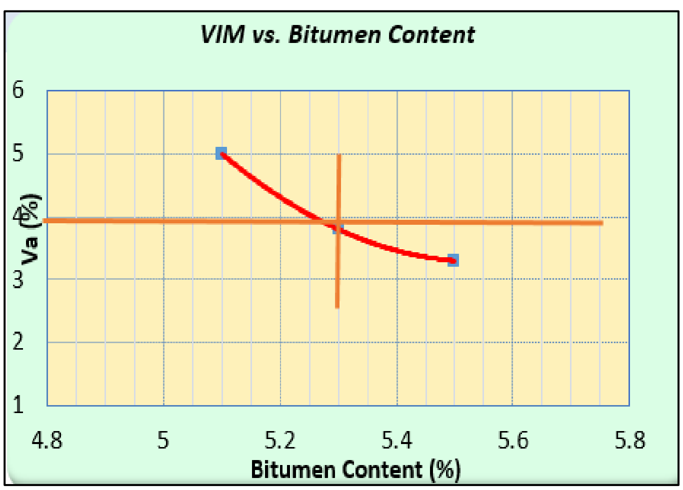
4.3.2.1 Mixture Volumetric Results

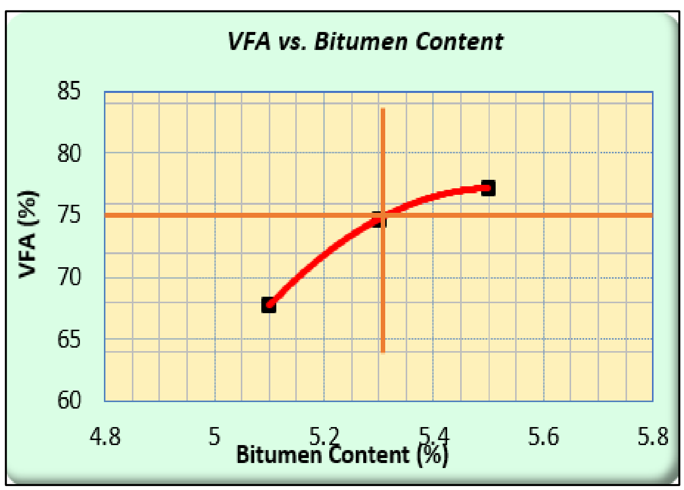
The design/target air void content is four percent and by taking in to account the target air void, the maximum theoretical density test is conducted for the estimated/initial binder content and the corresponding (Gmm) of the mix was acquired then the gyratory compaction was conducted accordingly at Ndesign (125 number of cycles for compaction). Consequently, considering the out puts of the test results for the compacted mix at different conditions, the volumetric parameters and the mixture characterization based on compaction is made for the first trial then based on established air void and other parameters, additional 2 trials with different bitumen content were proceeded/executed accordingly.

The following table shows the volumetric ratios after the test specimens are subjected to the gyratory compaction for different binder content

Table 4-14 summary of Volumetric data for the pure bitumen (non- modified)

Bitumen content (%)	Bulk SG of specimen (Gmb)	Max SG of loose mix(Gmm)	VIM (%)	VMA (%)	VFA (%)
5.1	2.498	2.63	5	15.5	67.7
5.3	2.518	2.618	4	15	74.7
5.5	2.525	2.61	3.3	14.4	77.2





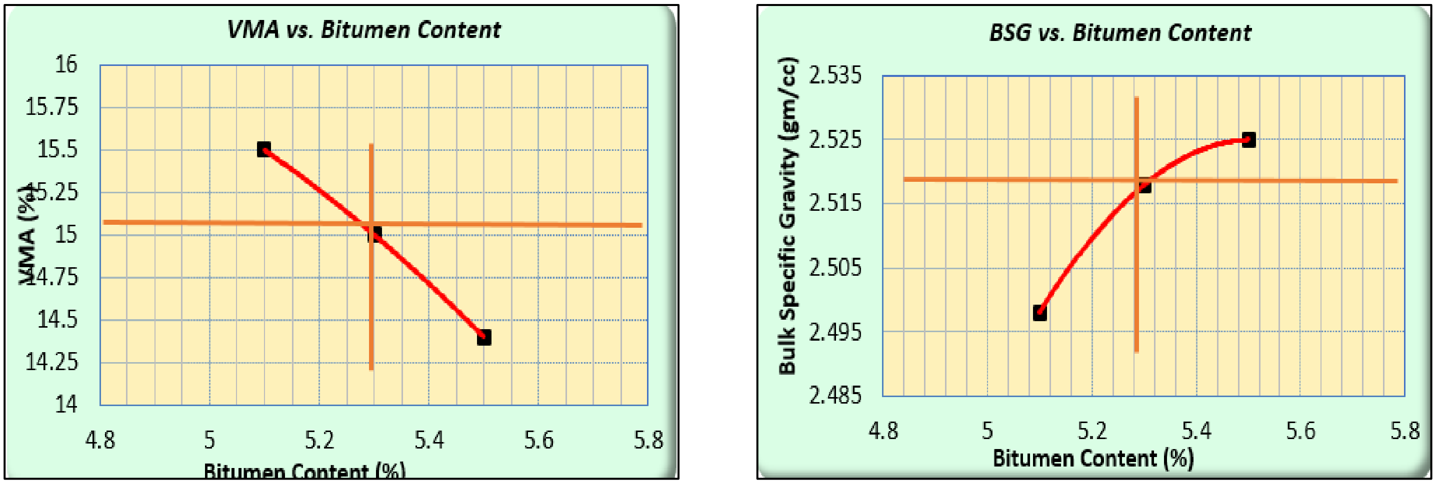
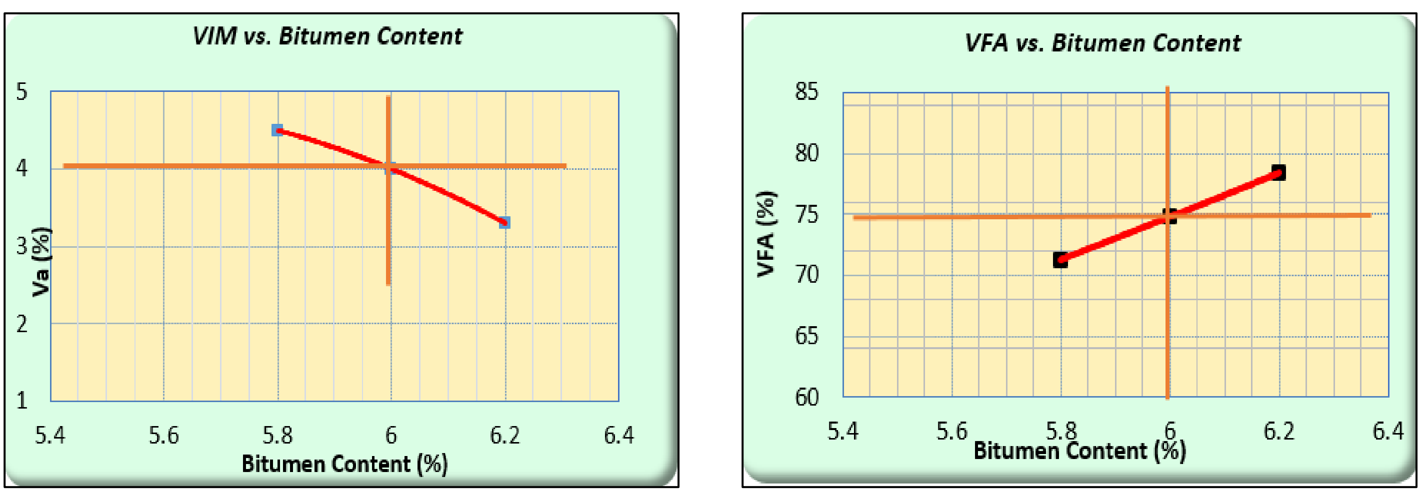


Figure 4-6 optimum bitumen content selection (Graphical Presentation) for the non-modified bitumen

Table 4-15 summary of Volumetric data for the pure bitumen (modified)

Bitumen content (%)	***Bulk SG of specimen (G_{mb})***	***Max SG of loose mix (G_{mm})***	***VIM (%)***	***VMA (%)***	***VFA (%)***
5.8	2.511	2.629	4.5	15.7	71.3
6.0	2.527	2.623	4.0	15.5	74.8
6.2	2.534	2.620	3.3	15.3	78.4



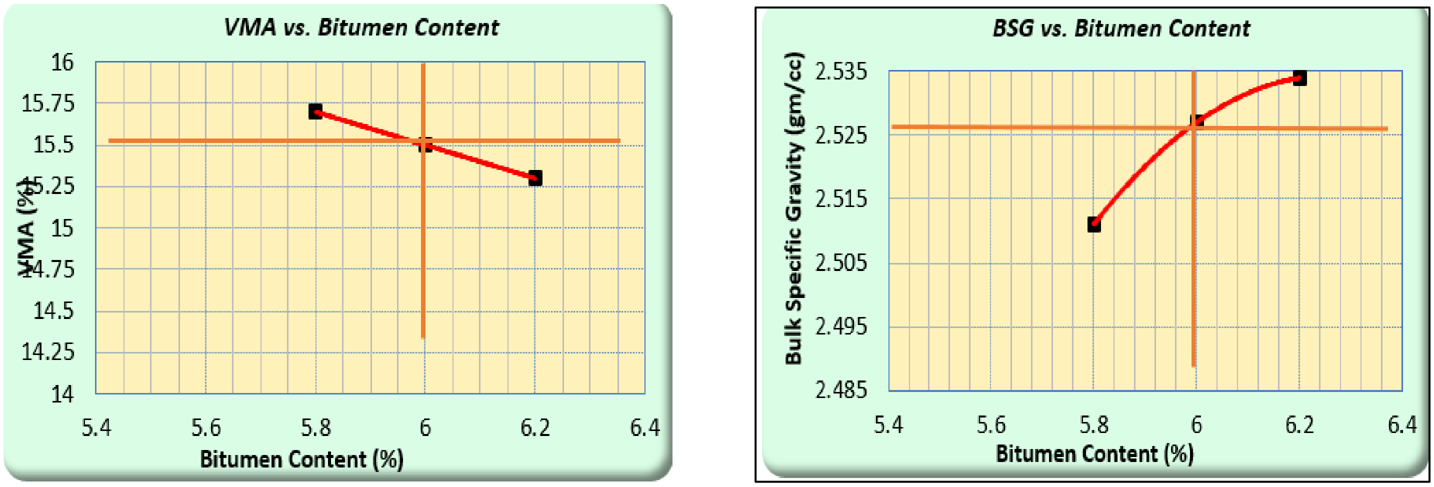


Figure 4-7 optimum bitumen content selection (Graphical Presentation) for the modified bitumen (with 14% PVC)

From the above graph and tables, it can be noted that the optimum bitumen content for the modified and non-modified mix, at 4% air void is 6% and 5.3% respectively. And at both optimum content all volumetric parameters conform with the requirements of AASHTO M -323 2014, for traffic level exceeding 30Million ESAL. After the volumetric properties determined from gyratory compaction, compaction curves have been checked at three different points, by using the data from the software outputs at Nintioal (9 gyration), Ndesign (125 gyration) and N maximum (205 gyration) for optimum bitumen content, in order to ensure adherence to specification criteria as seen in the figure below.

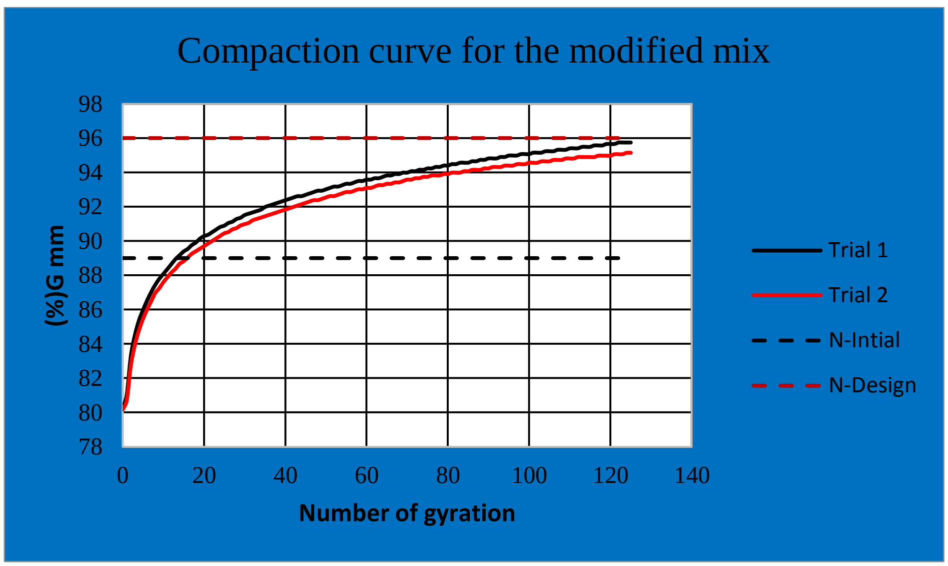


Figure 4-8 Plot of Gyratory Compaction curve for modified mix at N design (125 gyration cycle)

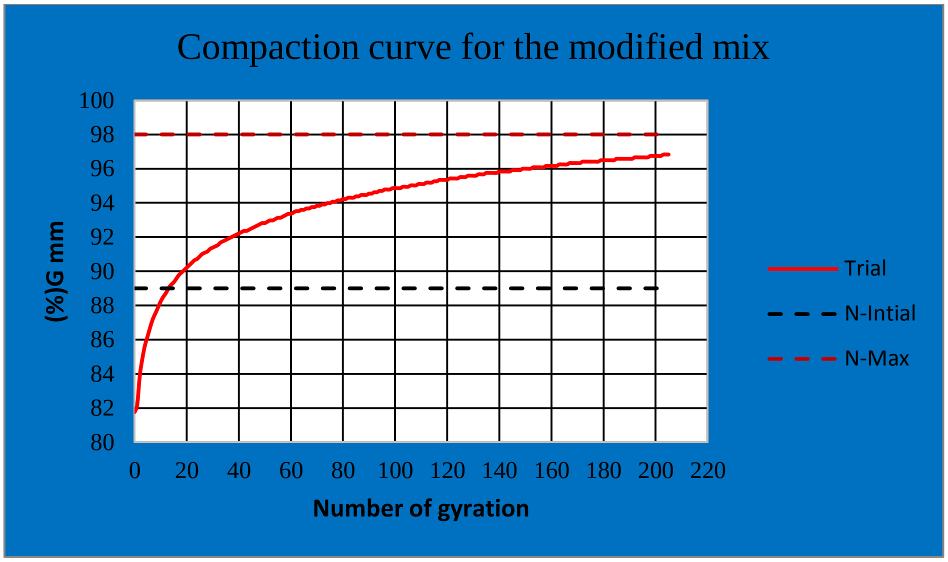


Figure 4-9 Plot of Gyratory Compaction curve for modified mix at N max (205 gyration cycle)

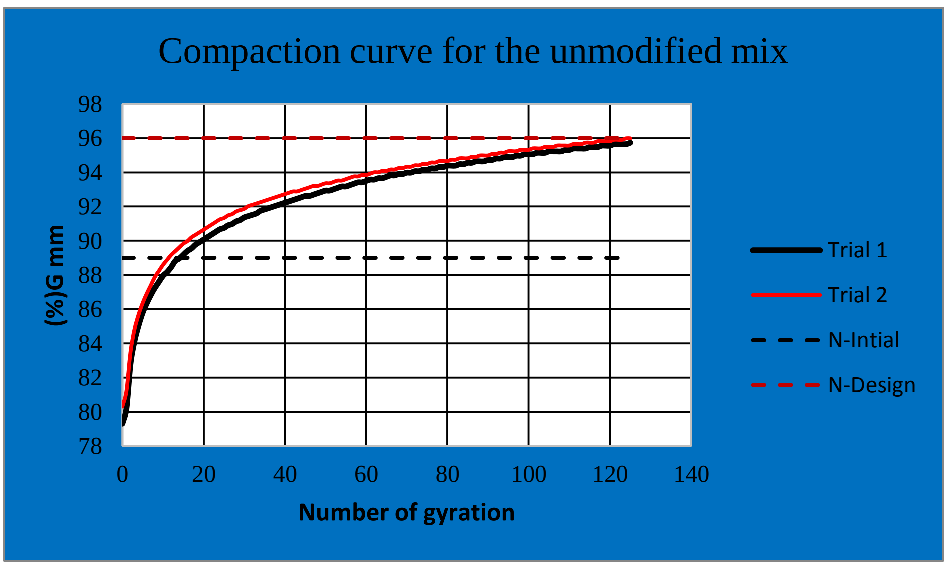


Figure 4-10 Plot of Gyratory Compaction curve for non-modified mix at N design (125 gyration cycle)

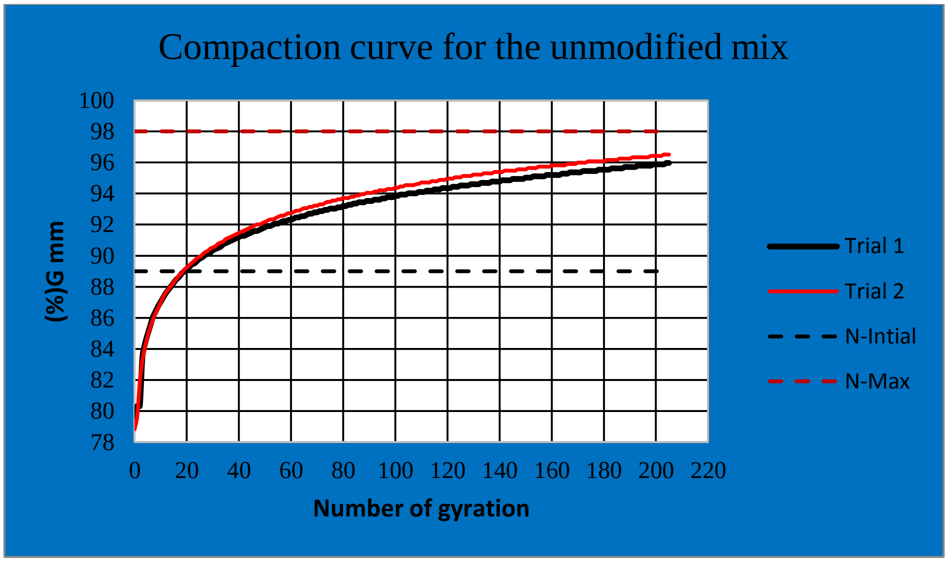


Figure 4-11 Plot of Gyratory Compaction curve for non- modified mix at N max (205 gyration cycle)

4.3.2.2 Dust binder ratio

Table 4-16 Dust to binder ratio computation

Bitumen content	Gb specific Gravity of bitumen	Gsa (apparent specific gravity of the combined aggregate)	Gsb (bulk specific gravity of the combined aggregate)	Gse (effective specific gravity of the combined aggregate)= (Gse = Gsb + 0.6(Gsa −Gsb))	Pba (absorbed asphalt)	Effective Bitumen content	amount of material passing 75µm sieve	Dust Binder Ratio
5.3	1.026	2.944	2.806	2.889	1.048	4.252	5.07	1.192
6	1.041	2.944	2.806	2.889	1.063	4.937	5.07	1.027

As depicted in the above table, the dust to binder ratio is within the acceptable ranges i.e. between 0.6 to 1.2.

4.4 Performance Testing of Trial Mixes

The performance tests were conducted with the objective of evaluating the performance of the bituminous mixes for two type of major pavement defects one is rutting and the other is striping (wheel tracking test and moisture susceptibility test (resistance of compacted asphalt mixture to moisture induced damage) was conducted accordingly.

4.4.1 Wheel tracking test

Based on the proportion of the design mixes specimen were prepared for both modified and non-modified mixes and were subjected to compaction using slab compactor (i.e. with 25 number of pass which simulates the actual site condition) and after the compaction, the compacted samples/moulds were detained for 24hrs at 64oc. Consequently, the test samples were subjected to wheel tracking test for 6hrs at 20,000 number of passes (i.e. the number of pass simulates heavy traffic condition which exceeds 30million ESAL) with controlling temperature of 64oc. The designated temperature (i.e. 64oc) was selected for comparison purpose of the two specimens at similar temperature since the non-modified bitumen was categorized as PG 64.

The following graph represents the wheel tracking test report for rut depth of compacted specimen

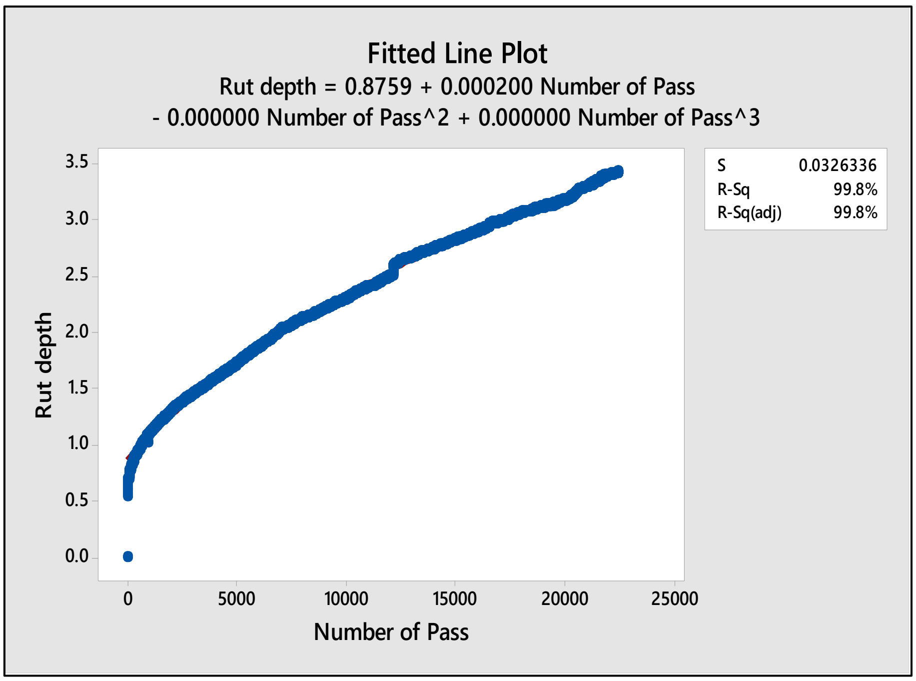


Figure 4-12 Wheel Tracking Testing report for rut depth of compacted specimen for the non-modified mix

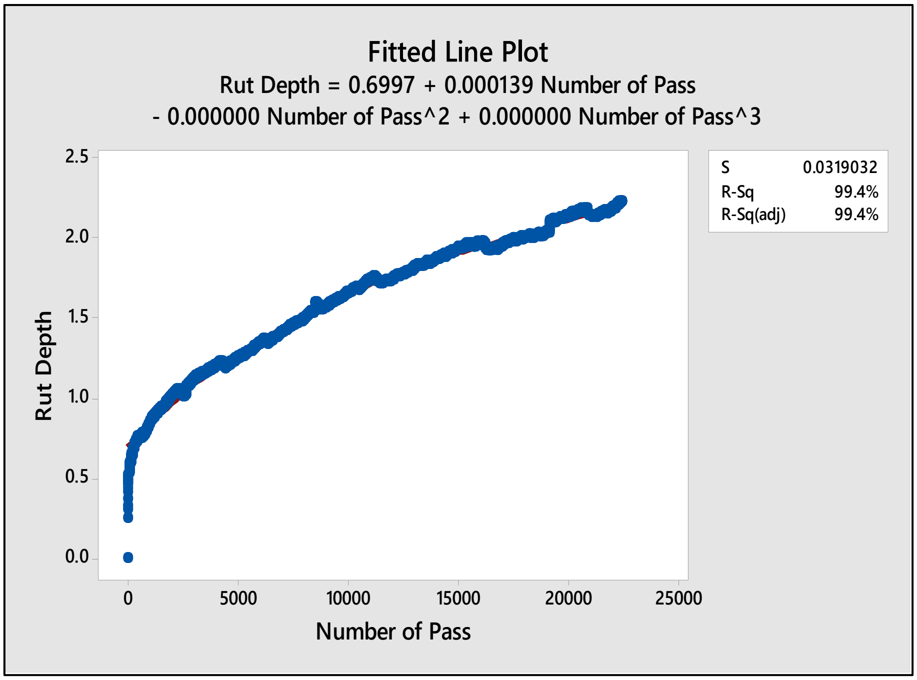


Figure 4-13 Wheel Tracking Testing report for rut depth of compacted specimen for the modified mix

According to Colorado DOT recommends a maximum rut depth 10mm at 20,000 load cycle. And the city of Hamburg, Germany, uses a maximum allowable rut depth 4mm at 19,200 load cycles. (FHWA, 2003). In this regard, both the modified and non-modified mix has rut resistant less the specified values i.e. after 20,000 load cycles the rut depth for the non-modified mix was 3.419 mm, and for the modified mix was 2.229 mm, which shows a 35% reduction in rut depth.

4.4.2 Moisture susceptibility test (resistance of compacted asphalt mixture to moisture induced damage)

Asphalt mixes might be sensitive to the presence of water in the pavement. Water causes separation of asphalt from the aggregates. Since the asphalt is the binding entity that holds the aggregates together, rapid failure of the pavement can be expected if the asphalt cannot act as a binder. This phenomenon is often referred to as stripping. And both the proposed mixes (modified and non – modified) were evaluated through moisture susceptibility test accordingly the resulting output of the test is presented in the table 4-18 below: -

Table 4-17 Indirect Tensile Strength Test of Bituminous Mixture for treated/conditioned and unconditioned sample for the modified mix

Speciemen No	UT1	UT2	UT3	T1	T2	T3	Average	
Average Height (mm)	62.775	64	62.95	62.75	63.175	63.3	Indirect Tensile Strength (Kpa)	
Average Diameter (mm)	101.65	101.575	101.45	101.5	101.5	101.5	dry subset	conditioned subset
Corrected Maximum Load (N)	18530	19770	19260	16950	17150	17105	19186.7	17068.3
Indirect Tensile Strength (Kpa)	1848.7	1936.1	1919.9	1694.2	1702.7	1694.86	1901.6	1697.25
Tensile Strength Ration (TSR), UT/T, %	91.645	87.9454	88.2764				**89.26**	

Table 4-18 Indirect Tensile Strength Test of Bituminous Mixture for treated/conditioned and unconditioned sample for the unmodified mix

Speciemen No	UT1	UT2	UT3	1	2	3	Average	
Average Height (mm)	63.35	62.825	63.075	62.7	63.35	63.225	Indirect Tensile Strength (Kpa)	
Average Diameter (mm)	101.575	101.575	101.675	101.6	101.6	101.55	dry subset	conditioned subset
Corrected Maximum Load (N)	17140	17165	16865	15150	15150	14935	17056.7	15078.3
Indirect Tensile Strength (Kpa)	1695.734	1712.4	1674.2	1514	1498.5	1480.87	1694.1	1497.79
Tensile Strength Ration (TSR), S2/S1, %	89.284078	87.508	88.4548				**88.41**	

Typical TSR value range from 70% to 90% in both scenarios (modified mix condition and non-modified mix conditions) the TSR value greater than 70%. In addition, the modified specimens have higher TSR value (i.e. 89.26%) which indicates good resistance to moisture induced damage and the lesser reduction in strength in water socking condition relative to the non – modified mix

5 Conclusion and recommendation

Nowadays, most of our road corridors are experiencing big shortfalls on long term and adequate service provision due to the presence of different failures on the road surface among which rutting is one type of failure. Rutting is mostly encountered due to heavy traffic and temperature. And on those locations which experience both at extreme levels, either using rigid pavement or using higher penetration grade or modified bitumen are the available options. In this respect, PVC modified bitumen mixes are among the options being tested, and there are existing literature on the use of PVC modified bitumen in the asphalt mixture and most of them were conducted based on Marshall test method which has weak correlation with the actual field performance. And this study focuses on a specific type of failure (rutting) based on evaluations made on improved test methods with better correlation with actual field performance (i.e. Super-pave test method). The main goal of this research is to study the effect of adding a bitumen modifier (i.e. thermoplastic polymer/waste PVC) on the performance of flexible pavements under high temperature and heavy traffic loading.

5.1 Conclusion

From the results obtained, the following conclusions can be derived:

- ❖ Asphalt tests
  - ✓ Based on the test results of PG determination, the modified bitumen with 14% PVC has better temperature resistance than the non-modified pure bitumen. According to MSCR test, the modified bitumen with 14% PVC was able to resist and perform well as maximum up to a standard traffic level (less than 10million ESAL) at 70^{o}c. However, the non – modified bitumen was able to resist and perform well as a maximum of the same traffic level at 64^{o}c.
  - ✓ The modified bitumen at 14% PVC, the amount of residual strain left in the binder specimen after repeated creep and recovery at the maximum stress showed 45% decreas compared to the non modified binder. Thus, it implies lower rutting depth.

- ✓ The 14% PVC modified bitumen has a lower plastic strain (i.e. $\varepsilon_{plastic} = \varepsilon_{total} - \varepsilon_{elastic}$), the recoverable strain or elastic starin is larger compaired to the non – modified binder.

❖ Asphalt mix

- ✓ From the prepared mix design based on similar aggregate structure for both modified and non-modified bitumen, it was noted that at the optimum bitumen content it was able to reduce the bitumen consumption up to 2.6% due to replacing the part of bitumen with 14% waste PVC. Here, interms of large sacale production the percent is significant for saving the bitumen consumption and combating the environmental impact due to accumulation of waste plastic materials. Further, this also reduce waste management costs due to recycling of the PVC material for further consumption.

❖ Performance test

- ✓ Even though the MSCR test result shows that the maximum traffic level that can be accommodated by the modified and non-modified bitumen at 64^{o}c is in between 10million and 30 million ESALS and less than 10 million ESAL respectively, from the wheel track test, it was observed that in both scenarios it was possible to attain more than 30 million ESAL within the allowable rut depth up to end of the design life.
- ✓ Due to the applied modification on the bitumen rut depth at the design life of the asphalt mix was able to reduce by 35%.
- ✓ The modified mix has better resistance to moisture induced damage and has lesser reduction in strength in water socking condition relative to the non – modified mix.

5.2 Recommendation

- The results form this research are promising, and it will be highly recommended to use the PVC modifier in asphalt mixes in hot areas with heavy traffic. It improves the performance of the pavements, and at the same time reuses waste materials which is good for the environment. However, the researcher recommends further studies on the following issues:
    - The research only focuses on the performance study (rutting performance) of waste PVC modified asphalt and bituminous mixture. A separate study shall be made for how the waste PVC materials are collected and processed in order to get the end product.
    - The effect of adding waste PVC shall also be studied for different penetration grade bitumen.
    - Further chemical property/composition tests for the PVC and combination of bitumen and PVC shall be conducted.
    - In the application of modified mixes there should be separate safety guideline (special provisions) since there exist harmful gases while burning plastics. In this regard, it should be conducted with in isolated or confined equipment.
    - The cost analysis (cost reduction) shall be further evaluated since the amount of bitumen used has definitely reduced due to the percentage of waste material added. Plus, not only the bitumen consumption, the cost to manage the waste material and the environmental damage has also reduced since plastic materials are non-degradable materials.

References

- (ASSHTO), A. A. o. S. H. a. T. O., 2014. *America Association of State Highway and Transportation Officials (ASSHTO).* USA: s.n.
- (ASTM), A. S. f. t. a. M., 2003-2004 . *ASTM Standards.* USA: s.n.
- (MS4), M. S. N., 2007. *Asphalt Handbook.* USA: Asphalt Institute.
- (SP-2), S. M. S. 2., 1996. *Strategic Highway Research Program (SHRP).* USA: National Research Council.
- Admas, A., 2017. *EVALUATION OF RUBBERIZED BITUMEN AS PAVEMENT MATERIAL,* Addis Ababa: s.n.
- Alam and Ahamade, 2013. Impact of Solid waste on Health and Environment.
- Ambika Behl, P. J. ,. G. S., 2012. *STUDY ON WASTE POLYVINYL CHLORIDE MODIFIED BITUMEN FOR PAVING APPLICATIONS.* Australia, ARRB Group Ltd and Authors.
- B.L.Swami, Y.A.Mehta & S.Bose, a., 2004. A comparison of the marshall and superpave design procedure for materials sourced in India. *The International Journal of Pavement Engineering, vol. 5, issue 3, pp.163173,2004.*
- BaleA.S, 2011. Potential reuse of plastic waste in road construction. *Eco-web India.*
- Byram, Xiao, D., Wang, K. & Hall, K., 2012. *Sensetivity analysis of climatic Influence on MEPDG flexible pavement performnce pridiction.* Washington DC, s.n.
- Ethiopia road and railway, 2019. *www.export.gov.* [Online].
- F.L., R., P.S., K., E.R., B. & T.W., L. D. a. K., 1996. Hot Mix Asphalt Material, Mixtures Design, and Construction.. *National Asphalt Pavement Association Education Foundation.*

- FHWA-SA-95-003, February 1995. *Background of Superpave Asphalt Mixture Design and Analysis.* U.S: National Asphalt Training Centre Demonstration Project 101, U.S. Department of Transportation (Federal Highway Administration)..
- Gashaw, M., 2018. *Mapping Temperature Zone of Ethiopia for Binder Performance Grading System,* Addis Ababa: s.n.
- Ghani, U. & Tanoli, a. W. A., 2015. Performance evaluation of waste PVC modified bitumen. *International Journal of Advanced Structures and Geotechnical Engineering.*
- H.U.Bahia, 1993. *Physical properties of Asphalt Cement "SHARP - A-626",* Washington DC: National Research Councile.
- Ishai, 1987. Methdology for the Analysis of Asphalt Age Hardning. *Testing and Evaluation,* pp. 127-132.
- JorgeC, 2013. Impact of Traffic Over Load on road pavement performance. *Article in Journal of Transportation Engineering.*
- martin_medina_martinez, 2013. *Globalization, Development, and Municipal Solid Waste Management in Third World Cities.* Tijuana, mexico: s.n.
- MauskarJ.M, 2008. study on performance evaluation of polymer coated bitumen built roads. *I.A.S CPCB India* .
- McLeod & N.W, 1956. *Relationships Between Density, Bitumen Content, and Voids Properties of Compacted Bituminous -Paving Mixtures.* s.l., s.n., p. 35.
- MilindV, Mohod & Dr.K.N.Kadam, &., 2016. A Comparative study on rigid and flexible Pavement. *ISOR Journal of Mechanical Ad Civil Engineering* .
- Modak, 2010. Review on community based municipal Solid waste. *Zurbrugg.*
- Monoyoncho, 2013. Waste Management in Urban areas.

- Read & Whiteoak, J. a., 2003. *Shell Bitumen Handbook.*. London: s.n.
- Roberts, F. L. et al., 1991. *Hot mix asphalt materials, mixture design and construction," First Edition".* Lanham, Maryland: NAPA Education Foundation.
- Shirish N. Nemade, P. V. T., 2013. Utilization of Polymer Waste for Modification of bitumen in Road Construction. *Scientific Reviews and Chemical Communications.*
- TimmD, TisdaleS & TurochyR, a., 2005. Axle load spectra characterization by mixed distribution modeling. *Transport Engineering*, pp. 83-88.
- WillwayT, L.Baldachin & S.Reeves, &., 2008. *Maintaining Pavement in a changing Climate.* United Kingdom: Department of Transport.

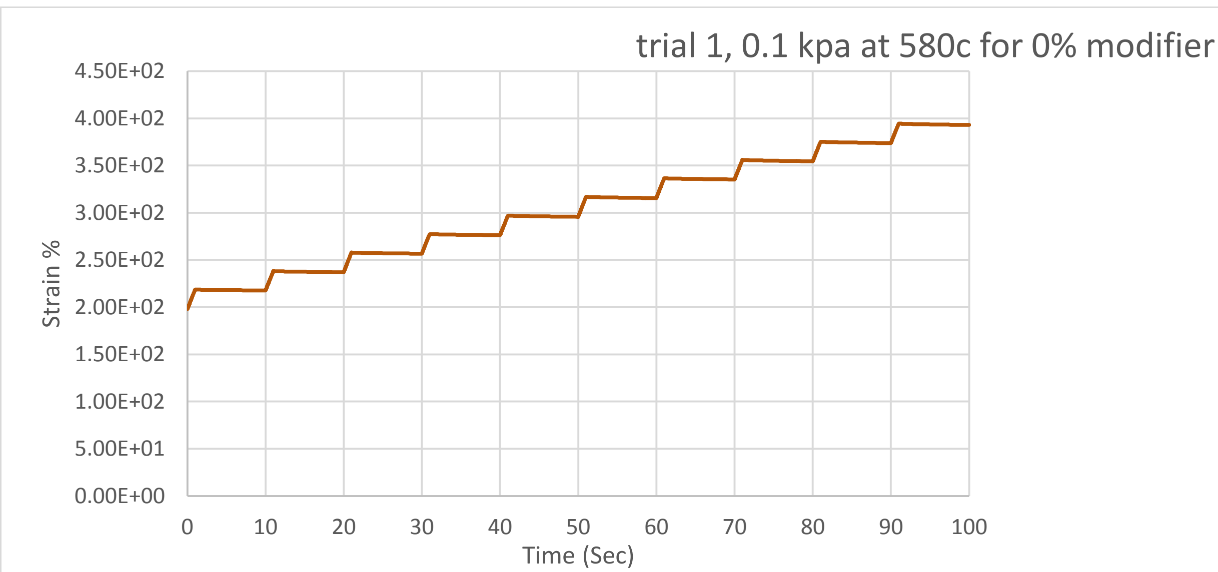
Appendix

Appendix A

Asphalt Tests (MSCR) Analysis

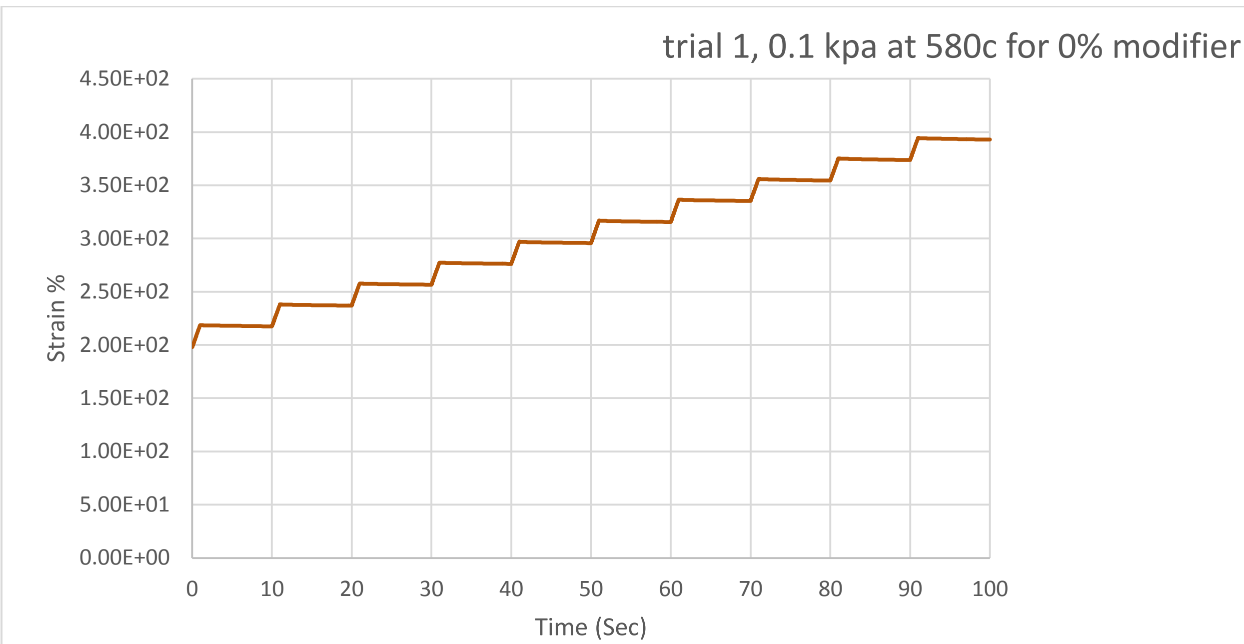
Jnr Computation at stress level 100Pa for 0% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_0	ε_c	$\varepsilon_{1}=\varepsilon_c-\varepsilon_0$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	$J_{nr}(0.1,N)$=□10/0.1kPa		Jnr diff=$(J_{nr3.2}-J_{nr,0.1})/J_{nr0.1}$*100
1	197.92613	218.72542	20.79929	217.52700	5.8	19.60087	1.96		5.85
2	217.79331	238.13986	20.34655	236.99470	5.6	19.20139	1.92		9.28
3	237.31428	257.79399	20.47971	256.59557	5.9	19.28129	1.93		9.44
4	256.91515	277.34160	20.42645	276.19644	5.6	19.28129	1.93		9.17
5	276.51602	296.96909	20.45308	295.69078	6.2	19.17476	1.92		9.87
6	295.98372	316.83628	20.85255	315.53133	6.3	19.54760	1.95		8.25
7	315.85091	336.49041	20.63950	335.21209	6.2	19.36118	1.94		9.80
8	335.53167	355.98474	20.45308	354.41348	7.7	18.88181	1.89		13.12
9	354.73306	375.18614	20.45308	373.69477	7.3	18.96171	1.90		12.77
10	374.01435	394.46742	20.45308	392.92279	7.6	18.90844	1.89		12.53
Temprature		58°C			6.4		1.92		10.01
						Avg	1.9220		
						Min	1.8882		
						Max	1.9601		
					% Normalized Range		3.7412		



Jnr Computation at stress level 3200Pa for 0% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	**ε_0**	**ε_c**	**$\varepsilon_1=\varepsilon_c-\varepsilon_0$**	**□r**	**□r(3.2,N)=(□c-□r)/□1*100**	**□10=□r-□o**	**Jnr(3.2,N)=□10/3.2kPa**
1	404.02817	1073.25393	669.22576	1067.95418	0.8	663.926	2.07
2	1079.61883	1753.55840	673.93957	1751.05500	0.4	671.436	2.10
3	1762.13375	2439.77505	677.64130	2437.35160	0.4	675.218	2.11
4	2448.32382	3125.96518	677.64136	3121.89053	0.6	673.567	2.10
5	3133.26223	3811.46285	678.20062	3807.38820	0.6	674.126	2.11
6	3818.33379	4499.78347	681.44968	4495.44247	0.6	677.109	2.12
7	4506.97395	5191.53948	684.56553	5187.22515	0.6	680.251	2.13
8	5198.67674	5886.46475	687.78800	5882.15041	0.6	683.474	2.14
9	5893.14927	6581.92265	688.77338	6577.42183	0.7	684.273	2.14
10	6588.74026	7274.13143	685.39117	7269.60401	0.7	680.864	2.13
Temprature		**58°C**			**0.59**		**2.11**
						Avg	**2.1138**
						Min	**2.0748**
						Max	**2.1384**
					% Normalized Range		**3.0080**

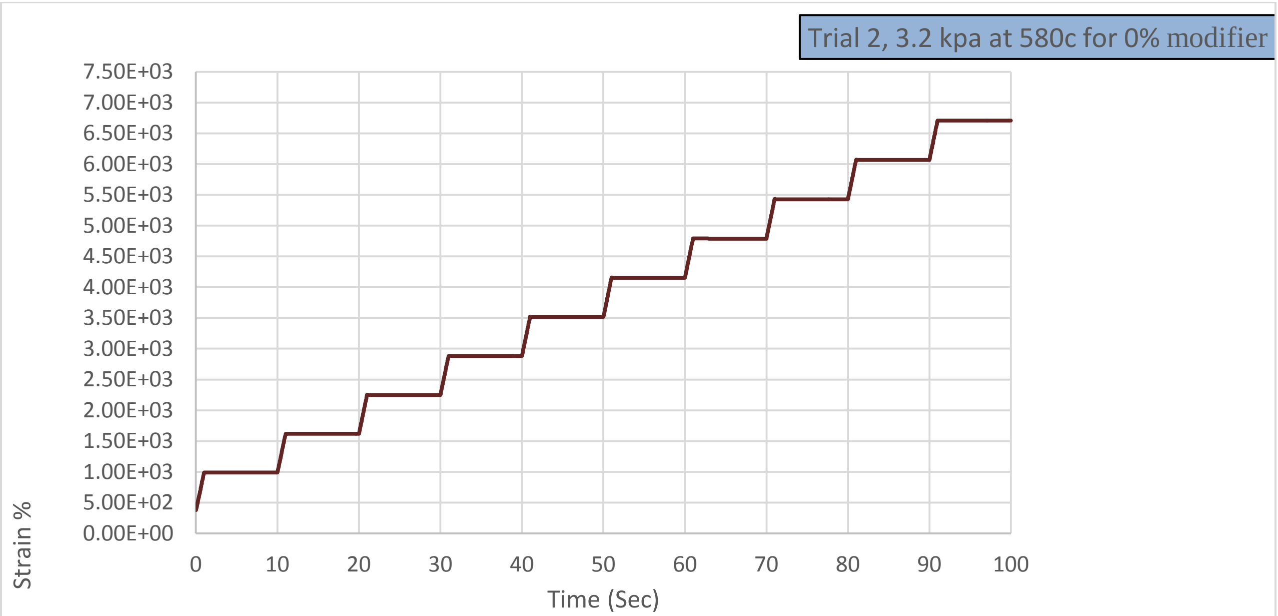


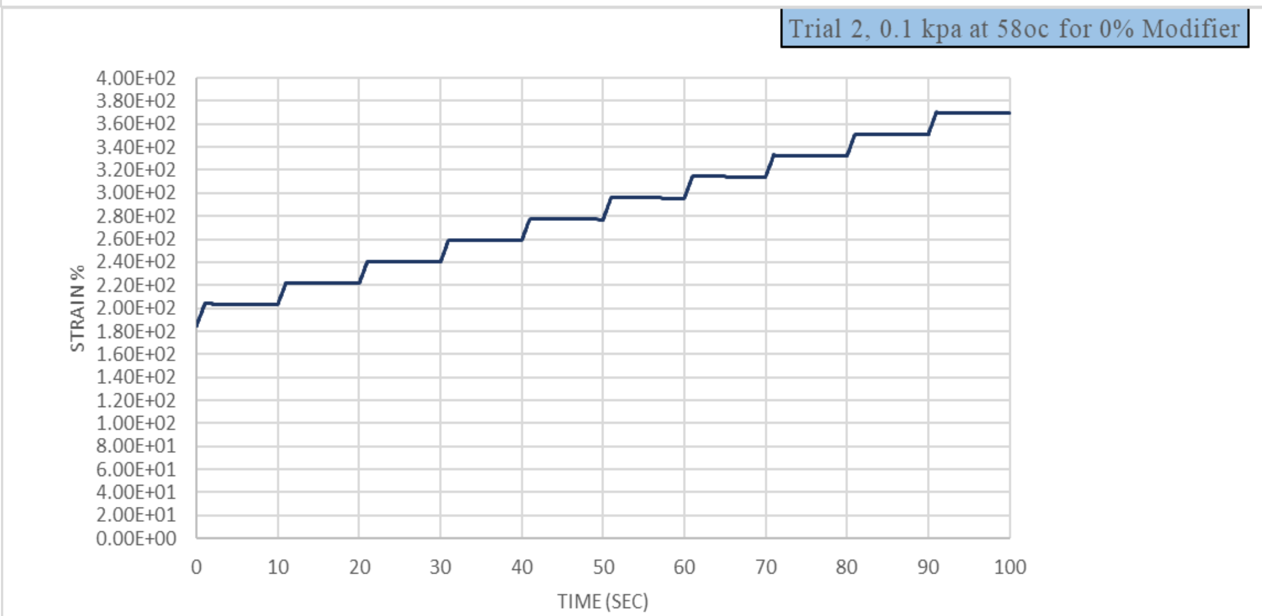
Jnr Computation at stress level 100Pa for 0% modifier (trial 2)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}
0.1 KPa	ε_0	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_0$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	J_{nr}(0.1,N)=□10/0.1kPa
1	185.06306	203.91824	18.85518	203.38561	2.8	18.32255	1.83
2	203.65193	222.13427	18.48234	221.54837	3.2	17.89644	1.79
3	221.84132	240.66987	18.82855	240.00408	3.5	18.16276	1.82
4	240.27039	259.31199	19.04160	258.64620	3.5	18.37581	1.84
5	258.93915	277.63454	18.69539	277.02202	3.3	18.08286	1.81
6	277.28833	296.19678	18.90844	295.55762	3.4	18.26928	1.83
7	295.85056	314.67911	18.82855	314.03995	3.4	18.18939	1.82
8	314.33290	332.86850	18.53560	332.22934	3.4	17.89644	1.79
9	332.52229	351.37747	18.85518	350.76494	3.2	18.24265	1.82
10	351.05789	370.12613	19.06823	369.48697	3.4	18.42907	1.84
Temprature		58°C			3.3		1.82
						Avg	1.8187
						Min	1.7896
						Max	1.8429
					% Normalized Range		2.9287

Jnr Computation at stress level 3200Pa for 0% modifier (trial 2)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_0	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_0$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10/3.2kPa
1	379.42056	990.34970	610.92914	986.56804	0.6	607.147	1.90
2	996.90111	1619.01549	622.11439	1615.44689	0.6	618.546	1.93
3	1625.51364	2251.32980	625.81616	2247.68133	0.6	622.168	1.94
4	2258.04102	2885.16224	627.12122	2881.54029	0.6	623.499	1.95
5	2891.97988	3520.67233	628.69245	3516.78410	0.6	624.804	1.95
6	3527.22369	4156.36891	629.14522	4152.45400	0.6	625.230	1.95
7	4163.00012	4793.42357	630.42346	4789.53541	0.6	626.535	1.96
8	4799.86848	5431.78336	631.91488	5427.76198	0.6	627.894	1.96
9	5438.12168	6071.87414	633.75246	6067.90603	0.6	629.784	1.97
10	6078.29236	6710.63335	632.34099	6706.50543	0.7	628.213	1.96
Temprature		58°C			0.61		1.95
						Avg	1.9481
						Min	1.8973
						Max	1.9681
					% Normalized Range		3.6313


Trial 2, 3.2 kpa at 580c for 0% modifier
7.50E+03
7.00E+03
6.50E+03
6.00E+03
5.50E+03
5.00E+03
4.50E+03
4.00E+03
3.50E+03
3.00E+03
2.50E+03
2.00E+03
1.50E+03
1.00E+03
5.00E+02
0.00E+00
Strain %
0 10 20 30 40 50 60 70 80 90 100
Time (Sec)

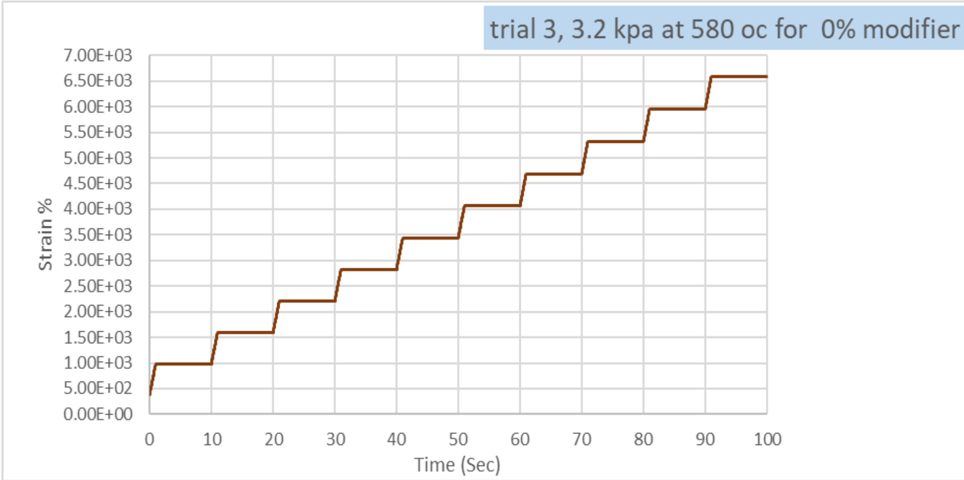

Trial 2, 0.1 kpa at 58oc for 0% Modifier
4.00E+02
3.80E+02
3.60E+02
3.40E+02
3.20E+02
3.00E+02
2.80E+02
2.60E+02
2.40E+02
2.20E+02
2.00E+02
1.80E+02
1.60E+02
1.40E+02
1.20E+02
1.00E+02
8.00E+01
6.00E+01
4.00E+01
2.00E+01
0.00E+00
STRAIN %
0 10 20 30 40 50 60 70 80 90 100
TIME (SEC)

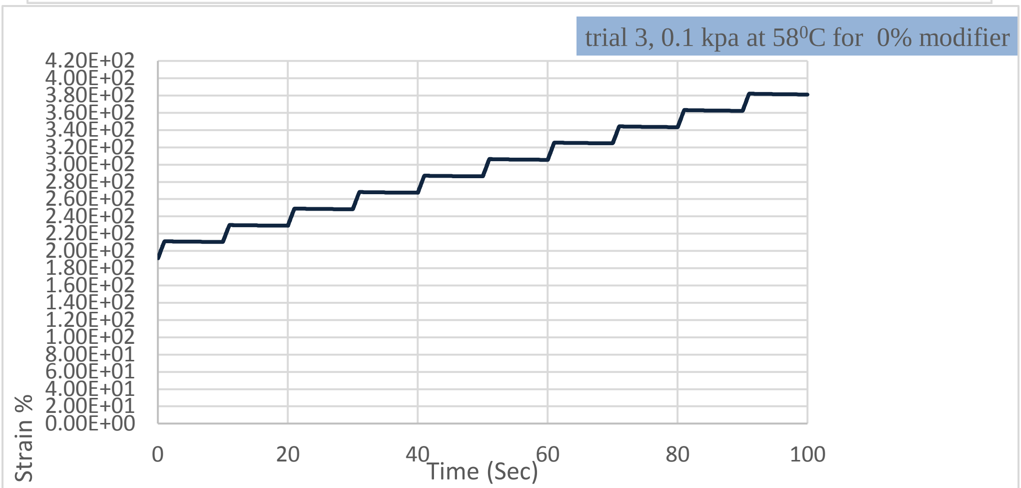
Jnr Computation at stress level 100Pa for 0% modifier (trial 3)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_0	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_0$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	J_{nr}(0.1,N)=□10/0.1kPa		Jnr diff=($J_{nr3.2}$-$J_{nr,0.1}$)/$J_{nr0.1}$*100
1	191.49460	211.32183	19.82723	210.45630	4.4	18.96171	1.90		-2.15
2	210.72262	230.13707	19.41444	229.27154	4.5	18.54892	1.85		0.95
3	229.57780	249.23193	19.65413	248.29982	4.7	18.72202	1.87		0.02
4	248.59277	268.32680	19.73402	267.42132	4.6	18.82855	1.88		0.46
5	267.72758	287.30182	19.57423	286.35640	4.8	18.62881	1.86		2.52
6	286.63603	306.51653	19.88050	305.54447	4.9	18.90844	1.89		1.44
7	305.85074	325.58476	19.73402	324.62602	4.9	18.77529	1.88		2.34
8	324.93228	344.42662	19.49434	343.32141	5.7	18.38913	1.84		5.22
9	343.62768	363.28180	19.65413	362.22986	5.4	18.60218	1.86		3.84
10	362.53612	382.29677	19.76066	381.20488	5.5	18.66876	1.87		3.65
Temprature		58°C			4.9		1.87		1.83
						Avg	1.8703		
						Min	1.8389		
						Max	1.8962		
					% Normalized Range		3.0614		

Jnr Computation at stress level 3200Pa for 0% modifier (trial 3)

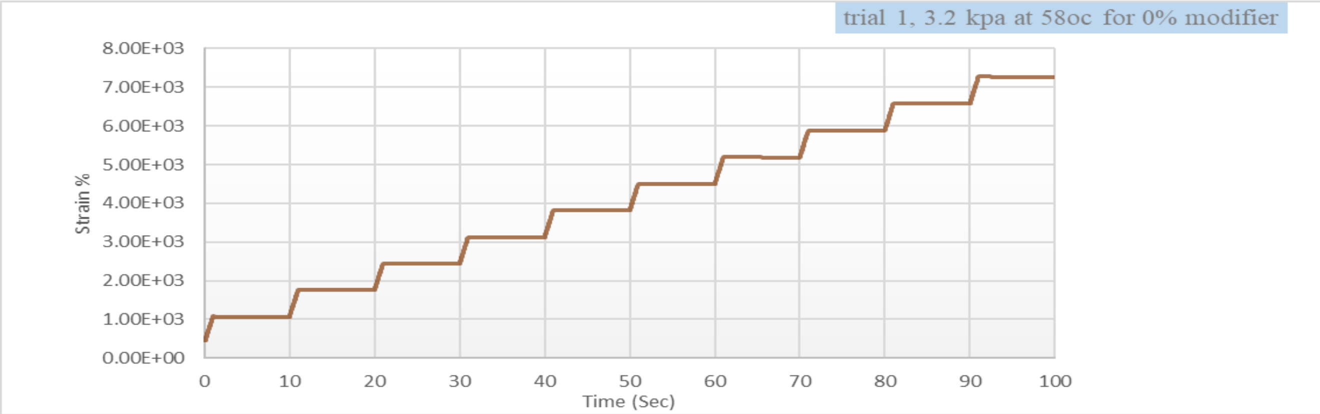
Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_0	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_0$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10/3.2kPa
1	391.33820	988.79179	597.45358	985.06333	0.6	593.725	1.86
2	994.83713	1597.61702	602.77989	1594.02178	0.6	599.185	1.87
3	1603.90211	2206.89507	602.99296	2203.14001	0.6	599.238	1.87
4	2213.41981	2822.43153	609.01171	2818.70307	0.6	605.283	1.89
5	2828.82308	3443.56054	614.73746	3439.93867	0.6	611.116	1.91
6	3449.95215	4067.40607	617.45392	4063.73089	0.6	613.779	1.92
7	4074.03732	4692.45000	618.41267	4688.93459	0.6	614.897	1.92
8	4699.18776	5321.46198	622.27423	5318.37268	0.5	619.185	1.93
9	5328.65248	5949.99460	621.34213	5946.77215	0.5	618.120	1.93
10	5956.91880	6579.43269	622.51389	6576.13037	0.5	619.212	1.94
Temprature		58°C			0.58		1.90
						Avg	1.9043
						Min	1.8554
						Max	1.9350
					% Normalized Range		4.1824

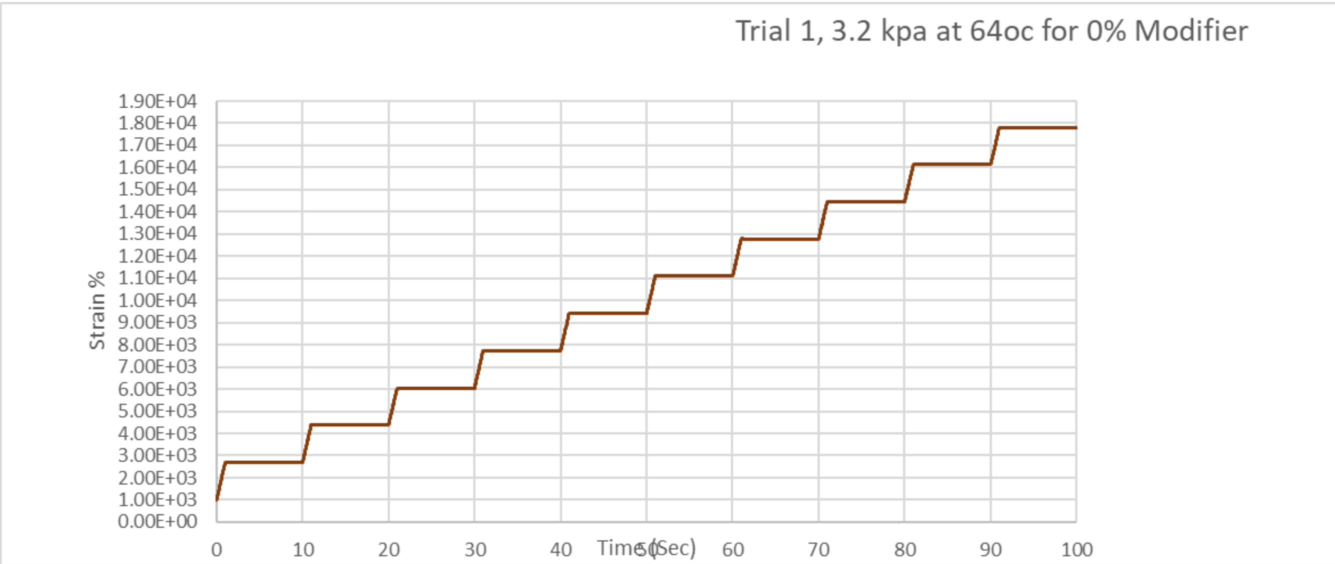




Jnr Computation at stress level 100Pa for 0% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_0	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_0$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	$J_{nr}(0.1,N)=$□$_{10}/0.1kPa$		$Jnr\ diff=(J_{nr3.2}-J_{nr,0.1})/J_{nr0.1}*100$
1	492.71446	524.72262	32.00816	522.61872	6.6	29.90427	2.99		13.61
2	540.83778	573.00573	32.16795	570.74204	7.0	29.90427	2.99		12.99
3	588.98773	621.12905	32.14132	618.89200	7.0	29.90427	2.99		8.87
4	637.11105	669.19911	32.08806	667.01531	6.8	29.90427	2.99		7.97
5	685.20774	717.56211	32.35438	715.37832	6.7	30.17058	3.02		7.66
6	733.59737	765.52564	31.92827	763.23532	7.2	29.63795	2.96		11.36
7	781.45437	813.72885	32.27448	811.38527	7.3	29.93090	2.99		11.22
8	829.60433	861.82554	32.22121	859.48196	7.3	29.87763	2.99		10.16
9	877.72765	910.18855	32.46090	907.79170	7.4	30.06406	3.01		8.17
10	926.01076	958.39176	32.38101	955.96829	7.5	29.95753	3.00		8.81
Temprature		64°C			7.1		2.99		10.08
						Avg	2.9926		
						Min	2.9638		
						Max	3.0171		
					% Normalized Range		1.7799		



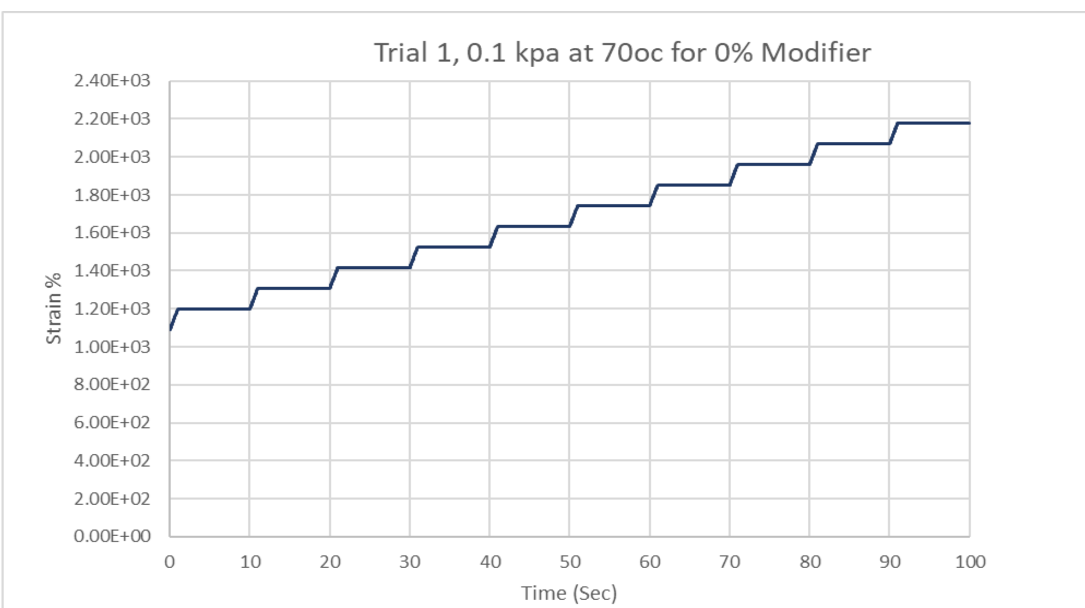


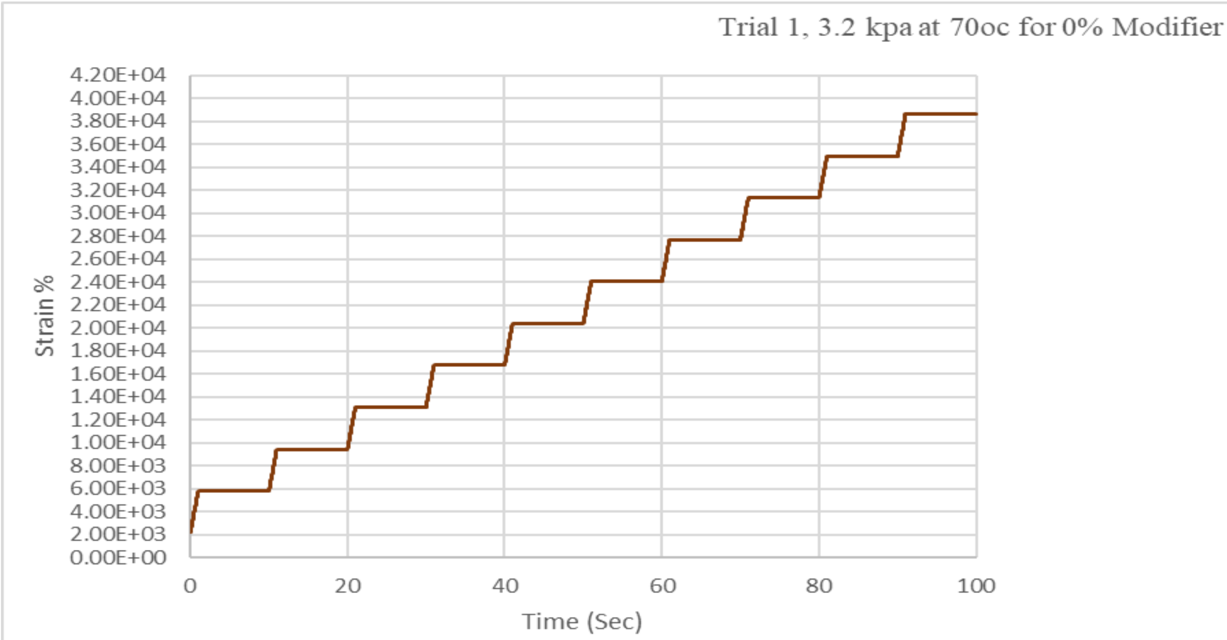
Jnr Computation at stress level 100Pa for 0% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	J_{nr}(0.1,N)=□10/0.1kPa		Jnr diff=($J_{nr3.2}$-$J_{nr,0.1}$)/$J_{nr0.1}$*100
1	1090.24491	1197.73010	107.48519	1197.73010	0.0	107.48519	10.75		3.33
2	1199.00842	1306.81318	107.80477	1306.70665	0.1	107.69823	10.77		5.71
3	1307.98497	1415.97615	107.99118	1415.86962	0.1	107.88466	10.79		4.65
4	1417.17457	1524.84617	107.67160	1524.81955	0.0	107.64498	10.76		4.73
5	1526.09786	1633.71621	107.61834	1633.52978	0.2	107.43192	10.74		4.91
6	1634.78147	1742.34655	107.56508	1742.02696	0.3	107.24549	10.72		5.19
7	1743.30528	1850.89699	107.59171	1850.52414	0.3	107.21886	10.72		5.38
8	1851.80246	1959.52733	107.72487	1959.07459	0.4	107.27213	10.73		4.44
9	1960.32627	2068.18430	107.85803	2067.67829	0.5	107.35202	10.74		4.93
10	2068.92998	2176.65484	107.72486	2176.04231	0.6	107.11233	10.71		5.15
Temprature		70°C			0.2		10.74		4.84
						Avg	10.7435		
						Min	10.7112		
						Max	10.7885		
					% Normalized Range		0.7189		

Jnr Computation at stress level 3200Pa for 0% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	**ε_o**	**ε_c**	**ε_1=ε_c-ε_o**	**□r**	**□r(3.2,N)=(□c-□r)/□1*100**	**□10=□r-□o**	**Jnr(3.2,N)=□10/3.2 kPa**
1	2215.82994	5754.31865	3538.48871	5769.79201	-0.4	3553.962	11.11
2	5809.76606	9435.36710	3625.60104	9453.05031	-0.5	3643.284	11.39
3	9492.70478	13089.51687	3596.81210	13105.38959	-0.4	3612.685	11.29
4	13145.20385	16735.73088	3590.52703	16752.72208	-0.5	3607.518	11.27
5	16792.21676	20384.15533	3591.93857	20398.80257	-0.4	3606.586	11.27
6	20439.14946	24031.83352	3592.68406	24049.09085	-0.5	3609.941	11.28
7	24089.01164	27689.92495	3600.91330	27704.57249	-0.4	3615.561	11.30
8	27744.91938	31313.04901	3568.12963	31330.09356	-0.5	3585.174	11.20
9	31372.27803	34961.87311	3589.59508	34976.99987	-0.4	3604.722	11.26
10	35016.62771	38604.19881	3587.57110	38620.68336	-0.5	3604.056	11.26
Temprature		**70°C**			**-0.45**		**11.26**
						Avg	**11.2636**
						Min	**11.1061**
						Max	**11.3853**
					% Normalized Range		**2.4782**



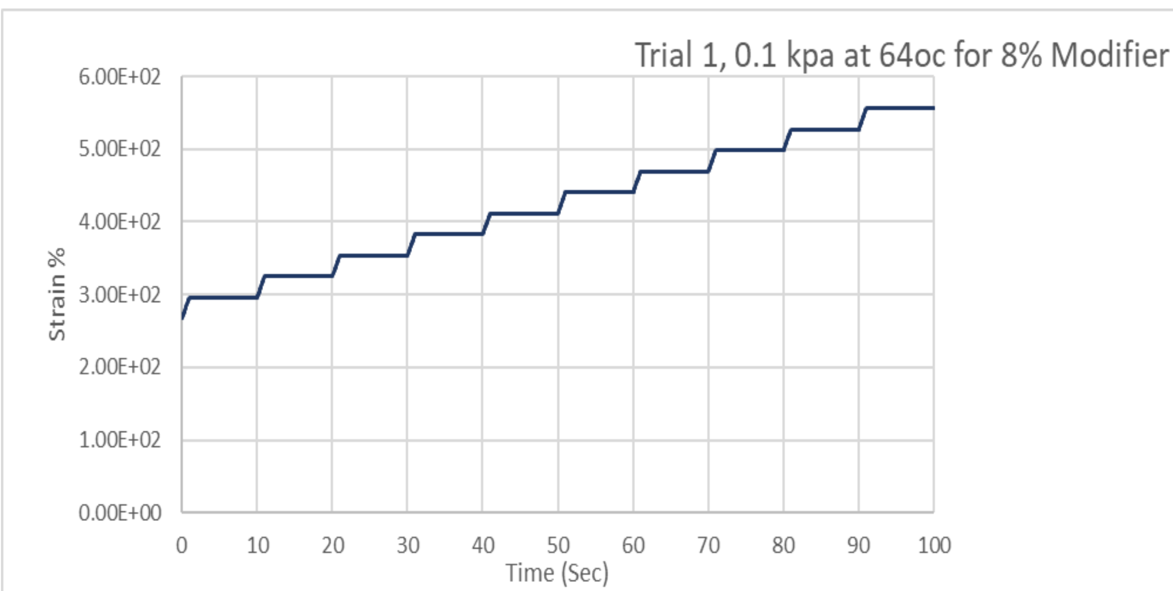


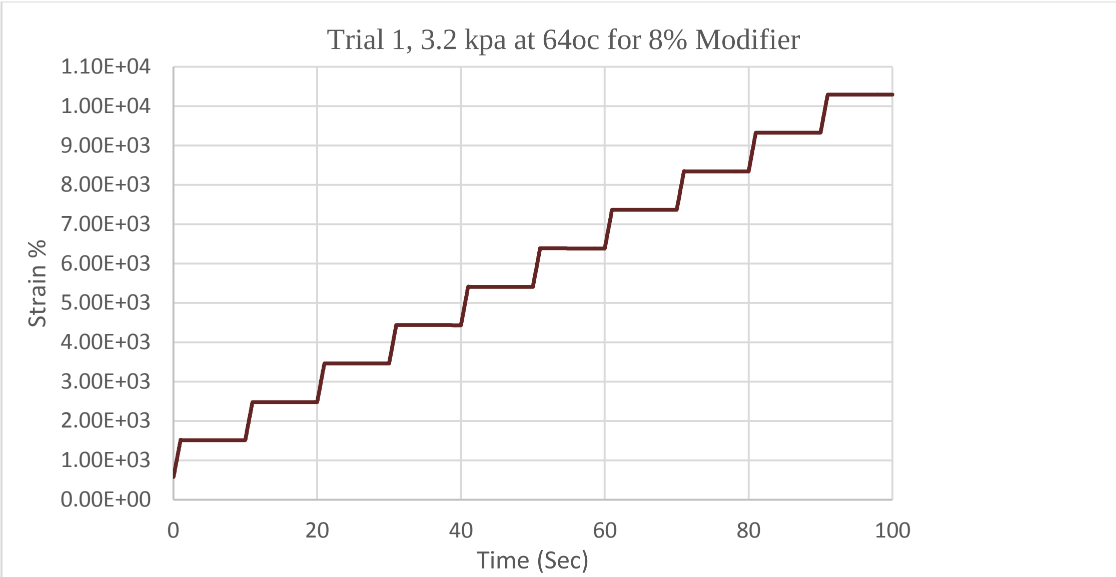
Jnr Computation at stress level 100Pa for 8% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_0	ε_c	$\varepsilon_1 = \varepsilon_c - \varepsilon_0$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	J_{nr}(0.1,N)=□10/0.1kPa		Jnr diff=($J_{nr3.2}$-$J_{nr,0.1}$)/$J_{nr0.1}$*100
1	267.14169	296.06362	28.92193	295.71741	1.2	28.57572	2.86		2.95
2	296.11688	324.98555	28.86866	324.61270	1.3	28.49582	2.85		4.33
3	325.06544	353.66779	28.60235	353.32158	1.2	28.25614	2.83		6.74
4	353.77432	382.90930	29.13498	382.58972	1.1	28.81540	2.88		4.15
5	383.01582	411.59154	28.57572	411.27196	1.1	28.25614	2.83		6.08
6	411.69807	440.62000	28.92193	440.32705	1.0	28.62898	2.86		5.16
7	440.77979	469.24898	28.46919	468.92940	1.1	28.14961	2.81		6.79
8	469.35551	498.67691	29.32140	498.33070	1.2	28.97519	2.90		4.31
9	498.73018	527.14611	28.41593	526.82653	1.1	28.09635	2.81		7.07
10	527.27926	556.22783	28.94856	555.90825	1.1	28.62898	2.86		4.42
Temprature		64°C			1.1		2.85		5.20
						Avg	2.8488		
						Min	2.8096		
						Max	2.8975		
					% Normalized Range		3.0850		

Jnr Computation at stress level 3200Pa for 8% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_0	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_0$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10 /3.2kPa
1	570.34258	1514.27337	943.93079	1511.74338	0.3	941.401	2.94
2	1526.92340	2481.05416	954.13076	2478.31108	0.3	951.388	2.97
3	2493.43783	3461.52352	968.08569	3458.56742	0.3	965.130	3.02
4	3473.58765	4437.11930	963.53165	4433.97687	0.3	960.389	3.00
5	4448.73078	5411.22386	962.49307	5407.89494	0.3	959.164	3.00
6	5422.86190	6389.03008	966.16818	6386.23373	0.3	963.372	3.01
7	6401.33385	7366.03731	964.70345	7363.32098	0.3	961.987	3.01
8	7378.60752	8348.02480	969.41728	8345.73449	0.2	967.127	3.02
9	8360.99440	9325.77783	964.78342	9323.64719	0.2	962.653	3.01
10	9338.82720	10297.77826	958.95106	10295.43461	0.2	956.607	2.99
Temprature		**64°C**			**0.28**		**3.00**
						Avg	**2.9966**
						Min	**2.9419**
						Max	**3.0223**
					% Normalized Range		**2.6828**



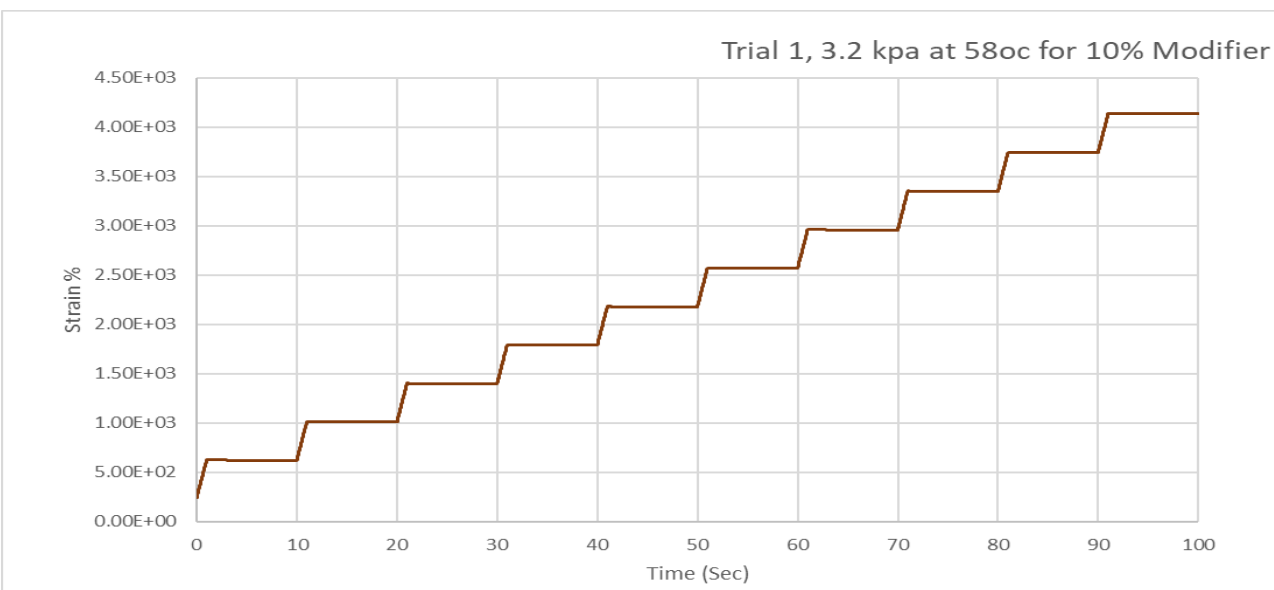


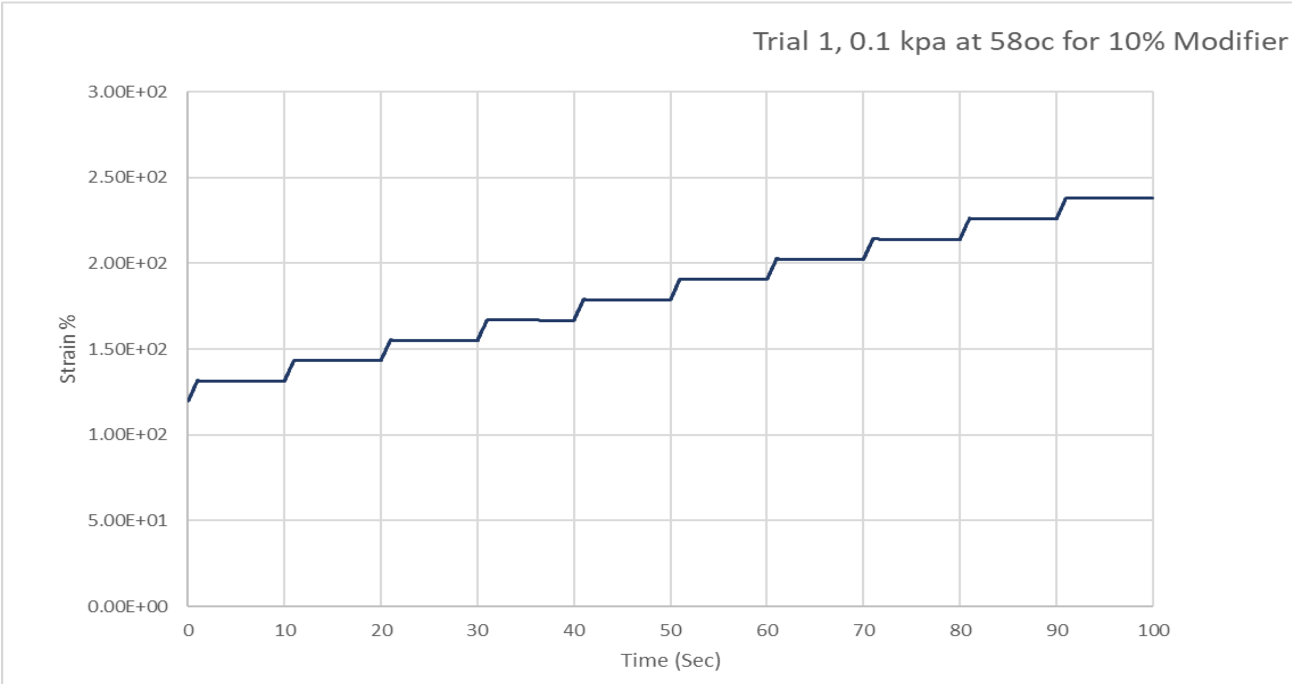
Jnr Computation at stress level 100Pa for 10% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_0	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_0$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	J_{nr}(0.1,N)=□10/0.1kPa		Jnr diff=($J_{nr3.2}$-$J_{nr,0.1}$)/$J_{nr0.1}$*100
1	119.54930	131.64005	12.09075	131.34710	2.4	11.79780	1.18		0.01
2	131.56016	143.67754	12.11738	143.35796	2.6	11.79780	1.18		0.97
3	143.54438	155.31555	11.77117	154.96934	2.9	11.42496	1.14		4.55
4	155.15577	167.08673	11.93096	166.71388	3.1	11.55812	1.16		3.43
5	166.92694	178.96443	12.03749	178.59158	3.1	11.66465	1.17		2.61
6	178.77800	190.84212	12.06412	190.46928	3.1	11.69128	1.17		2.34
7	190.68233	202.63993	11.95759	202.26708	3.1	11.58475	1.16		3.38
8	202.50677	214.25131	11.74454	213.85183	3.4	11.34507	1.13		5.82
9	214.09152	226.18227	12.09075	225.80943	3.1	11.71791	1.17		2.72
10	225.99585	238.11323	12.11738	237.71376	3.3	11.71791	1.17		2.90
Temprature		58°C			3.0		1.16		2.87
						Avg	1.1630		
						Min	1.1345		
						Max	1.1798		
					% Normalized Range		3.8928		

Jnr Computation at stress level 3200Pa for 10% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10 /3.2kPa
1	244.55808	627.60055	383.04247	622.14107	1.4	377.583	1.18
2	628.95876	1015.46332	386.50457	1010.13702	1.4	381.178	1.19
3	1017.22102	1404.97729	387.75627	1399.46454	1.4	382.244	1.19
4	1406.38875	1794.62437	388.23561	1788.92523	1.5	382.536	1.20
5	1795.95598	2184.67098	388.71500	2178.97181	1.5	383.016	1.20
6	2186.02918	2574.63765	388.60846	2568.91184	1.5	382.883	1.20
7	2575.88932	2965.00378	389.11446	2959.11819	1.5	383.229	1.20
8	2966.25546	3356.16887	389.91341	3350.41646	1.5	384.161	1.20
9	3357.34068	3748.21283	390.87215	3742.51366	1.5	385.173	1.20
10	3749.41125	4141.13559	391.72434	4135.25000	1.5	385.839	1.21
Temprature		**58°C**			**1.46**		**1.20**
						Avg	**1.1962**
						Min	**1.1799**
						Max	**1.2057**
					% Normalized Range		**2.1568**

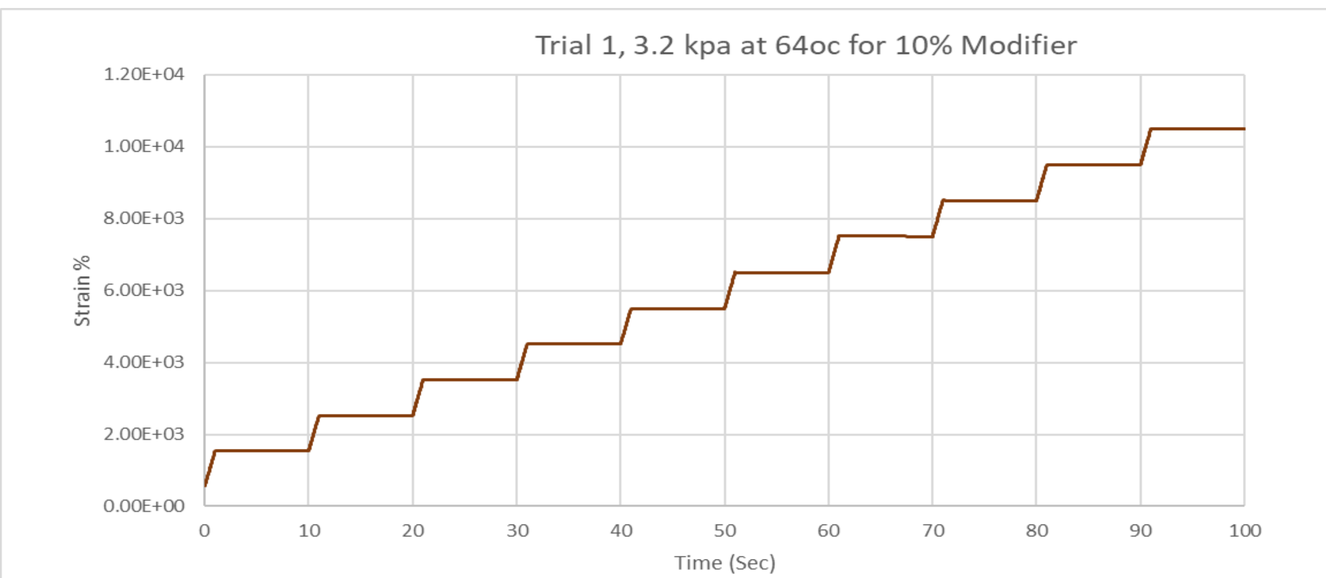


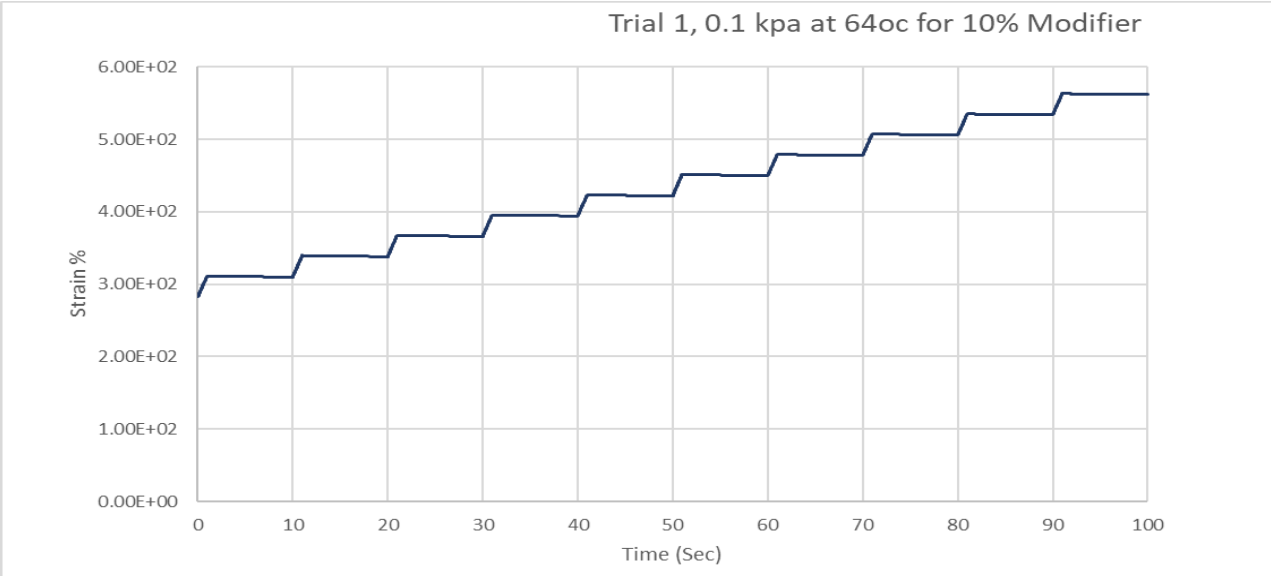


Trial 1, with 10% Modifier									
Stress Cycle	**Initial strain at the beginning of creep portion**	**Strain at the end of creep portion (after 1 sec)**	**Adjusted strain value at the end of the creep portion**	**Strain at end of the Recovery portion**	**% Recovery**	**the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)**	**Jnr, Kpa^{-1}**		**Jnr diff**
0.1 KPa	**ε_0**	**ε_c**	**$\varepsilon_1=\varepsilon_c-\varepsilon_0$**	**□r**	**□r(0.1,N)=(□c-□r)/□1*100**	**□10=□r-□o**	**J_{nr}(0.1,N)=□10/ 0.1kPa**		**Jnr diff=($J_{nr3.2}$-$J_{nr,0.1}$)/$J_{nr0.1}$*100**
1	282.64129	311.43006	28.78877	310.01859	4.9	27.37730	2.74		10.06
2	310.49796	339.71283	29.21488	338.19483	5.2	27.69688	2.77		9.16
3	338.64757	367.59613	28.94856	366.02487	5.4	27.37730	2.74		10.89
4	366.53087	395.82564	29.29477	394.33427	5.1	27.80340	2.78		9.71
5	394.81364	423.60241	28.78877	422.05777	5.4	27.24414	2.72		12.46
6	422.51051	451.69876	29.18825	450.15412	5.3	27.64361	2.76		11.53
7	450.63349	479.50216	28.86867	477.85100	5.7	27.21751	2.72		13.47
8	478.33037	507.70503	29.37467	506.10714	5.4	27.77677	2.78		10.58
9	506.55987	535.34864	28.78877	533.72412	5.6	27.16424	2.72		12.86
10	534.17685	563.49826	29.32140	561.84710	5.6	27.67025	2.77		10.24
Temprature		**64°C**			**5.4**		**2.75**		**11.10**
						Avg	**2.7497**		
						Min	**2.7164**		
						Max	**2.7803**		
					% Normalized Range		**2.3245**		

Jnr Computation at stress level 3200Pa for 10% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10 /3.2kPa
1	577.26680	1546.39111	969.12431	1541.43759	0.5	964.171	3.01
2	1556.96382	2529.09751	972.13369	2524.43702	0.5	967.473	3.02
3	2540.06978	3515.77216	975.70238	3511.51102	0.4	971.441	3.04
4	3527.11715	4507.13375	980.01660	4503.19231	0.4	976.075	3.05
5	4518.71854	5503.20932	984.49077	5499.16134	0.4	980.443	3.06
6	5514.52778	6504.93079	990.40301	6501.12250	0.4	986.595	3.08
7	6516.75525	7509.20893	992.45367	7505.05433	0.4	988.299	3.09
8	7520.76698	8508.18724	987.42026	8503.63330	0.5	982.866	3.07
9	8518.91984	9505.00847	986.08862	9499.97508	0.5	981.055	3.07
10	9515.52794	10496.47675	980.94881	10491.65637	0.5	976.128	3.05
Temprature		**64°C**			**0.45**		**3.05**
						Avg	**3.0545**
						Min	**3.0130**
						Max	**3.0884**
					% Normalized Range		**2.4685**



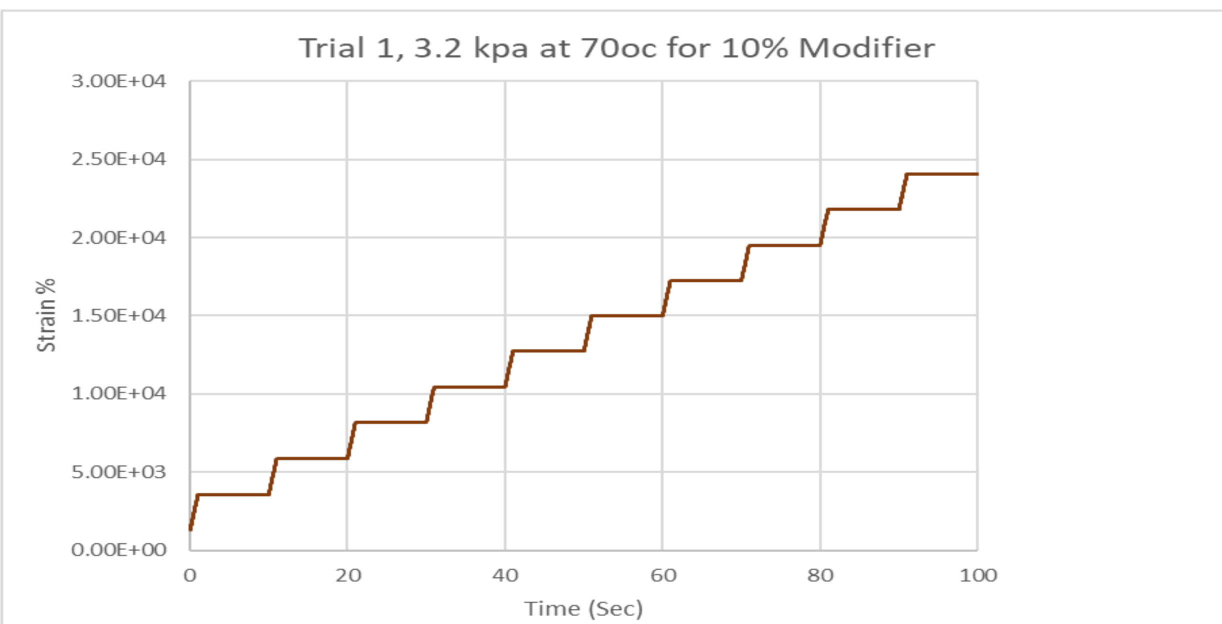


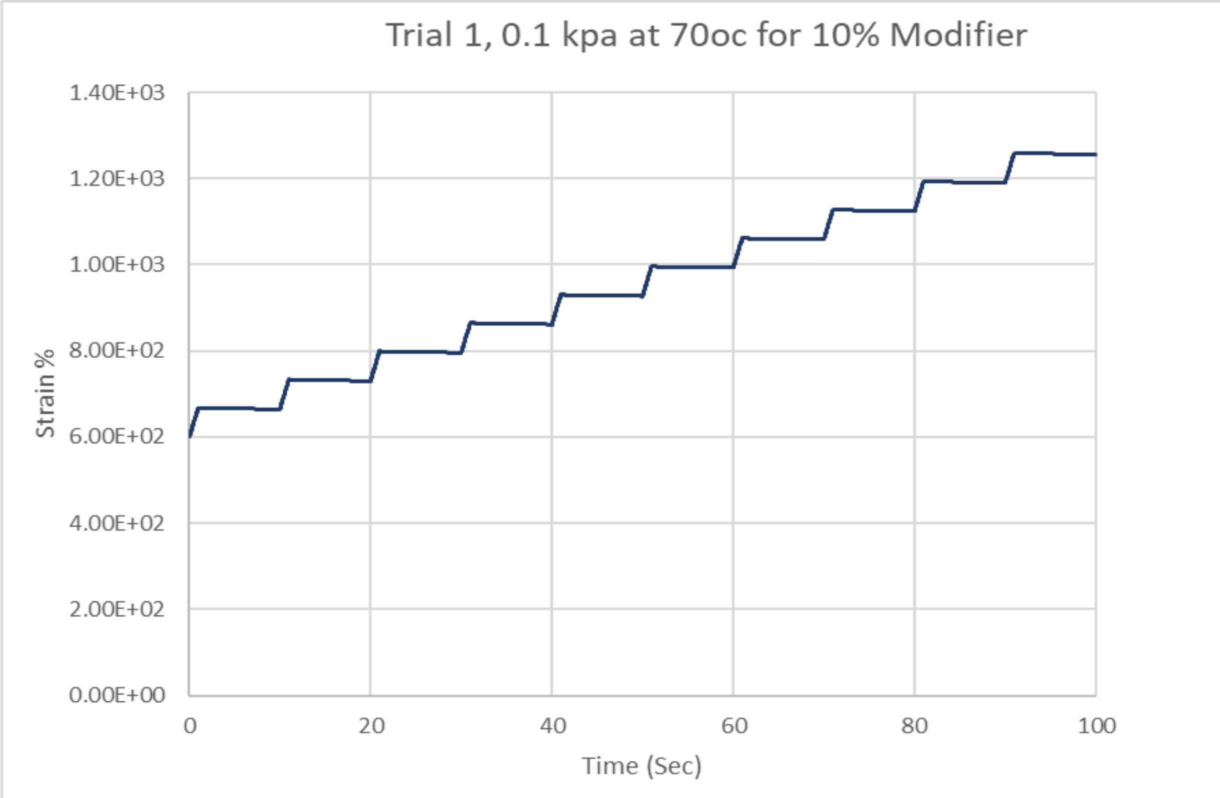
Jnr Computation at stress level 100Pa for 10% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_0	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_0$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	$J_{nr}(0.1,N)=$□10/0.1kPa		Jnr diff=$(J_{nr3.2}-J_{nr,0.1})/J_{nr0.1}*100$
1	599.87703	667.57458	67.69756	664.59184	4.4	64.71481	6.47		9.06
2	665.47069	733.43456	67.96387	730.05234	5.0	64.58166	6.46		10.70
3	730.98445	799.10811	68.12366	795.67263	5.0	64.68818	6.47		9.92
4	796.65800	864.88819	68.23018	861.42608	5.1	64.76808	6.48		8.74
5	862.35818	930.29543	67.93724	926.91321	5.0	64.55502	6.46		8.74
6	927.84531	995.88908	68.04377	992.82644	4.5	64.98113	6.50		7.43
7	993.73192	1061.50937	67.77745	1058.28694	4.8	64.55502	6.46		7.89
8	1059.21905	1127.84871	68.62966	1124.49313	4.9	65.27408	6.53		7.42
9	1125.39860	1193.78858	68.38998	1190.40637	4.9	65.00776	6.50		7.73
10	1191.36510	1259.51539	68.15029	1256.21308	4.8	64.84797	6.48		7.39
Temprature		70°C			4.8		6.48		8.50
						Avg	6.4797		
						Min	6.4555		
						Max	6.5274		
					% Normalized Range		1.1097		

Jnr Computation at stress level 3200Pa for 10% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_0	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_0$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10 /3.2kPa
1	1285.69427	3541.01900	2255.32473	3544.21471	-0.1	2258.520	7.06
2	3574.36169	5860.12621	2285.76452	5862.12356	-0.1	2287.762	7.15
3	5892.05749	8165.94441	2273.88692	8167.48891	-0.1	2275.431	7.11
4	8197.02337	10447.39444	2250.37107	10450.64364	-0.1	2253.620	7.04
5	10480.41778	12723.41181	2242.99403	12726.68768	-0.1	2246.270	7.02
6	12757.89993	14990.37463	2232.47471	14991.81275	-0.1	2233.913	6.98
7	15021.24068	17247.40375	2226.16307	17249.96034	-0.1	2228.720	6.96
8	17280.29375	19520.01233	2239.71858	19524.06023	-0.2	2243.766	7.01
9	19555.24585	21793.55283	2238.30698	21796.32265	-0.1	2241.077	7.00
10	21825.88374	24052.47290	2226.58916	24054.36371	-0.1	2228.480	6.96
Temprature		**70°C**			**-0.12**		**7.03**
						Avg	**7.0305**
						Min	**6.9640**
						Max	**7.1493**
					% Normalized Range		**2.6350**



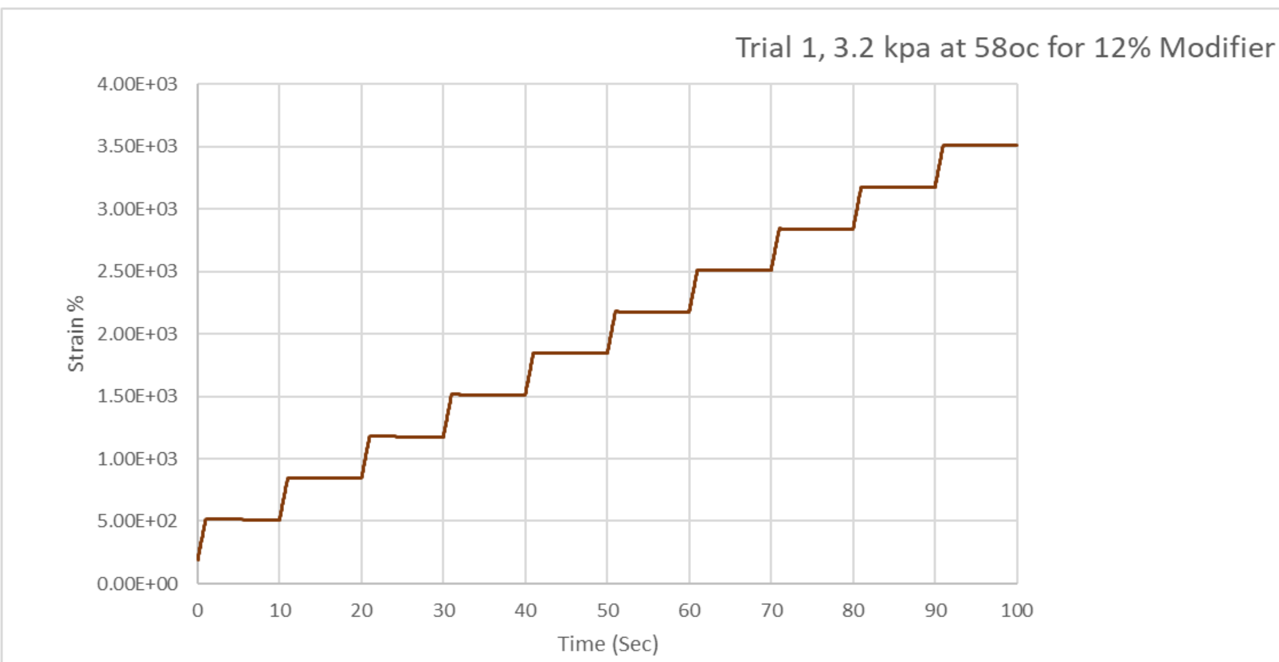


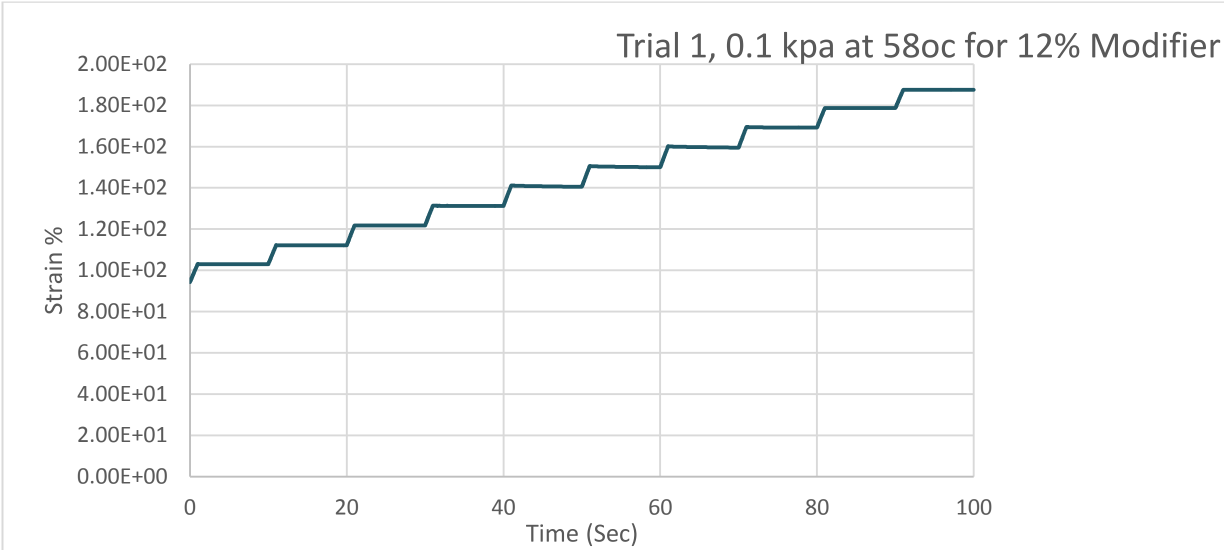
Jnr Computation at stress level 100Pa for 12% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_0	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_0$	$□_r$	□r(0.1,N)=(□c-□r)/$□_1$*100	$□_{10}$=□r-□o	$J_{nr}(0.1,N)=□_{10}/$ 0.1kPa		Jnr diff=$(J_{nr3.2}-J_{nr,0.1})/J_{nr0.1}$*100
1	94.32916	103.09096	8.76180	103.03770	0.6	8.70854	0.87		14.34
2	103.14423	112.22561	9.08138	112.11908	1.2	8.97485	0.90		13.19
3	112.27887	121.81299	9.53412	121.73309	0.8	9.45422	0.95		8.45
4	121.91951	131.42700	9.50748	131.29384	1.4	9.37433	0.94		10.04
5	131.45363	141.20080	9.74717	140.50838	7.1	9.05475	0.91		11.94
6	140.66817	150.65502	9.98685	149.98923	6.7	9.32106	0.93		8.86
7	150.12239	160.21577	10.09338	159.49672	7.1	9.37433	0.94		8.48
8	159.68314	169.53683	9.85370	169.19062	3.5	9.50748	0.95		6.90
9	169.37704	178.75137	9.37433	178.67148	0.9	9.29443	0.93		10.03
10	178.80463	187.61970	8.81506	187.53980	0.9	8.73517	0.87		17.65
Temprature		58°C			3.0		0.92		10.99
						Avg	0.9180		
						Min	0.8709		
						Max	0.9507		
					% Normalized Range		8.7032		

Jnr Computation at stress level 3200Pa for 12% modifier (trial 1)

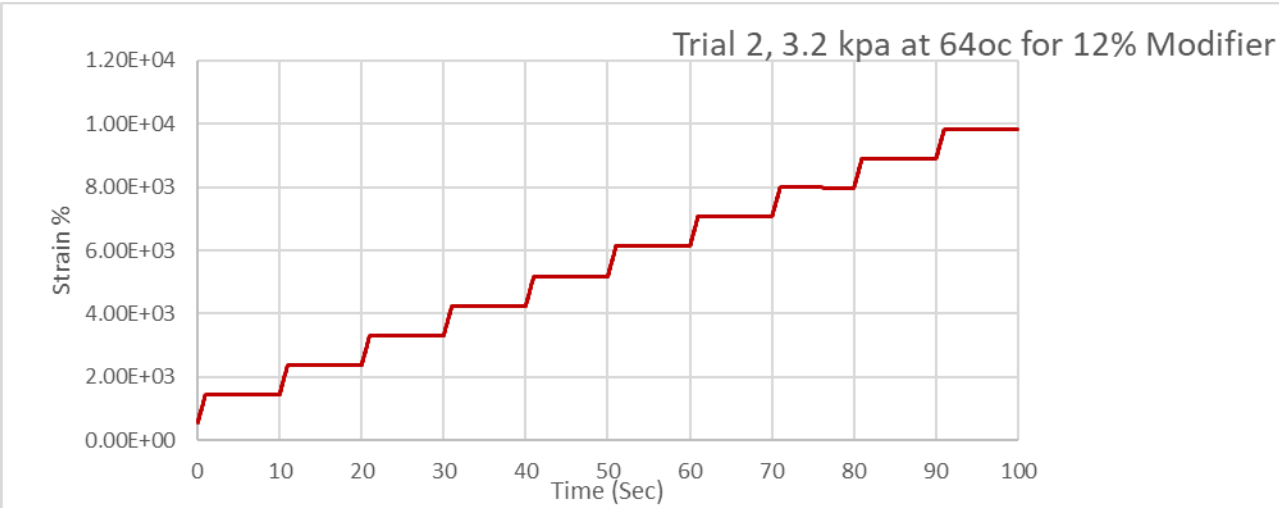
Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10 /3.2kPa
1	193.45202	519.68926	326.23724	512.09924	2.3	318.647	1.00
2	517.95819	847.28469	329.32650	843.02363	1.3	325.065	1.02
3	849.01574	1181.32499	332.30925	1177.11716	1.3	328.101	1.03
4	1183.26906	1517.33600	334.06694	1513.36786	1.2	330.099	1.03
5	1519.43987	1850.01806	330.57819	1843.78625	1.9	324.346	1.01
6	1849.83162	2181.12887	331.29724	2174.52423	2.0	324.693	1.01
7	2180.56960	2512.66577	332.09617	2505.98126	2.0	325.412	1.02
8	2512.42611	2844.22935	331.80324	2837.65134	2.0	325.225	1.02
9	2843.77661	3177.47068	333.69407	3171.02586	1.9	327.249	1.02
10	3177.15113	3512.46972	335.31860	3506.02490	1.9	328.874	1.03
Temprature		58°C			1.78		1.02
						Avg	1.0180
						Min	0.9958
						Max	1.0316
					% Normalized Range		3.5152

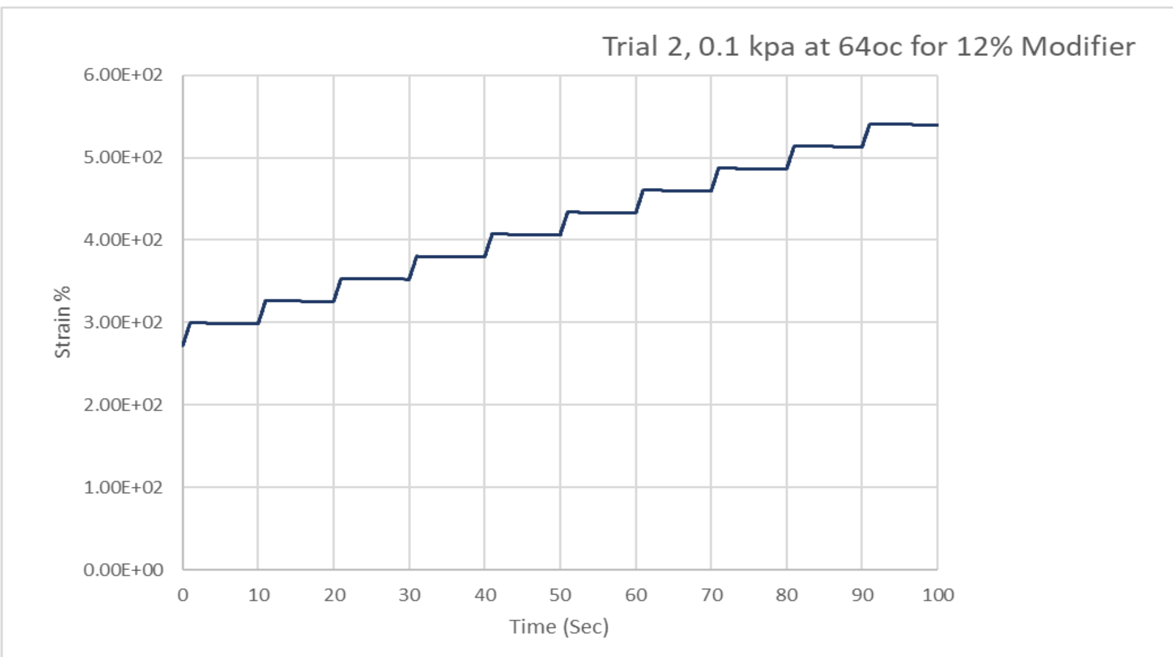




Jnr Computation at stress level 100Pa for 12% modifier (trial 2)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	**ε_0**	**ε_c**	**$\varepsilon_1=\varepsilon_c-\varepsilon_0$**	**□r**	**□r(0.1,N)=(□c-□r)/□1*100**	**□10=□r-□o**	**J_{nr}(0.1,N)=□10/0.1kPa**		**Jnr diff=($J_{nr3.2}$-$J_{nr,0.1}$)/$J_{nr0.1}$*100**
1	271.69570	299.57899	27.88330	298.51373	3.8	26.81803	2.68		4.88
2	298.93984	326.53018	27.59035	325.38503	4.2	26.44519	2.64		7.23
3	325.83776	353.48138	27.64361	352.30959	4.2	26.47182	2.65		8.12
4	352.70906	380.29941	27.59035	379.10099	4.3	26.39193	2.64		9.15
5	379.52709	407.35713	27.83003	406.13207	4.4	26.60498	2.66		8.72
6	406.58481	433.88221	27.29740	432.63052	4.6	26.04571	2.60		10.82
7	433.08326	460.64698	27.56372	459.39529	4.5	26.31203	2.63		9.06
8	459.82140	487.22533	27.40393	485.97364	4.6	26.15224	2.62		8.91
9	486.42638	514.17652	27.75014	512.97809	4.3	26.55172	2.66		6.70
10	513.45746	540.86139	27.40393	539.63633	4.5	26.17887	2.62		7.90
Temprature		**64°C**			**4.3**		**2.64**		**8.15**
						Avg	**2.6397**		
						Min	**2.6046**		
						Max	**2.6818**		
					% Normalized Range		**2.9258**		


Trial 2, 3.2 kpa at 64oc for 12% Modifier
Strain %
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
0
10
20
30
40
50
60
70
80
90
100
Time (Sec)

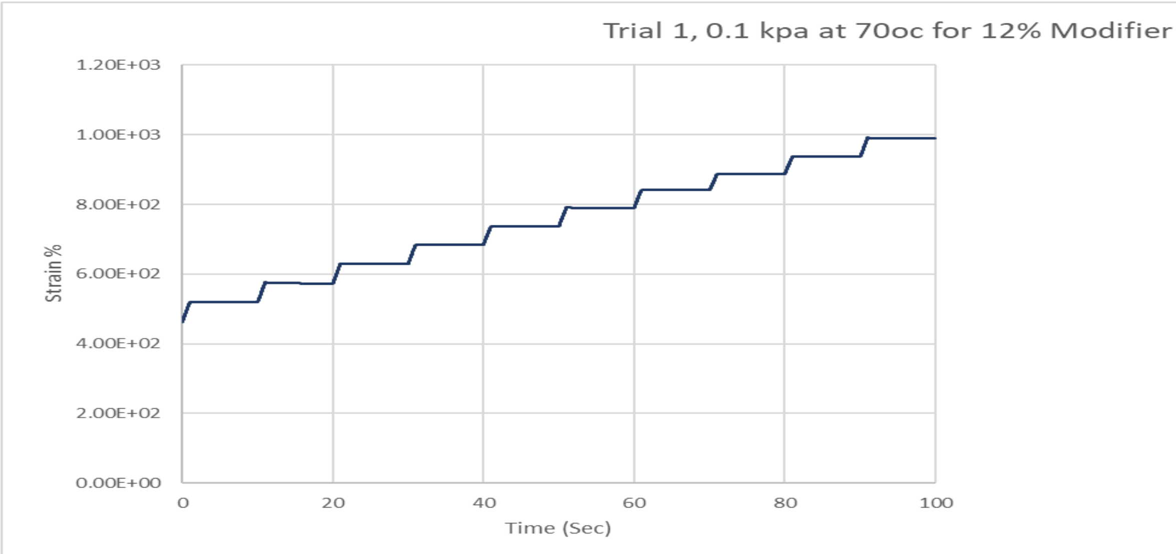

Trial 2, 0.1 kpa at 64oc for 12% Modifier
Strain %
6.00E+02
5.00E+02
4.00E+02
3.00E+02
2.00E+02
1.00E+02
0.00E+00
0
10
20
30
40
50
60
70
80
90
100
Time (Sec)

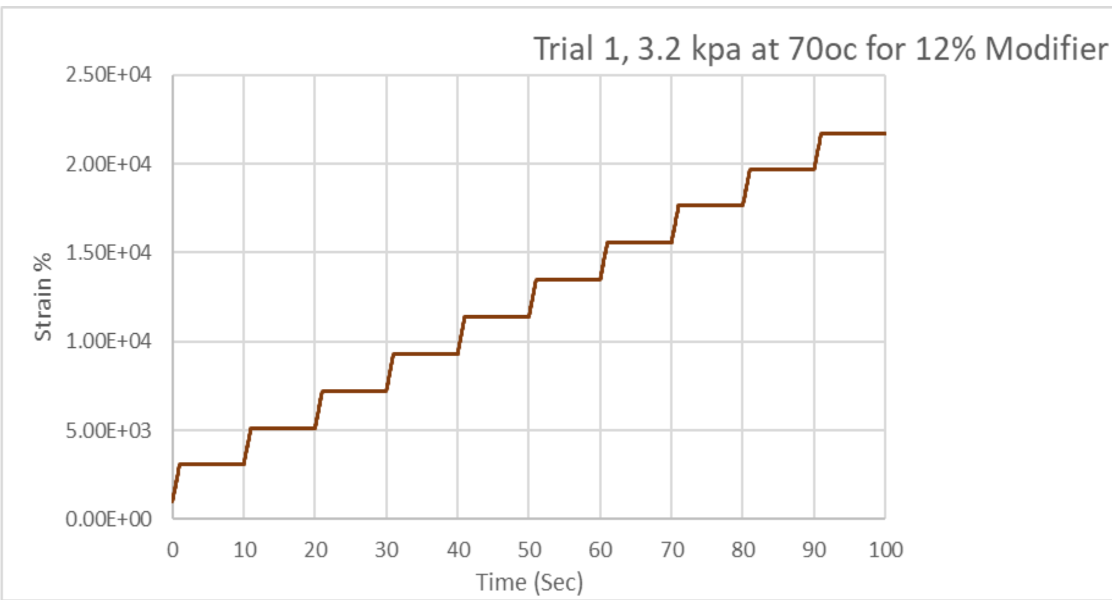
Jnr Computation at stress level 100Pa for 12% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	J_{nr}(0.1,N)=□10/0.1kPa		Jnr diff=($J_{nr3.2}$-$J_{nr,0.1}$)/$J_{nr0.1}$*100
1	463.15034	519.20989	56.05954	518.65062	1.0	55.50028	5.55		14.63
2	519.44957	575.74880	56.29923	572.36658	6.0	52.91701	5.29		20.69
3	573.19216	630.37022	57.17807	628.74570	2.8	55.55354	5.56		15.82
4	629.59791	684.56556	54.96765	684.51229	0.1	54.91438	5.49		17.11
5	685.20472	737.05647	51.85175	736.15099	1.7	50.94627	5.09		26.46
6	736.94994	790.95884	54.00891	789.73379	2.3	52.78385	5.28		22.17
7	790.55937	841.55890	50.99953	841.53227	0.1	50.97290	5.10		26.32
8	842.14480	887.07232	44.92753	887.04569	0.1	44.90090	4.49		41.94
9	887.76475	936.82017	49.05543	936.82017	0.0	49.05543	4.91		28.86
10	937.45933	991.14866	53.68932	990.96224	0.3	53.50291	5.35		18.00
Temprature		70°C			1.4		5.21		23.20
						Avg	5.2105		
						Min	4.4901		
						Max	5.5554		
					% Normalized Range		20.4447		

Jnr Computation at stress level 3200Pa for 12% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10 /3.2kPa
1	1017.70037	3054.45939	2036.75902	3053.50050	0.0	2035.800	6.36
2	3080.74464	5123.36254	2042.61790	5124.40130	-0.1	2043.657	6.39
3	5151.99165	7209.70973	2057.71808	7210.98810	-0.1	2058.996	6.43
4	7238.52519	9296.61602	2058.09083	9296.40293	0.0	2057.878	6.43
5	9324.04654	11385.70607	2061.65952	11385.70607	0.0	2061.660	6.44
6	11413.72252	13475.51525	2061.79273	13477.19297	-0.1	2063.470	6.45
7	13504.78332	15564.07273	2059.28941	15565.21788	-0.1	2060.435	6.44
8	15592.59518	17632.31024	2039.71506	17632.09715	0.0	2039.502	6.37
9	17660.96582	19684.78173	2023.81591	19683.71645	0.1	2022.751	6.32
10	19711.41332	21730.46231	2019.04899	21731.74068	-0.1	2020.327	6.31
Temprature		70°C			-0.02		6.40
						Avg	6.3951
						Min	6.3135
						Max	6.4483
					% Normalized Range		2.1082


Trial 1, 0.1 kpa at 70oc for 12% Modifier
Strain %
Time (Sec)
1.20E+03
1.00E+03
8.00E+02
6.00E+02
4.00E+02
2.00E+02
0.00E+00
0
20
40
60
80
100

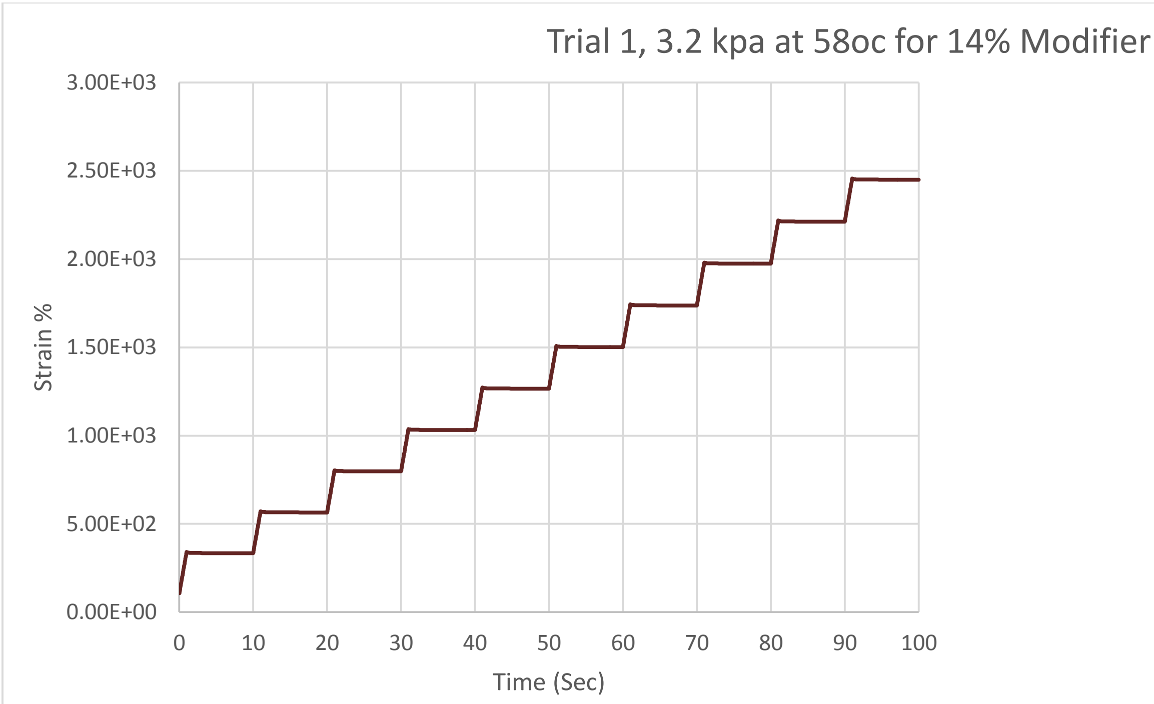

Trial 1, 3.2 kpa at 70oc for 12% Modifier
Strain %
Time (Sec)
2.50E+04
2.00E+04
1.50E+04
1.00E+04
5.00E+03
0.00E+00
0
10
20
30
40
50
60
70
80
90
100

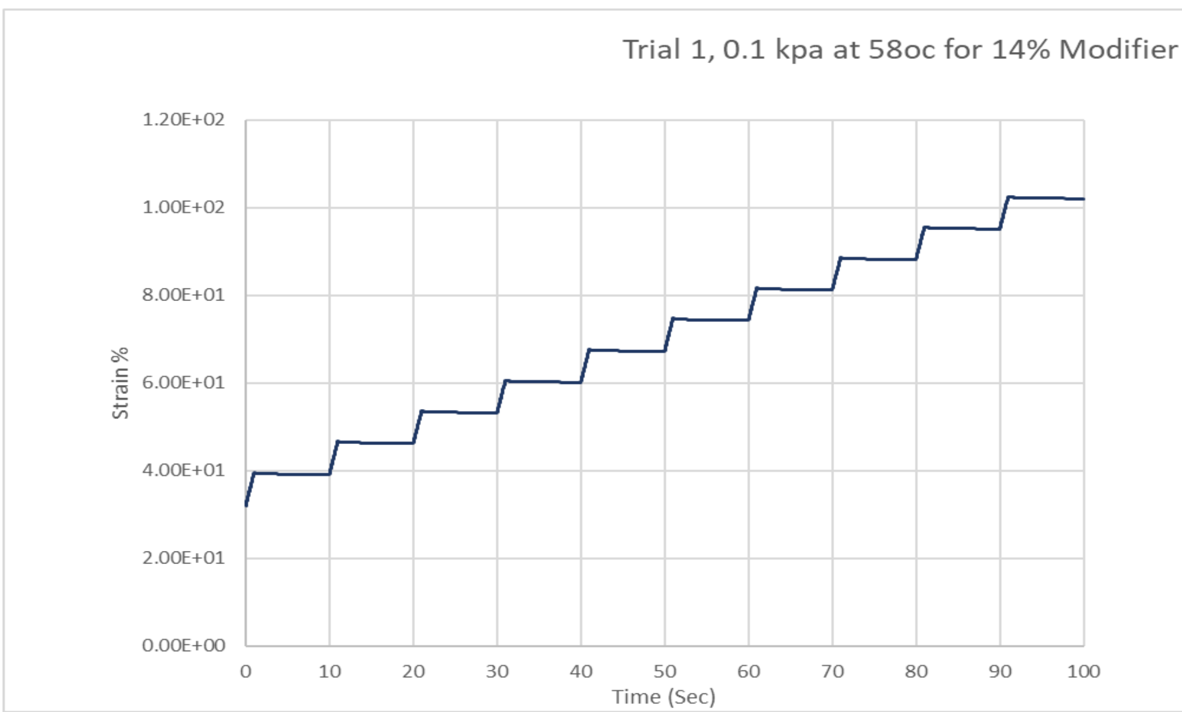
Jnr Computation at stress level 100Pa for 14% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	J_{nr}(0.1,N)=□10/ 0.1kPa		Jnr diff=($J_{nr3.2}$-$J_{nr,0.1}$)/$J_{nr0.1}$*100
1	32.20793	39.46805	7.26011	39.06857	5.5	6.86064	0.69		3.36
2	39.20173	46.60532	7.40359	46.20585	5.4	7.00411	0.70		1.05
3	46.31237	53.60943	7.29706	53.15670	6.2	6.84432	0.68		4.11
4	53.28985	60.56028	7.27043	60.10755	6.2	6.81769	0.68		5.20
5	60.24071	67.61766	7.37696	67.16492	6.1	6.92422	0.69		3.82
6	67.29808	74.70167	7.40359	74.22230	6.5	6.92422	0.69		4.16
7	74.32883	81.62589	7.29706	81.17315	6.2	6.84432	0.68		5.54
8	81.30631	88.60337	7.29706	88.09737	6.9	6.79106	0.68		6.95
9	88.23053	95.55422	7.32369	95.10148	6.2	6.87096	0.69		5.92
10	95.23464	102.47844	7.24380	101.99907	6.6	6.76443	0.68		7.57
Temprature		58°C			6.2		0.69		4.77
						Avg	0.6865		
						Min	0.6764		
						Max	0.7004		
					% Normalized Range		3.4916		

Jnr Computation at stress level 3200Pa for 14% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10 /3.2kPa
1	106.47318	340.24547	233.77229	333.40114	2.9	226.928	0.71
2	338.08830	571.11491	233.02661	564.56353	2.8	226.475	0.71
3	569.14416	803.66212	234.51796	797.16402	2.8	228.020	0.71
4	801.82455	1037.72736	235.90281	1031.33577	2.7	229.511	0.72
5	1035.86314	1272.35184	236.48870	1265.90698	2.7	230.044	0.72
6	1270.56751	1507.77525	237.20774	1501.35706	2.7	230.790	0.72
7	1506.01759	1743.43840	237.42081	1737.17997	2.6	231.162	0.72
8	1741.76061	1980.64615	238.88554	1974.17467	2.7	232.414	0.73
9	1978.91509	2218.25338	239.33828	2211.80853	2.7	232.893	0.73
10	2216.78864	2455.83397	239.04533	2449.62883	2.6	232.840	0.73
Temprature		58°C			2.73		0.72
						Avg	0.7191
						Min	0.7077
						Max	0.7278
					% Normalized Range		2.7892


Trial 1, 3.2 kpa at 58oc for 14% Modifier
3.00E+03
2.50E+03
2.00E+03
1.50E+03
1.00E+03
5.00E+02
0.00E+00
Strain %
0
10
20
30
40
50
60
70
80
90
100
Time (Sec)

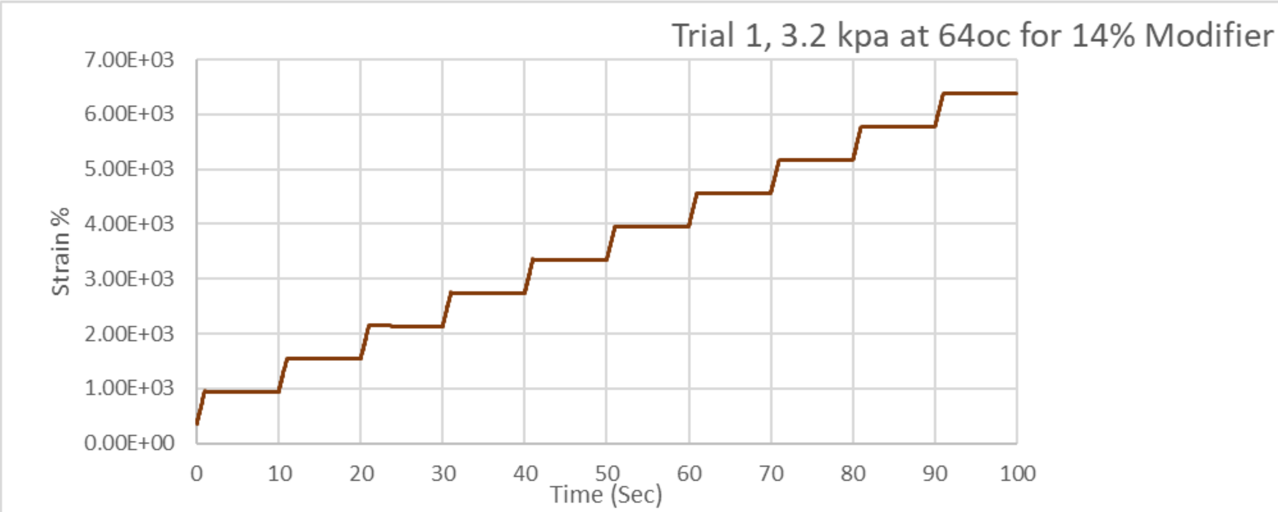

Trial 1, 0.1 kpa at 58oc for 14% Modifier
1.20E+02
1.00E+02
8.00E+01
6.00E+01
4.00E+01
2.00E+01
0.00E+00
Strain %
0
10
20
30
40
50
60
70
80
90
100
Time (Sec)

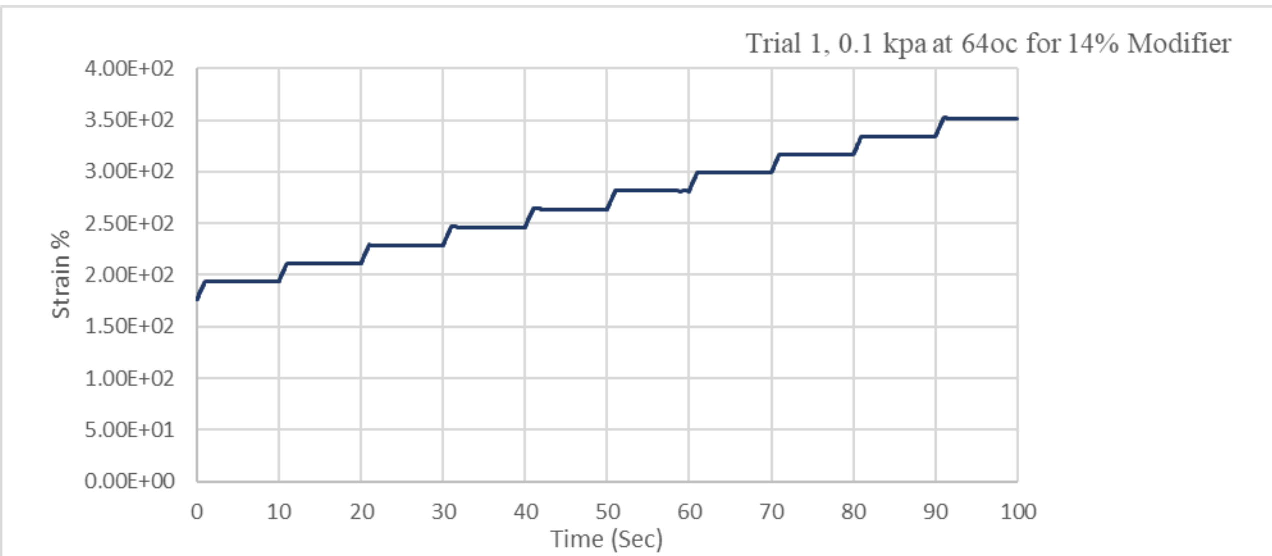
Jnr Computation at stress level 100Pa for 14% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	J_{nr}(0.1,N)=□10/0.1kPa		Jnr diff=($J_{nr3.2}$-$J_{nr,0.1}$)/$J_{nr0.1}$*100
1	176.06158	194.06455	18.00297	193.63844	2.4	17.57686	1.76		3.39
2	193.93139	211.58815	17.65676	211.16204	2.4	17.23065	1.72		6.19
3	211.45499	229.11175	17.65676	228.65901	2.6	17.20402	1.72		7.18
4	228.97859	246.68861	17.71002	246.23587	2.6	17.25728	1.73		7.61
5	246.55545	264.10568	17.55023	263.65295	2.6	17.09749	1.71		8.94
6	263.94589	281.68255	17.73665	281.17655	2.9	17.23065	1.72		8.22
7	281.49613	299.39257	17.89644	298.91320	2.7	17.41707	1.74		6.91
8	299.25941	317.02269	17.76329	316.51669	2.8	17.25728	1.73		7.69
9	316.78301	334.43977	17.65676	333.93377	2.9	17.15076	1.72		8.50
10	334.27998	352.12316	17.84318	351.64379	2.7	17.36381	1.74		6.91
Temprature		64°C			2.6		1.73		7.15
						Avg	1.7279		
						Min	1.7097		
						Max	1.7577		
					% Normalized Range		2.7744		

Jnr Computation at stress level 3200Pa for 14% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10/3.2kPa
1	361.63064	948.77776	587.14712	943.13186	1.0	581.501	1.82
2	953.62471	1544.39375	590.76904	1539.12064	0.9	585.496	1.83
3	1549.45370	2144.75010	595.29639	2139.50370	0.9	590.050	1.84
4	2149.99655	2749.52739	599.53085	2744.25432	0.9	594.258	1.86
5	2754.53412	3356.03569	601.50156	3350.57624	0.9	596.042	1.86
6	3360.85604	3962.83697	601.98094	3957.53730	0.9	596.681	1.86
7	3967.87037	4569.02575	601.15538	4563.75267	0.9	595.882	1.86
8	4574.21890	5174.25574	600.03685	5168.92940	0.9	594.711	1.86
9	5179.79510	5780.36457	600.56948	5775.25131	0.9	595.456	1.86
10	5785.69090	6384.84892	599.15801	6379.73562	0.9	594.045	1.86
Temprature		64°C			0.89		1.85
						Avg	1.8513
						Min	1.8172
						Max	1.8646
					% Normalized Range		2.5624


Trial 1, 3.2 kpa at 64oc for 14% Modifier
Strain %
7.00E+03
6.00E+03
5.00E+03
4.00E+03
3.00E+03
2.00E+03
1.00E+03
0.00E+00
0
10
20
30
40
50
60
70
80
90
100
Time (Sec)

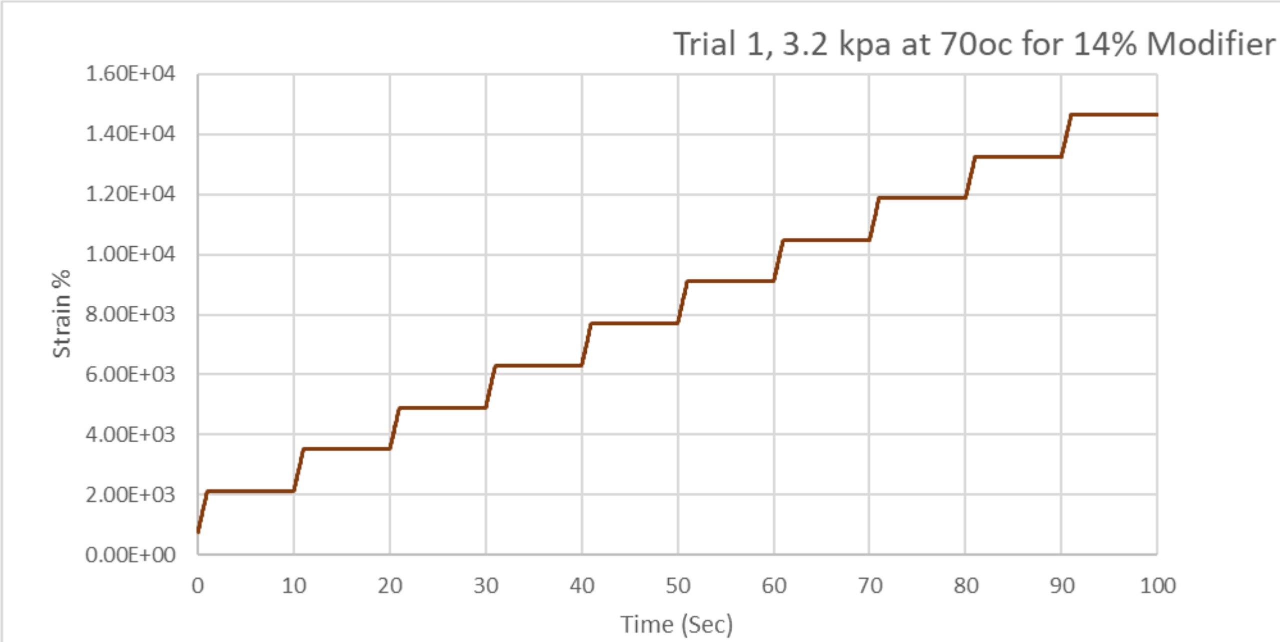

Trial 1, 0.1 kpa at 64oc for 14% Modifier
Strain %
4.00E+02
3.50E+02
3.00E+02
2.50E+02
2.00E+02
1.50E+02
1.00E+02
5.00E+01
0.00E+00
0
10
20
30
40
50
60
70
80
90
100
Time (Sec)

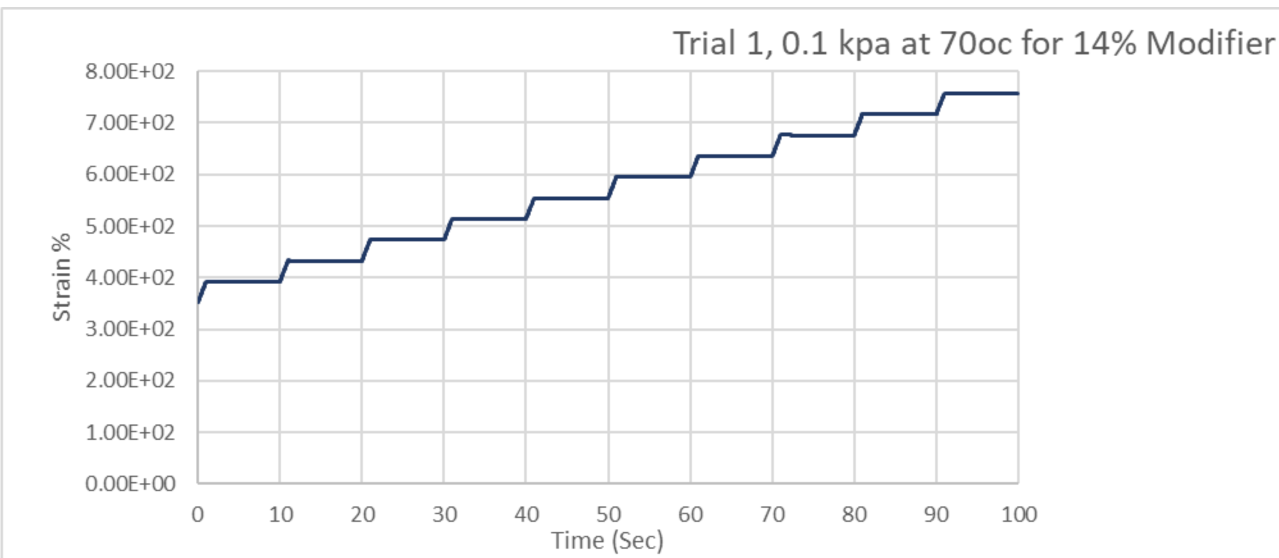
Jnr Computation at stress level 100Pa for 14% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□$_r$	□r(0.1,N)=(□c-□r)/□$_1$*100	□$_{10}$=□r-□o	J$_{nr}$(0.1,N)=□$_{10}$/0.1kPa		Jnr diff=(J$_{nr3.2}$-J$_{nr,0.1}$)/J$_{nr0.1}$*100
1	354.06990	392.47005	38.40015	392.09721	1.0	38.02731	3.80		3.91
2	394.73637	433.08326	38.34689	432.63052	1.2	37.89416	3.79		5.36
3	435.26968	473.45678	38.18710	472.97742	1.3	37.70773	3.77		6.70
4	475.61657	514.28304	38.66647	513.77704	1.3	38.16047	3.82		6.19
5	514.38957	554.60330	40.21373	554.15056	1.1	39.76100	3.98		1.61
6	556.78972	595.03009	38.24037	594.52409	1.3	37.73436	3.77		6.38
7	597.18988	635.88298	38.69310	635.40361	1.2	38.21373	3.82		4.77
8	638.04277	676.65598	38.61321	676.20324	1.2	38.16047	3.82		4.86
9	678.86903	717.45560	38.58658	716.94960	1.3	38.08057	3.81		4.68
10	719.61539	758.20197	38.58658	757.74923	1.2	38.13384	3.81		4.46
Temprature		**70°C**			**1.2**		**3.82**		**4.89**
						Avg	**3.8187**		
						Min	**3.7708**		
						Max	**3.9761**		
					% Normalized Range		**5.3768**		

Jnr Computation at stress level 100Pa for 14% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□$_r$	□r(3.2,N)=(□c-□r)/□$_1$*100	□$_{10}$=□r-□o	Jnr(3.2,N)=□$_{10}$/3.2kPa
1	863.25557	2129.96959	1266.71403	2127.65276	0.2	1264.397	3.95
2	2233.29226	3513.74820	1280.45594	3510.87197	0.2	1277.580	3.99
3	3616.83105	4907.24727	1290.41622	4904.31770	0.2	1287.487	4.02
4	5010.25015	6309.37487	1299.12472	6306.97801	0.2	1296.728	4.05
5	6412.61751	7707.34802	1294.73050	7705.45721	0.1	1292.840	4.04
6	7811.22986	9097.35828	1286.12842	9095.78711	0.1	1284.557	4.01
7	9201.26681	10484.49248	1283.22566	10482.49513	0.2	1281.228	4.00
8	10588.42757	11871.30704	1282.87947	11868.91019	0.2	1280.483	4.00
9	11974.46979	13252.39569	1277.92589	13250.13205	0.2	1275.662	3.99
10	13355.69165	14632.12624	1276.43459	14630.39517	0.1	1274.704	3.98
Temprature		**70°C**			**0.17**		**4.00**
						Avg	**4.0049**
						Min	**3.9512**
						Max	**4.0523**
					% Normalized Range		**2.5227**


Trial 1, 3.2 kpa at 70oc for 14% Modifier
1.60E+04
1.40E+04
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
Strain %
0
10
20
30
40
50
60
70
80
90
100
Time (Sec)

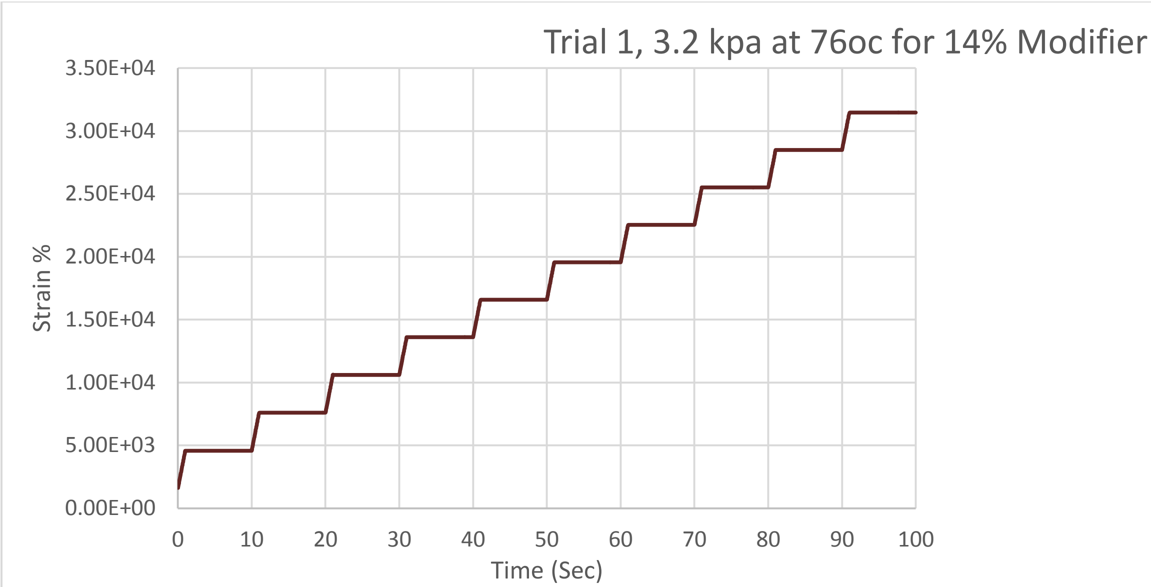

Trial 1, 0.1 kpa at 70oc for 14% Modifier
8.00E+02
7.00E+02
6.00E+02
5.00E+02
4.00E+02
3.00E+02
2.00E+02
1.00E+02
0.00E+00
Strain %
0
10
20
30
40
50
60
70
80
90
100
Time (Sec)

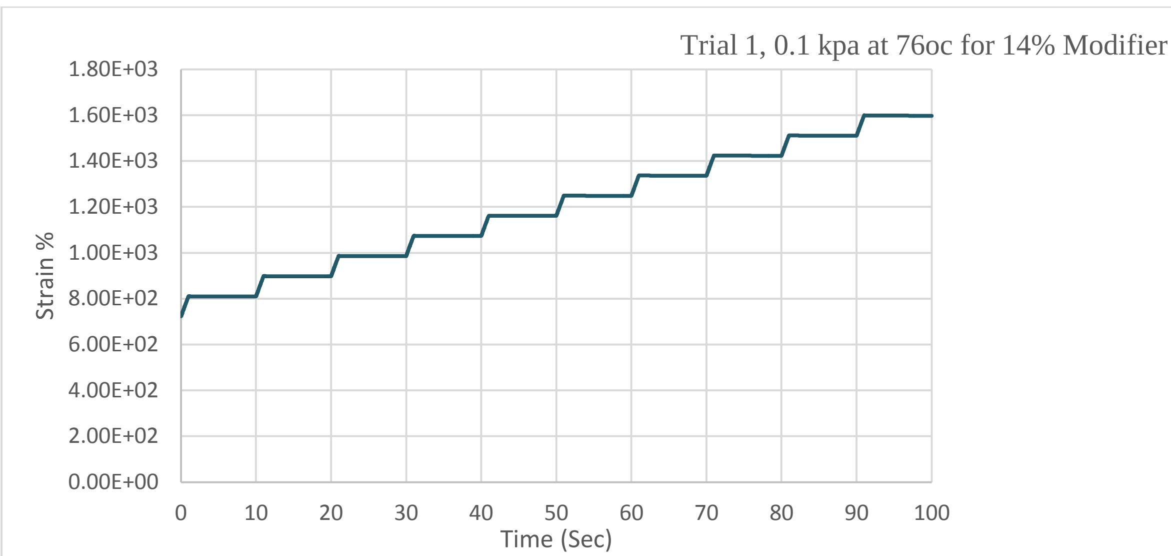
Jnr Computation at stress level 100Pa for 14% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa^{-1}		Jnr diff
0.1 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(0.1,N)=(□c-□r)/□1*100	□10=□r-□o	$J_{nr}(0.1,N)$=□10/0.1kPa		Jnr diff=$(J_{nr3.2}-J_{nr,0.1})/J_{nr0.1}$*100
1	722.67539	810.18687	87.51147	809.65423	0.6	86.97884	8.70		5.56
2	810.77276	898.28424	87.51147	897.56518	0.8	86.79242	8.68		7.59
3	898.76360	986.08866	87.32505	985.31634	0.9	86.55274	8.66		7.65
4	986.51476	1074.07950	87.56474	1073.20066	1.0	86.68590	8.67		6.48
5	1074.29256	1161.96382	87.67127	1160.87192	1.2	86.57937	8.66		6.10
6	1161.99045	1249.63508	87.64463	1248.56982	1.2	86.57937	8.66		5.92
7	1249.71498	1337.38624	87.67127	1336.18782	1.4	86.47284	8.65		6.31
8	1337.43950	1424.47161	87.03211	1423.21992	1.4	85.78042	8.58		7.30
9	1424.39171	1511.92982	87.53811	1510.59824	1.5	86.20652	8.62		6.55
10	1511.71676	1599.17498	87.45821	1597.79013	1.6	86.07336	8.61		6.73
Temprature		76°C			1.2		8.65		6.62
						Avg	8.6470		
						Min	8.5780		
						Max	8.6979		
					% Normalized Range		1.3859		

Jnr Computation at stress level 3200Pa for 14% modifier (trial 1)

Stress Cycle	Initial strain at the beginning of creep portion	Strain at the end of creep portion (after 1 sec)	Adjusted strain value at the end of the creep portion	Strain at end of the Recovery portion	% Recovery	the strain value at the end of the recovery portion, after 10 seconds (Non recovery strain)	Jnr, Kpa-1
3.2 KPa	ε_o	ε_c	$\varepsilon_1=\varepsilon_c-\varepsilon_o$	□r	□r(3.2,N)=(□c-□r)/□1*100	□10=□r-□o	Jnr(3.2,N)=□10/3.2kPa
1	1633.39659	4565.16415	2931.76756	4571.44917	-0.2	2938.053	9.18
2	4607.34858	7585.85453	2978.50596	7595.41542	-0.3	2988.067	9.34
3	7631.36809	10605.55995	2974.19186	10613.06984	-0.3	2981.702	9.32
4	10649.20893	13595.41089	2946.20196	13603.00065	-0.3	2953.792	9.23
5	13639.11311	16569.22937	2930.11626	16578.55064	-0.3	2939.438	9.19
6	16614.39679	19542.56922	2928.17244	19548.96063	-0.2	2934.564	9.17
7	19585.36604	22518.14545	2932.77940	22527.14694	-0.3	2941.781	9.19
8	22562.91319	25499.60763	2936.69443	25508.15613	-0.3	2945.243	9.20
9	25543.86911	28476.38250	2932.51338	28483.27995	-0.2	2939.411	9.19
10	28519.17936	31449.10932	2929.92996	31459.01621	-0.3	2939.837	9.19
Temprature		76°C			-0.28		9.22
						Avg	9.2193
						Min	9.1705
						Max	9.3377
					% Normalized Range		1.8135


Trial 1, 3.2 kpa at 76oc for 14% Modifier
Strain %
3.50E+04
3.00E+04
2.50E+04
2.00E+04
1.50E+04
1.00E+04
5.00E+03
0.00E+00
0
10
20
30
40
50
60
70
80
90
100
Time (Sec)


Trial 1, 0.1 kpa at 76oc for 14% Modifier
Strain %
1.80E+03
1.60E+03
1.40E+03
1.20E+03
1.00E+03
8.00E+02
6.00E+02
4.00E+02
2.00E+02
0.00E+00
0
10
20
30
40
50
60
70
80
90
100
Time (Sec)

Appendix B

Asphalt mix prepation

Specific gravity computation

Average specific Gravity of the Aggregates

Trial blend- Computation

Hot Bin Compartment→	13/20	6/13	3/6	0/3	Dust
Composition (%)	26	24	18	30	2
Bulk Sp. Gr.	2.780	2.805	2.814	2.821	2.862
Apparent Sp. Gr.	2.929	2.950	2.960	2.950	
Water Absorption (%)	1.69	1.76	1.70	1.54	_

WATER ABSORPTION, BULK & APPARENT SPECIFIC GRAVITY OF COMBINED AGGREGATE

Bulk Sp. Gsb. =

$$\frac{100}{\frac{26}{2.780}+\frac{24}{2.805}+\frac{18}{2.814}+\frac{30}{2.821}+\frac{2}{2.862}} \qquad \mathbf{2.806}$$

Apparent Sp. Gsb. =

$$\frac{100}{\frac{26}{2.929}+\frac{24}{2.950}+\frac{18}{2.960}+\frac{30}{2.950}+\frac{2.0}{2.862}} \qquad \mathbf{2.944}$$

Water Absorption (%) =

$$\frac{1.69*26+1.76*24+1.7*18+1.54*30+2*0}{100} \qquad \mathbf{1.63}$$

Super-pave Volumetric data at the optimum content for the non-modified mix

SUPERPAVE VOLUMETRIC MIX DATA

JMF #		Mix Type	SPECIFIC GRAVITY OF BINDER (A)	1.026	TEST Control No. 5.3
Location	SITE LABORATORY		# Gyrations @ Nini	9	
Date Sampled					
Date Tested			# Gyrations @ N_{des}	125	
Tested by	beza				
Source of Mix	SITE LABORATORY		Compaction Tem.	155 ^{0}C	

Sample No.	Binder % Cement (A) ①	Thick-ness	SPECIMEN WEIGHT(g) IN AIR (B) ③	IN WATER (C) ④	S.S.D IN AIR (D) ⑤	SPECIMEN VOLUME B=⑤-④ C=③-④ ⑥	Density S.S.D ⑤/B E	Bulk ③/B ⑦	T.D ⑧	% binder by vol ①xE/B.SG ⑨	Voids (Percent) Air void (1-⑦/⑧)×100 ⑩	VMA 100-(100-①)x⑦/ASG ⑪	VFA ⑪-⑩*100/⑪ ⑫
A	5.3	110.0	4731.2	2864.3	4748.7	1884.4	2.520	2.511					
B		110.0	4741.5	2879.5	4757.2	1877.7	2.534	2.525					
						1881.1	2.527	2.518	2.618	13.1	4	15.0	74.7

SUPERPAVE DENSIFICATION DATA

S.G OF AGGREGATE			
13-20	0.26	2.78	2.929
6.0-13	0.24	2.805	2.95
3.0-6	0.18	2.814	2.96
0-3	0.3	2.821	2.95
filler	0.02	2.862	2.862
Weighted Average Bulk S.G of Agg			2.806
Weighted Ave. App.S.G of of Total Agg			2.945

# Gyr.	Specimen #1 Ht. (mm)	Specimen #1 % Gmm (Corr.)	Specimen #2 Ht. (mm)	Specimen #2 % Gmm (Corr.)	Avg.
9	120.3	87.7	119.9	88.5	88.1
125	110.0	95.9	110.0	96.4	96.2

Super-pave Volumetric data at the optimum content for the non-modified mix

SUPERPAVE VOLUMETRIC MIX DATA

JMF #		Mix Type		SPECIFIC GRAVITY OF BINDER (A)	1.041	TEST Control No.	6.0
Location		# Gyrations @ Nini	9				
Date Sampled							
Date Tested		# Gyrations @ N_{des}	125				
Tested by							
Source of Mix		Compaction Tem.	**160 ^{0}C**				

	①		③	④	⑤	⑥	E	⑦	⑧	⑨	⑩	⑪	⑫
Sample No.	Binder %	Thick-ness (mm)	SPECIMEN WEIGHT(g) IN AIR	IN WATER	S.S.D IN AIR	SPECIMEN VOLUME	Density S.S.D	Bulk	T.D	% binder by vol	Voids (Percent) Air void	VMA	VFA
						B=⑤-④	⑤/B	③/B			(1-⑦/⑧)	100-(100-①)x⑦/ASG	⑪-⑩*100
	A		B	C	D	C=③-④				①xE/B.SG	×100		⑪
A	6.0	110.0	4779.7	2895.7	4788.1	1892.4	2.530	2.526					
B		111.1	4795.6	2904.1	4809.1	1905.0	2.524	2.517					
						1898.7	2.527	2.522	2.623	14.6	4	15.5	74.8

SUPERPAVE DENSIFICATION DATA

S.G OF AGGREGATE	13-20	0.26	2.78	2.929
	6.0-13	0.24	2.805	2.95
	3.0-6	0.18	2.814	2.96
	0-3	0.3	2.821	2.95
	filler	0.02	2.862	2.862
Weighted Average Bulk S.G of Agg			2.806	
Weighted Ave. App.S.G of of Total Agg			2.945	

# Gyr.	Specimen #1 Ht. (mm)	% Gmm (Corr.)	Specimen #2 Ht. (mm)	% Gmm (Corr.)	Avg.
9	120.2	88.1	121.4	87.8	**88.0**
125	110.0	96.3	111.1	96.0	**96.1**