BE CIVIL ENGINEERING PROJECT REPORT

PERFORMANCE EVALUATION OFASPHALT MIXTURESWITH BITUMEN PARTIALLY REPLACED WITH WASTE COOKING OIL AND CRUMB RUBBER

Project submitted in partial fulfillment of requirements for the degree of

BE Civil Engineering

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This is to certify that the

BE Civil Engineering Project entitled

Performance Evaluation of Asphalt Mixtures with Bitumen PartiallyReplaced with Waste Cooking Oil and Crumb Rubber

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Has been accepted towards the partial fulfillment of requirements for BE Civil Engineering Degree

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Dedication

Dedicated to our parents who prayed for us since ever and our teachers without whose support this effort would never have been completed.

ACKNOWLEDGEMENT

All thanks and praise to Allah Almighty.

We bow our heads before Almighty Allah for providing us opportunity and resources to give complete shape to our research work. There are several individuals whose contributions have been vital for completion of this project. Asst Prof Dr Imran Khan, our project advisor and Lab Engineer Jalal Habib were a beacon of guideline and driving force behind this research. He contributed valuable ideas, invaluable guidance and enthusiastic encouragement throughout our research work. Also many thanks to our faculty members and teachers for guiding and helping us whenever it was needed.

All Syndicate members

LIST OF ACRONYMS

AASHTO	-	American Association of State Highway and Transportation
AC	-	Asphalt Concrete
ARL	-	Attock Refinery Limited
ASTM	-	American Standard Test Method
BS	-	British Standard
CIPR	-	Cold-In-Place Recycling
WCO	-	Waste Cooking oil
HMA	-	Hot-Mix Asphalt
TSR	-	Tensile Strength Ratio
ITS	-	Indirect Tensile Strength
M_R	-	Resilient Modulus
LDPE	-	Low Density Polymer Ethylene
HDPE	-	High Density Polymer Ethylene
JMF	-	Job Mix Formula
LOS	-	Level of Service
CRMA	-	Crumb Rubber Modified Asphalt

NHA	-	National Highway Authority
NMAS	-	Nominal Maximum Aggregate Size
OAC	-	Optimum Asphalt Content
OBC	-	Optimum Bitumen Content
PG	-	Performance Grade
CR	-	Crumb Rubber
UTM	-	Universal Testing Machine
VFA	-	Voids Filled with Asphalt
VMA	-	Voids in Mineral Aggregate
WMA	-	Warm Mix Asphalt

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ABSTRACT

Crumb Rubber Modified Asphalt(CRMA) has numerous benefits similar as increased rutting resistance and reflective cracking resistance, but there are also major concerns that limits its farther operation. These major concerns include low solubility of Crumb Rubber(CR) in asphalt, high density when its incorporated in higher quantities and poor storehouse stability. To counter these limitations of CRMA, a hybrid approach was taken in this study by introducing Waste Cooking Oil(WCO) in CRMA to produce a balance between stiffness and fluidity and to optimize the application of WCO along with CR to reduce the volume of base bitumen by adding the donation of waste materials. A laboratory-based study was conducted to ascertain resilient modulus, Tensile strength ratio(TSR), and endless distortion of modified asphalt mixtures. It was observed that WCO can regulate the part of CR in asphalt because it eased the swelling action of CR in asphalt as indicated by enhanced performance parcels. It was also found that the resilient modulus was increased by 44 percent respectively as compared to control mixtures, whereas the humidity resistance was increased by 7.

Furthermore,advanced tablets of the modifier led to drop in resilient modulus, rutting resistance, and humidity resistance. Eventually, the results the modifier has a significant impact on the performance pointers of modified asphalt-mix.

CHAPTER 1

INTRODUCTION

1.1 General

Pakistan is one of the most populous countries of the world. The nation is rapidly urbanizing because of social and economic opportunities. Pakistan has the highest rate of urbanization in South Asia, with 37.44% of the population residing in urban areas. Nearly half of the people of the Pakistan will live in urban areas by 2025. This drastic escalation lead to need of repairing and maintenance of our present pavements due to a loss in budgetary funds for an efficient, safe, and cost-effective roadway transportation system during the last several decades. In the last few decades, asphalt reclamation and recycling have shown tremendous improvement, which is highly desirable.

In Pakistan there is a growing infrastructure deficit due to the country's spending of approximately 2.1 percent of its GDP on road development. Its alarming because of a downward trend in the development expenditures made by the government and the little role played by the private sector in the development of infrastructure. It is possible that Pakistan would not reach its target of 130 billion dollars in funding for the construction of its road infrastructure between 2016 and 2040. The magnitude of this deficit is greater than Pakistan's entire outstanding obligations to its foreign creditors. Therefore, it is essential to use materials that do not harm the environment in this case to bring down the cost of the road infrastructure. The proportion of bitumen modifiers in the asphalt mix that has acceptable properties is directly proportional to savings for the government and the less of a burden it will be financially.

Reclaiming and recycling asphalt fulfills delivering efficient and safe road map while also reduce energy consumption and environmental impact compared to conservative pavement restoration. By doing this different agencies may increase their available funds, however care must be taken because asphalt recycling is not feasible for all roads. As a

Keeping in view our economic situation, it is important to cut investment expenses and establish a low-cost, efficient, and environment friendly roadway system. Asphalt reclamation and recycling has made great development in the last few decades, and right now its a preferred way of repairing old pavements in terms of both technological and natural advantages.

Passenger and freight traffic on Pakistan's highways make up around 92 and 96 percent, respectively. Because of the importance of preserving this infrastructure, it is necessary to employ effective preservation methods that are both cheaper to implement and long-lasting, to reduce rehabilitation and maintenance costs while also providing passengers with reliable transportation options.

In whole of the world, AC is the widely used paving medium for new roads. Since roads are vital to the country's economy, they must be preserved. In a society where roads are the primary transportation route, the lifetime of asphalt pavements is necessary. Due to the fact that bitumen is expensive, long-lasting asphalt blends are gaining attention. Distresses occur due to the pavement's long-term exposure to traffic and environmental deterioration. Researchers have spent the last few years trying to find ways to extend the service life of pavement materials and eventually saving expenses.

HMA is primarily composed of aggregate and bitumen. To make asphalt concrete more durable and resistant to the degrading effects of traffic and environment, numerous modifiers are used. Due to water damage, pavements are degrading at an alarming rate. In the presence of water/moisture, the binder will not adhere to the aggregate. The pavement will collapse fast if the binder cannot bond the aggregate..

CRM could be an effective addition for easing the disposal of discarded tires. Its addition lead to rutting resistance improvement, the flexibility of HMA mixes is increased, and asphalt binder ageing is delayed. Using thin layers of modified binder HMA mixes to create long-lasting roads may be a huge benefit. SBS and SBR are commercial polymers, and their usage raises construction. Alternatively, CRM has the potential to be both ecologically friendly and cost-effective and improve the bitumen binder's characteristics and durability.

1.2 Problem Statement

Every year a substantial amount is spent on design, building, rehabilitation, and maintenance of roads to achieve the appropriate levels ofservice and prevent difficulties. Extreme weather and uncontrolled traffic loads are the leading causes of pavement related issues. One of the leading problems in Pakistan are ruts because of weather variations as summers are immensely hot followed by chilly winters. Asphalt pavements are likely to crumble and deteriorate over time in this climate. Crumb Rubber Modified Bitumen (CRMB) addresses rutting in asphaltic concrete, which is product of recycled rubber. Meanwhile, polymers and other additions to Bitumen are not used in Pakistan rather adjustments are done by altering the aggregate grade and binder amount. CR in bitumen helps to extend life of pavements and also lowers noise pollution and makes the ride quality better.

CR when incorporated into bitumen raises the temperature at which the bitumen softens, as well as its viscosity. This diminishes the bitumen's capacity to penetrate and its thermal susceptibility. Moreover, asphalt rubber mixtures can possibly significantly further develop the long-lasting twisting obstruction and improve rutting opposition at low temperatures. This could expand the toughness of the asphalts, despite the fact that these combinations regularly utilize a more prominent amount of cover. Past examination has uncovered that crumb rubber can't be degraded or softened into asphalt binder, as demonstrated in the investigation of the relevant writing. There will be a higher contrast in thickness between the binder and the undissolved rubber when less rubber parts are decayed in the binder than when more rubber parts are disintegrated. Phase separation is more likely to occur because of this. Furthermore, several researches resulted in using cooking oil as a modifier.

1.3 Research Objectives

Following objectives are aimed:

- Assessment of moisture susceptibility of CR-WCO modified asphalt through Tensile Strength Ratio (TSR).
- Evaluation of the effect of CR-WCO on stiffness by evaluating Resilient Modulus (MR).

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1.4 Scope

To reach the goals a strategy was developed. Research was done about pre-treatment of Crumb Rubber and the addition of CR-WCO in base bitumen. To fulfill the objectives research strategy was devised, which is outlined as follows :

- Investigation of asphalt mix design, including previous publications on CR-WCO as a modifier as well as scientific journals.
- Penetration test, ductility test and softening point tests were done to decide the binder to be used for project.
- Chemical composition of CR and WCO was carried out.
- Resilient modulus test, Tensile Strength Ratio test were used to determine strength, Stiffness,moisture susceptibility of different modified and unmodified CR-WCO HMA.

1.5 Organization of Thesis

The division of the research is shown in Figure 1.1. and its divided into following chapters:

Chapter 1 that includes introduction, problem statement, research goals, and scope of the study.

Chapter 2 comprises of literature study and examination of the different characteristics of CR-WCO when used in Pavements. It also shows the comprehensive literature study done for the project.

Chapter 3 gives info about the material used, the testing and the background of those tests, and it explains the importance of the findings that have been acquired from performance tests.

Chapter 4 gives description of the results of experiments. This chapter has complete compilation of results. It gives a comprehensive explanation of the experimental program's graphs, charts, and tables, as well as all relevant data. The findings and interpretations are also discussed in Chapter 4.

Chapter 5 contains suggestions and findings. Previous chapter was focused on future research horizons and how researchers can use results of this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter shows research summary concerning properties of asphalt binder, containing Waste Cooking oil (WCO) and Crumb Rubber (CR). Keeping in view previous studies, the effects of WCO and CR on various performance parameters is discussed.

2.2 Background

A nations development is judged by the quality of roads and how well their maintenance is. Therefore, its imperative to invest in road projects. Bitumen being the primary constituent of asphalt, which is in use in construction for long time. However, commonly utilized pavements are unable to fulfill the practical needs of both the existing traffic loadings and future traffic loads. Therefore, it's a requirement to look for materials that are safer,more trustworthy, and more environmentally friendly. The performance of asphalt mixture has aging effects,temperature susceptibility and viscocity.

In light of increase in traffic, high axle loadings, and a decrease in the number of services for maintenance, roads are detoriating rapidly in last few decades. Primitive bitumen binder needs to be improved, primarily in resistance to permanentdeformation areas and fatigue cracking, resulting in diminishing distresses and increasing lifespan of pavements. There are studies which have been conducted to look for ways to modify bitumen binder eventually leading to improvements in pavements.

2.3 Modifications in Pavement Binders

Binder is modified to reach followingimprovements:

- High viscosity during summer to prevent ruts.
- Prevention against thermal cracking, material show have low stiffness at low

temperatures.

- Increasing the adhesion of aggregate particles to asphalt can reduce peeling.
- To broaden the temperature range at which asphalt can perform its intended function.
- To reduce non-load-associated thermal cracking while simultaneously producing an elastic blend at a low temperature.
- At a high temperature to make blends rigid.
- To enhance fatigue resistance.
- To increase the material's resistance to oxidation and aging.
- To strengthen the pavement's resistance to gasoline when fuel spills occur.
- To upgrade the general usefulness of the asphalt.

At any one second, a modifier could upgrade one element while corrupting another. A fuel-resistant modifier, for instance, may be effective at high temperatures to prevent fuel solubility and rutting but not at low temperatures or the other way around. To be clear, not every case calls for every modifier.

2.4 Asphalt Modification Using Crumb Rubber

Waste tire rubber that has been mechanically shrunk, ground, and reduced to sizes even smaller than 1 mm is frequently used to make Crumb Rubber Modified Asphalt (CRMA). It has been displayed to further develop protection from rutting, advance adaptability in HMA blends, slow the maturing system of black-top cover, and cut down on intelligent breaking. By employing thinner layers of modified binder HMA mixes, it is possible to significantly improve roadway durability. The Crumb Rubber that was employed as a polymer in this investigation is shown in Figure 2.1.

Figure 2.1: Crumb rubber

Natural rubber comes from the plants that actually make rubber. The native to South America Hevea brasiliensis species is the most well-known of these plants. Estates in Indonesia, the Malay Landmass, and Sri Lanka are liable for the creation of in excess of 90% of all-regular elastic available today. The general name for this particular variety of plant rubber is "para rubber." The chemical process known as polymerization is typically used to produce synthetic rubber, which is produced in a manner that is comparable to that of the production of plastics. Examples of these synthetic rubbers include butyl rubber, Buna rubbers, and neoprene. As a rule, they are planned in view of specific qualities to satisfy capabilities. The two types of synthetic rubber that are most frequently utilized in the production of tires are butadiene rubber and styrene butadiene rubber.

In 1960, Charles Mac Donald discovered that by combining regular bitumen with crumb rubber and letting the mixture mix for 45 to 60 minutes, novel material qualities could be developed. Pavement mixes were able to absorb more liquid bitumen because of the increased size of the rubber particles when exposed to higher temperatures. Around the middle of the 1980s, researchers in Europe started working on newer polymers and additives that could be used to modify bitumen binder.

2.5 Common Methods For Making Crumb Rubber

Crumb tire rubber can be utilized in numerous ways. Rubber particles are graded and come in a wide range of sizes and shapes. The cross section screen or strainer size through which morsel elastic is passed all through the assembling system fills in as the norm by which it is perceived or estimated. Manufacturing involves following two processes.

2.5.1 Shredding

Granulated piece tire elastic is created start with this phase of the assembling system. Tires that have been cut up or left completely are both ready to be moved to destroying plants. They are exposed to handling, which brings about a decrease in the molecule size to the fitting levels. Magnets and separators are utilized during the time spent eliminating the steel belt and fiber fortifications from the tires. The actual qualities of a bitumen-elastic blend can be impacted by the morsel elastic molecule size. By and large, little contrasts in molecule size have little impact on blend execution. The various sizes of CR are shown in Figure 2.2.

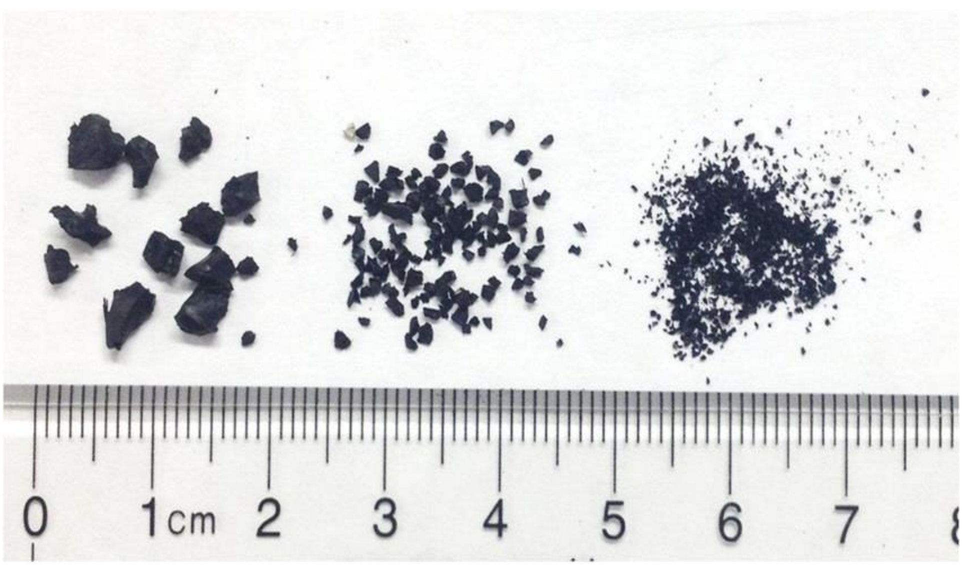


Figure 2.2: CR of various sizes

2.5.2 Grinding and Granulation

After the shredded tires have been used, any one of the following three processes can be used to produce crumb rubber: Granulated Morsel elastic modifier is the item acquired from the granulator cycle, which brings about cubical, equally framed particles. The Cracker-mill process results in particles that are unevenly shaped and torn, ranging in size from 4.75 mm (No. 4 sieve) to 11.42 mm (Number 40 sieve), is the technique that is utilized the most frequently. This strategy is known as squashed Piece elastic modifier. The micro-milling technique, which results in an extremely fine powdered Crumb rubber modifier, is the third method.

2.6 Criteria for Crumb Rubber-Modified Asphalt's Performance

The addition of CR results in higher softening points and lower penetration values. A portion of the general benefits of CR that have been accounted for incorporate lower material expenses, expanded weakness opposition, less intelligent breaking, improved rutting obstruction, more grounded flexibility, expanded versatility, and further developed properties under cyclic burdens. Nonetheless, a few scientists likewise revealed an impediments of consolidating CR like weakness to deterioration and oxygen retention, as well as enormous sub-atomic weight, which required the requirement for mechanical homogenization and halfway breakdown of the elastic mixtures. Tire rubber is difficult to degrade due to its chemical stability. As a result, the most common industrial method for processing tire rubber waste is landfilling.

Due to its excellent performance and positive effects on the environment, scrap tire rubber has been extensively used in asphalt pavement in recent years. Crumb rubber is added to asphalt to improve its overall performance. It is made from shredded scrap tires. Airey and others, 2004) used the dry method to look at how the interaction between rubber and bitumen affected the short-term and long-term aging of asphaltic mixes. Crushed rock (CR) was used in the study as part of the aggregate in a dense bituminous macadam with a maximum aggregate size of 20 mm. The levels of modification ranged from 3% to 5%. This procedure made use of granulated crumb rubber with sizes ranging from 2 mm to 8 mm. Samples were subjected to both short-term and long-term conditioning following the creation of CRM mixes and Control mixes with the Superpave Gyratory Compactor. In both short-term and long-term aging, an increased percentage of CR was found to have increased the stiffness modulus values. The rutting resistance had also been enhanced by the addition of CR. The aging effect on asphalt binder's rheological and physical properties is lessened when rubberized bitumen binder is used. The propeller blender was utilized to consolidate the bitumen and the morsel elastic under predictable mixing conditions, which incorporated a temperature of 180 degrees Celsius, a period of an hour, and a rotational speed of 200 cycles each moment.

The aging resistance of the modified bitumen was analyzed by carrying out the Brookfield viscosity test at 135 degree Celsius, the penetration test at 25 degree Celsius, the softening point test at 25 degree Celsius, and the dynamic shear test with the help of ASTM D-4 in order to investigate how oxidative ageing influences the rheological properties of rubberized modified bitumen. The results demonstrated that using a rubber-modified binder lessened the effect of ageing on the binder's physical and rheological properties. At 76 degrees Celsius, both the ageing index of viscosity and the ageing index of G*/ sin were lower, indicating this. As the data showed, tire rubber particles released antioxidants into the asphalt, which helped reduce the ageing effect. The findings of the study were correct in pointing this out. Cell reinforcement was delivered simultaneously as the extent of piece elastic expanded. As seen by the maturing record of consistency, CRMA held up better after some time. The value of the sample decreased as a result of both short-term and long-term aging. Shredded rubber was added to the binder to increase its stiffness and resistance to rutting.

Because it makes use of waste materials, some researchers have suggested that the Crumb Rubber in HMA is a good option for sustainable development. This is because recycling materials is part of the solution. It improves protection from rutting crumbling and delivers asphalts that have unrivaled perseverance by diminishing the bothers made in asphaltic asphalt. This outcome in asphalts that can endure rutting for longer. Street clients will before long approach streets that are both more secure and smoother. Additionally, the use of crumb Rubber in HMA mixes will preserve the environment while also reducing pollution concerns.

As indicated by the discoveries, the blends in with a more prominent shear rate were more successful at lower temperatures than the mixes with a lower shear rate. Higher viscosities, improved resistance to rutting, and a lower likelihood of cracking at low temperatures are the outcomes of higher percentages of crumb rubber in CR modified binders. Santos et al. conducted a study in which (2020), the crumb rubber that was used to make Crumb Rubber Modifier (CRM) was made in two different ways and came from two different places. The two sources delivered piece elastic with a size of 0.425 millimeters. A wet method was used to mix the Crumb Rubber Modifier with the basic asphalt binder for the first time before adding it to the asphalt concrete mixture. The temperature of the blend was 177 degrees Celsius, and the blending speed was 700 cycles each moment. One of the methods used to evaluate the characteristics of these Crumb Rubber Modifier binders was the viscosity test, which was carried out in accordance with the Superpave binder test protocols. At a temperature of 25 degrees Celsius, tests were exposed to infiltration, malleability, and flexible recuperation tests. The investigation revealed improved physical properties of rubber-modified binder. While elastic recovery increased, both penetration value and ductility decreased. Thus, the fastener was made more versatile and the elastic's protection from rutting was expanded. By increasing the rutting factor, adding crumb rubber to bitumen increased the rubberized pavement mix's resistance to rutting.

As indicated by the discoveries of Mashaan et al., (2012), the addition of recycled tire rubber to asphalt concrete enhances the material's mechanical and physical properties. The typical bitumen with an 80/100 penetration grade and Crumb Rubber (CR) with a 30 mesh (0.6mm) size were used in this study. The rubber-modified mixture was made with the help of a propeller mixer. This blender could pivot at a speed of 200 rpm for a term of 30 minutes all through the mixing system. As per the discoveries of the tests, expanding how much CR in the folio made the entrance point values decline while at the same time raising the conditioning point and the thickness. This is because the interaction between the CR and the binder makes it stiffer and better able to recover from elastic deformation. At 135 degrees Celsius, the binder's viscosity increased as a result of the quantity of asphaltenes that were present. The aftereffects of the tests on the firmness modulus showed that rising CR brought about higher solidness values than the control blends.

2.7 Issues with CRMA

According to earlier experiments, crumb rubber cannot be entirely broken down or melted down into a binder. It is common knowledge that the radius of the rubber and the disparity in densities between the rubber and the binder have a direct bearing on how quickly undissolved rubber flows through a binder. The majority of the undissolved rubber in the binder is made up of carbon black, which has a density that is 1.8 to 2.1 times greater than asphalt binder (1.15 grammes per cubic centimetre). Additionally, some rubber components are released into the binder during the depolymerization and devulcanization process, changing the viscosity of the binder.

This means that the undissolved rubber particles will be larger and have a greater density difference with the binder when the rubber components in the asphalt are less degraded. This makes phase separation more likely to happen. To maximise their compatibility with the asphalt binder, the rubber components may be dissolved and distributed in the asphalt binder in the form of a network. As a result, the presence of undissolved rubber particles affects the characteristics of rubber asphalt. If the rubber is applied to the asphalt with more precision, a more uniform appearance will result. The high-temperature, low-temperature, and performance stability performance of rubber asphalt depends on the preservation of the integrity and independence of rubber particles. Rubber particles that have floculated or agglomerated may be harmful to the performance of rubber asphalt. Rubber-made asphalt pavements might function better in both hot and cold conditions while also lasting longer. However, because the extra rubber particles are dispersed unevenly and aggregated, the asphalt pavement's performance might not be as trustworthy.

In addition to eliminating "black pollution" caused by waste tires accumulating on it, asphalt modified with CR reduces reflection cracks, reduces vehicle noise, and improves a surface's resistance to skidding when wet. During the production process for crumb rubber modified asphalt (CRMA), the CR particles expand due to the presence of light oil in HMA. These particles regain some of their original viscosity and flexibility as a result of partial desulfurization. Clean asphalt thickens while light oil is absorbed. All of these properties have improved as a result of CRMA's synergistic effects. In addition to the asphalt, waste crumb rubber (CR) made from used tires may also enhance the properties of binders, which in turn improves the performance of asphalt pavement. Additionally, it may help alleviate environmental issues brought on by these materials. The carbon black and sulfur content of the CR enhance binders' high temperature integrity. While pavement life is extended and vehicle comfort is improved, road noise may be reduced. In spite of this, customary CRMA is ready by adding CR to black-top and afterward shearing at high velocity, which results in the majority of the CR for the most part expanding as well as other actual responses, harming the adequacy of CRMA and lessening the amount of CR, to such an extent that the level of CR in CRMA is commonly roughly 20%(Riekstins et al., 2022). It is feasible to upgrade the treatment of CR content through the utilization of enactment treatment and a last mix system Compound, mechanical, designing, and natural treatment methods are utilized to change the CR's physicochemical qualities to build the actual stability of CRMA.

Thermal treatment of the CR brought about an extensive expansion in the CRMA's maturing and exhaustion obstruction. Radiation has previously been used by researchers to activate CR and measure its activation properties. The wet process and high viscosity of rubber-modified asphalt have been linked to price increases. Life cycle cost analysis was used by many researchers to compare the cost of rubber modified asphalt to that of conventional asphalt. At first, it was thought that rubber-modified asphalt cost nearly twice as much as regular asphalt. However, since 2000, the price has been going down. The efficiency of asphalt plants, bitumen modification, higher production temperatures, and WMA technologies are all cited as major causes of the price increase. Some studies indicate that because CR modified asphalt has the potential to decrease the efficiency of the asphalt plant by as much as 30 percent, it has a higher direct cost than regular asphalt. Along these lines, the expense of CR changed black-top is somewhere in the range of 10% and 20% more than that of ordinary black-top. Due to its increased durability and performance, studies have demonstrated that CR asphalt may reduce maintenance costs. Because of the closeness of the gear expected to change bitumen with polymers, this investigation didn't consider the expense of acquiring new equipment(Wang et al., 2022).

Crumb rubber fragments embedded in asphalt are unable to expand to their full potential as a result of the increased absorption of light oil in asphalt that is brought on by CR at high doses. Additionally, there is an increase in CRMA's viscosity, which has a negative effect on pavement performance. Therefore, the dosage of CR should not be increased more than 10% to 20% (Jiao et al., 2022). Utilizing actual strategies like ultrasonic waves, a few scientists attempted to break the three-layered network construction of CR by breaking the surface initiation of CR and working with expanding so CRMA can be ready with an all the more even and conservative organization design and better execution. CRMA will profit from this by having a more uniform and minimized network structure, as well as further developed execution. Although these strategies might work on CRMA's exhibition somewhat, it will be hard to utilize them for an enormous scope because of the tremendous expansion in item pricing(Tang et al., 2022).

Irfan et al., (2018) examined crumb rubber-modified asphalt mixes to ascertain their permanent deformation, indirect tensile strength, and resilient modulus. Overall, blends made with crumb rubber changed combinations had a Marshall soundness of 30 and a tough modulus of 43% higher than the control combinations. However, crumb rubber-modified combinations showed a 12% improvement in permanent deformation when compared to unmodified control combinations. Field studies on the treatment's short-term effectiveness revealed a 36.16 percent decrease in the International Roughness Index of the crumb rubber-modified asphalt mixture. The control mixed pavement experienced a decrease in the International Roughness Index (IRI) of 24.20%.

In any case, traditional CRMA is notable to have unfortunate capacity solidness and consequently is not difficult to part. According to a number of studies, there are a number of ways to improve the interaction between asphalt and rubber. These methodologies incorporate, upgrading the surface action of the CR, and debasing the design of morsel elastic to further develop the elastic black-top framework. The three processes that make the most significant contributions to the pre-devulcanization and degradation of CR are plasticization, palletization through mechanical extrusion, and microwave radiation. In any case, these cycles are generally not completed in fluid conditions, which prompts the dirtying of the encompassing air and water as an immediate outcome of the arrival of hydrogen Sulfide gas that is created during the devulcanization cycle. However, the modified asphalt's properties will be severely restricted if the degree to which CR degrades cannot be precisely controlled. Subsequently, a few scientists utilized distillates, for example, furfural oil as an expanding specialist while pre-treating CR. These methods might make it easier for the CR particles to deteriorate.

2.8 Role of Waste Cooking Oil in Asphalt Mixtures

It is hard to reuse WCO since the performance of the oil corrupts with time when it is utilized again and again. The petroleum industry has made a number of changes to the refining process to increase gasoline production while decreasing asphalt residue, which has led to an increase in asphalt prices (Paliukaite et al., 2016). Therefore, one of the most important objectives in pavement technology is to improve the asphalt binder's low-temperature performance (Lei et al., 2017). When utilized in this manner, waste oils can be used to modify asphalt to improve its low-temperature performance, reduce its cost, and reduce environmental pollution.

Thus, the utilization of WCO has drawn in a lot of interest in recent years as a response to manage waste and monetary advantages (Saffar et al., 2021). Over the most recent decade, a lot of examination on asphalt that has been treated with cooking oil has been done. Numerous scientists saw that the temperature weakness of asphalt can be brought down subsequent to utilizing waste oil refining bottoms as a straightforward extender for asphalt. Before WCO-modified asphalt can be used in real-world applications, extensive research into its chemical and rheological properties is required due to the wide range of raw materials and processing methods (Liu et al., 2022).

Some of the bio-oils that can be used to make asphalt binder are cooking oil waste. A wide variety of organic molecules, ranging in chemical composition from C to O, are found in bio-oil (Su et al., 2018). Plant oils can be extracted, distilled, or squeezed from plant oils like soybean, peanut, and/or rapeseed oils. Oil got from plants and pyrolysis is the most widely recognized sort of bio-oil used in bio-asphalt creation. Distillation and other conventional methods were ineffective at removing oil from water. Following a warm pretreatment/overhauling technique, bio-oil produces biofuel, biomass weighty oil, and different results. The waste cooking oil that was used for this investigation is shown in Figure 2.3.

Figure 2.3: Waste cooking oil used for asphalt modification

Acording to a few examinations, how much water and unpredictable mixtures in bio-oil are to be utilized to gauge the pretreatment temperature and time(Portugal et al., 2017). There are contrasts in the characteristics of bio-asphalt in light of the sorts and measures of bio-oil utilized in it. In recent years, agricultural and forestry waste biomass materials have been the subject of some research (Luo et al., 2017). Recent research has shown that binders made from agricultural or forest waste have a high viscosity but poor performance at higher temperatures. Bio-asphalt, which is produced using plant waste, has additionally been demonstrated to be impervious to weakness and maturing.

Lei et al., (According to his study of the engineering characteristics of asphalt binder, 2015) observed that waste cooking oil residues had a significant impact on the infrared spectrum and rheology of asphalt binder. This may result in improved low-temperature performance of asphalt binder. Temperature-prompted black-top asphalt breaking is a significant issue in cool temperature regions. As a result, it is essential to enhance the binder's stiffness and low temperature fracture properties. For instance, due to its chemical structure, some studies have categorized asphalt as a mixture of polar and nonpolar molecules. Therefore, improving the binder's low-temperature capabilities can be accomplished by increasing the amount of oil in the asphalt (Liu et al., 2022).

2.9 Summary of Literature Review

In view of the examination of the relevant literature, it may be concluded that Waste cooking oil (WCO) can possibly manage the job of crumb rubber (CR) in the modified binder mix by making a harmony between the stiffness and fluidity of the binder. The literature review that has been discussed is comprehensively summarized in Table 2.1. It is evident from Table 2.1 that researchers are attempting to combine waste cooking oil with a polymer because polymers can increase the asphalt's resistance to rutting.

According to Table 2.1, rubber asphalt was found to improve asphalt mixtures' high-temperature performance as well as their durability over time in the majority of studies. However, due to the uneven distribution of rubber particles, a higher percentage of CR may result in unstable asphalt pavement performance. Due to its widespread distribution and poor solubility in asphalt, crumb rubber tends to be found in the asphalt binder as undissolved particles. Subsequently, traditional rubber asphalts experiences various downsides, the most outstanding of which are its high consistency and poor storage stability.

Table 2.1: Summary of Literature Review

Research paper description	Polymer Type	Test Performed	Outcomes
Incorporating Waste Cooking oil Products and Polymers into Enhanced Modified Asphalt Products	Crumb Rubber (20%), Waste Cooking oil (7.5%, 12.5%, and 15%)	Dynamic Viscosity MSCR Test Consistency Tests	Binder modified with O, and CR exhibited that they had a low warm weakness, high upsides of high temperature PG, and high rutting opposition.
Highly dissolved Rubber Asphalt prepared using a composite Waste Cooking oil addition	Crumb Rubber, Waste Cooking oil(5%, 15%, 25%, 35%)	Solubility Test Storage Stability MSCR Test	In rubber asphalt, the consideration of composite waste cooking oil improves the solubility of the crumb rubber.
The effect of bio-oil on the performance of rubberized asphalt at high temperatures	Crumb Rubber (Mesh 20 and Mesh 80), Bio oil (0%,5%, 10%, 15%)	MSCR Test RV test Temperature sweep test	crumb rubber changed black-top's versatile properties might be further developed by a transient maturing process that mixes scrap elastic and bio-oil in a warmed black-top scattering framework during warming.
The influence of styrene-butadienerubber (SBR) andwaste oils on the physical characteristics of aged asphalt	SBR(1% and 3%), WCO/WCO (5%, 10%, 15%)	RV Test DSR Test FTIR Test BBR Test	WCO rejuvenated asphalt demonstrated some benefits in fatigue cracking resistance whereas WCO rejuvenated asphalt had greater resistance to rutting and creep recovery.

Modified bitumen production using Waste motor oil, coal tar, and waste tires	Used Cooking oil (20%), Coal Tar (30%), Waste tire (50%)	Consistency Tests Viscosity tests	Modified bitumen exhibited a stronger resistance to permanent deformation but a poorer resistance to fatigue cracking was less responsive to temperature change, contained fewer volatiles, and was less flammable.
Rubberized Binders with Recycled Heavy Bio-oil as a Performance Enhancer	Asphalt Rubber (18%), Heavy bio oil (3%)	Storage Stability Test RV Tests MSCR Tests	The bio–ARs demonstrated higher rutting and fatigue resistance, but somewhat worse low temperature performance compared to a traditional AR binder.
The effect of long-term ageing on the fatigue performance of crumb rubber modified bitumen	Crumb Rubber (5%, 10%, 15%, 22%), Warm Mix additive	Time sweep test DSR Test	CRMB binders outperform plain bitumen in terms of fatigue resistance. Adding warm-mix additives has distinct impacts on the fatigue performance of a neat bitumen binder than a CRMB binder.
Activating agent's effect on Crumb Rubber modified Asphalt's performance	Crumb Rubber (33%), WCO (10%-20%)	Viscosity Test DSR Test	For A-CRMA to work at its best, the dose of WCO must be carefully chosen to ensure that the WCR is fully swollen without diluting the asphalt and lowering its effectiveness.

Waste cooking oil has a good resistance to ageing, and it likewise significantly eliminates the quantity of pollutants that is delivered into the water. Additionally, the addition of used cooking oil can be used to lower a bitumen's viscosity and softening point while simultaneously increasing its penetration. As a result, the temperatures required for compaction and the production of an asphalt mixture are reduced. The fluid modifier is likewise useful in upgrading the rubber treated bitumen's functionality and bringing down the conditioning point.

Thus, to tackle the issues that are related with rubber treated asphalt, waste cooking oil and crumb rubber were combined to make a CR-WCO modifier that will partly replace the base bitumen. The CR-WCO modifier was made by combining Crumb Rubber and waste cooking oil, as indicated by previous research. For the purpose of pre-treating the rubber, the resulting mixture was then heated for two hours in an oven set to 100 degrees Celsius. To halfway supplant the base bitumen, various rates of CR-WCO modifier was utilized, and the exhibition of the CR-WCO changed asphalts blends was assessed, by numerous execution tests.

CHAPTER 3

RESEARCH MEHTODOLOGY

3.1 Introduction

This chapter emphasize a comprehensive analysis of the Research Methodology that was used to acquire the goals of the research. Firstly, we collected the material which was efficient for this research. The optimum bitumen content was evaluate using Marshall mix design. The MS-2 manual was followed to running an analysis of the volumetric attributes Va, VMA, VFA, Flow, and stability For performance testing, a Superpave Gyratory Compactor was used.

This chapter shows the study technique that was implemented to visualize specifics about the mixing of CR-WCO with bitumen and further testing of the mix's performance, as described in chapter 1. Four steps were taken in the evaluation of the effectiveness of the laboratory created samples. Traditional testing of the binder was done, in the very first step. These tests included the penetration test, the ductility test, and the softening point test. The IDT and MR tests were brought out on the prepared Superpave Gyratory Compacted samples. After that, the rut resistance of modified and unmodified Superpave gyratory samples were determined.

Aggregates from Babozai Query, 60/70 bitumen from Attock Refinery, Waste cooking oil from our mess and Crumb Rubber (Mesh # 40) from a local firm in Peshawar werematerials that were chosen this research. To find the chemical composition of the waste materials test was conducted. After that, the materials were characterized in accordance with their predetermined criteria. To ascertain the performance of modified asphalt mixes, Gyratory compacted samples were utilized. Marshall samples were prepared for determining the OBC, while Superpave Gyratory compacted samples were prepared in order to ascertain the resilient modulus, Tensile Strength Ratio (TSR) of CR-WCO modified samples. The research methodology that was adopted for this investigation is shown in figure 3.1.

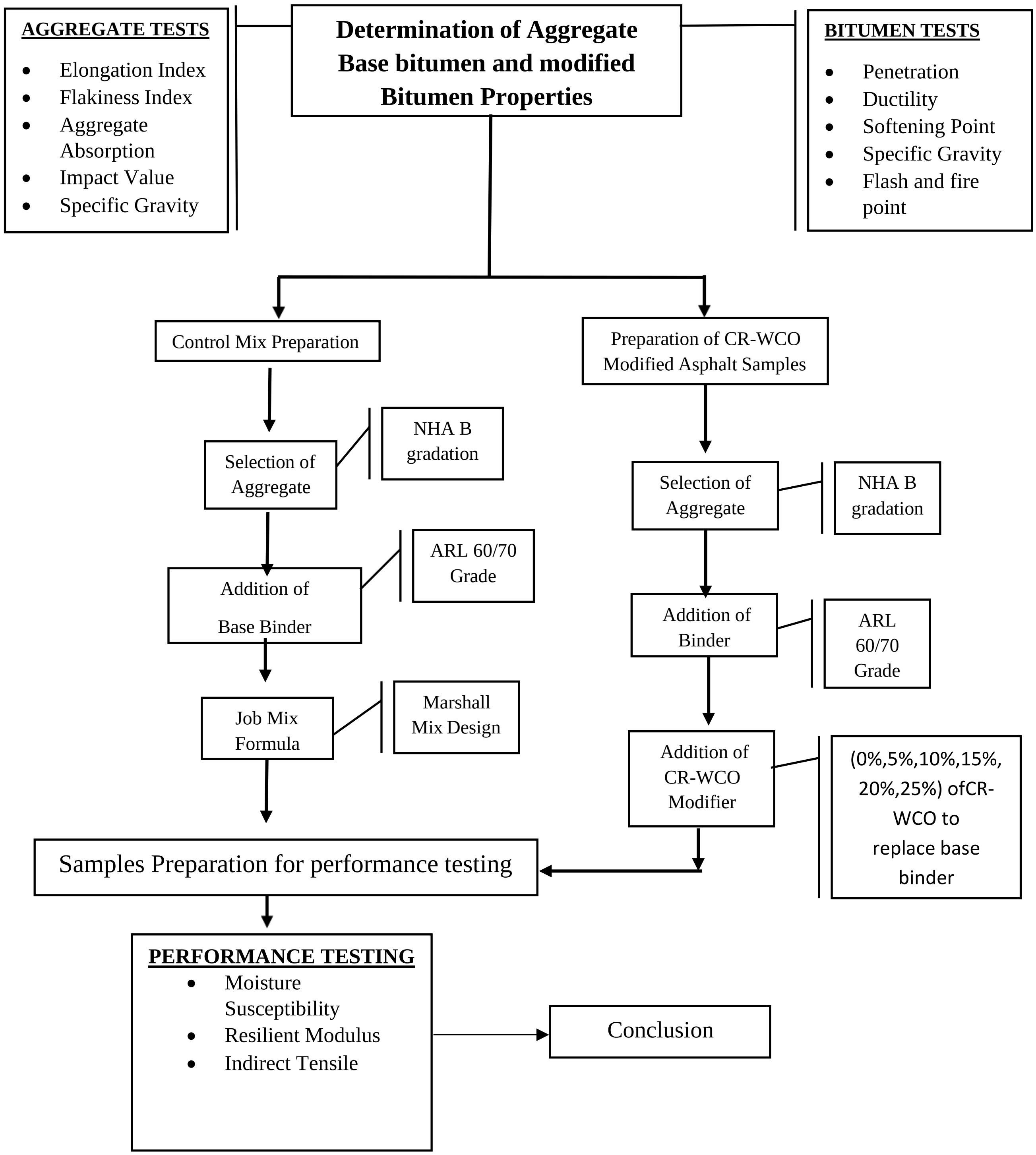


Figure 3.1: Research methodology

3.2 Aggregate Testing

Since the power of asphalt mixtures is related to the properties of aggregates, such as their strength and durability, therefore, the important formula for the mixing it. Various experiments were performed on the aggregate, including sieve analysis, aggregate gradation, the Los Angeles abrasion test, the aggregate impact value test, as well as specific gravity measurements for coarse and fine aggregates, amongst others. Aggregate samples will put through a way of tests to establish their engineering capabilities. These fundamental attributes included water absorption, specific gravity, strength, and durability. Aggregate shape and texture enhance aggregate strength as well as a slew of other technical characteristics. The gradation of the aggregates may also influence the properties of HMA.

3.2.1 Sieve Analysis and Gradation

Size, shape, texture, and grade of the aggregate are essential factors when we talk about asphalt mixtures. Aggregates need to have low porosity and should be strong and durable. Babozai query aggregates were sieved in the laboratory. The quantitative amount kept each sieve was placed in individual bags. Table 3.1 shows details of the gradation that was choose for this investigation.

Table 3.1: Description of Aggregate Gradation

Sieve Designation		NHA Class-B Specification Range (% Passing)	Upper Limit	Lower Limit	Our Selection (% Passing)
mm	**inch**				
25	1	–	-	-	
19	3/4.	100	100	100	100
12.5	1/2.	75-90	75	90	82.5
9.5	3/8.	60-80	60	80	70
4.75	No. 4	40-60	40	60	50
2.38	No. 8	20-40	20	40	30
1.18	No. 16	5-15.	5	15	10
0.075	No. 200	3-8.	3	8	5.5
Pan	Pan	-	-	-	Pan

The graphical plot of NHA class B gradation is depicted in Figure 3.2. For this gradation, the Nominal Maximum Aggregate Size (NMAS) is 19 mm.

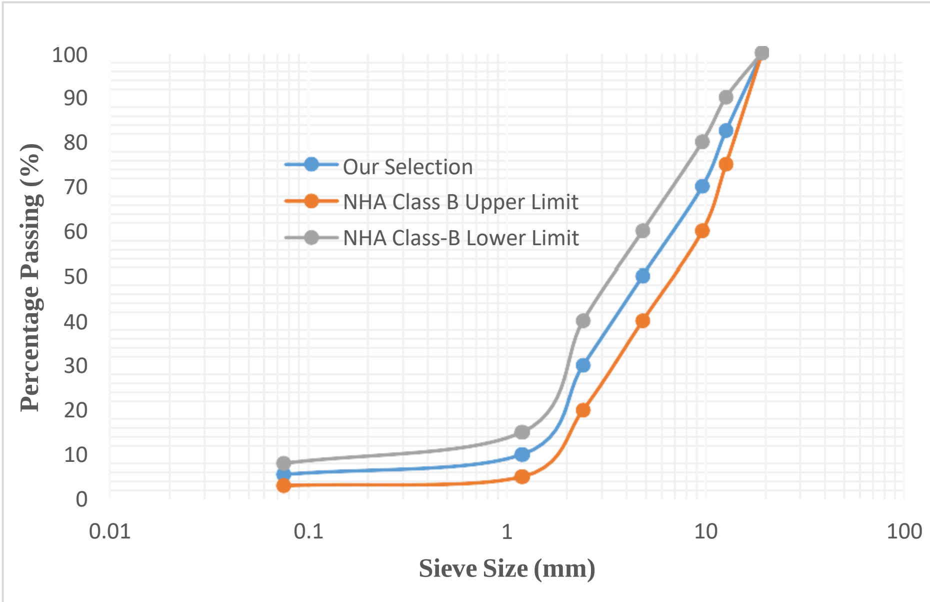


Figure 3.2: NHA class B gradation plot

3.2.2 Aggregate Impact Value Test

Due of the impact force and pounding action of traffic, an aggregate may be shattered into v ery small fragments.Aggregates must therefore be sufficiently hard and solid to survive fract ures brought on by the impact loading action of traffic.This test is conducted in compliance with BS 812 and IS 383 standards.350 grammes of material that could pass through a 14mm screen and remain on a 10mm sieve were chosen for this test.A tamping rod was used to stir each layer of the three aggregate layers in the Impact testing machine cup 25 times.After co mpaction, the aggregates were smashed with a 14 kg standard hammer that was dropped fro m a 38 cm height. They needed to be sorted through a 2.36mm sieve in order to be extracted from the cup. It is stated what percentage of particles pass through a 2.36mm sieve. The aggregate impact value is calculated using the proportion of aggregate retained on this sieve.

3.2.3 Los Angeles Abrasion Test

Asphalt mixes must be capable of withstanding disintegration, degradation, and crushing since heavy traffic loads may do so. To achieve this, aggregates are put through a LA abrasion test to determine how tough and durable they are. This test is conducted in compliance with AASHTO T 96-92's specifications.The resultant material was sieved using sieve number 12 after the aggregate had been exposed to abrasion in line with standard operating procedure using the predetermined number of balls. The weight lost as a result of abrasion was then determined, and by guidelines, this value had to be less than 40. Figure 3.3 depicts the equipment that was used to calculate the Los Angeles abrasion value.

Figure 3.3: Los Angeles abrasion test

3.2.4 Specific Gravity of Aggregates

The weight of a given volume of aggregates in comparison to water at 24°C is its specific gravity. The specific gravity test was performed on coarse total and fine total as per ASTM C127, (2004) and American Society for Testing and Materials, (2015). These weights includes the oven dried weights of aggregate, aggregates submerged in water and saturated surface dried weight of aggregates. In accordance with ASTM C 128, tests were performed to ascertain the specific gravity of fine aggregates and the amount of water they absorb. When making mixtures for asphalt paving, the specific gravities of the coarse aggregate particles need to be carefully considered. It is frequently used by engineers when planning paved and unpaved regions. Bulk specific gravity might be used to find the VMA and the amount of binder absorbed. Another term for specific gravity is "relative density," which describes the weight-to-volume properties of aggregate materials e.g. "relative thickness" is termed as specific gravity of aggregate material. At the point when an item is kept at a sconstant temperature, there is its mass to volume proportion. Coarse aggregates remain visible after sieve no. 4. The specific gravity and water absorption rate of coarse aggregate particles were determined using ASTM C127. After passing sieve #4, the aggregate was oven dried and kept in water for 24 hours. After that, the saturated weight of aggregate was determined. After that, the aggregates' specific gravity, water absorption, and submerged weight were determined. In contrast to the saturated surface-dry stage, where water may be found in pores of aggregate, the oven-dried sample does not contain any water.

3.2.5 Aggregate Crushing Value

For the crushing value test, a steel cylinder with open ends, a base plate, a plunger with a 150 mm diameter of piston and was provided a hole for lifting through a rod, a cylindrical measure, a balance, a tamping rod, and a 28 compressive testing machine were used. The aggregates for further processing were those that passed through a 1/2-inch sieve but remained on a 3/8-inch sieve. A sample of aggregate was then layered onto a cylindrical measure in three distinct increments, with 25 tamping performed on each successive layer, after being meticulously cleaned, dried in the oven, and weighed (W1). After that, the sample was set in the cylinder with the base plate in three separate layers. The cylinder was then placed inside a compression testing machine, and a constant load of 4 tons per minute was added until the total load reached 40 tons. After that, a 2.36-millimeter mesh was used to sieve the crushed aggregate from the steel cylinder.

3.2.6 Shape Test of Aggregate

The proportions of flaky and elongated particles in aggregate can be calculated using the shape test of aggregates. Flaky particles are aggregate particles whose smallest diameter is less than 0.6 times the average dimension of the sample aggregates. Elongated aggregates are totals that have a greater size that is more than 1.8 times of the sample aggregate's average dimension. The flakiness and Elongated index were determined as per the separate ASTM standards. 98% of the particles were fractured. The aggregate had met the criteria of all thestandards.Table shows the tests performed on aggregate.

Table 3.2: Laboratory Test Results of Aggregate

Type of Description		Standards	Results	Specification
Fractured Particles Test		ASTM D 5821	98	90% (Min)
Aggregate impact value		BS 812	16.09%	30% (Max.)
Aggregate crushing value		BS 812	15.67%	30% (Max.)
Los Angeles Abrasion test		ASTM C 131	25.89%	45% (Max)
Flakiness Index		ASTM D 4791	7,09%	15% (Max)
Elongation Index		ASTM D 4791	2,37%	15% (Max.)
Deleterious Material Test	Coarse Aggregate	ASTM C 142	0.21%	-
	Fine Aggregate	ASTM C 142	1.30%	-
Specific gravity	Coarse Aggregate	ASTM C 127	2.650	-
	Fine Aggregate	ASTM C 128	2.56	-
	Mineral Filler	ASTM C 128	2.43	-
Aggregate water absorption	Coarse Aggregate	ASTM C 127	0.82%	3% (Max.)
	Fine Aggregate	ASTM C 128	1.76%	3% (Max.)

3.3 Bitumen characterization

Three of the following properties: consistency, safety, and purity a binder must have. Variations in temperature have severe impact on binders properties. That's why, consistency of Asphalt Binder needs to be compared with respect to temperature. Consistency of the bitumen is measured by using penetration test. Several laboratory tests are conducted for the properties of Asphalt Binder.

- Bitum test for Flash and Fire Point.
- Bitumen test for Ductility.
- Bitumen test for Softening Point.
- Bitumen test for Penetration Grade.
- By Consistency and Superpave performance testing (0 percent to 30 percent)ARL 60/70 modified binder and the CR-WCO modified binder were put.The consistency tests were performed e.g penetration test, the softening point test, the ductility and the flash and fire test

3.3.1 Penetration Test

It is the most effective empirical test. The bitumen sample is tested by vertically penetrating it with a standard needle under the loading, duration, and temperature. A tenth of a millimeter is the unit of measurement for the penetration. Bitumen can be classified into several different classes using this test. A higher penetration number means that the fluid consistency of the sample is more. Bitumen with a higher penetration rate are often recommended for use in cooler climates, while bitumen with a lower penetration rate are generally recommended for use in warmer areas. The standard operating temperature of the penetration test is 25 degrees Celsius, but by adjusting the needle load and penetration, it can be performed at different temperatures such as 0 degrees Celsius, 4 degrees Celsius and 46 degrees Celsius. Tests were performed according to ASTM D5 and AASHTO T 49-93 standards. The base bitumen samples were immersed in a 25 °C water bath to check different percentages of CR-WCO. A needle load of 100 grams and a test time of 5 seconds were used to determine the penetration values of the bitumen samples..

3.3.2 Softening Point Test

The softening point test is performed according to standards given by Drews (2008) and AASHTO T 53-92.This test is used to find the temperature at which binder begin to soft ,which can be between 30 and 150 degree Celsius.

3.3.3 Ductility Test

The test is performed according to (ASTM D 113-07, 2002) and AASHTO T 51-93 specifications. In this test, a standard piece of asphalt is stretched to breaking point at a standard speed of 5 centimeters per minute at a temperature of 25 degrees Celsius. Less ductile binders have poor adhesion properties which cannot be used. Pouring the bitumen into ductility molds produced either modified or unmodified sample bitumen. After immersing in a water bath at 25 degrees Celsius, each test sample was taken at a speed of 5 centimetres per minute. A reading was recorded, but only the sample break point was recorded.

3.3.4 Fire and Flash Point Test

The flash and fire point is a way of calculating the highest temperature that asphalt can heat to without the risk of ignition while still in the vicinity of an open flame. After the samples were poured into the open cups, they were heated at a predetermined rate to determine the fire point and flash point. The point where the sample catches fire is called the fire point whereas the point where a small flame ignites on the surface is called the flash point.

3.4 Preparation of CR-WCO Modified Bitumen

The CR-WCO modifier was prepared based on research studies by combining 25 percent of waste cooking oil (by weight of crumb rubber) and Crumb Rubber, after which the combination was placed in a 100 °C oven for 2 hours for rubber pre-treatment. Different percentages of CR-WCO modifiers were used to partially replace the base bitumen, and the properties of the modified bitumen and the evaluation of the performance of the resulting asphalt mixtures are carried out through various performance tests.

3.5 Preparation of CR-WCO Modified Asphalt mixtures

Mixing machinery and sample preparation is necessary to properly mix CR-WCO with bitumen in a high-shear mixer. However, the laboratory does not have access to High Shear mixers; thus, a 1000 rpm seed drill was used to manually mix the two substances. To achieve maximum contact surface with bitumen welded shaft was used and then transformed to resemble a propeller. Table 3.3 shows the composition of different CR-WCO-modified asphalt samples.

Table 3.3: Composition of Different CR-WCO Modified Samples

TYPE OF SAMPLE	ABBREVIATION	VIRGIN BITUMEN USAGE (%)	PERCENTAGE OF CR-WCO (%)
Virgin binder	Control Binder	100	0
Virgin binder+5% CR-WCO	5% CR-WCO	95	5
Virgin binder+10% CR-WCO	10% CR-WCO	90	10
Virgin binder+15% CR-WCO	15% CR-WCO	85	15
Virgin binder+20% CR-WCO	20% CR-WCO	80	20
Virgin binder+25% CR-WCO	25% CR-WCO	75	25

Different amounts of CR-WCO (5 percent, 10 percent, 15 percent, 20 percent and 25 percent) were used in the bitumen sample preparation process. The CR-WCO and bitumen were combined in a drill machine at a speed of 1000 rpm and a temperature above 180 degrees Celsius was maintained for 15 minutes. During mixing, it was necessary to maintain a temperature above 180 degrees Celsius and at least 1000 revolutions per minute. The three most important factors in mixing CR-WCO are temperature, mixing time, and mixing speed. For these three parameters, temperatures between 180°C and 200°C, durations between 10 minutes and 30 minutes, and speeds between 1000 and 250 rpm were most often used. These values have been collected from several global surveys and research projects. In such cases, it is always necessary to adjust both time and speed, because mixing time can be shortened by increasing the speed.

3.6 Marshall Mix Design

The maximum load that a mixed specimen can withstand at a standard temperature of 60°C is called Marshall Stability. Flow is the process by which the specimen deforms as more force is applied. The Marshall Mixes that are necessary for locating the OBC is done according to standard procedure. All of the volumetric properties, like stability and flow, were checked for compliance with the criteria. at last, OBC was found.The aggregates were dried by heating them in an oven to 110 degrees Celsius following the sieve analysis. To make a compacted test with a dia of four inches utilizing the Marshall mix plan technique (ASTM D6926), 1200 grams of totals is required. The amount of bitumen required for each sample was calculated, and the results ranged from 3.5 percent to 4%, 4.5 percent to 5.0 percent, and 5.0 percent to 5.5 percent, respectively.

The samples were prepared using the following methods:

- The total that would be used was taken from the Babozai quarry, and its fundamental properties were known. The aggregates were mixed in a way that was suitable, well-graded, sturdy, and rough in texture.

- The asphalt binder was chosen following the completion of rheological tests on it, such as the penetration test, the ductility test, and the softening point test.

- In order to produce standard-sized specimens according to molds, heated binder and aggregate were combined in large quantities to prepare the samples. During the most common way of getting ready Marshal Examples, various measures of binder in range going from 3.5 percent to 5.5 percent were applied.

- 75 blows were delivered to each side of the Marshal Samples to compact them. The falling height was 18 inches, according to ASTM D 1559. Subsequent to being ready, examples were permitted to cool prior to being removed from molds with the help of a hydraulic jack system.
- The Marshal method was used to calculate the volumetric properties after the sample preparations were completed.

3.7 Formulation of Job Mix Formula with Marshall Test

The OBC should be noted for execution testing. All of the samples were thoroughly tested to determine their stability, flow, density, Gmb, Gmm, Air voids, VMA, and VFA for this purpose The consequences of these tests were aggregated, and Graphical plots and mix were created utilizing this information. The binder's basic capability is to cover the total's surface of aggregates completely. This procedure will safeguard the aggregate against water damage. The procedures followed to determine the optimal bitumen content are depicted in Figure 3.4.

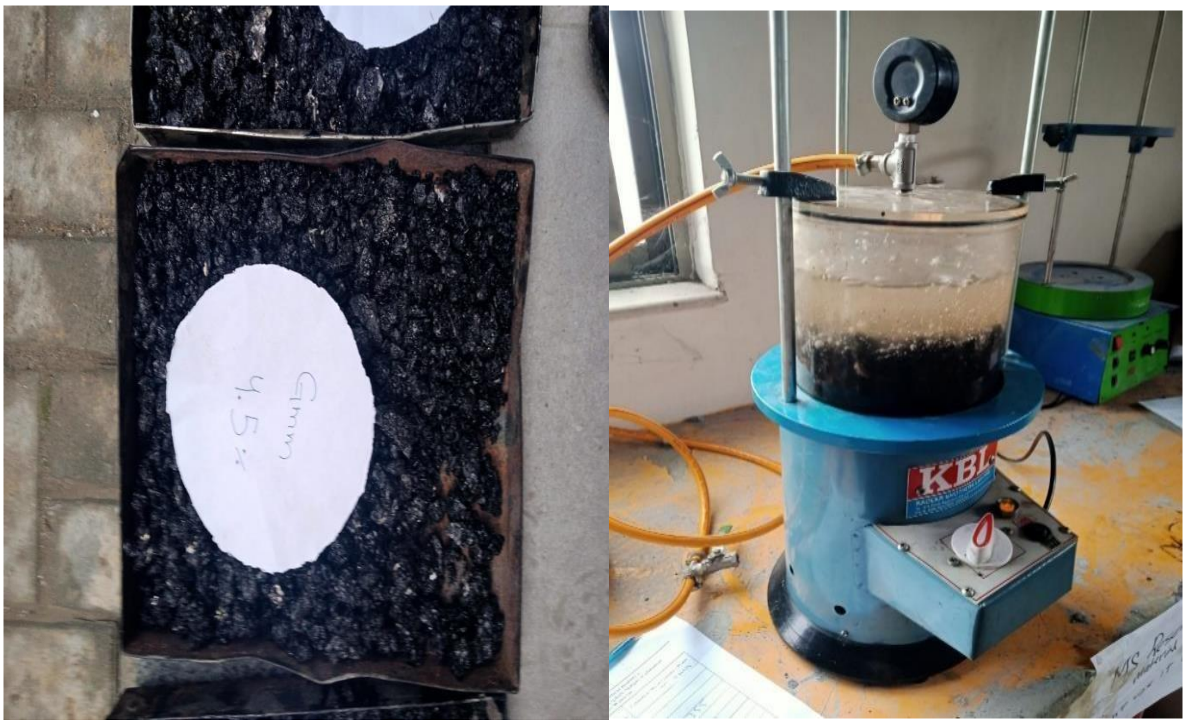


Figure 3.4: Formulation of job mix formula with marshal test

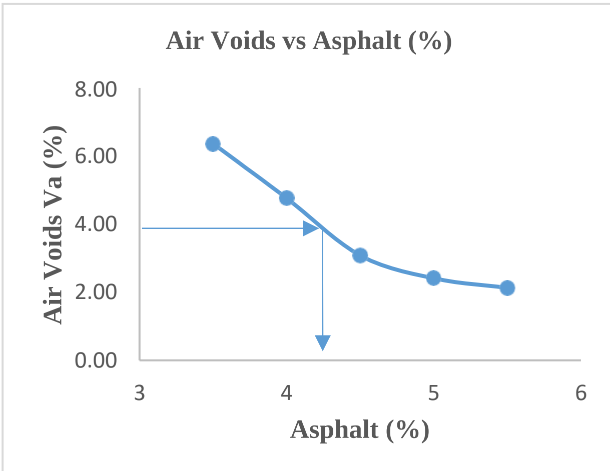
Uncoated aggregate will be apparent if the mixture does not contain enough bitumen. At last, this could prompt raveling or stripping in view of the decreased strength and toughness. A mix that contains an excessive amount of bitumen will likely result in pavement rutting, be less resistant to skidding, and be very susceptible to bleeding. To put it another way, the amount of asphalt binder in the mix has a direct impact on how well the pavement performs. The mix should meet a gradation criteria specified in specifications. The appropriate proportion of the various aggregate sizes must be provided to ensure that the aggregates form an effective interlocking structure.

Furthermore, the totals should fulfill determined total properties as well as source total properties to be utilized. A decent mix configuration will at last bring about a mix that is endorsed, comprising of total and black-top fastener. This suggested combination, which also takes into account the aggregate gradation and the kind of asphalt binder (JMF), is frequently referred to as the "job mix formula." The Marshall test doesn't utilize a standard procedure for choosing and evaluating asphalt binder. The most common approach in this field is the Superpave PG binder system. A number of preparatory experiments are used to determine the asphalt binder's connection between temperature and viscosity. The Marshall mix design-evaluated volumetric parameters are shown in Table 3.4.

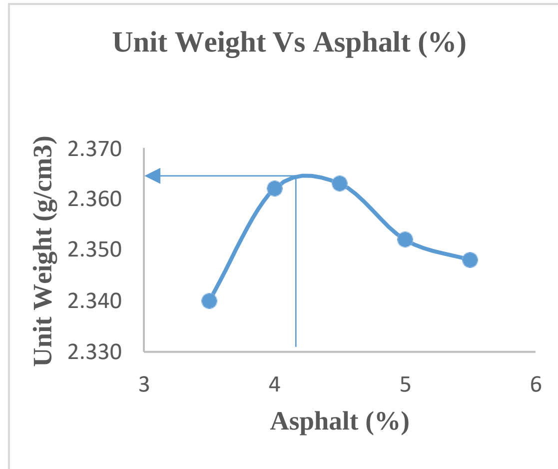
Table 3.4: Determination of Optimum Bitumen Content

%age of bitumen content	Bulk Specific gravity (G_{mb})	Specific gravity (G_{mm})	%age Air voids in agg. (V_a)	%age voids in bitumen (V_b)	Voids in mineral agg. VMA	Voids filled with Asphalt VFA	Stability (KN)	Flow (mm)
3.5	2.340	2.499	6.36	7.95	14.31	55.55	14.25	1.85
4	2.362	2.480	4.76	9.17	13.93	65.85	15.35	2.48
4.5	2.363	2.438	3.08	10.32	13.40	77.04	15.05	2.87
5	2.352	2.410	2.41	11.42	13.82	82.59	14.07	3.31
5.5	2.348	2.399	2.13	12.54	14.66	85.50	13.20	3.91

The Optimum Bitumen Content (OBC) was determined by comparing the values of various Marshall Mix Design parameters to the plotted graphs. The graphs used to calculate the OBC for stability, flow, VFA, VA, and unit weight against bitumen content are depicted in Figure 3.8.



(a)



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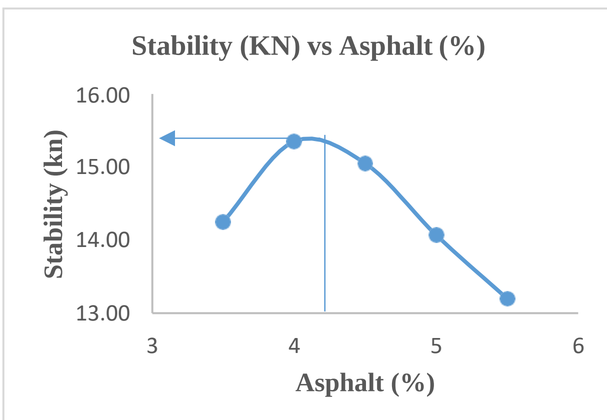

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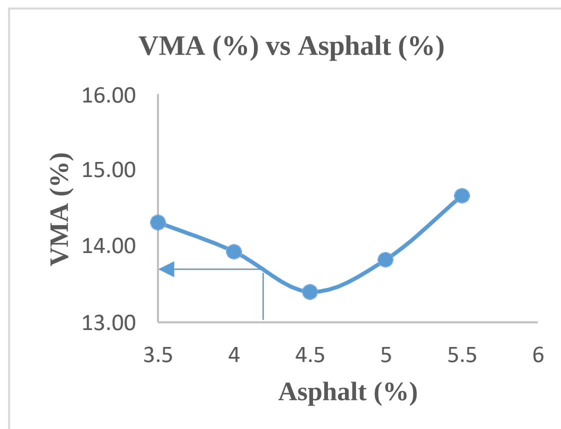

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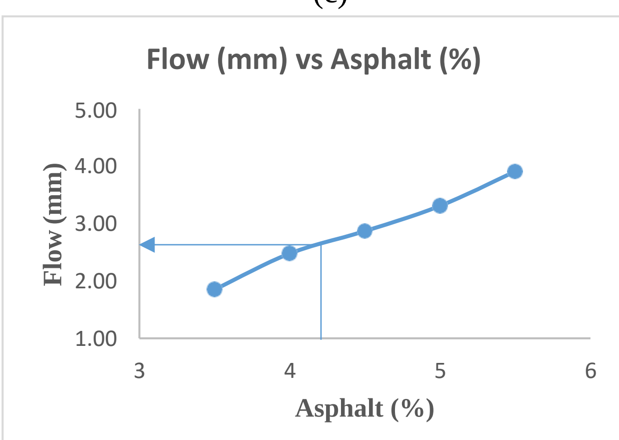

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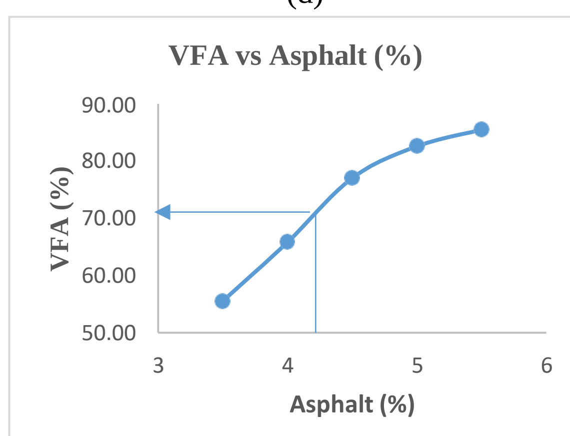

(f)

Figure 3.5: Marshall parameters for determination of OBC

From Figure 3.5, it very well may be seen that at 4% air voids, the OBC was viewed as 4.18%. Table 3.5 sums up the Marshall parameters that were utilized to affirm the optimum bitumen content. Additionally, it was discovered that other parameters like flow, stability, unit weight, VMA, and VFA met the specified requirements. Figure 3.5(a) shows the chart between air voids against various asphalt content. The optimal bitumen content was found to be 4.18 percent at 4% air voids. The relationship between unit weight and asphalt content is depicted in Figure 3.5(b). The relationship between asphalt content and stability is depicted in Figure 3.5(c). The stability was found to be 15.4 at 4.18 percent asphalt content. The relationship between VMA and various asphalt content is depicted in Figure 3.5(d). The VMA was found to be 13.8% at 4.18 percent air voids. The plot of flow against different asphalt content is depicted in Figure 3.5(d). The stream at 4.18% air voids was viewed as 2.79mm. The plot of VFA against various asphalt content is depicted in Figure 3.5(f). The VFA was found to be 70% at 4.18.

.

Table 3.5: Marshall Parameters for determination of Optimum Bitumen Content

Marshall Parameters	Measured Value	Criteria	Remarks
OBC (%)	4.18	At 4 % air void	------
Unit Weight (g/cm3)	2.365	NA	------
VMA (%)	13.8	13 (min)	pass
VFA (%)	70	65-75	pass
Stability (KN)	15.4	8.006 (min)	pass
Flow (mm)	2.79	2.0-3.5	pass

The Marshall test results for samples containing various percentages of CR-WCO are shown in Table 3.6. The Marshall stability value of 15.45 KN indicates that the sample containing 15% CR-WCO has the highest stability. However, the stability values decreased when there were higher proportions of CR-WCO. As a result, it is possible to draw the conclusion that the asphalt mix with 15% modifier has a balance between stiffness and fluidity, as demonstrated by its improved stability in comparison to the control mix.

Table 3.6: Volumetrics parameters of CR-WCO modified asphalt

Binder	CR-WCO (%)	Voids (%)			Stability (KN)	Flow (mm)
		Air voids	VMA	VFA		
60/70	0	6.65	13.76	66.19	13.01	1.75
	5	5.71	13.65	58.11	14.29	1.95
	10	4.29	13.47	68.11	15.08	2.41
	15	4.18	13.8	70	15.45	2.79
	20	3.21	14.62	78.06	14.02	3.37
	25	2.81	15.34	81.64	12.91	3.97

3.8 Sample Preparation for Asphalt Mix

The aggregates were heated to temperatures somewhere in the range of 105 and 110 degrees Celsius to precondition the totals for making the asphalt mixes. The mixing temperature for HMA mix is 160 degrees Celsius, and the compacting temperature is 135 degrees Celsius. Six-inch-diameter gyratory compacted specimens were made with 6000 grams of aggregate and a gyratory compactor. The specimens were rotated 125 times with a gyratory angle of 1.16 degrees and pressure of 600 kPa applied to compact them. Each specimen was cut with a saw cutter to the required dimensions to produce a standard sample for the wheel tracker testing.

3.9 Waste Cooking oil Physical Properties

Waste cooking oil (WCO) is a byproduct of the cooking and restaurants. There are a few natural benefits to utilizing WCO, including diminished soil and water contamination(Yan et al., 2022). Added substances in the WCO incorporate polymers that might work on the presentation of the fastener, as well as viscosity modifiers that may further develop lubrication. Because its chemical composition is comparable to asphalt flow, it mixes easily and activates the old binder.

3.10 Sample Potential for Rutting Investigation

Rutting is the longitudinal depressions caused by the accumulation of small deformations in asphalt materials over time and cyclic traffic loads. Roads frequently suffer from a type of long-term wear and tear known as pavement rutting. As part of the investigation into the tendency toward rutting, a HWTT was used to administer a series of tests on the specimens to determine their resistance to permanent deformation. The HWTT is an electrically driven machine that can move a 203 millimeter-diameter, 50 millimeter-wide, 230 millimeter-long tire. The steel wheel has a weight of 700 Newtons, and the pressure it puts out is the same as the pressure that the rear tire of a double axle puts out. The contact stresses become shift as an immediate result of an expansion in the trench profundity's comparing ascend in the contact region. During the test, the steel wheel moves forward and backward over the specimen. Figure 3.6 depicts the apparatus used to determine the rutting of samples.

Figure 3.6: HWTT apparatus for rut depth calculation

There are two distinct ways to test with a twin wheel tracker: the main mode is an air/dry mode, and the subsequent mode is a wet mode. The specimen was evaluated in dry conditions during this test. Due to the fact that the steel wheel moves across the specimen, the Wheel Tracking Apparatus is able to determine how the surface has been affected by rutting. Before the test could be carried out, the sample had to be saw cut to fit the required size of the machine's mold, which has a thickness of 63 millimeters and a diameter of 150 millimeters. To ensure that the sample would not move in response to the wheel's rotation, the spaces left empty after the specimen was placed in the mold were filled with plastic or wood. In order to enable the wheel to be fixed, the steel tray was adjusted and positioned directly underneath it. When the steel tray containing the sample was securely fastened in place, the wheel tracking device was activated. Some examples of fundamental data, such as the code, diameter, weight, and height, were entered in the laptop that was connected to the machine. The wheels were set to move at a speed of 60 ppm (passes per minute). The number of passes was set at 10,000 and was maintained as indicated to determine the asphalt mixtures' potential for rutting.

The last step of the test was moving the wheel to and fro to mean the headway that had been made. On LCD of the framework that was associated with the machine, the quantity of passes was shown. The wheel was considered passing two times on the off chance that it made a full pivot in the two bearings. Simultaneously as the wheel is turning, a gadget called LVDT distinguishes the depth of impact of rut in millimeters of unit.

3.11 Moisture Susceptibility Test

The tests were completed in accordance with ASTM D 6931-07 to lay out the moisture susceptibility of the material. Unconditioned tests were performed on three examples taken from every % of CR-WCO. Preceding the testing, the unconditioned examples were molded in a water shower at 25 degrees Celsius (77.18 degrees Fahrenheit) for 60 minutes. After being conditioned, three samples of each mixture were also examined. In accordance with ALDOT-361, the samples were conditioned in a water bath heated to 60 degrees Celsius (140 degrees Fahrenheit) for 24 hours and a water bath heated to 25 degrees Celsius (77 degrees Fahrenheit) for one hour. Regardless of whether the specimen had been conditioned, it was placed in the UTM machine in such a way that the load would transfer in the sample diametrically at a rate of fifty millimeters per minute. After that, the specimens' measurements and the loads at which they failed were used to calculate the tensile strength. The average conditioned tensile strength was divided by the average unconditioned tensile strength to calculate tensile strength ratios. An elasticity proportion of 80% is expected according to Superpave guidelines. A rigidity proportion, curtailed as TSR, is a correlation of the elasticity of a molded example to that of an unconditioned example. The formula for determining samples' tensile strengths is shown in Equation 1.

$$St = 2000P/\boldsymbol{\pi}Dt \qquad (1)$$

Here:

D = Specimen diameter of sample (mm)

P = Maximum load applied on sample (N)

St = Tensile strength of sample (Kpa)

t = Specimen height before tensile test (mm)

3.12 Resilient Modulus Test

A pavement structure's resilience to drivers' traffic loads can be evaluated using resilient modulus data. Additionally, resilient modulus provides data for analysis and pavement design and evaluation. To foresee pavement performance and analysis asphalt response to traffic pressure, the resilient modulus is viewed as a significant parameter. Figure 3.7 shows the course of action of resilient modulus mechanical assembly. UTM was utilized to decide the resilient modulus of CR-WCO altered asphalt mixtures.

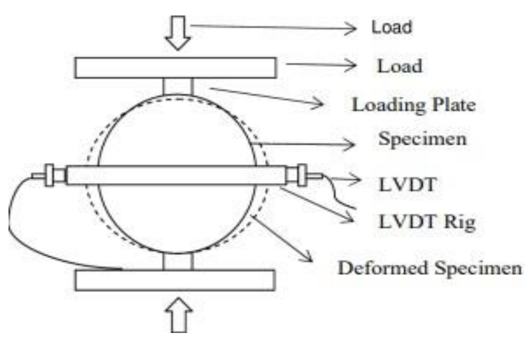

Figure 3.7: Resilient modulus apparatus

It was possible to conduct resilient modulus tests on modified and unmodified asphalt mixtures with the help of Superpave gyratory compacted HMA samples. At 25 degrees Celsius, samples were loaded into the loading device, which was kept at that temperature. A haversine waveform should be provided vertically in the specimen's vertical diametric plane to determine the resilient modulus using the repeated-load indirect tension test. The use of load and the resilient modulus were resolved utilizing horizontal elastic deformation. Equations are used to multiply each load pulse's recovered horizontal deformation and horizontal deformation caused by horizontal deformation to calculate the resilient modulus. Figure 3.8 depicts the apparatus used to evaluate the resilient modulus of CR-WCO modified asphalt mixtures.

Figure 3.8: Universal testing Machine

3.13 Summary

The laboratory characterization of aggregates and asphalt binder for the purpose of making asphalt mixes is the topic of discussion in this chapter. Only the kinds of materials that met the standard requirements of the criteria and specifications were used to make asphalt mix. OBC was determined by performing calculations on the volumetric parameters of the produced asphalt mix samples. The procedures for sample preparation for performance tests like the moisture susceptibility, resilient modulus, and rutting resistance tests were discussed at the chapter's conclusion.

The method that was followed throughout the various phases of the experimental investigation is explained in detail in this chapter. To ensure that they can be used in this investigation, aggregate and bitumen were evaluated. Tests on bitumen following the mixing of CR-WCO are presented with their respective ASTM standards to provide a better understanding of the properties. The amount of asphalt in the bitumen is measured by these tests. A JMF was created using the NHA Class B gradation standards in the second phase. The volumetric characteristics of Marshall testing specimens are described with reference to applicable standards and specifications, and a succinct explanation of the Marshall Test technique is provided.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

Moisture accumulated on the road surface can have a detrimental effect. This tends to lead to premature failure of his HMA pavement, making it the easiest, simplest and most commonly used approach to assess moisture-related damage using UTM.This study focuses on the incorporation of CR-WCO as an asphalt binder replacement in HMA mixtures and analysis of the effects of this modification on moisture sensitivity, modulus and rut resistance of CR-WCO modified asphalt mixtures . After calculating the OBC and adding the optimum additive level, the samples were prepared for performance testing. For this study he used NHA Class B. This chapter describes the results of various experiments. B. Details moisture sensitivity (ITS), modulus (MR) and rut resistance. In addition, analysis and comparison of test data of conventional samples and his CR-WCO modified samples are performed and discussed. Analysis of results obtained from various laboratory experiments using HMA-Mix was performed using Microsoft Excel. Finally, an analysis was performed to determine the impact of CR-WCO on the performance properties of modified asphalts.

4.2 Consistency Tests

Five different percentages of CR-WCO were used to evaluate rheological properties such as permeability and softening point.5 percent, 10 percent, 15 percent, 20 and 25 weight percent. As the temperature rises and falls, the consistency of the asphalt binder changes accordingly In most cases, asphalt binders are tested for penetration or viscosity to assess consistency. The temperature used for the penetration test was 25 degrees Celsius, the load used was 100 grams, and the test time was 5 seconds. Bitumen is a substance with viscoelastic properties. However, it gradually softens and becomes less viscous as the temperature rises. After consistency tests, it was confirmed that Grade 60/70 virgin asphalt met all criteria for all tests according to the respective standards. Table 4.1 shows the results of consistency tests performed on the base bitumen. The penetration of the base asphalt was 69 °C at 25 °C, while the softening point of the base asphalt was 50 °C.

Table 4.1: Consistency Test Results

Test Description	Result	Standards	Specifications
Penetration Test @ 25ºC	69	ASTM 5	60/70
Flash Point (ºC)	268	ASTM D 92	232 minimum
Fire Point (ºC)	291	ASTM D 92	232 minimum
Specific Gravity (kg/cm3)	1.03	ASTM D 70	1.01-1.06
Softening Point (ºC)	50	ASTM D36-06	49-56
Ductility Test (cm)	111	ASTM D 113-99	100 minimum

The softening point and penetration properties of base binder and CR-WCO modified asphalt were evaluated. It was found that when the CR-WCO content increased to 10%, the penetration values decreased slightly, while the softening values increased slightly. However, when levels of CR-WCO were used above 10%, the penetration values increased significantly, while the softening point values decreased down to 30% CR-WCO samples. This indicates that WCO has a dominant impact on consistency scores compared to crumb gum. Otherwise, the softening point of CR modified asphalt increases with increasing CR content. result of permeation and softening point tests for CR-WCO modified asphalt and base bitumen are shown in Figure4.1

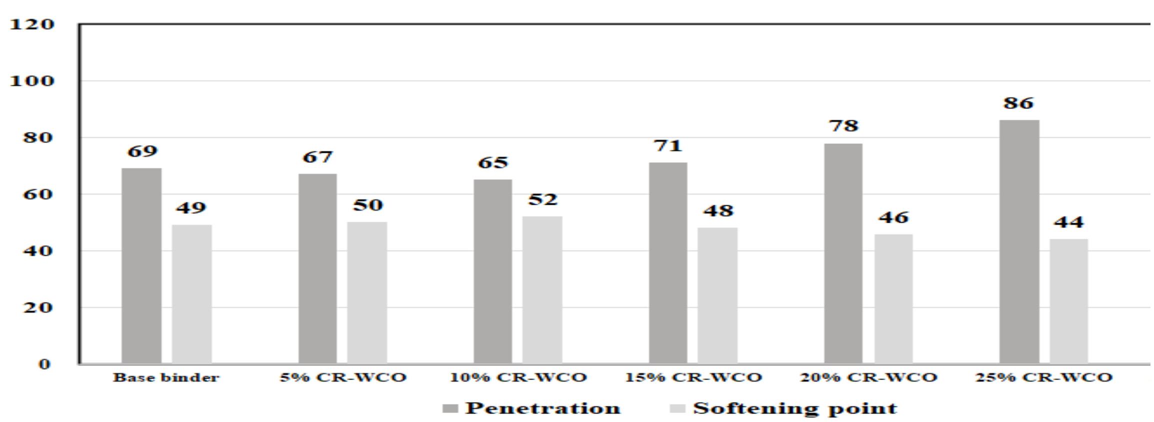

Figure 4.1: Results of consistency tests for CR-WCO modified binder

4.3 HMA Performance Testing

To study the performance of asphalt mixtures composed of pure binders and binders modified with varying amounts of CR-WCO, we investigated the performance of asphalt mixture samples by conducting moisture sensitivity and rutting tests. An evaluation was made.

Table 4.4: Tensile Strength Values of Different CR-WCO Modified Mixes

Base and Modified Binders	Average Unconditioned (KN)	Average Conditioned (KN)	Tensile Strength Ratio (%)
Base Binder	3.29	2.96	89.96
5 %CR-WCO	2.02	1.82	90.09
10 %CR-WCO	3.02	2.76	91.39
15 %CR-WCO	2.70	2.38	92.24
20 %CR-WCO	1.59	1.42	89.30
25 %CR-WCO	2.93	2.49	84.98

Figure 4.4 shows that as the CR-WCO content increases to 15%, the TSR value increases up to 92 and then decreases steadily. As a result, the 15% CR-WCO sample showed the best moisture resistance. As the CR-WCO content increases, the overall mixture becomes less stable and negatively impacts the TSR value. To be fair, all samples met the Super Pub standard of minimum TSR 80%.

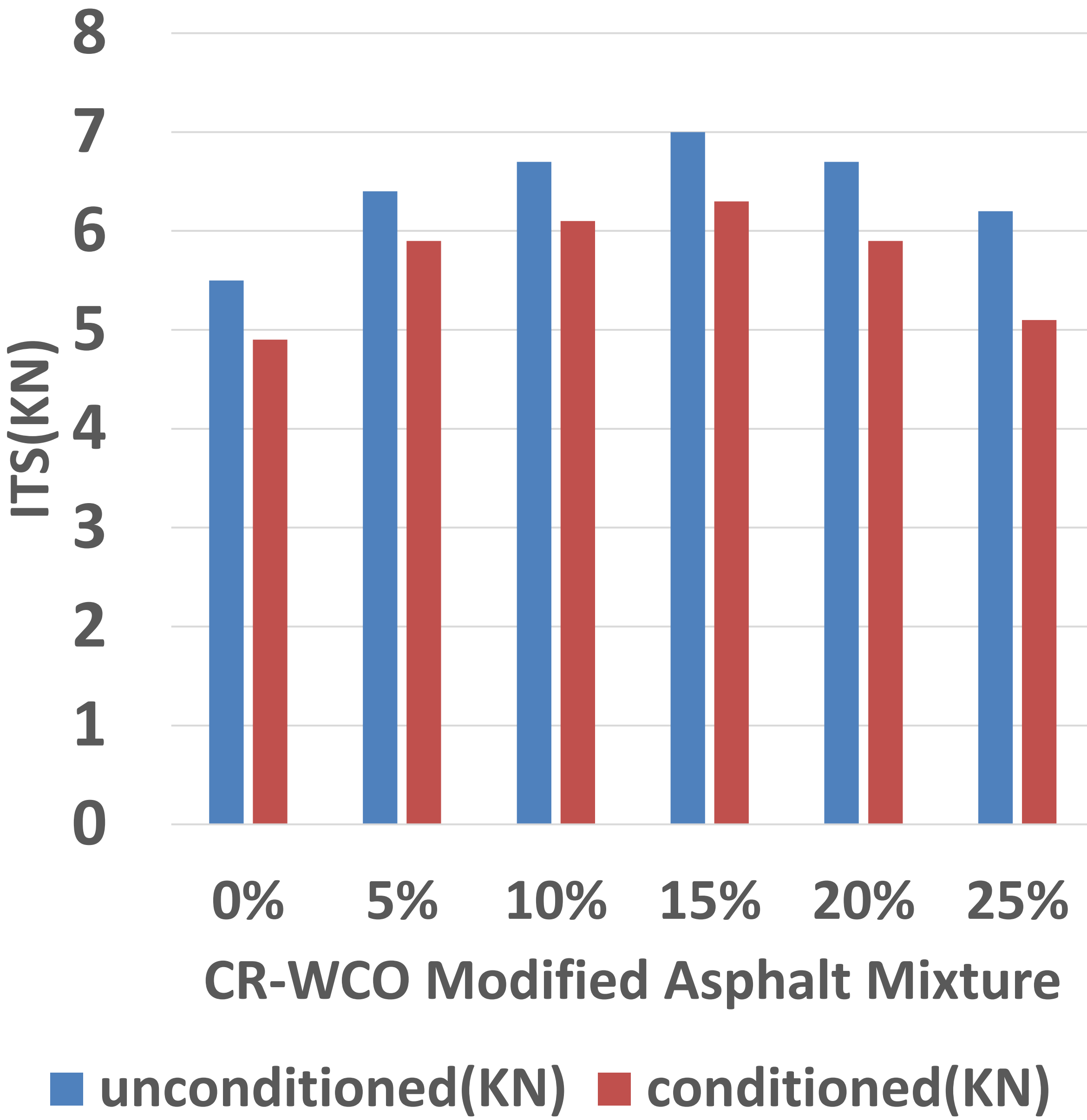

Figure 4.5: IDT values of conditioned and unconditioned asphalt samples

The IDT values for adjusted and unadjusted samples are shown in Figure 4.5. The 15% CR-WCO sample exhibits maximum IDT values as shown in Figure 4.5. However, when the amount of CR-WCO as modifier was used above 15%, the IDT value decreased significantly. This suggests that high amounts of WCO have a negative impact on IDT values. Therefore, we can conclude from the IDT results that 15 percent of the modifier should be used for optimal results.

4.3.1 Resilient Modulus Test

When a material is subjected to cyclic loading, Young's modulus is used to determine the ratio of applied stress to recoverable strain. This ratio serves as a relative indicator of the material's mixed stiffness. Performance testing can be used to determine material quality and gather data for pavement design. One way to do this is using Young's modulus. Elastic modulus is an important statistic to consider when estimating pavement performance and studying how pavements respond to traffic loads. MR testing of samples prepared by cutting cored samples used a contact peak load of 20 percent of the IDT strength. The experiment was conducted at temperature of 25°C:

.

Table 4.5 shows the elastic moduli of modified asphalt mixtures. Table 4.5 shows that the sample containing 15% CR-WCO has the highest Young's modulus value.

Table 4.5: Resilient Modulus Values of Different CR-WCO modified Mixtures

PERCENT	Mega pascals
BASE BINDER	3108
5% CR/WCO	4489
10% CR/WCO	4738
15% CR/WCO	5599
20% CR/WCO	4305
25% CR/WCO	3685

Figure 4.6 shows the Young's modulus of the CR-WCO modified asphalt mixture. It was also observed that higher CR-WCO doses incorporated modifiers at levels greater than 15 percent, resulting in lower modulus values. This indicates that the asphalt mixture with 15 percent CR-WCO has the best balance of stiffness and flow.

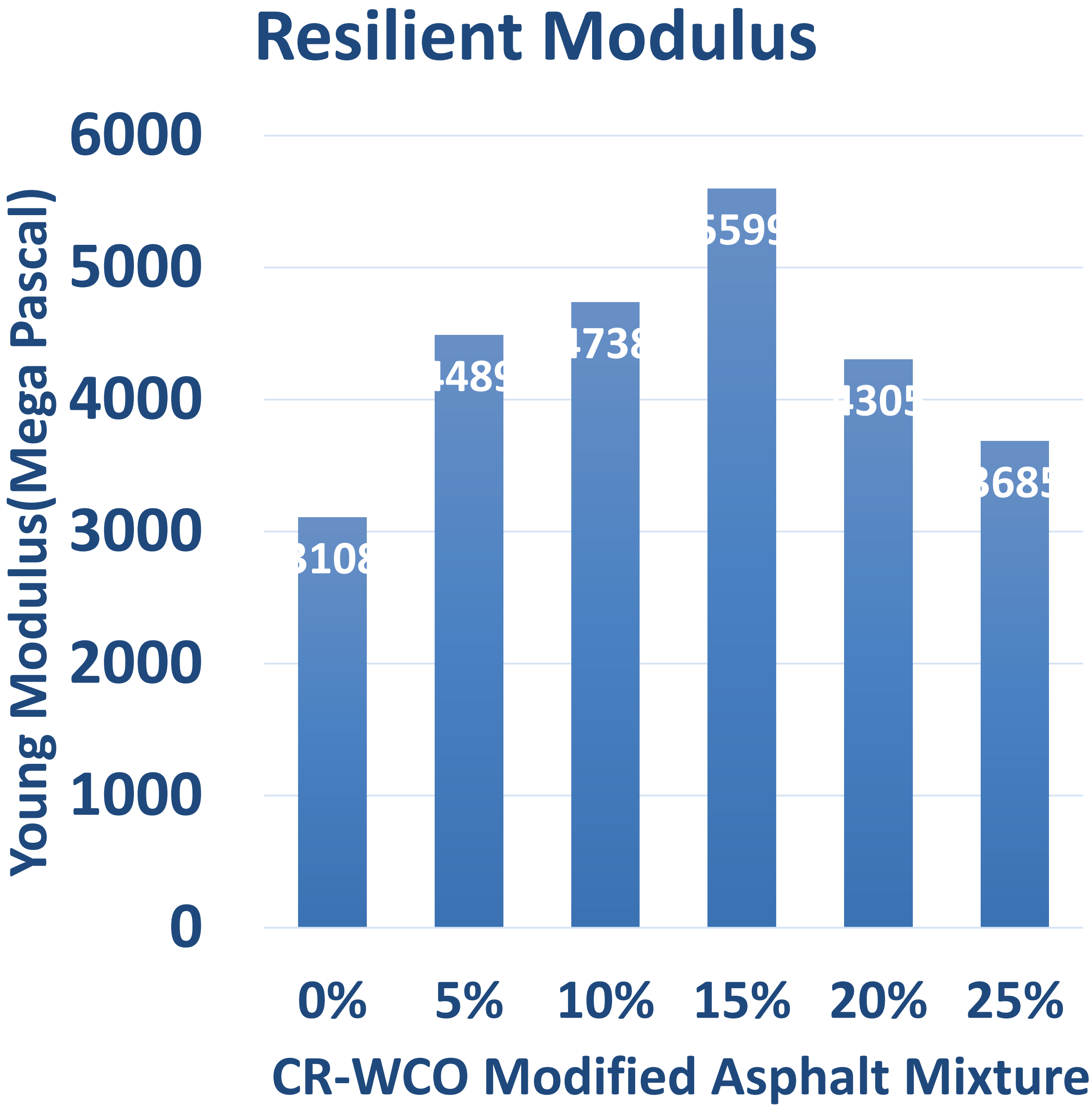

Figure 4.6: Resilient modulus values of different asphalt mixtures

The results show that adding 15% CR-WCO increased the modulus by 1.80 times. However, when the proportion of CR-WCO increased from 15 percent of CR-WCO, the value of Young's modulus started to decrease. Therefore, considering these results, we can conclude that the modified sample containing 15 percent CR-WCO has the best performance.

4.4 Summary:

The findings of tests and analyses conducted on the performance assessment of CR- WCO modified and unmodified HMA samples were used as the foundation for this chapter. Microsoft Excel was used in the process of statistical analysis. IDT test and the resilient modulus tests are included in the first phase. Experiments were carried out to investigate the impact of elevating the CR-WCO content to a higher percentage. It was discovered that the IDT and MR value both increased with an increase in the CR-WCO percent (up to 20%) at a temperature of 25 degrees Celsius. In the second phase, correlations were developed between different test results.

The rut resistance of an asphalt mix containing 15 percent CR-WCO is increased by up to 2.17 times when compared to the rut resistance of an unmodified asphalt mix. The resilient modulus of the samples that incorporated 20 percent CR-WCO was 1.80 times higherthan the resilient modulus of the unmodified asphalt mix. When 20 percent CR-WCO is added to the asphalt mix, the TSR (Tensile Strength Ratio) increased by as much as 1.07 times the TSR value of the unmodified asphalt mix. It is possible to draw the following conclusion based on the findings: the asphalt mix that contains 15% CR-WCO performs the best.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

WCO-CR was used as a modifier in this research project to evaluate the effect it can have on the performance and physical of the modified asphalt mix. By improving performance parameters the road life can be increased. Lab analysis was carried out to see the properties of bitumen changing and their effect on road performance.

The initial step includes the determination of materials from the Babozai quarry, the availability of bitumen grade ARL 60/70 crumb rubber and waste cooking oil, and the testing of those materials by the prerequisites that have been laid out. After that, the CR-WCO in both binder grades were mixed manually with high shear, and the mixing process was finished. During the first round of testing, modified mixtures were exposed to consistency tests to assess the rheological attributes. Marshal testing on an OBC in accordance with the NHA Class B Specifications was the next step. How modified HMA samples acted in terms of strength and volume was determined. Standard specimens with a diameter of four inches and a width of two inches were used for the testing. An IDT test using a UTM machine was performed at a temperature of 25 degrees Celsius to determine the resilient modulus and the cracking potential of HMA mixes.

The HMA performance tests revealed that 15% of CR-WCO-modified HMA samples with ARL 60/70 modifications exhibited the highest levels of IDT, MR.

5.2 Conclusions

The reason for the trial work that was completed was to research the effect of different % of CR-WCO on mixture of asphalt. The characteristics of moisture susceptibility and resilient modulus were carefully examined and developed. Following are a few things that are determined to be valid after broad examination and examination:

- The HMA mix with 15% CR-WCO was found to have the highest moisture susceptibility and resilient modulus values.
- Both the aggregates and the bitumen have passed individual essential testing standard.
- The addition of 15% CR-WCO increased rut resistance by as much as 2.17 times in comparison to an unmodified asphalt mix.
- The TSR value significantly increased as a result of the addition of 15 percent CR-WCO, which significantly enhanced the asphalt mix.
- The discoveries of the examination give proof that the use of CR-WCO brings about upgrades to the attributes of modified asphalt concrete that act as execution markers. Improved resistance to rutting, resilient modulus, and moisture damage are among these enhancements.
- The results of the study indicate that crumb rubber and waste cooking oil can be utilized in asphalt pavements in an efficient manner.

5.3 Recommendations

According to the findings of the research that was carried out, it is possible to effectively to

. use both crumb rubber and waste cooking oil.

- The adoption of CR-WCO modified binders in our local industry will improve the road performance and will result in reduced expenses.
- The findings of the research provide evidence that the usage of CR-WCO results in improvements to the characteristics of modified asphalt concrete that serve as performance indicators.
- Therefore, it is recommended that asphalt binder should be modified with 15 percent CR-WCO to get the optimum properties of asphalt mix.

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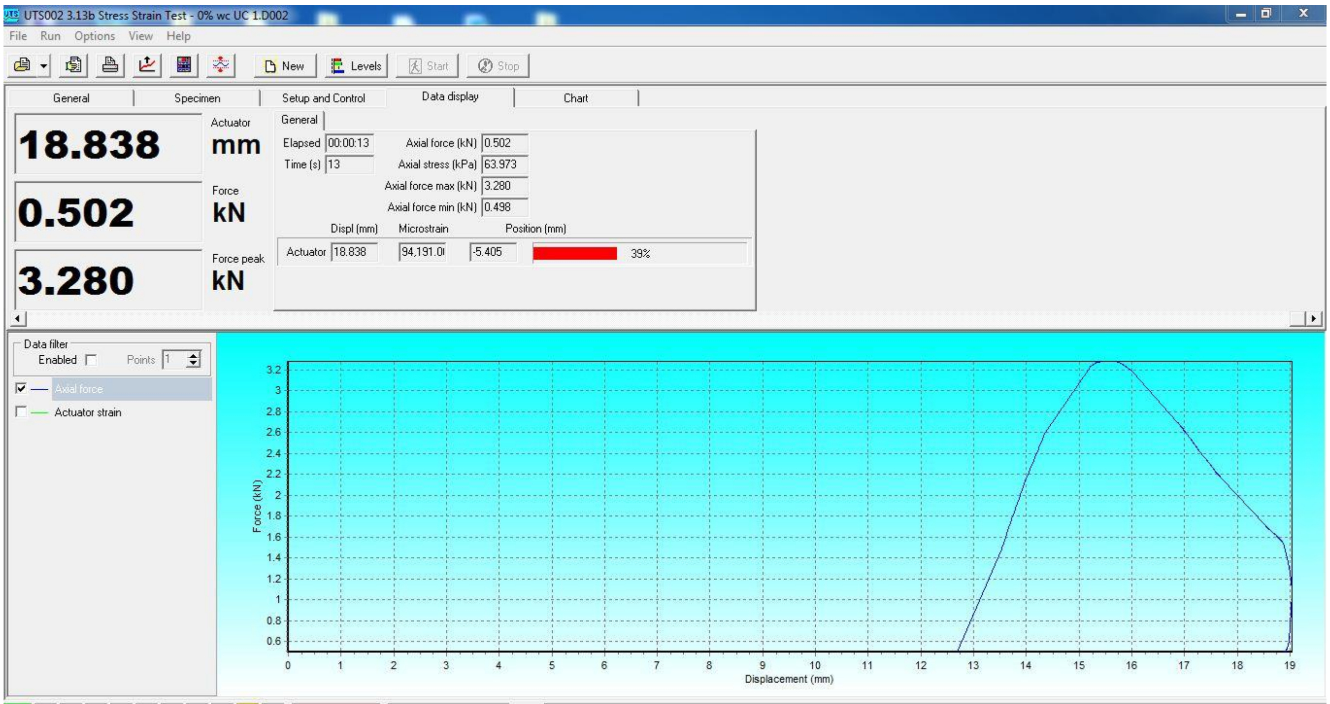
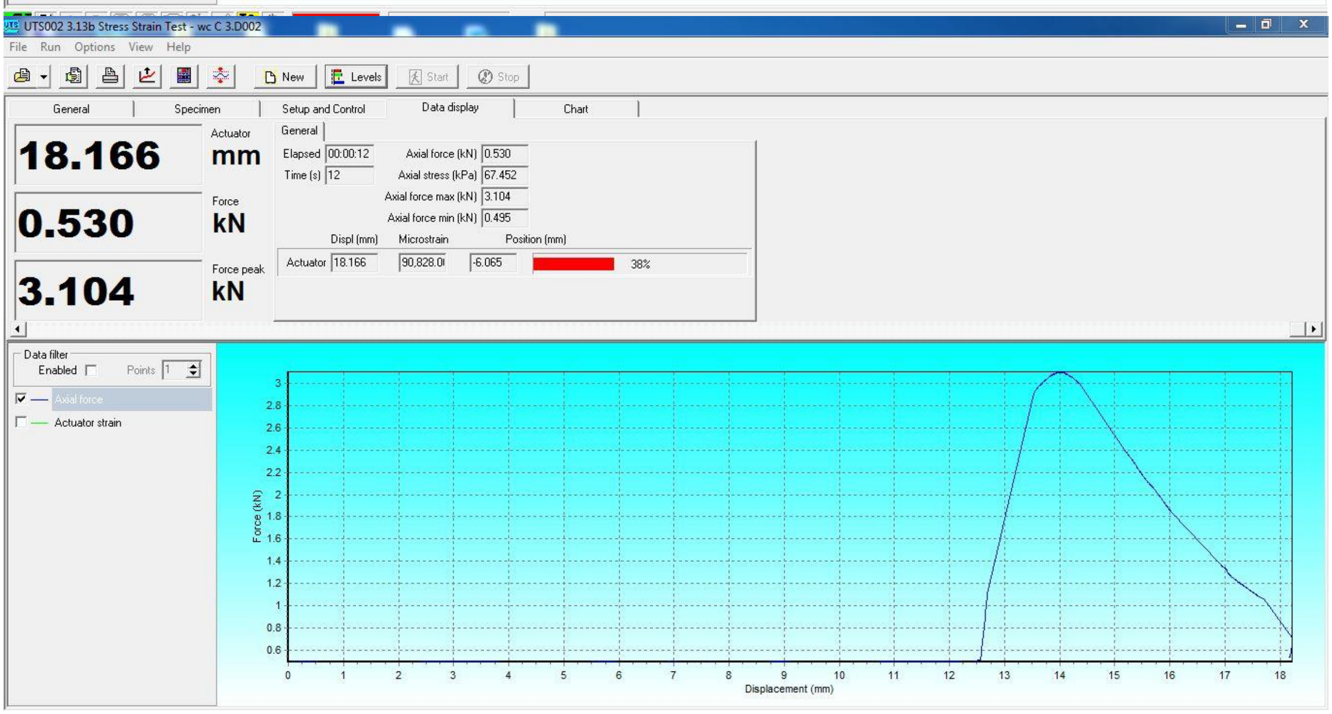
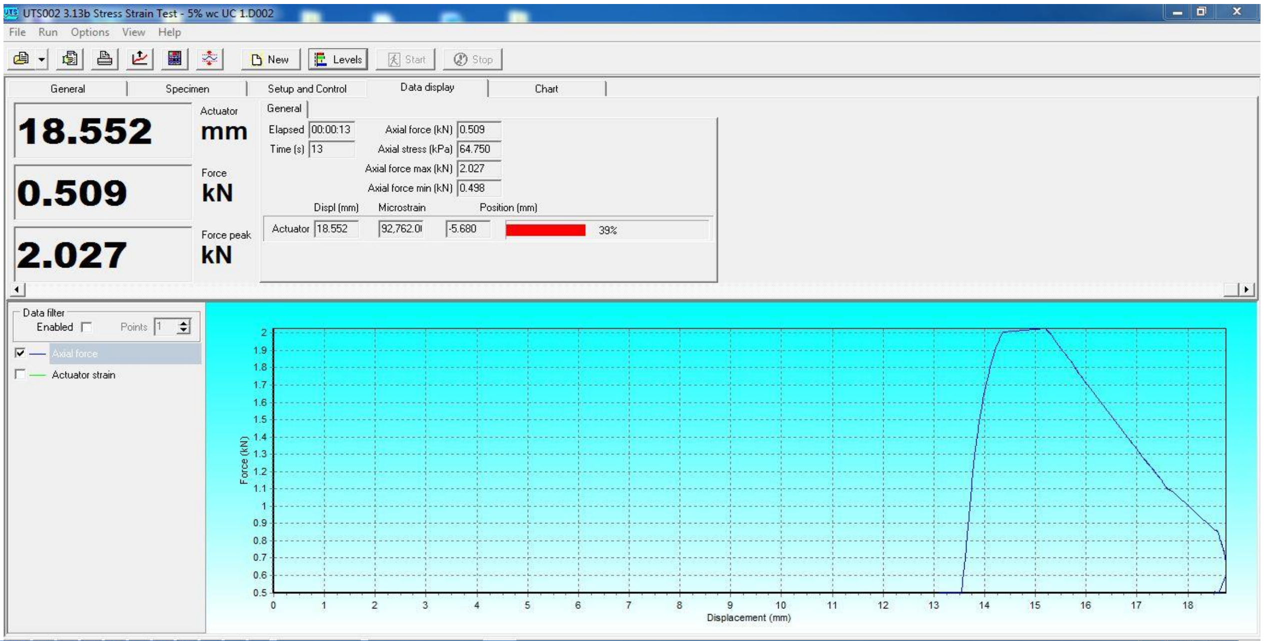
APPENDICES

APPENDIX-I

RESULTS OF TSR/IDT



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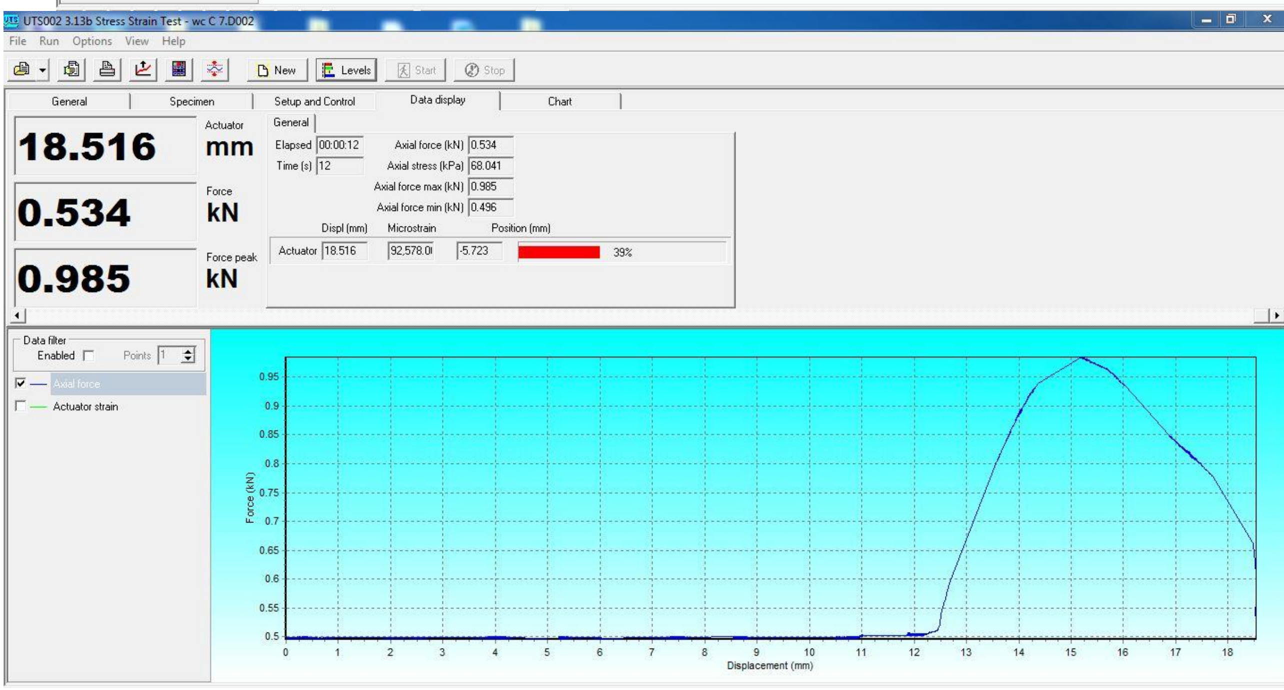
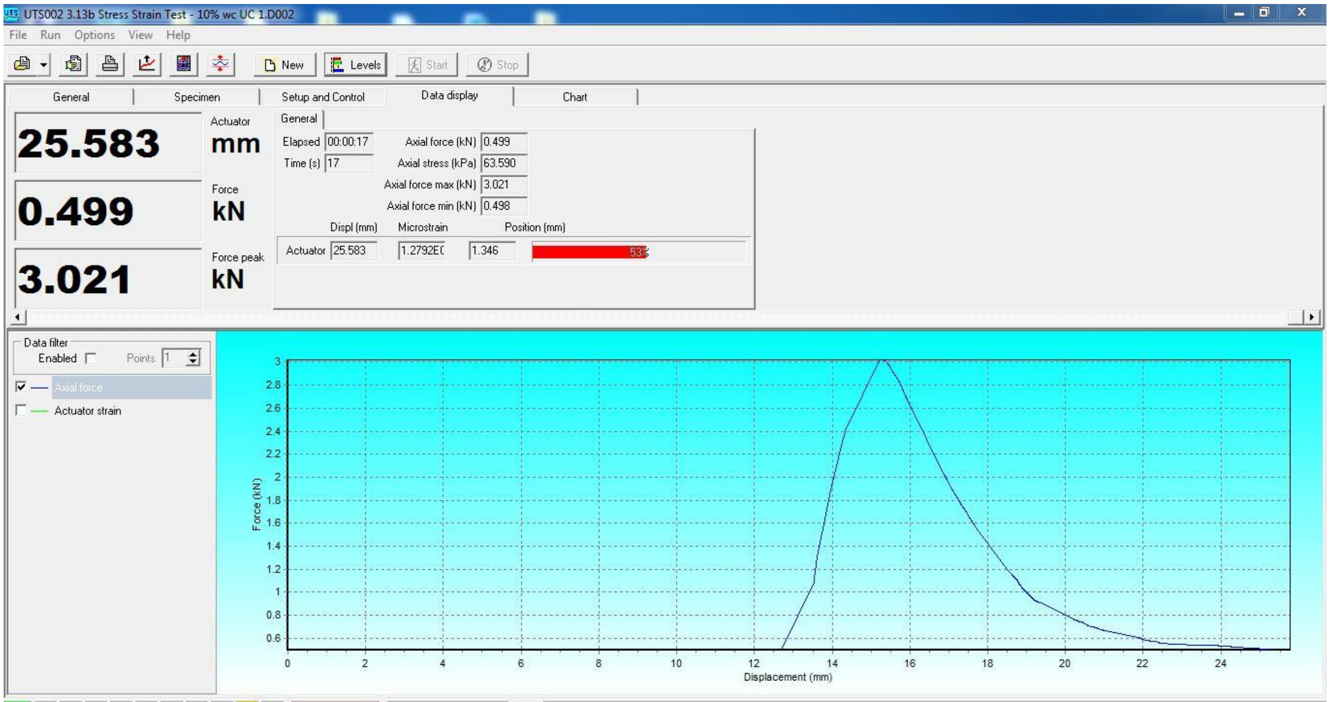
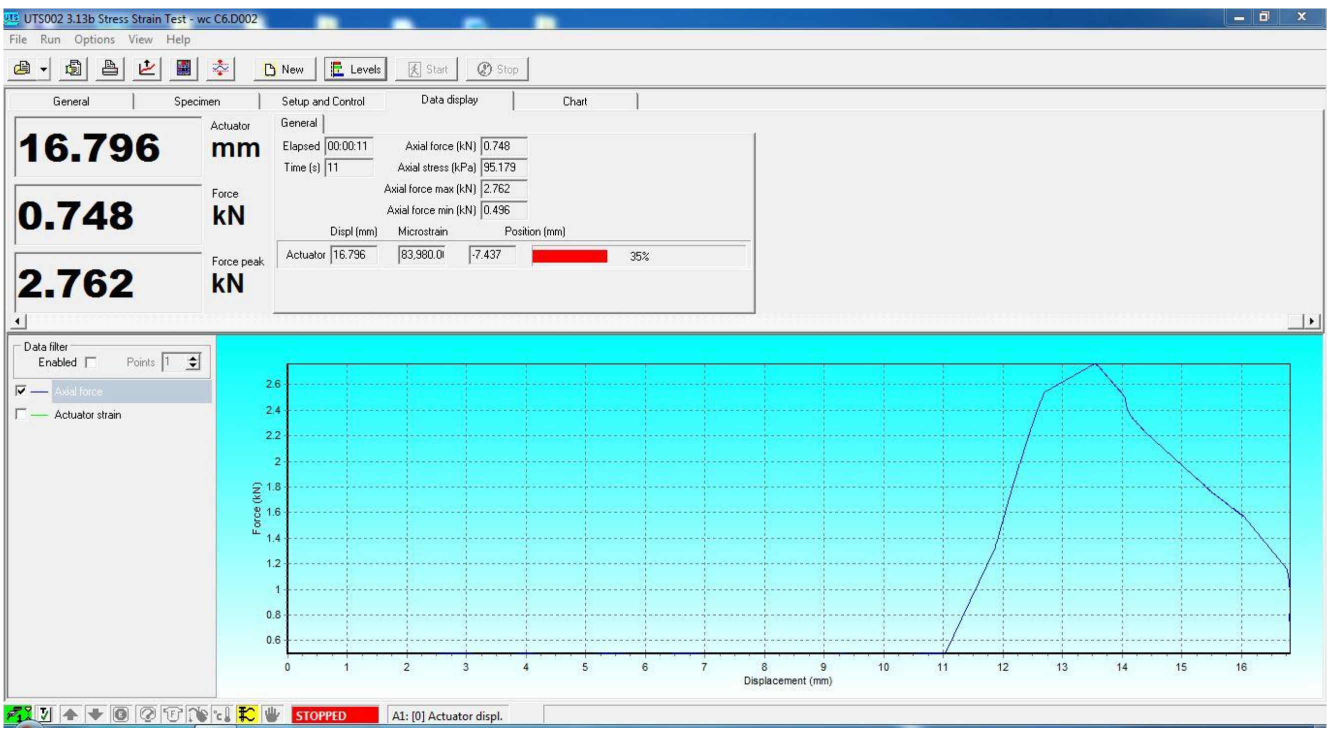
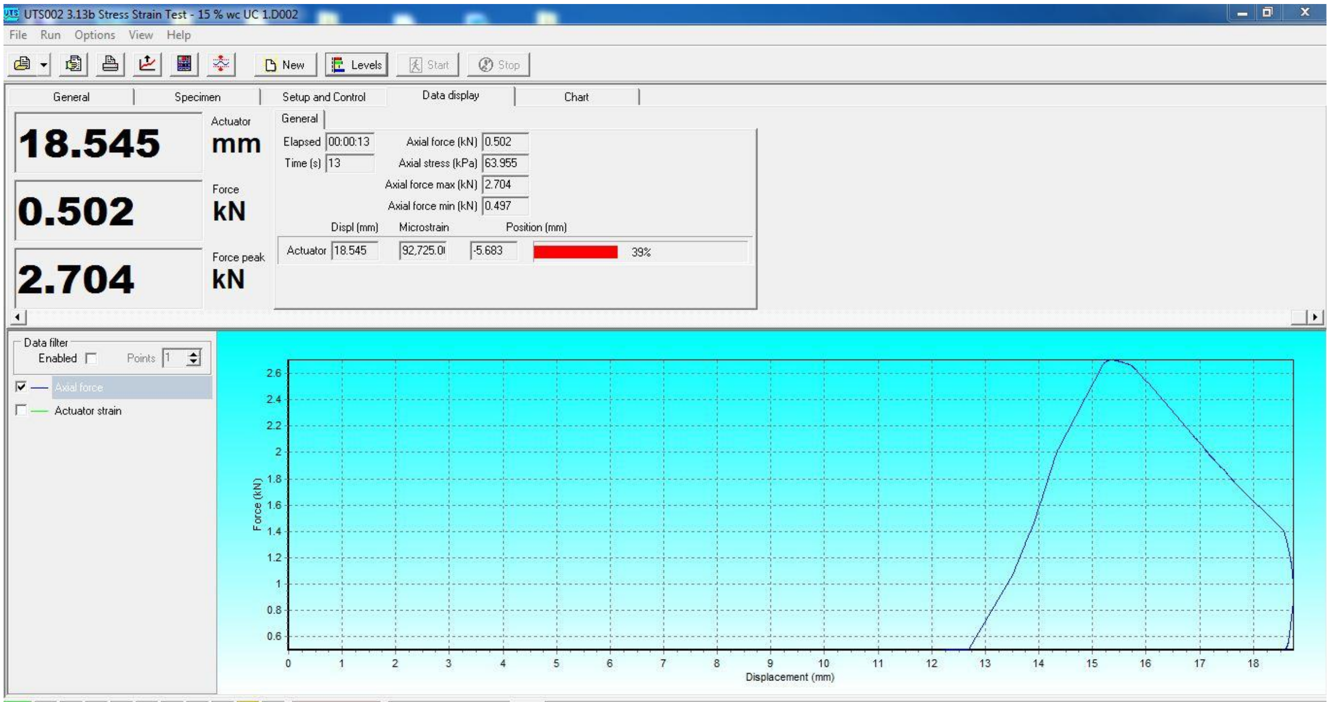
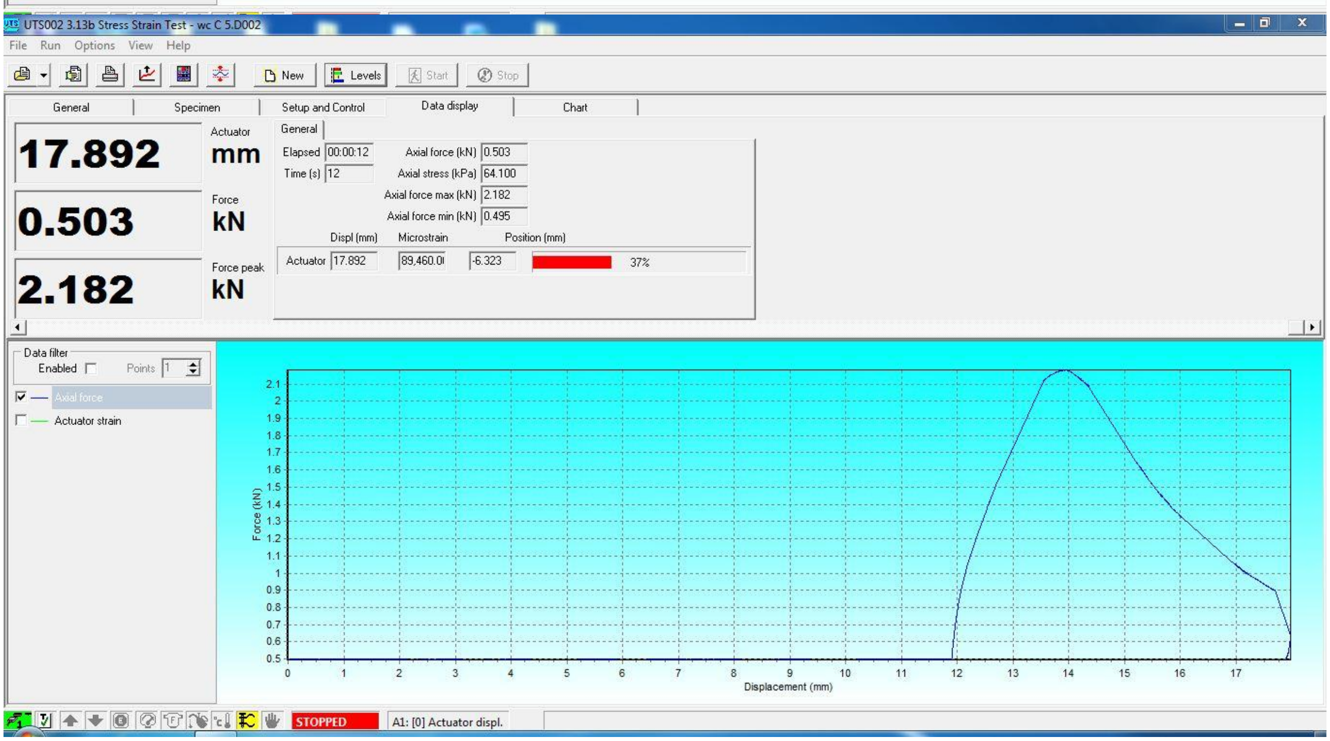
Force (kN)
Displacement (mm)

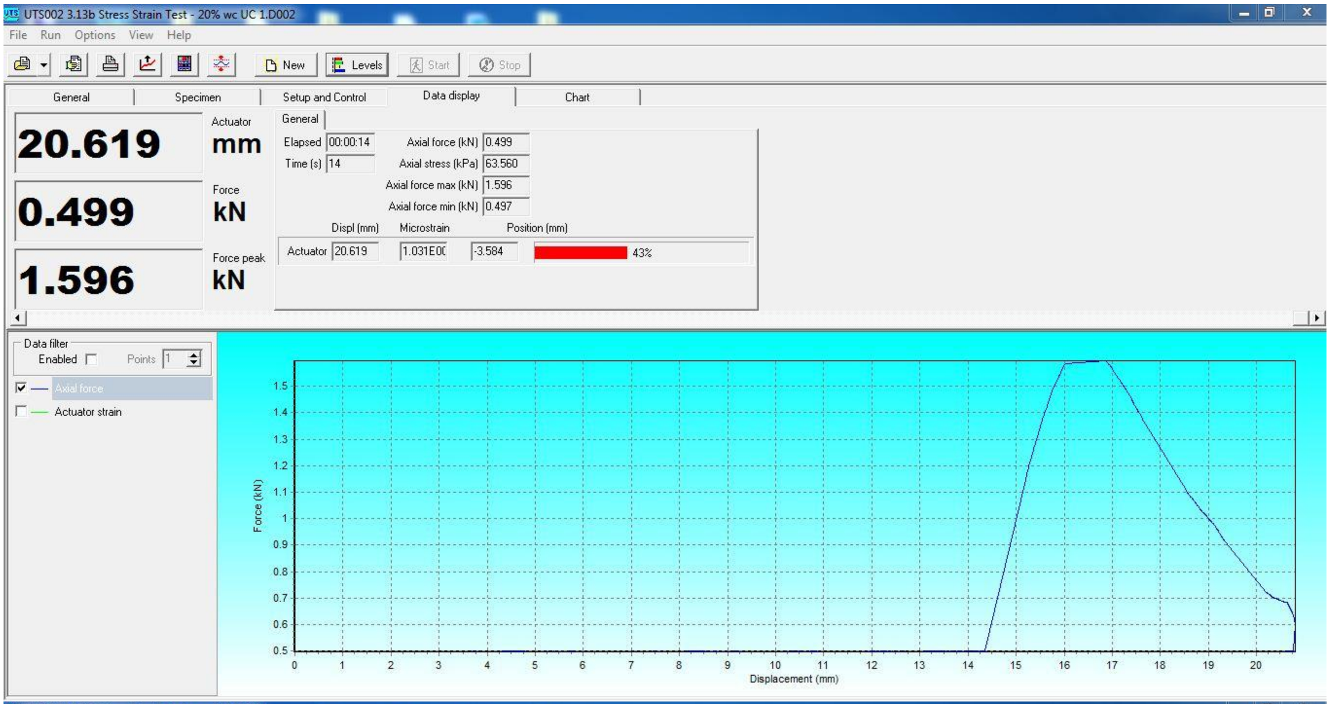

UTS002 3.13b Stress Strain Test - wc C 7.D002
File Run Options View Help
New
Levels
Start
Stop
General
Specimen
Setup and Control
Data display
Chart
18.516
Actuator
mm
0.534
Force
kN
0.985
Force peak
kN
General
Elapsed 00:00:12
Time (s) 12
Axial force (kN) 0.534
Axial stress (kPa) 68.041
Axial force max (kN) 0.985
Axial force min (kN) 0.496
Displ (mm)
Microstrain
Position (mm)
Actuator 18.516
92,578.0
-5.723
39%
Data filter
Enabled
Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)

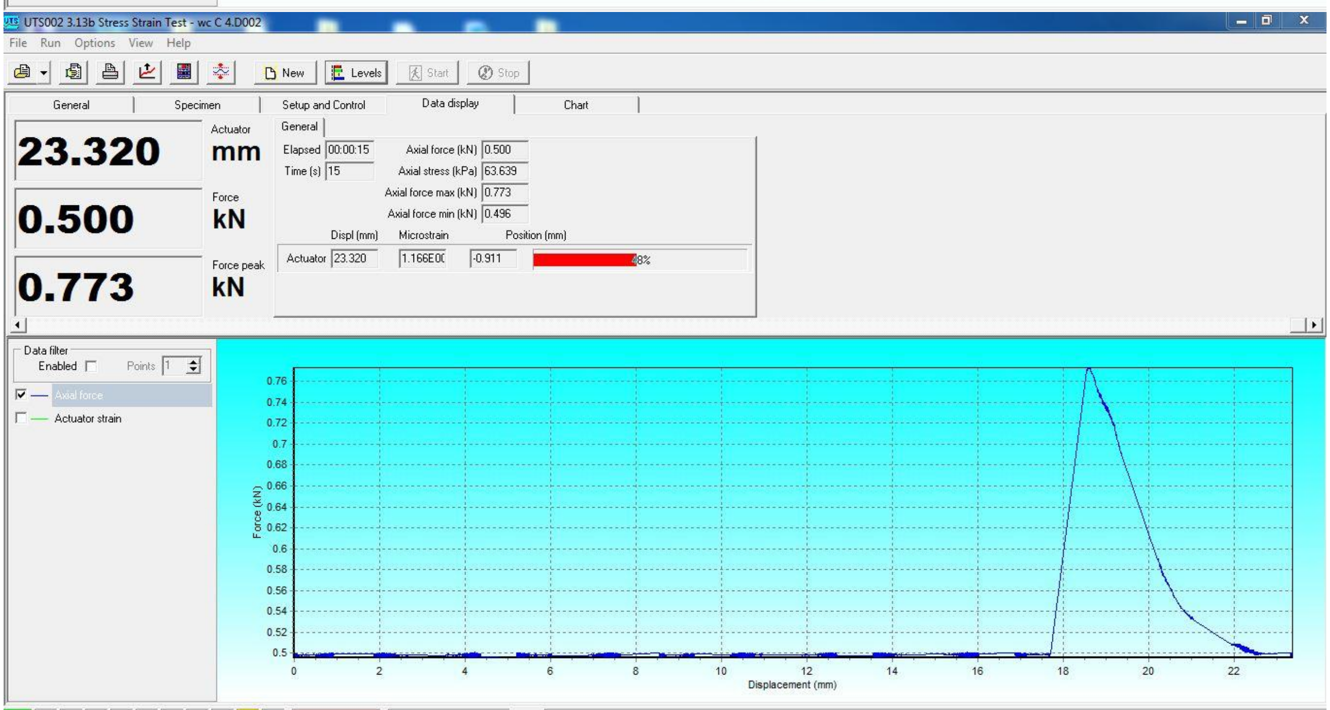

UTS002 3.13b Stress Strain Test - 10% wc UC 1.D002
File Run Options View Help
New Levels Start Stop
General Specimen Setup and Control Data display Chart
25.583 Actuator mm
0.499 Force kN
3.021 Force peak kN
Elapsed 00:00:17 Time (s) 17
Axial force (kN) 0.499
Axial stress (kPa) 63.590
Axial force max (kN) 3.021
Axial force min (kN) 0.498
Displ (mm) Microstrain Position (mm)
Actuator 25.583 1.2792E(1.346
Data filter Enabled Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)

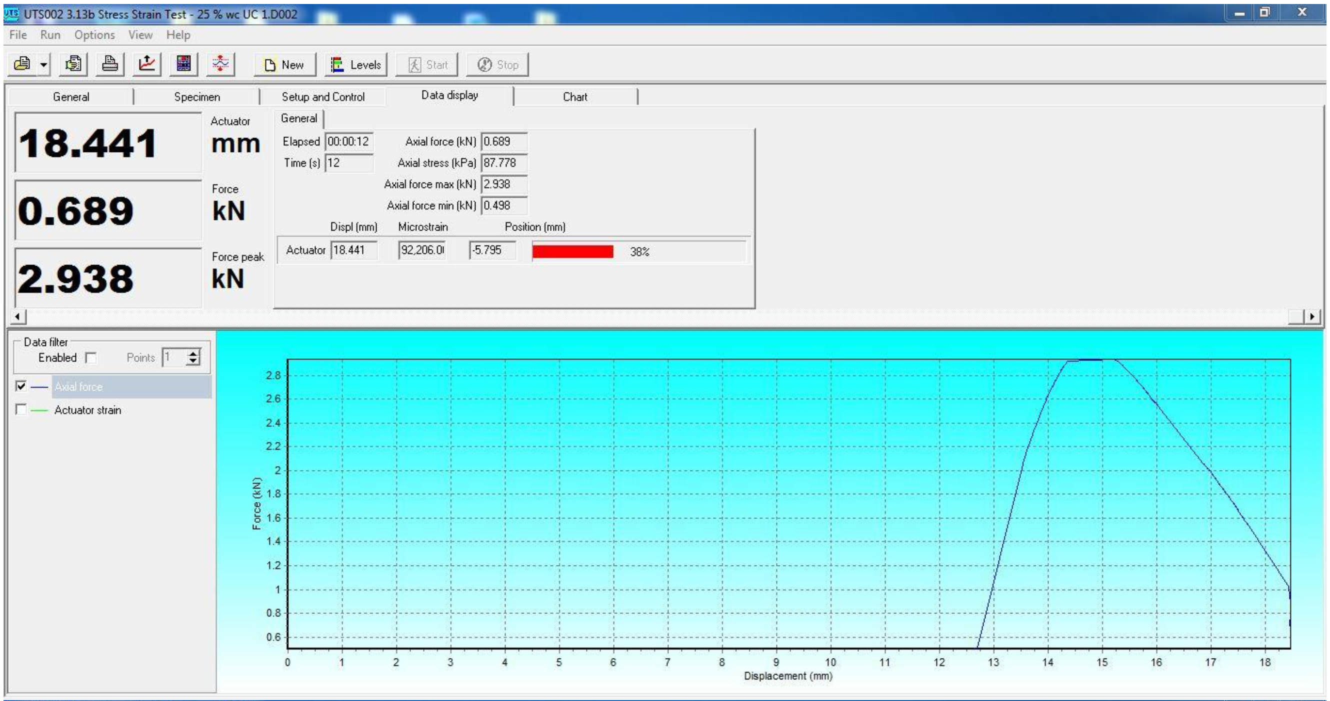

UTS002 3.13b Stress Strain Test - wc C6.D002
File Run Options View Help
New Levels Start Stop
General Specimen Setup and Control Data display Chart
16.796 Actuator mm
0.748 Force kN
2.762 Force peak kN
Elapsed 00:00:11 Time (s) 11
Axial force (kN) 0.748
Axial stress (kPa) 95.179
Axial force max (kN) 2.762
Axial force min (kN) 0.496
Displ (mm) Microstrain Position (mm)
Actuator 16.796 83,980.0(-7.437 35%
Data filter Enabled Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)
STOPPED
A1: [0] Actuator displ.

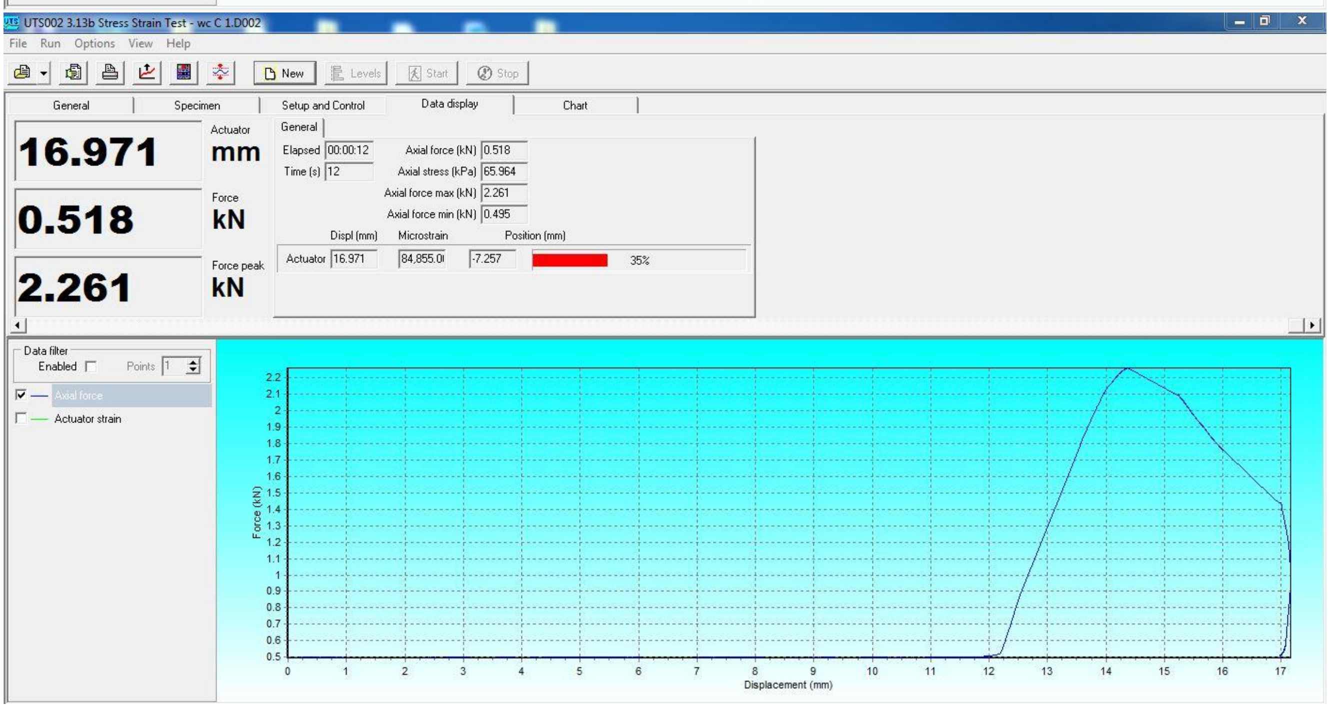

UTS002 3.13b Stress Strain Test - 15 % wc UC 1.D002
File Run Options View Help
New Levels Start Stop
General Specimen Setup and Control Data display Chart
18.545 Actuator mm
0.502 Force kN
2.704 Force peak kN
General
Elapsed 00:00:13 Axial force (kN) 0.502
Time (s) 13 Axial stress (kPa) 63.955
Axial force max (kN) 2.704
Axial force min (kN) 0.497
Displ (mm) Microstrain Position (mm)
Actuator 18.545 92,725.0 -5.683 39%
Data filter
Enabled Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)


UTS002 3.13b Stress Strain Test - wc C 5.D002
File Run Options View Help
New Levels Start Stop
General Specimen Setup and Control Data display Chart
17.892 Actuator mm
0.503 Force kN
2.182 Force peak kN
General
Elapsed 00:00:12 Axial force (kN) 0.503
Time (s) 12 Axial stress (kPa) 64.100
Axial force max (kN) 2.182
Axial force min (kN) 0.495
Displ (mm) Microstrain Position (mm)
Actuator 17.892 89,460.0 -6.323 37%
Data filter
Enabled Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)
STOPPED
A1: [0] Actuator displ.


UTS002 3.13b Stress Strain Test - 20% wc UC 1.D002
File Run Options View Help
New
Levels
Start
Stop
General
Specimen
Setup and Control
Data display
Chart
20.619
Actuator
mm
0.499
Force
kN
1.596
Force peak
kN
Elapsed 00:00:14
Time (s) 14
Axial force (kN) 0.499
Axial stress (kPa) 63.560
Axial force max (kN) 1.596
Axial force min (kN) 0.497
Displ (mm)
Microstrain
Position (mm)
Actuator 20.619
1.031E0(
-3.584
43%
Data filter
Enabled
Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)

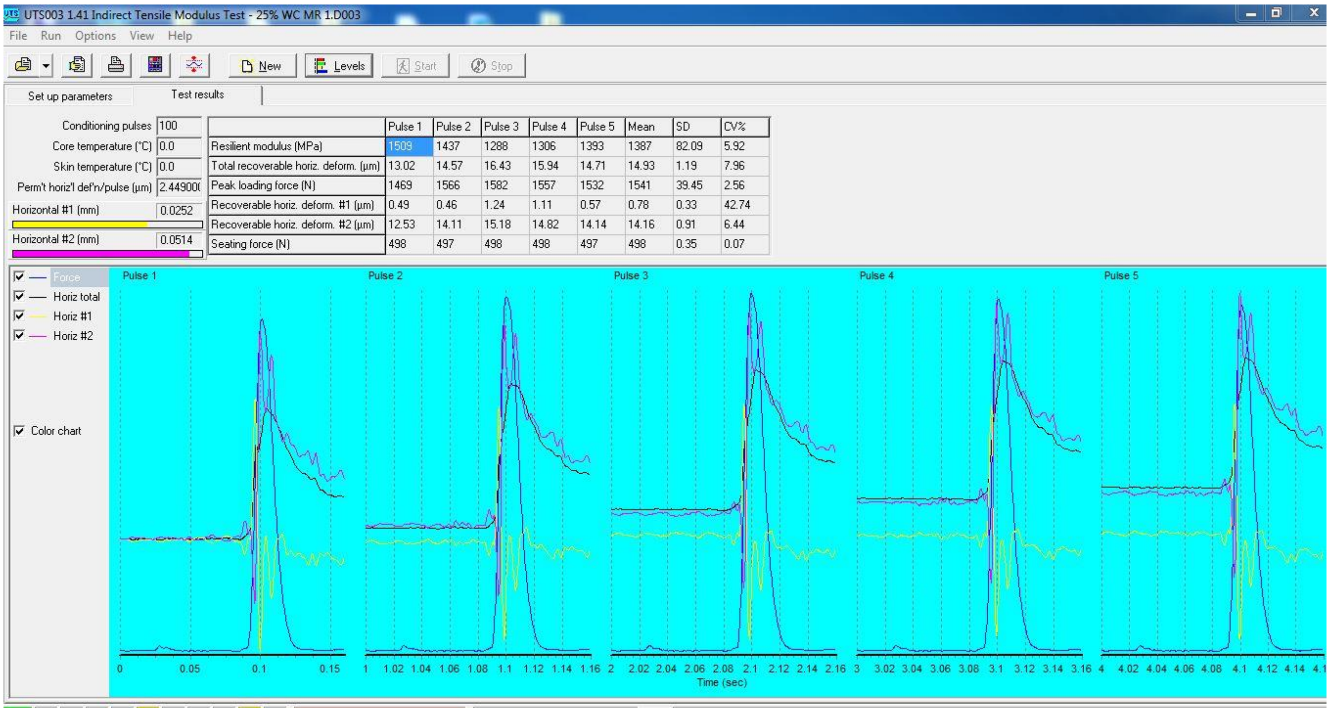

UTS002 3.13b Stress Strain Test - wc C 4.D002
File Run Options View Help
New
Levels
Start
Stop
General
Specimen
Setup and Control
Data display
Chart
23.320
Actuator
mm
0.500
Force
kN
0.773
Force peak
kN
Elapsed 00:00:15
Time (s) 15
Axial force (kN) 0.500
Axial stress (kPa) 63.639
Axial force max (kN) 0.773
Axial force min (kN) 0.496
Displ (mm)
Microstrain
Position (mm)
Actuator 23.320
1.166E0(
-0.911
Data filter
Enabled
Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)


UTS002 3.13b Stress Strain Test - 25 % wc UC 1.D002
File Run Options View Help
New
Levels
Start
Stop
General
Specimen
Setup and Control
Data display
Chart
18.441
Actuator
mm
0.689
Force
kN
2.938
Force peak
kN
General
Elapsed 00:00:12
Time (s) 12
Axial force (kN) 0.689
Axial stress (kPa) 87.778
Axial force max (kN) 2.938
Axial force min (kN) 0.498
Displ (mm)
Microstrain
Position (mm)
Actuator 18.441
92,206.0
-5.795
38%
Data filter
Enabled
Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)

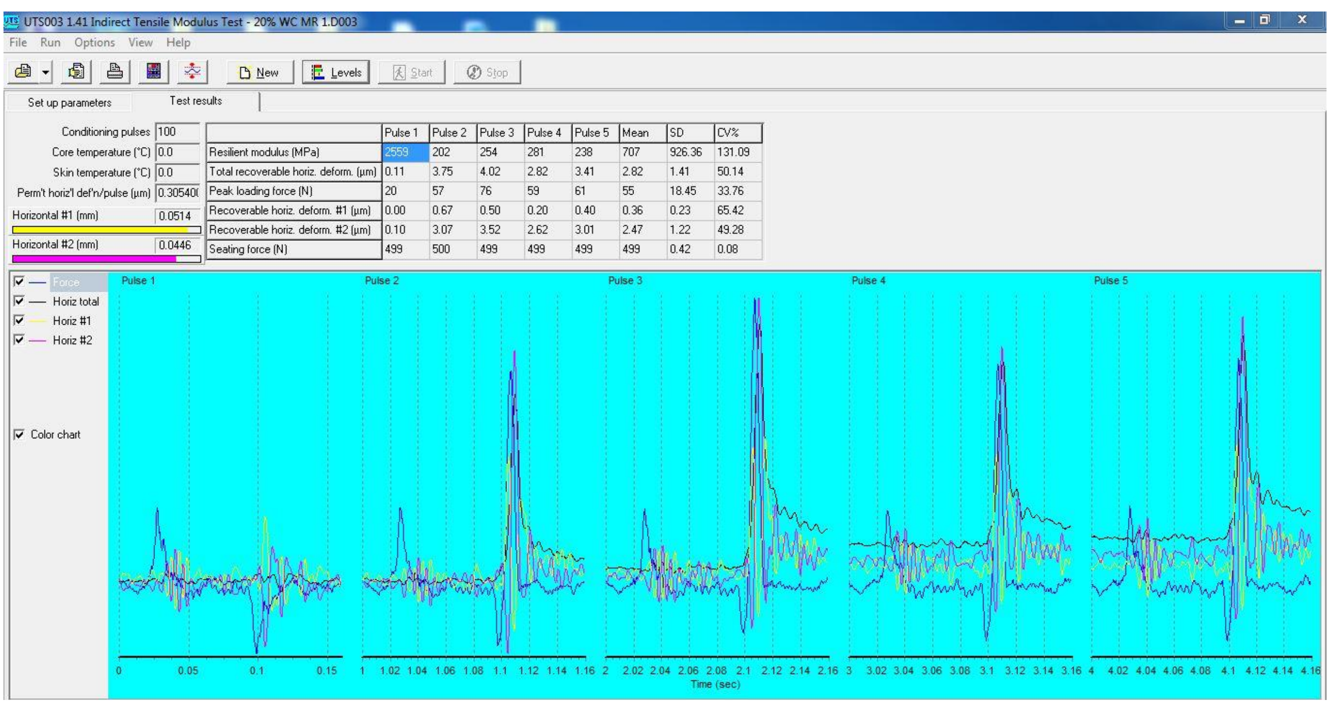

UTS002 3.13b Stress Strain Test - wc C 1.D002
File Run Options View Help
New
Levels
Start
Stop
General
Specimen
Setup and Control
Data display
Chart
16.971
Actuator
mm
0.518
Force
kN
2.261
Force peak
kN
General
Elapsed 00:00:12
Time (s) 12
Axial force (kN) 0.518
Axial stress (kPa) 65.964
Axial force max (kN) 2.261
Axial force min (kN) 0.495
Displ (mm)
Microstrain
Position (mm)
Actuator 16.971
84,855.0
-7.257
35%
Data filter
Enabled
Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)

APPENDIX-II

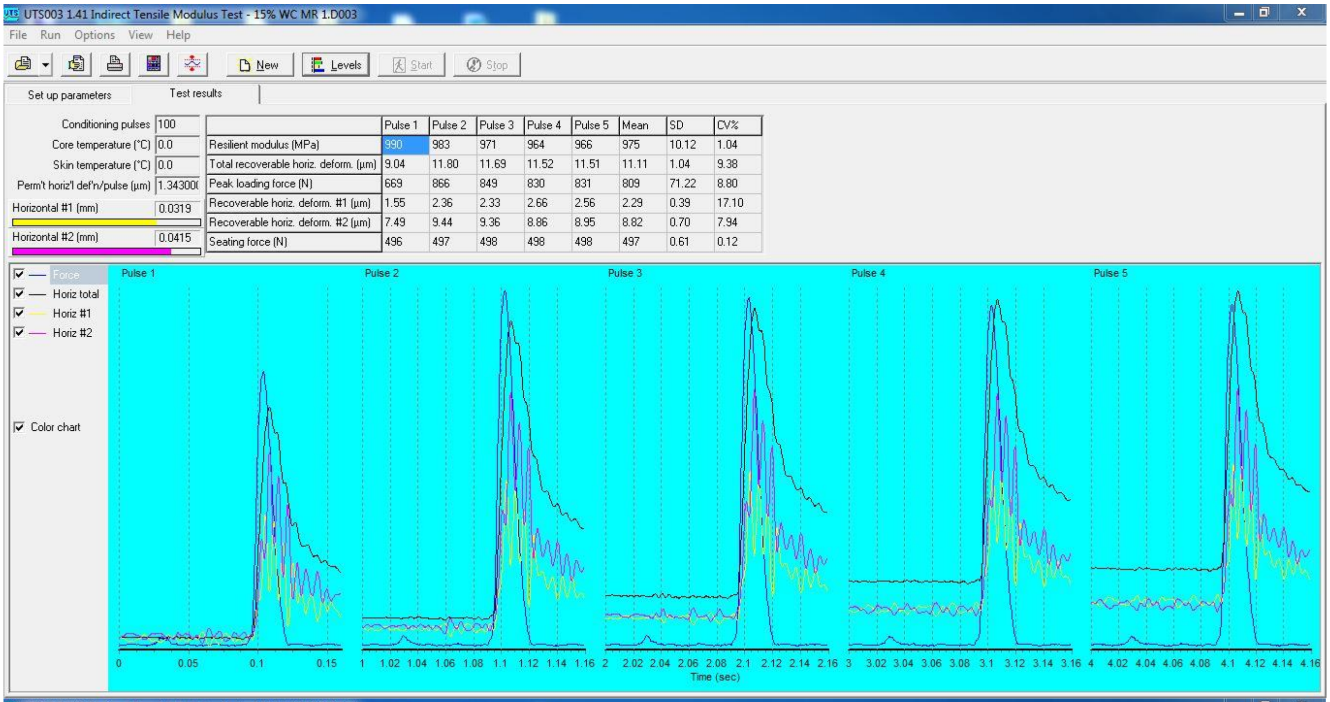
RESULTS OF RESILIENT MODULUS



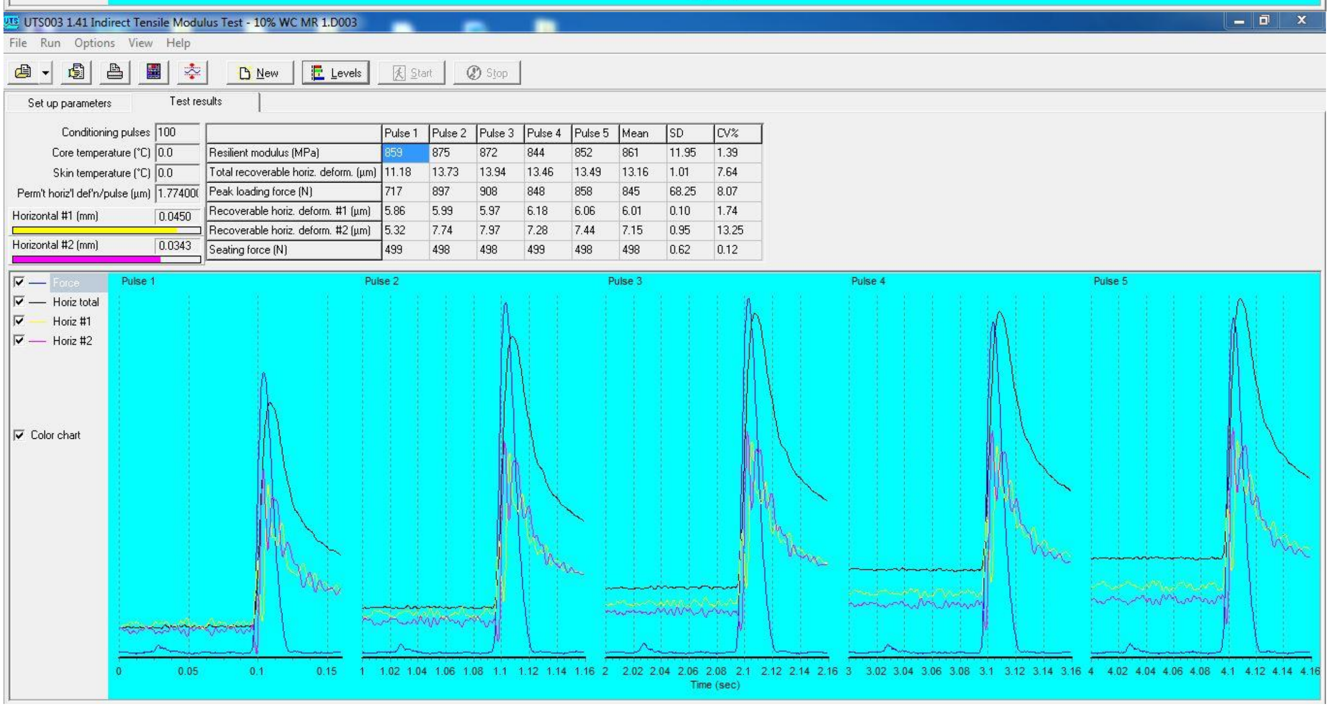
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	SD	CV%
Resilient modulus (MPa)	1509	1437	1288	1306	1393	1387	82.09	5.92
Total recoverable horiz. deform. (µm)	13.02	14.57	16.43	15.94	14.71	14.93	1.19	7.96
Peak loading force (N)	1469	1566	1582	1557	1532	1541	39.45	2.56
Recoverable horiz. deform. #1 (µm)	0.49	0.46	1.24	1.11	0.57	0.78	0.33	42.74
Recoverable horiz. deform. #2 (µm)	12.53	14.11	15.18	14.82	14.14	14.16	0.91	6.44
Seating force (N)	498	497	498	498	497	498	0.35	0.07



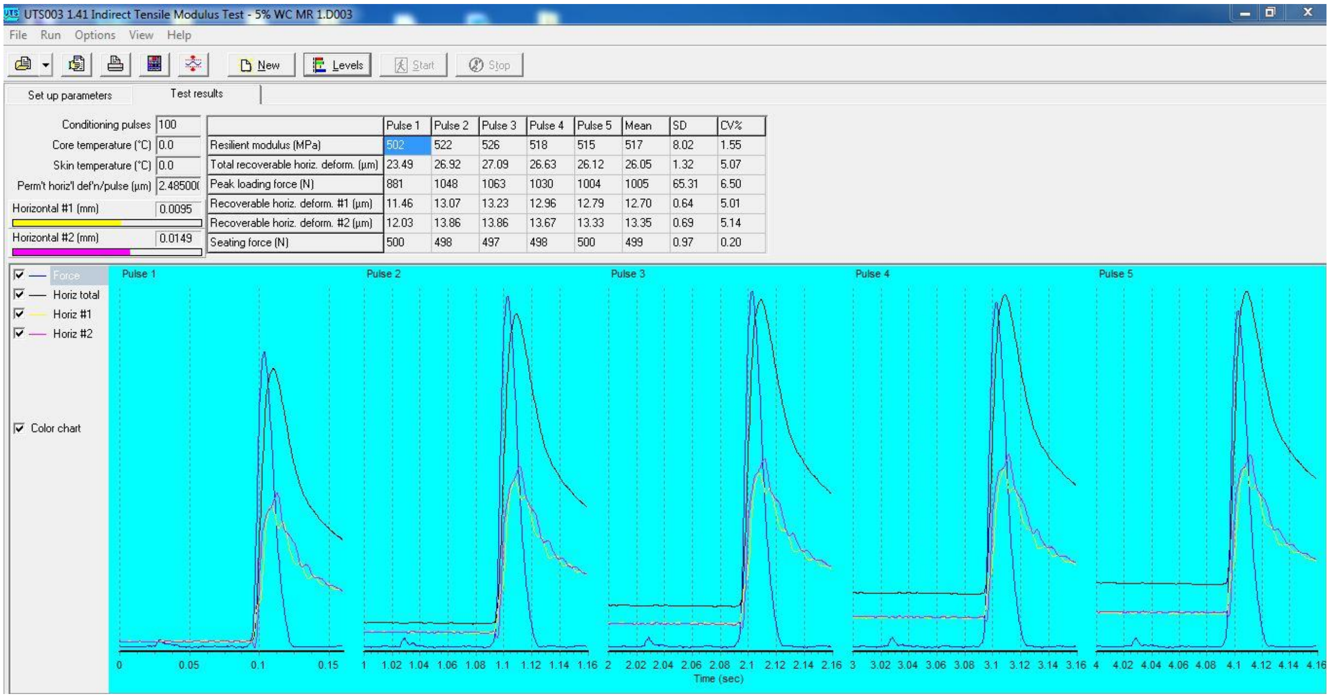
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	SD	CV%
Resilient modulus (MPa)	2559	202	254	281	238	707	926.36	131.09
Total recoverable horiz. deform. (µm)	0.11	3.75	4.02	2.82	3.41	2.82	1.41	50.14
Peak loading force (N)	20	57	76	59	61	55	18.45	33.76
Recoverable horiz. deform. #1 (µm)	0.00	0.67	0.50	0.20	0.40	0.36	0.23	65.42
Recoverable horiz. deform. #2 (µm)	0.10	3.07	3.52	2.62	3.01	2.47	1.22	49.28
Seating force (N)	499	500	499	499	499	499	0.42	0.08

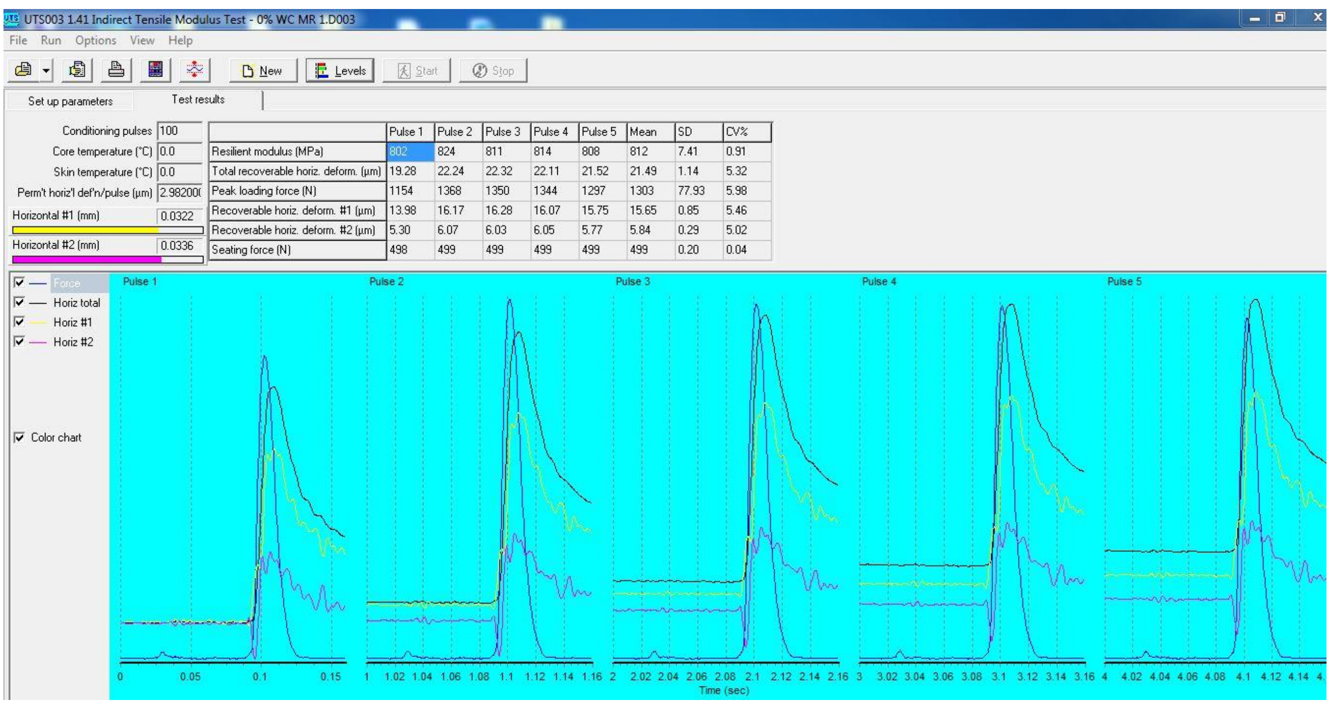


	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	SD	CV%
Resilient modulus (MPa)	990	983	971	964	966	975	10.12	1.04
Total recoverable horiz. deform. (µm)	9.04	11.80	11.69	11.52	11.51	11.11	1.04	9.38
Peak loading force (N)	669	866	849	830	831	809	71.22	8.80
Recoverable horiz. deform. #1 (µm)	1.55	2.36	2.33	2.66	2.56	2.29	0.39	17.10
Recoverable horiz. deform. #2 (µm)	7.49	9.44	9.36	8.86	8.95	8.82	0.70	7.94
Seating force (N)	496	497	498	498	498	497	0.61	0.12



	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	SD	CV%
Resilient modulus (MPa)	859	875	872	844	852	861	11.95	1.39
Total recoverable horiz. deform. (µm)	11.18	13.73	13.94	13.46	13.49	13.16	1.01	7.64
Peak loading force (N)	717	897	908	848	858	845	68.25	8.07
Recoverable horiz. deform. #1 (µm)	5.86	5.99	5.97	6.18	6.06	6.01	0.10	1.74
Recoverable horiz. deform. #2 (µm)	5.32	7.74	7.97	7.28	7.44	7.15	0.95	13.25
Seating force (N)	499	498	498	499	498	498	0.62	0.12


UTS003 1.41 Indirect Tensile Modulus Test - 5% WC MR 1.D003
File Run Options View Help
New
Levels
Start
Stop
Set up parameters
Test results
Conditioning pulses 100
Core temperature (°C) 0.0
Skin temperature (°C) 0.0
Perm't horiz'l def'n/pulse (µm) 2.485000
Horizontal #1 (mm) 0.0095
Horizontal #2 (mm) 0.0149
Pulse 1 Pulse 2 Pulse 3 Pulse 4 Pulse 5 Mean SD CV%
Resilient modulus (MPa) 502 522 526 518 515 517 8.02 1.55
Total recoverable horiz. deform. (µm) 23.49 26.92 27.09 26.63 26.12 26.05 1.32 5.07
Peak loading force (N) 881 1048 1063 1030 1004 1005 65.31 6.50
Recoverable horiz. deform. #1 (µm) 11.46 13.07 13.23 12.96 12.79 12.70 0.64 5.01
Recoverable horiz. deform. #2 (µm) 12.03 13.86 13.86 13.67 13.33 13.35 0.69 5.14
Seating force (N) 500 498 497 498 500 499 0.97 0.20
Force
Horiz total
Horiz #1
Horiz #2
Color chart
Pulse 1
Pulse 2
Pulse 3
Pulse 4
Pulse 5
Time (sec)


UTS003 1.41 Indirect Tensile Modulus Test - 0% WC MR 1.D003
File Run Options View Help
New
Levels
Start
Stop
Set up parameters
Test results
Conditioning pulses 100
Core temperature (°C) 0.0
Skin temperature (°C) 0.0
Perm't horiz'l def'n/pulse (µm) 2.982000
Horizontal #1 (mm) 0.0322
Horizontal #2 (mm) 0.0336
Pulse 1 Pulse 2 Pulse 3 Pulse 4 Pulse 5 Mean SD CV%
Resilient modulus (MPa) 802 824 811 814 808 812 7.41 0.91
Total recoverable horiz. deform. (µm) 19.28 22.24 22.32 22.11 21.52 21.49 1.14 5.32
Peak loading force (N) 1154 1368 1350 1344 1297 1303 77.93 5.98
Recoverable horiz. deform. #1 (µm) 13.98 16.17 16.28 16.07 15.75 15.65 0.85 5.46
Recoverable horiz. deform. #2 (µm) 5.30 6.07 6.03 6.05 5.77 5.84 0.29 5.02
Seating force (N) 498 499 499 499 499 499 0.20 0.04
Force
Horiz total
Horiz #1
Horiz #2
Color chart
Pulse 1
Pulse 2
Pulse 3
Pulse 4
Pulse 5
Time (sec)