DISSERTATION RC- 186601

DESIGN AND PROPERTIES OF CRUMB RUBBER AGGREGATES REPLACEMENT IN HOT MIXTURE ASPHALT CONCRETE

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DOCTORAL PROGRAM
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DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF CIVIL, PLANNING AND GEO ENGINEERING
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA
2020

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STATEMENT OF APPROVAL

T he dissertation was prepared to fulfill one of the requirements for obtaining

A **Doctoral degree (Dr.)**

In

Institut Teknologi Sepuluh Nopember

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Date : 30 April 2020

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ABSTRACT

Pavement surface characteristics are important since pavement surface relates directly to the safety, and comfort riding. This research aims to establish the impact of crumb rubber used on the flexible pavement by dry method. Rubber crumb is rubber waste which is processed through mechanical grinding or tire milling into small splinters. Indonesia is a country with a tropical climate that is different from Libya which has a hot climate. This difference influences road construction and repair in both countries. In Indonesia for example, the pavement surface requires a lot of petroleum asphalt as a binder. The damage is usually caused by high temperatures and rainfall. In Indonesia, petroleum asphalt is used as a pavement mixture. Although it meets the requirements of the specification, it often shows a decrease in service behavior due to rutting, fracture, and other forms of damage. The problems in this study are about the composition of crumb rubber side properties to have the high durability of flexible pavement with high temperatures. Since there are several of crumb rubber which come from many types of tires waste, these different types may have different impacts. Each type may have differences in improved high durability that can predict the permanent deformation with high temperature; moreover, it can affect its strength and fatigue life of a pavement. The objective of this research is to know the composition of the character of various crumb rubber come from sources of tire wastes and to have high durability of flexible pavement with different percentages of crumb rubber. This crumb rubber was collected from sources of vehicles (car, bike, motorcycle, truck). The experiment was done respectively through several phases as follows: preparation, quality examination of materials such as aggregate and asphalt, mixed-planning, and specimen testing implementation with Marshall Test. Properties of crumb rubber-like type stability and flow of durability can affect the different stability and flexibility of pavement. The data collected from the laboratory experiments were presented in different forms like tables, charts, diagrams, etc. The results from the crumb rubber asphalt mixture show that there is an increase in the amount of crumb rubber in a mixture of hot mix concrete asphalt. This mixture can increase the Marshall stability by 2.5 % % crumb rubber higher than the other mixtures with crumb rubber. The Indirect Tensile Strength properties (ITS) has a better low-temperature cold region with 2.5 % % crumb rubber. At certain stress levels, the samples with higher crumb rubber content failed faster than samples with less crumb rubber content in the condition of fatigue, stiffness, and permeability.

Keywords: Tire wastes, HMA, UCS, ITS, ITSM, ITFT, Permeability

ACKNOWLADGEMENT

First and foremost, I would like to thank Almighty Allah for his grace and for giving me strength and knowledge to complete this dissertation. Without Him, it will not be possible to achieve it all. Then, this dissertation could not be finished without the assistance, support , and guidance from those:

1-Bapak **Prof.Ir.Indrasurya B.Mochtar,M.Sc,Ph.D,** my promotor, a guide who always gives time in the midst of busy activity, with greetings, motivations, direction and guidance. He has given full of coolness on various occasions, aroused enthusiasm and inspiration in the confusion of doubt. uncertainty and darkness until slowly finding a bright spot, the author gave the highest respect.

2-Ibu **Ir.Ervina Ahyudanari, M.E,Ph.D** , Co-promotor, who has guided me to provide service with unlimited time, transmit enthusiasm by giving inspiring instructions, patiently always inserting motivational messages that can uncover darkness and ward off gloom, doubt, uncertainty. It makes the darkness slowly find bright spots, in this way the author gave the highest respect

3-Bapak **Ir.Ary setyawyan M.Sc. Ph.D**., the External Examiner from UNS (Universitas Sebalas Maret Surakarta), as much as possible for his patience in giving various instructions, suggestions, corrections, and advice at various meetings which were planned unintentionally had aroused the spirit of the writer; here, the author gave the highest respect.

4-Ibu **Ir. Hera Widyastuti, M.T.Ph.D,** the Internal examiner from the Civil Engineering department, ITS, a senior who have provided various instructions, suggestions, and very rigorous corrections for the improvement of the format and content of the writing; the author gave the highest respect .

5-Bapak **Prof.Ir.Nyoman Sutantra, M.Sc, Ph.D**., the ITS internal examiner, an outstanding professor from the Mechanical Engineering department, a senior who has provided various instructions, suggestions, and very rigorous corrections to improve the format and content of the writing, the author gave the highest respect.

.6-Bapak **Dr.Catur Arif Prastyanto, S.T., M.Eng**, Bapak **Data Iranata, S.T., M.T. PhD** . Bpak, **Ir.Dr. Hitapriya Suprayitno S.T,.M.Eng Ibu Dr. Yudhi Lastiasih S.T, M.T** and Almarhumah Ibu **Endah wahyuni, ST, M.Sc, Ph.D**. for all the suggestions and input on the proposal eligibility exam and the dissertation feasibility exam, so that this dissertation will be more valuable in its limitations.

7-Bapak **Ir. I Putu Artama Wiguna, M.T., Ph.D.** as head Postgraduate program of civil engineering for a variety of services in pursuing a Doctoral program in ITS civil engineering degrees.

8- Bapak **Prof. Ir. Nyoman Arya Thanaya, M.E., Ph.D**. as head Laboratory of transportation and highway, professors from the Civil Engineering Department at University Udayana, Bali seniors who have provided various instructions, suggestions, and very rigorous corrections for the improvement of the research.

9-Bapak **Iswandaru Widyatmoko.S.T., M.Sc, Ph.D., C.Eng.FCIHT, FIAT** seniors who have provided various instructions, suggestions, and very rigorous corrections for the improvement of the research.

10-Bapak **Dr.Abdelnaser Omran** as Academic Attache Libyan Embassies in Malaysia and Indonesia For his support, kindness and help me during doing my dissertation, the author gives highs respect.

11-Bapak. **Ahmed Abodyia Alabead Bsc.MBA** For his support, kindness and help me during doing my dissertation, the author gives highs respect.

12-Bapak **Assistant Prof.Dr Belal Ahmed Hamida G.Allah** lecture of Electrical and Computer Engineering (International Islamic University Malaysia) For his support, advice, kindness and help me during doing my dissertation, the author gives highs respect.

13- Bapak.**Osamah Alhadi Ateeyah Alloush** Lecture at Al Asmarya university Libya. Computer Department, Master information system from ITS for his support, patience, and help me to review my dissertation, the author gives highs respect.

14- Bapak. **Dr.Triyanda Gunawan, S.Si** as Lecture of the Chemistry Department for assistance during doing my research in Lab chemistry, Science Faculty, ITS (Institut Teknologi Sepuluh Nopember) Sukolilo, Surabaya.

15-The technical staff of Highway Laboratory, Department Civil Engineering, and technical staff of soil Mechanics Laboratory in ITS (Institut Teknologi Sepuluh Nopember) Sukolilo, Surabaya.

.16- Bapak **Ir. Subarkah, M.T**., as the Head of Highway Laboratory, Department Civil Engineering, Bapak.**Sukamto, and Mr. Pranoto** as the technical staff of

Highway Laboratory, Department Civil EngineeringUII (Universitas Islam Indonesia) Yogyakarta For his advice, kindness and help me during doing my experiment in Lbaorarory UII, the author gives highs respect.

17-The technical staff of Highway Laboratory, Department Civil Engineering in UGM (Universitas Gadjah Mada) Yogyakarta.

18-Bapak.**Prof.Dr.Ir.Suharjono**, as the Head of Manufacturing process Laboratory, Department Mechanical Engineering ITS (Institut Teknologi Sepuluh Nopember) Sukolilo, Surabaya.

19-Bapak.**Erfan Rofianto**, as staff of the Chemistry Department for assisting the author to obtain the FTIR data, Science Faculty, ITS (Institut Teknologi Sepuluh Nopember) Sukolilo, Surabaya.

20-Chemistry Laboratory technical personnel, Department, Faculty of Science, Airlangga. Surabaya.

21-Energy and Environment Laboratory, LPPM ITS (ITS (Institut Teknologi Sepuluh Nopember) Sukolilo, Surabaya.

22-All my friends in the department of Civil Engineering for cooperation, assistance, advice and support me during my study batch 2015-2020 at ITS.

23-Civil Engineering staff for their kind help, especially Mr. Robin, Mr. Endang, Mrs. Lusy, Mrs. Aliyati , Mr.Achmad Fauzi, Mr.Djunarko, and Mrs.Ria.

24-Faculty of Civil, Environment , and Geo- Engineering staff for their kind help and attention.

Last but not least, I am utterly grateful to my sincere gratitude and love for my dad, Ali Lhwaint. Even though it could no longer be spoken, my heartfelt thanks to my beloved mom, who is smiling up there, as being Ph.D. is one prayer to me, support me a lot of, advice, gave me permission to do my Ph.D., patience, love, and encouragement throughout the years, I would like to extend my sincere gratitude my beloved brothers and sisters keep support me, love, and praying throughout the years. Finally, the appreciation also goes to my mom low, and all my relatives and my friends in my city Waddan, Libya for praying and kind help during my study in Indonesia.

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LIST CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

HMA	Hot Mix Asphalt
AC	Asphalt Concerte
CR	Crumb rubber
CRMA	Crumb rubber modified asphalt
PRA	Plastic Rubber Asphalt
SBSA	Styrene butadiene styrene asphalt
RTR-MBs	Recycled Tyre Rubber Modified Bitumen
PG	performance grade
TDM	The theoretical maximum density
UCS	Unconfined Compressive Strength
ITS	Indirect Tensile Strength
ITSM	Indirect Tensile Strength Modulus
ITFT	Indirect Tensile Fatigue Test
MS	Marshall Stability
MQ	Marshall Quotient
VIM	Voids in Mix
VFWA	Void filled with asphalt
VAM	Voids in mineral aggregate
OBC	Optimum Bituminous Content
XRF	X-ray fluorescence
FTIR	Fourier Transform Infra-Red
TGA	Thermogravimetric Analysis
DTA	Thermal Differential Analysis
SEM	Scanning Electron Microscope
SHRP	Strategic Highway Research Program
SPT	Simple Quality Test
BS	Britch standard
T	Thikness
D	Dimater
F	Force

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CHAPTER 1
INTRODUCTION

1.1 Background

Roadways are an important part of the infrastructure for transportation in many countries. Road construction engineers should take into account both the safety requirements of Vehicle drivers and the economical considerations of road construction. In general, to achieve safe and economical road design road designers have to implement the safety and economy into three basic requirements for designing good roads, which are: environmental factors, traffic flow conditions, and pavement mixtures quality (Peralta, 2009).

A properly designed road will endure to the end of the road designed life without so much maintenance. However, due to certain distress such as fatigue failure, rutting, and other pavement deteriorations, the pavement performance will be greatly affected by time, the pavement characteristics change with time, and this may lead to pavement cracking (Mahrez, 1999). The discomforts on the pavement surface generally are more associated with the properties of pavement binder and pavement mixture, in which an asphaltic binder of the flexible pavement is the most common in causing poor pavement performance. Rutting, fatigue cracking, and water-related damages are among the main distress that causes the pavement surface to fail permanently.

Flexible pavements usually experience at least two major distresses, which are fatigue cracking, and rutting. atigue cracking is caused by repetitive loading which can lead to a substantial reduction in the versatile serviceability of pavements. Flexible pavement fatigue performance could be measured by the cracking performance of asphalt mixtures in the laboratory. However, more advanced researches are now available on a method to prolong fatigue cracking, so that pavement can be made more durable against cracking and rutting. One such method is by using a crumb rubber of tire wastes as an admixture in the pavement bitumen binder (Huang, 2014).

It had been proven that mixing crumb rubber from tire wastes into asphalt had caused the flexible pavement to become more elastic and high resistance to fatigue cracking, low-temperature cracking, and rutting, besides it became more durable against rainwater. Nowadays, the use of tire waste materials in the asphalt paving industries is growing rapidly (Huang, 2014).

Roadways in our daily lives are critical. A lot of experiments are spent every year by countries around the world on the construction and maintenance of roadways. In the case of a country like Libya in Africa, the temperature in south Libya is fairly high during part of the year but will be down below freezing during the winter. The extreme annual temperature difference was initially thought to be the main problem of pavement design in Libya. However, most of the pavement cracking occurred during the high-temperature season, so that high-temperature cracking was found to be the most significant factor in causing rapid deterioration of road pavement in Libya (Shuler et al., 1986).

In Indonesia as a tropical country, however, the annual temperature difference is relatively minimal but the high intensity of rains is the most troublesome. Road damages in Indonesia occur mostly during the rainy season so that studies on more durable pavement materials against high-intensity rain are very much demanded. Cracks on the pavement are considered as the primary cause of rainwater to enter the pavement subgrade to cause weakening of the subgrade. The use of rubber as admixture inside asphaltic pavement mixture has been known to cause the pavement more flexible and more impermeable so that the pavement exhibited longer life without cracking and the rainwater was prevented from seeping through the pavement. The pavement is learned to become more water durable. (Al-Azri et al., 2006).

The highly durable pavement against rapid deteriorating would be of great benefit to the Libyan and Indonesian economy, where researchers and engineers can extend the road service life against fatigue cracking, high-temperature damages, and rutting. The use of crumb rubber could become one of the solutions. The crumb rubber in its original form is from tire wastes, which is already piling up to become environmental pollution in many cities in Libya as well as in the world. Apart from the evident environmental benefits, adding this waste rubber to asphalt mixes improves the long-term performance of road surfaces because it reduces the effect of traffic loads on the pavement (Shuler et al., 1986).

Nowadays, the disposal of different wastes produced by various industries is a great problem. These materials pose to become environmental pollution in the nearby locality because many of them are non-biodegradable as crumb rubber, plastic, rubbers, fly ash, bagasse ash, and tire waste (Singh, 2018). In the meantime, the number of vehicles in developing countries has risen significantly, together with the rapid development of infrastructure in recent years. More than one billion tires were discharged into landfills in 2008, and about 4 billion tires were already stored in the warehouses (Messenger (2013).

Due to the increase in the number of vehicles worldwide, waste tire disposal has raised, and lead to serious concern about pollution. The large volume of output and the quality of the material are two major factors contributing to this issue. A tire does not break down and can live 80 to 100 years in a landfill (Batayneh et al., 2008). Waste rubber and plastic are accumulating heavily in China and causing significant environmental issues.

The tire waste has been one of the major problems in many countries as well as Libya or Indonesia. Properly handled scrap tires or waste tires present major environmental problems. Tires exposed to the environment can hold water and become a breeding space for mosquitoes that carry disease. Tire piles can be set on fire through arson or accident. These fires are difficult to put out and produce heavy smoke and toxic runoff to waterways. Tire piles can also harbor other vermin, such as rats and snakes.

Due to the increasing number of scrap tire waste, some foreign countries came up with the idea of using it again, and luckily several uses have been discovered including in construction matter (Mukhija, 2006). People have learned so far that the idea of reusing waste tires in road construction is currently feasible to improve the quality of the pavement. To improve the hot mix asphalt (HMA), adding crumb rubber into asphalt could be an alternative solution (Wang et al 2013).

Generally, flexible pavements consist of a composition of coarse aggregates, fine aggregates, asphalt, and fillers. Sometimes, additives are also added in the mixture to obtain a good and quality asphalt mixture (Palit et al., 2004).

Hot mix asphalt was a dense-graded mixture of coarse aggregates, fine aggregates, and mineral fillers, which are mixed in a plant. It is delivered, spread, and compacted while the asphalt is sufficiently hot to guarantee the workability of the mixture. However, air temperature during pavement construction is a very significant factor to obtain good and durable pavement.

In many countries paving is restricted to summer months, because in winter the compacted base will cool the asphalt too much before it can be packed to the required density. Hot mix asphalt HMA is the form of asphalt concrete most commonly used on high traffic pavements such as those on major highways, racetracks, and airfields. The use of rubber as a mixture in asphalt is also expected to make the asphalt mixture becomes easier to compact during colder temperature so that the paving construction could be prolonged more beyond the summer months.

The use of scrap tire in asphalt pavement has been very popular in recent years. Crumb rubber modified asphalt (CRMA) can consume a significant number of scrap tires, and can also boost the asphaltic pavement performances by adding crumb rubber to asphalt. Several studies have shown that CRMA improves pavement life by increasing resistance against cracking and rutting, reducing traffic noise, and lowering overall maintenance costs. Furthermore, several investigators found that the use of crumb rubber in asphalt binders can improve fatigue resistance (Wang et al., 2013).

It is found that the fine crumb rubber modifies asphalt (CRMA) mixture exhibits the largest elasticity among the three asphalt mixtures considered (Bai et al., 2016), which are CRMA, Plastic Rubber Asphalt (PRA) mixture, and styrene-butadiene-styrene asphalt (SBSA) mixture. Plastic Rubber Asphalt (PRA) mixture is more environmental-friendly, yet it showed the least stability among the three mixtures (Yu et al., 2014). Also, mixtures containing the PRA binders are more prone to cracking at low temperatures (Rodríguez- et al., 2014).

The styrene-butadiene-styrene asphalt (SBSA) mixture has similar high-, low-temperature, and water durability performances than the CRMA. Nevertheless, the SBSA mixtures performances, in general, are still considered inferior to those of the CRMA. Comparing the described technologies and performances, a more recent study presented more favorable justifications and suggestions toward the use of recycled Tyre Rubber Modified Bitumen (RTR-MBs) (Presti, 2013), which is another name for the CRMA.

Recycling of crumb rubber into asphalt paving mixtures, especially the asphalt rubber technology, has been proven successful for decades. The addition of crumb rubber into asphalt binder can lead to increased resistance to the two major modes of asphalt pavement distress, which are rutting and fatigue cracking (Huang, 2014). Yet, further studies still needed to understand more of the crumb rubber as the added material to be used in pavement construction. Many of the characteristics of the crumb rubber itself are still less understood.

It is rather unfortunate, however, that the characteristics of the crumb rubber materials themselves are still relatively very little known. Hardly any of the previous studies provided a rather detailed composition of the crumb rubber, i.e. the size, shape, and type of waste tire that was used in a new mix design. Furthermore, there have not been any past experiments conducted on CRMA with an emphasis on temperature variations. Also still relatively unknown is about which CRMA mixture will give the longest fatigue life and, therefore, the slowest crack growth. The creep and recovery behavior of crumb rubber-modified asphalt mixtures under traffic loading also need further investigation, so that a more comprehensive study based on either theoretical or viscoelastic model of the CRMA is needed.

The Performance of the CRMA mixture was reported to be dependent on various factors such as a source of crumb rubber, blending conditions, mixture variables, aggregate gradation, and compaction method used (Sang et al., 2007). However, field temperature and the effects of water have not been taken into consideration Should the characteristics of CRMA with a variety of temperatures and with the presence of water are better understood, the field performance of pavements with crumb rubber modified asphalt can be predicted more accurately.

This study presents the incorporation of crumb rubber hot mix asphalt and its effect on the bearing capacity and cohesion of bituminous mixes. Crumb rubber, also called ground rubber is produced by shredding and grinding scrap used tires into very small particles. Utilization of used vehicle tires on road pavement construction is one solution that can improve hot mix asphalt pavement performance and solve waste problems to achieve sustainable development. This research aims at describing the impact of applying crumb rubber to the flexible pavement of Asphalt Concrete (AC) by using Dry Method Crumb Rubber. The crumb rubber was obtained by mechanically grinding (or by milling) used tires into small crude rubber crumb, then rubber crumbs are mixed into hot asphalt mixture to produce high-durability asphalt pavement.

Asphalt pavement also faces multiple types of stress. Mechanical or chemical stress (such as traffic loading, moisture damage, and oxidative aging) can eventually lead to pavement cracking. Furthermore, asphalt characteristics in water absorption and asphalt resistance against oxidation will affect pavement durability significantly. Asphalt water absorption may reduce the effective binder content in the pavement; whereas, oxidative hardening of asphalt will eventually lead to pavement fatigue cracking (Kristjánsdóttir et al., 2007). There is strong evidence that asphalt oxidation happens in the whole depth of pavement, dramatically affecting pavement durability (Al-Azri et al., 2006). However, both asphalt water absorption and asphalt oxidation behavior in fields are relatively still not known for the CRMA pavement, especially in their correlations with the pavement durability. Thus, more studies on CRMA are still required to understand the CRMA pavement performance in fields.

A common approach to improving distress resistance is the application of various modifiers to asphalt mixtures. Municipal waste and industrial by-products such as fly ash, waste rubber, copper slag, cork granules, and recycled polyethylene have been proposed over the past two decades to be used as modifiers for enhancing asphalt pavement quality and recycling purposes. It has been demonstrated that the use of some recycled waste materials improves the resistance of asphalt mixtures to thermal cracking, fatigue cracking, and permanent deformation compared to styrene-butadiene-styrene asphalt mixture (Bai et al., 2016).

Indonesia with a very wet tropical climate and Libya with its hot and dry climate, road construction, and repair will require a lot of petroleum asphalt as a binder. The pavement damages are mostly caused by high temperatures (in Libya) and rainfall (in Indonesia). The use of petroleum asphalt as a pavement mixture, although it meets the requirements of the specification, often shows a decrease in service behavior due to rutting, fracture, and other forms of damage. Nevertheless, the above condition may be somewhat improved by adding crumb rubber into the asphalt mixture. Therefore, it is still highly imperative to develop the design for the best-use of crumb rubber in the hot mix asphalt.

This research aims to evaluate the effect on asphalt mixes by adding crumb rubber. Performance-related to rutting and fatigue resistance are major considerations for this assessment. The main reason for using rubber modifiers in hot mixed asphalt is to obtain a stiffer HMA pavement at highest surface temperatures to withstand heat cracking; yet, the pavement can still maintain unchanged, or lower, rigidity during the lowest operating temperature, as in the case of more elastic HMA in South Libya,

The increased amount of crumb rubber in the mixture of asphalt concrete would reduce the strength of pavement, in terms of Marshall Stability. Nevertheless, this was not always accompanied by sufficient reduction in flow; thus, as expressed by the Marshall Quotient parameter, so that it resulted in less versatility of mixture. However, once properly constructed, rubberized asphalt pavements can perform much better than conventional asphalt roads. One technical problem that still needs to be addressed is storage stability – how to store crumb rubber modified asphalt at high temperatures for as long as possible without phase separation. (Huang, 2014).

The advantage in bonding properties leads to an advantage in mixed field performance where asphalt rubber is used (Bekheet et al., 2004). Such advantages include improved abrasion resistance, increased longevity and increased fatigue life, increased reflective cracking resistance, increased rutting resistance, reduced noise, reduced construction time reduction, energy, and resource are saving (Holleran, 2000). The use of waste tire rubber in asphalt paving mixtures and has been gaining more and more attention in the civil engineering area due to the associated economic, technical, and environmental benefits.

It should be noted here, however, this crumb rubber is originated from tire wastes that are sold to rubber processors. The processors grind the tire rubber into various mesh sizes. Because this material is from the tread portion of the used tire, it is free of steel and fabric and is a more uniform product than rubber processed from the whole used tire (Takallou, 1991). Furthermore, the rubber can be originated from various types of tires, such as tires of trucks, automobiles, motorcycles, bicycles, or other types of rubbers. Tire producers like MICHELIN, PIRELLI, COOPER, GOODYEAR, CONTINENTAL, DUNLOP, BF-GOODRICH, BRIDGESTONE , @ continentals, UNIROYAL and FURIA, etc. produced all varieties of tires. The final product of crumb rubber is already in the form of blending from various types of rubbers, regardless the origin. The rubber is really difficult to discern origin of the crumb rubber after the rubbers are blended and ground into crumbs of rubber. Therefore, this study does not attempt to differentiate the quality of CRMA by using tires from each type of their origin (i.e. automobile tires, truck tires, or bicycle tires); yet the chemical composition of various type of tires are studied to know whether the quality of each type of tires may affect the performance of CRMA

1.2 Problems of the research

This research discusses the chemical properties of crumb rubber from various source of tire waste to be used in hot mix asphalt concrete, which has never been attempted by anyone before this study. The knowledge obtained from this study should help determine which type of tires is more recommended for the CRMA application.

Furthermore, considering the importance of hot asphalt mixtures in obtaining good properties of CRMA to provide highly flexible pavement with high durability, the challenge in this study is to know the composition and properties of crumb rubber to provide flexible pavement with high longevity against various temperatures and the effect of high rainfall climate into the pavement. The high-temperature variation is prevalent for a country like Libya, and the high rainfall condition is common for a country like Indonesia.

Therefore, the main research problems to be solved in this study are:

1. How different is the chemical composition of various tire wastes with different origin in this study? Which type of tire is more recommended to be used as crumb rubber additive to the hot mix asphalt concrete (AC)?

2- What is the best proportion of crumb rubber (% CR) to be added into CRMA with a dry method to produce the most durable and resilient AC mixtures in general against fatigue cracking and rutting according to the Marshall Tests Properties, for all types of climate without considering temperature variation?

3- For countries with very high-temperature variation throughout the year like Libya, what are the recommended composition of crumb rubber inside the CRMA to produce the best performance of hot mix asphalt concrete?

4- For the wet climate and high rainfall conditions of a tropical country like Indonesia, what proportion of crumb rubber (%CR) is to be recommended against rain-induced premature deterioration of hot mixture of asphalt concrete?

1.3 Objectives of the research

The objectives of this research are:

1. To analyze the differences are the chemical composition of various tire wastes with different origin in this study, and Which type of tire is more recommended to be used as crumb rubber additive to the hot mix asphalt concrete (AC)

2. To know the best proportion of crumb rubber (% CR) to be added into CRMA with a dry method to produce the most durable and resilient AC mixtures in general against fatigue cracking and rutting according to the Marshall Tests Properties, for all types of climate without considering temperature variation

3. To suggest for the countries with very high-temperature variation throughout the year like Libya, what are the recommended composition of crumb rubber inside the CRMA to produce the best performance of hot mix asphalt concrete

4. To know the recommended proportion the wet climate and high rainfall conditions of a tropical country like Indonesia, what proportion of crumb rubber (%CR) is to be recommended against rain-induced premature deterioration of hot mixture of asphalt concrete.

1.4 Scope of the research

The Scope of the study focuses on the analysis of materials used in namely: Asphalt 60/70 pen and crumb rubber, modified by laboratory testing. Marshall Stability Test (MS), Unconfined Compressive Strength Test (UCS) with different temperatures of 24C°,30C°, 40C°, and 60C°) with different temperatures of 10C°, 25C°, 40C°, and 60C°, also Indirect Tensile Strength Modulus test at 20°C were studied. Additionally, that measured the Indirect Tensile Fatigue Test (ITFT) measures a different percentage of crumb rubber modified, and permeability tests. The important thing that needs to know was the performance of the materials, and the best mixture to get high durability of flexible pavement. The curing properties of CRM asphalt as functions of time were determined using the dry method to hot mix asphalt mixture. The research's primary objective was to model the total quantity of crumb rubber tire in a changed warm mixture of asphalt concrete. To clarify the scope of the research problems and to facilitate their analysis, some Scope of this research are stated as follows:

To clarify the scope of the research problems and to facilitate their analysis, some limitations of this research are stated as follows:

1. Gradation uses Bina Marga (Highway Agency), which is adjusted to the provisions Directorate General of Bina Marga (2010, 2012, and 2014).
2. The additive material used in the research is the crumb rubber produced by Indonesian Company, with the variations of 2.5%, 4.5%, 6.5%, and 8.5% CR toward optimum bitumen content by using types several of waste tires (bicycles tires, cars tires, Motorcycle tires, Truck tires.
3. The asphalt used is the one with the type of HMA 60/70 produced by the limited liability company of CO. PERTAMINA Cilacap with the variations of 2.5%, 4.5%, 6.5%, and 8.5 toward optimum bitumen.
4. The variations of the optimum bituminous content used are (5%, 5.5%, 6%, 6.5%,and 7%) toward the total mix.
5. The research is based on Marshall, ITS, UCS, ITSM, ITFT , and permeability tests.
6. The study is limited to the physical properties by discussing the chemical elements contained by the materials used.
7. This research discusses the impact of chemical properties for tires waste comes from different sources (Cars, Trucks, Bicycles, and Motorcycles) to get Crumb rubber on the mix design Asphalt.

1.5 Scientific Contribution

This research has a scientific contribution to contributions as a benefit of CR as the additive material to improve the quality of pavement layer construction structure flexible pavement through different of crumb rubber, also has other measured by many tests like (ITS, ITSM, ITFT, UCS, scrap tires are a part of the problem of solid waste management. This improves the quality of our roads and the highway. The results important to catch up with developed countries. Therefore, an optimum solution should be provided to improve the quality and compatibility of roads that can improve fatigue life. The World concerned about environmentally friendly construction technologies and sustainability, asphalt durability takes on an added significance. there is a keen interest in the concept of sustainable asphalt mixtures. However, environmental aspects are mostly covered.

1.6 Research State of the Art for Dissertation

State of the art in this dissertation will develop the design of hot mix asphalt modified by used crumb rubber to have high durability at different high temperatures. These tests have not been conducted in previous studies for tropical and hot regions. Through the exploitation of waste tires to know sources waste tires with different size, shape, and density gravity, physical and chemical properties of waste tires for selecting optimum of crumb rubber from waste tires in this modified mixture.

Wang et al (2013) stated that there are numerous physical indexes, such as crumb rubber powder size or gradation, density, fiber content , and metal content that will affect the pavement performance of crumb rubber powders. The chemical composition of crumb rubber powders also contains synthetic rubber, natural rubber, plasticizer, carbon black, and ash, and natural rubber plays a very important role in the properties of CRM asphalt binders. It is proposed that the rise in natural rubber in crumb rubber powders will intensify the reaction between asphalt binders and rubber, thereby dramatically increasing the viscosity of CRM asphalt binders.

Bai et al (2016) stated that the fine and coarse waste-tire rubber particles were supplied by a recycled rubber company in Wuhan, China. Both the mesh numbers of the crumb rubber and their corresponding size ranges are listed. There are efforts to make asphalt rubber binder performance graded as those developed by the Strategic Highway Research Program (SHRP) for neat asphalt and by Caltrans for polymer modified and tire rubber modified asphalts (Zhou et al., 2014).

Zhen et al (2014) concluded that the crumb rubber modifier (CRM) was manufactured by mechanically shredding waste tires at ambient temperature. To ensure uniformity, all the CRM used in this study were from the same production batch and within the same size range of minus 20 mesh. Ordinary tap water was used as the foaming water.

Many researchers have conducted in finding alternative materials to be used as a modifier in asphalt mixture to improve its properties to presents a study of laboratory evaluation on the performance of hot-mixed asphalt (HMA) using crumb rubber as an additive.

It is noted that crumb rubber was identified to have potency as a modifier in HMA due to the elastic behavior exposed by the rubber particles, especially in reducing the rutting potential. The crumb rubber asphalt mixture result indicated has an increased amount of crumb rubber in the HMA mixture will decrease the Marshall Stability and permeability test shows that asphalt concrete without crumb rubber lower than asphalt concrete with crumb rubber strength compare to other mixture. (Lhwaint et al,2017).

Stone mastic asphalt was modified with 0%, 2%, 4% and 6% crumb rubber.The Marshal properties were conducted. The result showed that marshal stability, Marshal Quotient, Voids in Mix (VIM) and Voids in mineral aggregate (VMA) decrease with a higher crumb rubber modifier. However, Marshal Flow and Void filled with asphalt (VFWA) increase when the crumb rubber modifier was increased.

Therefore, Crumb rubber could be used as an aggregate substitute for flexible stone mastic asphalt in the hot and arid regions because it is temperature tolerant and can prevent asphalt cracking (Abuseta2014). In terms of the results of stability, flow , and stiffness and fatigue life for the mix design, it did not touch on significance when using crumb rubber modified.

The research about develops the design of hot mix asphalt concrete by used crumb rubber to have high durability in different high temperatures not yet been done before. These tests have not happened in previous studies for tropical and hot regions through the exploitation of tires waste, and to know sources waste tires with different size, shape, and density gravity, chemical properties of waste tires for selecting optimum of crumb rubber from waste tires in this modified mixture. This table shows there are several types of researches have been done but not enough, from here will complete my research based on that:

Table 1.1. Researches related to aggregate with crumb rubber shows there are several types of researches

Crumb Rubber properties	Athours	Year	Topic	In this research
Chemical properties (XRF) -FTIR-TGA-DTA	Jusl, E., Nor, H. M., Jaya, R. P. & Zation	2014	Chemical properties of waste tire rubber granules. (using only one type of rubber without knowing the origin).	Tests were conducted for various sources of rubber tires (i.e. from truck tires, cars, motorcycles, and bicycles).
Chemical properties Crumb rubber	Lee, S.-J., AMIRKHANIAN, S. & SHATANAWI, K.	2006	- Design. - Effects of crumb rubber on the aging of asphalt binders. using only one type of rubber without knowing the origin.	Tests were conducted for various sources of rubber tires (i.e. from truck tires, cars, motorcycles, and bicycles), and mix design with different wight start from 2.5% CR, 4.5% CR, 6.5% CR, 8.5% CR.
Mechinacal Properties CR (stability)	Ahmad Abuseta	2014	The Design and Properties of Split Mastic Asphalt Modified with crumb rubber (only using one type of crumb rubber) without knowing influence Chemical properties in mix	Tests were conducted for various sources of rubber tires (i.e. from truck tires, cars, motorcycles, and bicycles), and mix design with different wight start from2.5%CR,4.5%CR,6.5%CR,8.5%CR to obtain more good stability in HMA design.

			design, especially in the stability.	
Mechinacal Properties CR (UCS)	Lhwaint, Hmaed, ets	2017	Analyzing properties of asphalt modified with crumb rubber compare to other mixture(only using one type of crumb rubber) without knowing influence Chemical properties in mix design especially in the USC.	Tests were conducted for various sources of rubber tires (i.e. from truck tires, cars, motorcycles, and bicycles), and mix design with different wight start from 2.5%CR,4.5%CR,6.5%CR, 8.5%CR to obtain more good stability in HMA design, and compare with previous research at high temperatures (40C°,60C°).
Mechinacal Properties CR (ITSM)	Lhwaint, Hmaed, ets	2017	Analyzing properties of asphalt modified with crumb rubber compare to other mixture (only using one type of crumb rubber) without knowing influence Chemical properties in mix design especially in ITSM.	Tests were conducted for various sources of rubber tires (i.e. from truck tires, cars, motorcycles, and bicycles), and mix design with different wight start from 2.5% CR, 4.5% CR, 6.5% CR, 8.5% CR to obtain more good stability in HMA design, and compare with previous research.
Mechinacal Properties CR (ITS)	Lhwaint, Hmaed, ets	2017 -2014	- Analyzing properties of asphalt modified with crumb rubber compare to other mixture.	Tests were conducted for various sources of rubber tires (i.e. from truck tires, cars, motorcycles, and bicycles), and mix design with different wight start from 2.5% CR, 4.5% CR,

	Ahmad Abuseta		- The Design and Properties of Split Mastic Asphalt Modified with Crumb Rubber (only using one type of crumb rubber) without knowing influence Chemical properties in mix design especially in ITSM.	6.5% CR, 8.5% CR to obtain more good stability in HMA design, and compare with previous research at different temperatures and with the low temperature at 10C° in the cold region.

Novelty this research can be clearly stated as follows:

1. Crumb rubber, CR, chemical composition:

This research will make empirical evidence about the best combination of crumb rubber based on chemical composition.

2. Composition of CR in CRMA for the best quality of hot mixtures of asphalt of CR concrete in general:

This research will analyze the best quality of HMA related to the composition in CRMA.

3. Most durable CRMA against high variation of temperature in the field :

This research focused on the country of the hot climate so it needs to develop the most durable CRMA in high temperatures.

4. Most resistant CRMA against rain-induced premature damages in the pavement:

This research is done in the tropical climate country so we need to develop the most resistant CRMA against rain-induced premature damages in the pavement.

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CHAPTER 2
LITERATURE REVIEW AND BASIC THEORY

2.1 Introduction

The first experiments in the 1840s included incorporating natural rubber into the asphalt binder to improve the efficiency of its construction. As early as 1843, the asphalt modification process involved natural and synthetic rubber (Thompson,1979).

The first use of asphalt concrete discharged car tires, the processes were called wet processes and dry processes in the 1960s, referring to the form in which crumb rubber is used. McDonald created the wet method with the amount of bitumen waste rubber varying from 5% to 25% by weight. To improve the technological properties of the binder, crumb rubber is added to bitumen. Dark non-polar fractions are usually consumed in the polymer networks at high temperatures. It makes the final bitumen harder and smaller crumb rubber particles expanding. The swelling will be avoided and removed if the temperature is too high or the time is too long. This results in rubber being converted into bitumen such anomalies can occur at 160–200 C° temperatures and depends on time Nevertheless, storage stability is one obstacle that restricts prevent crumb rubber -modified asphalt binder from applications. Because of the decreased swelling size, crumb rubber -modified particles migrate to the top of the storage container, which results in phase separation (Airey et al., 2004).

For road construction, the use of crumb rubber modifier (CRM) from scrap tires for hot bituminous mixtures has become a common practice over the years. (Santucci, 2009). As crumb rubber interacts with the bitumen used as a binder, it improves the rheological properties of the resulting mix (i.e. lower temperature tolerance and improved elastic performance) and increases its viscosity, allowing it to be used in larger quantities. All these factors contribute to the improvement of the mix's mechanical efficiency. More importantly, due to the increase in the thickness of the rubber binder film covering the aggregate, there is greater resistance to aging. The quality of the mix was also found to better respond to fatigue-related phenomena such as cracking and plastic deformation (Moreno et al., 2011).

Fatigue cracking, called alligator cracking and associated with repetitive traffic loading, is considered to be one of the most significant distress modes in flexible pavements. The fatigue life of asphalt pavement is directly related to various engineering properties of a typical hot mix asphalt (HMA). The complicated microstructure of asphalt concrete is related to the gradation of aggregate, the properties of aggregate–binder interface, the void size distribution, and the interconnectivity of voids. As a result, the fatigue property of asphalt mixtures is very complicated and sometimes difficult to predict (Wang et al., 2004).

The use of scrap tire in asphalt pavement has been very popular in recent years. Crumb rubber modified (CRM) can consume a considerable amount of scrap tires, moreover adding crumb rubber into asphalt can improve its performance (He et al., 2010) Several studies have shown that pavement with CRM asphalt improves pavement life by resistance to cracking and rutting decreases traffic noise and reduces overall maintenance costs.

Furthermore, some researchers found that crumb rubber was used in asphalt binders can enhance fatigue resistance (Wang et al., 2012). Asphalt mixture fatigue cracking is one of the major damage in asphalt pavements, which has a significant impact on pavement quality. The main influencing factor of fatigue cracking is the material property. With both the wet process and the dry process, the Mt. St. Helens Group, Oregon Dot , and Portland Oregon performed three case studies using crumb rubber. The results showed that rubber goods had outstanding thermal cracking tolerance even after a decade of operation. In fact, another advantage of using asphalt rubber is to increase the pavement lifespan. However, recommendations were made to assess the cost-effectiveness of asphalt rubber (Huang et al., 2007).

The addition of crumb rubber modifier (CRM) to asphalt/bitumen has been shown and proven by many research projects and field applications to be an effective method of increasing the performance grade (PG) of the asphalt, improves the high-temperature properties, decreases susceptibility to permanent deformation as well as providing resistance against reflective cracking (Dantas et al., 2003),(Lee et al., 2006).

In the last decades, many types of research indicated that the blends of asphalt with crumb rubber results in an improvement in the asphalt pavement's resistance to permanent deformations and cracking. In addition, rubberized asphalt mixtures can be helpful in reducing the thickness of asphalt overlays, noise, and reflective cracking potential, protecting the environment , and saving resources (Cong et al., 2011). Rubber, one type of polymer, is known to absorb solvents and swell. The extent of swelling is dependent on the temperature of the system, nature, and viscosity of the solvent and the type of polymers (Goddard, 1992).

The amount of the rubber absorbs the solvent increases until the content of the solvent becomes uniform and equilibrium swelling. (Vaniya et al., 2015).present an experimental study of the effect of the use of solid waste material crumb rubber in concrete by volume variation of crumb rubber. Crumb rubber usually consists of particles ranging in size from 4.75 mm (No.4 sieve) to less than 0.075 mm (No. 200 sieves).

Most processes that incorporate crumb rubber as an asphalt modifier use particles ranging in size from 0.6 mm to 0.15 mm (No. 30 to No. 100 sieve) and the use of natural and crumb rubber can improve the performance of the flexible pavement. In terms of the low-temperature value, an examination of 18–22% of the rubber content revealed a change of little importance. In this range, the tensile and fracture performance of the bitumen is affected compared to differences in the bitumen weight content between 6 and 9%,(Huang et al., 2007).

A study by (Khalid, 2005) the higher binder content resulted in longer fatigue life of the rubberized bitumen mixture and improved routing resistance, as well as results showing good resistance to fracture and fatigue cracking. (Liu et al., 2009) the quality of crumb rubber was found to be the most important factor followed by crumb rubber for and finally particle size. According to laboratory binder tests (Mashaan, 2013), it is clear that the quality of rubber crumbs played a major role in significantly influencing the efficiency and rheological properties of rubberized bitumen binders.

Throughout construction and road services, it could improve the performance properties of the deformation resistance of asphalt pavement. The growth in the rubber crumbs content was 4 to 20 percent, indicating a rise in the softening rate of the lining, ductility, elastic recovery, viscosity, complex shear unit, and rutting factor. This can be clarified by the absorption of rubber particles with a lighter bitumen oil fraction, resulting in an increase in rubber particles during the blending process. The 16 % and 20 % increase in rubber content showed a corresponding increase in the viscosity value of Brookfield higher than the specification limits of SHARP (3 Pa).

There are reasons why adding crumb rubber can boost the anti-fatigue quality of the asphalt mixture. One explanation is that there is some anti-aging agent component in crumb rubber powders, such as carbon black, which can increase the aging resistance of asphalt binders or asphalt mixtures when added. The other explanation is that when crumb rubber dust is applied to the asphalt binder, the viscosity and elasticity of the asphalt binder will increase, which will increase the thickness of the asphalt film on the surface of aggregates and then increase the aging resistance of the asphalt mixtures. There are different methods and standards for determining the fatigue property of asphalt mixtures today.

The effect on fatigue properties of the gradation point, asphalt consistency, test temperature, stress ratio, load frequency, and concentration of rubber powder and rubber powder scale of CRM asphalt mixtures were studied to analyze the laws of fatigue crack growth in CRM asphalt mixture (Liu, 2011).

The destination of used tires has become a hugely important environmental concern (Machin et al., 2017). Moreover, to improve the performance of pavements, several solutions use rubber from end-of-life tires (ELTs, often called by crumb rubber, to modify asphalt concrete have been proposed. Recycling of crumb rubber offers considerable environmental benefits such as a reduced need for landfill and reduced atmospheric pollution from burning.

Asphalt materials exposed to environmental factors such as sunlight, humidity, oxygen, and heat that affect the nature of the asphalt that has been widely studied. The combined interaction of these factors causes asphalt being susceptible to the change of physical, chemical and rheological property, which the previous study has no research that related to workability and still has some gap analysis that since crumb rubber could reduce the oxidation process, there is the possibility of keeping the pavement in fresh condition with different characters of waste tires, in the other words.

Another study is different from previous studies done by (Wang et al., 2016) because it focuses on whether aging resistance used rheological properties at a lower temperature indicated that SBSMA was the most sensitive to weather aging. Xiao long et al (2015), make asphalt binders; obtained after these asphalt emulsions are broken, have improved road performance at high temperature, compared to that from the original asphalt. (Read, 1996, et al., 2009), (Roberts, 1988) analyzes the correlation of rolling time for ice-breaking rate is strongly positive, while it is a strong negative of ice thickness and very strong positive of test temperature (Pealing et al 2013). Hot mix asphalt is usually produced early in the morning in Vietnam and shipped to workplaces and is ready to be paved from morning to midday. Upon combining and transporting from the mixing plant to the construction site, the total storage time in silos can be 2 h to more than 5 h. The length of time also depends on the distance between the plant and the site as well as the weather.

Therefore, due to the interaction within the mixture, the reliability of crumb rubber -modified between mixes is inconsistent. In some situations, because of this the robust natural phenomenon that happens during the process, the paving process may not be done. In Vietnam's specific condition, Changes in transport time and crumb rubber content in mixtures raise concerns about the lack of consistency and maximum additive quality between mixtures. Nevertheless, the evidence was not fully addressed. The healing time of the fine crumb rubber modified asphalt mixture studied in Hezna'ndez-Olivares et al. work was limited to 2 hands it was found that the optimal healing time was 1.5 h, giving the best performance. Based on the reported results, the curing time used in the study of Feiteira Dias et al. 2014) was chosen (Hernández et al., 2009).

If 1.5% crumb rubber and 1.9 % crumb rubber were used, the curing time was set at 90 min and 160 min. Moreno et al's attention was also drawn to the effect of healing time, who used fine to conduct a sophisticated study on this topic CR(F. Moreno).

The findings in this analysis are very close to those obtained by (Hernández et al., 2009). The introduction of rubber particles into road asphalt mixtures is generally accomplished by two technologies known as the wet process and dry process. In the wet process, ground rubber is blended with the bitumen at high temperatures before introducing to the aggregate; while in the dry process, the recycled tires rubbers are added by replacing a small part of the aggregate in the asphalt mixture. Fine rubber particles (0.075 to 1.2mm) are normally used with the wet process while coarser particles (0.4 to 10mm) are used with the dry process (Rahman et al., 2010). The micrograph of crumb rubbers modified asphalt binders indicated that the lightweight fraction in asphalt promoted a swelling of crumb rubber in the modified asphalt binder, and crumb rubbers with high swelling rate improved the crumb rubbers disperse in asphalt. (da Conceição et al., 2014). Stated that asphalt mixtures produced with cork and rubber granulate as partial aggregate substitutes. (Badeeb et al., 2016), stated that the asphalt component of the modified binders' ages like that of the base asphalt reduces the durability of asphalt pavements. After reviews between the dry and wet process, and study about the advantages and disadvantages of both processes.

This research will be going to focus on the dry process for mix design and study about crumb rubber still rather relevant to this study because of the same topics of pavement. All the above studies regarding the use of some additives for hot asphalt mixtures from the rubber crumbs have not been sufficient enough. Hence using crumb rubber to have durability strength at a very high temperature which can reach 60C° to develop hot asphalt mix with different percentages of 2.5 to 8.5 % crumb rubber. In previous studies have not addressed the larger waste sources of different tires from their components, physical and chemical properties and utilization of waste tire more widely in the development of hot asphalt mixtures (Jusli et al., 2014).

2.2 Basic Theory

2.2.1. Aggregate Properties

An essential factor that makes this mixture resistant to rutting is the aggregate structure and consistency in HMA. The stability of the aggregate structure is therefore important to ensure that a mixture is properly designed A study carried out by the Washington State Transportation Department recommends the following average standard:

a. High cubic shape and raw texture to withstand rutting and movement;
b. Durability that can endure cracking under heavy traffic loads;
c. High polishing resistance and high abrasion resistance.

Different types of aggregates were used in HMA, such as sandstone, calcareous, novaculite, blast furnace slag, primarily depending on the materials ' local availability. Mohammad et al. HMA quality tested using three different aggregates and found that sandstone produces the least permanent deformation, which is the most critical resistance factor. It was also concluded that calcareous HMA production is less attractive because of its high permanent deformation (Pasetto, 2012).

The impact of SMA using steel slag as aggregates were studied and found to effectively meet the requirements for acceptance of technical standards in the road field. It also showed higher mechanical characteristics than those with a full natural aggregate of the corresponding asphalts. The investigation by (Qiu, 2006). Found that aggregate gradation is an important factor that helps to better understand its effect on the capacity of an asphalt mixture (SMA). It was found in this research that the coarse aggregate stone-to-stone contract was formed when the volume of coarse aggregate was within the range of 95–105 percent of the rodded unit weight.

In the laboratory, samples of asphalt concrete are built and used for analysis. The cumulative particle form was assessed and used to measure the overall impact on the pavement. This study showed that the fine aggregate shape characteristics had a significant impact on the friction values obtained by BPT testing. Additionally, the gradation of the mixture was also influential (Huang, 1973). The aggregate gradation is also significant since larger aggregates incorporated in the mixture allow increased surface projections, which in turn increases the contact between the tire and the pavement.

This study also defined many properties to order to ensure adequate skid resistance before mixing material. Table 2.1. provides a shortlist of the cumulative properties and the desired scope during this analysis (Henry, 1979). Gradation of aggregates is one of the most important factors for the design of Hot Mix Asphalt. The aggregate gradations used for the mix design may be provided by the contractor or maybe from the actual gradations of the mix design aggregate samples as shown in Table 2.1.

Table 2.1 Hot Mix Asphalt Gradation

Sieve Size (mm)	**Gradation imit**	**Percentage Passing**
25	100-100	0-100
19	90-100	2-98
12.5	75-90	12 -88
9.5	60-82	20-88
4,75	46-64	40-60
2.36	30-49	55-45
1.18	18-38	65-35
0.6	12-28	75-25
0.3	7-20	84-16
0.15	5-13	90-10
.075	4-8	95-5
pan		100-0

(Source: Indonesian Standards, 2014)

Grading refers to the determination of the particle-size distribution for aggregate. Grading limits and maximum aggregate size are specified because these properties affect the amount of aggregate.

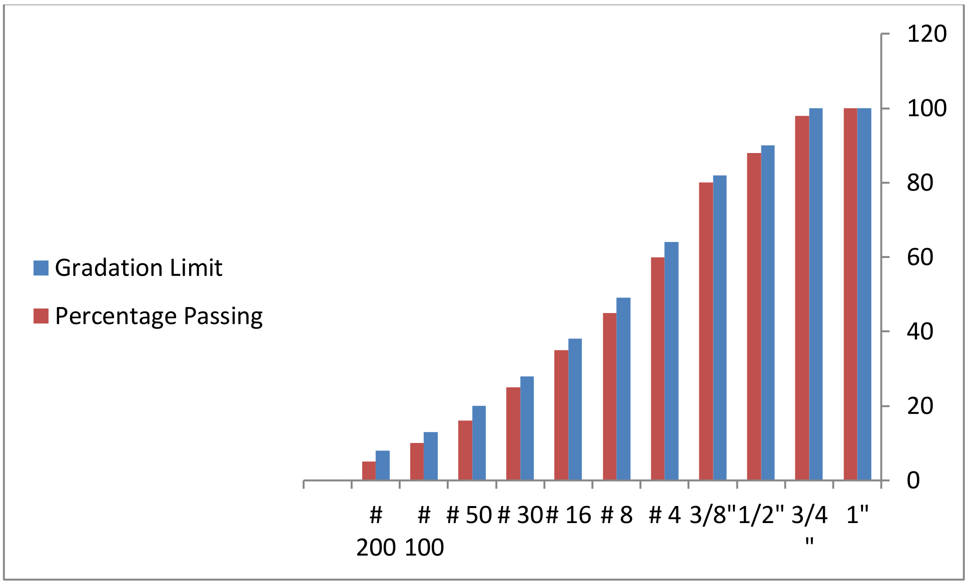


Figure 2.1 Aggregate graduation limit of AC

(Source: Indonesian Standards, 2014)

2.2.2. Asphalt Binder

The asphalt binder component of an asphalt pavement typically makes up about 5 to 6 percent of the total asphalt mixture, and coats and bonds the aggregate particles together. Asphalt cement is used in hot mix asphalt. Liquid asphalt, which is asphalt cement dispersed in water with the aid of an emulsifying agent or solvent, is used as the binder in surface treatments and cold mix asphalt pavements.

The properties of binders are often improved or enhanced by using additives or modifiers to improve adhesion (stripping resistance), flow, oxidation characteristics, and elasticity. Modifiers include oil, filler, powders, fibers, wax, solvents, emulsifiers, wetting agents, as well as other proprietary additives.

2.2.3. Hot Mix Asphalt

The asphalt mix is a composite material of graded aggregates bound with a mastic mortar (Buttlar, 2004). The physical properties and performance of hot mix asphalt (HMA) is governed by the properties of the aggregate (shape, surface texture, gradation, skeletal structure, modulus, etc.), properties of the asphalt binder (grade, complex modulus, relaxation characteristics, cohesion, etc.), and asphalt–aggregate interactions adhesion, absorption, physiochemical interactions, etc.) Properties of the hot mix asphalt.

1. HMA Weight-Volume Terms and Relationships

For both design and construction purposes, basic HMA weight-volume relationships are important to understand. Mix design is intended to decide the volume of asphalt binders and aggregates required to produce a mixture with the desired properties (Roberts et al., 1991). Since weight measurements are usually much easier, however, they are typically converted to volume using specific gravity.

Table 2.2. The following is a brief discussion of the more important volume properties of HMAWhere:

X:	b	equals	Binder
	c	equals	Stone
	m	equals	Mixtuer

Y:	B	equals	Bulk
	E	equals	Effective
	A	equals	Apparent
	M	equals	Maximum

For example, Gmm = gravity, mixture, maximum = the maximum gravity of the mixture. Other common abbreviations are:

V_T	equals	Total volume of the compacted specimen	W_T	equals	Total weight of the compacted specimen
V_a	equals	Volume of air voids	W_D	equals	Dry weight
V_b	equals	Volume of asphalt binder	W_{SSD}	equals	Saturated surface dry (SSD) weight
V_{be}	equals	Volume of effective asphalt binder	W_{sub}	equals	Weight submerged in water
V_{ba}	equals	Volume of absorbed asphalt binder	W_b	equals	Weight of the asphalt binder
V_{agg}	equals	Volume of aggregate	W_{be}	equals	Weight of effective asphalt binder

V_{eff}	equals	Effective volume of aggregate = (V_T – V_{AC})	W_{ba}	equals	Weight of absorbed asphalt binder
	equals		Wagg	equals	Weight of aggregate
G_{sa}	equals	Apparent specific gravity of the aggregate			
G_b	equals	Asphalt binder specific gravity	Pb	equals	Asphalt content by weight of mix (percent)
G_{sb}	equals	Bulk specific gravity of the aggregate	Ps	equals	Aggregate content by weight of mix (percent)
Gse	equals	Effective specific gravity of the aggregate	P_a	equals	Percent air voids
G_{mb}	equals	Bulk specific gravity of the compacted mixture		equals	
G_{mm}	equals	Maximum theoretical specific gravity of the mixture	γ_W	equals	Unit weight of water

2. HMA Constituents

HMA usually consists of three materials: an aggregate, asphalt binder, and dust. HMA is typically characterized by volume so it's important to know how volumetrically these three materials contribute to each other.

A- Bulk Specific Gravity of the Compacted Asphalt Mixture (Gmb)

The proportion of the air mass of a unit volume of a permeable material (including both permeable and impermeable voids which are normal for the component to the air mass of equivalent density at a given temperature equal to the volume of distilled gas-free water).

This factor is used to calculate the compacted mixture's weight per unit volume. Measuring Gmb as accurately as possible is very important. Since it is used to translate weight measurements into quantities, any minor errors in the Gmb will be reflected in large volume errors that may go undetected. The standard calculation of mass-specific gravity is:

AASHTO T 166: Bulk Compacted Bituminous Mixture Basic gravity Using Saturated Surface-Dry Specimen:

$$G_{mm} = \frac{W_D}{W_{SSD} - W_{Sub}} \quad \text{(2.1)}$$

B- Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures (Gmm)

The mass ratio of a given volume of voids (Va = 0) HMA to a mass of the same volume of pure gas-free water at the same temperature at a specified temperature (usually 25 ° C). The theoretical maximum density (TMD) is given by multiplying Gmm by the unit weight of water. AASHTO T 209 and ASTM D 2041: Maximum theoretical possible gravity and density of mixtures of bituminous paving.

$$G_{mm} = \frac{W_D + W_b}{V_{eff} - V_b} \quad G_{mm} = \frac{1}{\frac{1-P_b}{G_{se}} + \frac{P_b}{G_b}} \quad \text{(2.2)}$$

C- Voids (expressed in percentages)

The total size of the small air pockets in a compact paving mixture between the coated aggregate particles expressed as a percentage of the compacted paving mixtures bulk volume. A mixture's amount of air vacuum is extremely important and is closely linked to stability and longevity. In regular 12.5 mm (0.5 inches) dense-graded mixtures, Nominal peak aggregate air voids below 3% result in an unstable mixture while air voids above 8% result in a water-permeable mixture.

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100 \quad \text{(2.3)}$$

D- Voids in the Mineral Aggregate (VMA)

The density of the intergranular disparity between the aggregate particles of a compacted paving mixture consisting of the air voids and the active asphalt material, as a percentage of the specimen's total volume. If VMA is too small, there is insufficient space in the mix to add enough asphalt binder to cover the individual aggregate particles adequately. Mixes with a high VMA are often more resistant to minor changes in asphalt binder quality. Excessive VMA results in unacceptably poor stability of the mixture (Roberts et al., 1996). Typically define a minimum VMA, and a maximum VMA may or may not be specified.

$$\text{VMA} = \left(1 - \frac{G_{mb}(1-P_b)}{G_{sb}}\right) \times 100 \;\; \text{VMA} = 100 - \left[\frac{G_{mb}-P_S}{G_{sb}}\right] \quad \text{……………..…….(2.4)}$$

E- Voids Filled with Asphalt (VFWA)

The part of the voids containing asphalt binder in the mineral aggregate. It is the amount of active material of asphalt that can also be described as the percentage of the VFMA volume filled with asphalt concrete. VFWA is inversely related to air voids: the VFWA rises as the air voids decrease

$$\text{VFA} = \frac{V_{be}}{V_{be}-V_v} \times 100 \;\; \text{VFA} = \frac{VMA-V_a}{VMA} \;\; \text{VFA} = VMA - P_a \quad \text{…………………(2.5)}$$

F- Other Definitions

i. **Effective Asphalt Content (P_{be})**

The overall value of the HMA asphalt binder less the part of the asphalt binder that is lost to the aggregate through absorption.

ii. **The Volume of Absorbed Asphalt (VBA)**

The density of asphalt binder in the HMA was incorporated in the pore structure of the aggregates. The size of the asphalt binder in the HMA doesn't compensate for the active asphalt quality

$$.V_{ba} = \left(\frac{W_{ba}}{W_{agg}}\right) \times 100 \;\; V_{ba} = \left(\frac{G_{se}\text{-}G_{sb}}{G_{sb}G_{se}}\right) G_b \times 100 \quad \text{………………………..(2.6)}$$

2.3 Crumb Rubber Properties

Crumb rubber is recycled rubber that is obtained by mechanical shearing or grinding turns into small particles. Crumb rubber is generally produced from scrap tires for cars and trucks. The use of CRM in asphalt mixtures was promoted to improve the performance of asphalt mixtures and benefit the environment. With different aggregate gradations or asphalt concrete, CRM may react differently.

Therefore, the quality can be evaluated by conducting the study on the CRM asphalt concrete mixes whether a particular combination can boost the desired properties or vice versa (Xiao et al., 2007). There are three major groups dependent on particles in the crumb rubber industry size is shown in Figure 2.2

a. Type 1 Rubber Powder (0.3–0.6 mm) crumb rubber;
b. Type 2 Shred (2.36-0.85 mm) crumb rubber;
c. Type 3: Granules (1-4 mm) crumb rubber

Rubber Powder (0.3–0.6 mm) Shred (2.36-0.85 mm) Granules (1-4 mm)

Figure 2.2 Difference sizes of crumb rubber (Xiao et al., 2007)

Some previous research shows a general tendency against Marshall Mixes that the dry process of integrating CRM into asphalt mixtures decreased rutting resistance whilst the wet process of incorporating CRM into the mixtures increased rutting resistance. (Bahuguna et al., 2006). Rubber is used as an aggregate by the dry process. Usually, before loading the mixture with a pure asphalt binder, 2–3% rubber is pre-mixed with the aggregates. (Hossain et al., 1999).

Before mixing the crumb rubber with the asphalt cement with aggregates, the process is known as the wet processes. Whereas ' dry process ' refers to a method that first mixes crumb rubber with hot aggregates before mixing it with an asphalt binder called the Rubber Modified Asphalt Concrete mix (Elliott, 1993).

The development of Modified asphalt materials to improve the overall performance of pavements has been the focus of several research efforts made over the past few decades. Crumb rubber is the recycled rubber obtained by mechanical shearing or grinding of tires into small particles (Palit et al., 2004).

Waste rubber tires that cannot be processed for useful applications are numbered in the millions around the world. The buildup of old rubber tires in landfills is commonly considered a major threat to the environment, and it is unquestionably a burden on landfill space (Ghaly and Cahill IV, 2005). The test results by (Radziszewski, 2007) show that asphalt mixtures with rubberized bitumen binders are characterized by high resistance to permanent deformations. Most research on CRM mixes is based on the design of Marshall Mix (Shuler et al., 1986).

2.3.1. Advantages and Disadvantages of Asphalt Rubber binder in strategies for paving.

Asphalt rubber binder can offer significant advantages over traditional asphalt binders and even asphalt binders modified in polymer, (Holleran, 2000) these benefits include:

a. Can use crumb rubber (2.0 mm) of large size.
b. Uses the binder antioxidants
c. The viscosity and viscoelastic properties of the binder are greatly improved
d. Allows substantially higher binder content
e. Makes the film thicker for aggregates
f. Reduced binder degradation
g. The increased softening point of the binder
h. Increased binder resistance
i. Enhanced binder low-temperature properties.

The advantages of binder properties lead to benefits in the field performance of the mixes used in asphalt rubber (Bekheet et al., 2004). These are the advantages;

-Improved abrasion resistance, especially in snow regions

a. Reduced oxidation
b. Durability increased
c. Increased fatigue life
d. Increased resistance to reflective cracking
e. Increased rutting resistance
f. Low noise
g. Can reduce the thickness of the pavement

h. Reduced building time •
i. Increased construction safety •
j. Power and natural resource savings

Reduced maintenance costs. The most important advantages of using CRM include:

a. Improved asphalt paving mixes mechanical performance.
b. Lower road preservation and maintenance costs (Sousa et al., 2001), as reflected in higher energy and resource savings. This process contributes to sustainable development and is more environmentally friendly because it also involves the recovery of waste materials and a reduction in their volume at landfills.
c. Further security assurances due to better long-term color contrast for pavement markings, as carbon black in the rubber serves as a pigment that keeps the pavement blacker for a longer time (Ayerra et al., 2008)
d. Reduction of the road surface noise level (García et al., 2008).So I have added some journals or previous studies in the background and because of the researches before are not the same with this research seeking the composition of crumb rubber to have durability pavement. Based on these reasons there is a possibility to make the gap analysis closer to predicting permanent deformation with high, and compaction of asphalt concrete directly affects its strength and service life to keep the pavement in fresh condition.

2.3.2. Disadvantages

An asphalt-impregnated fabric or composite can trap water in the pavement. A moisture barrier under a new overlay can be a detriment to its performance, particularly if the overlay is not compacted properly. Rapid premature failures have occurred when a moisture barrier was placed on an old pavement then the overlay is insufficiently compacted such that it is permeable to water Surface water enters the permeable overlay and is trapped by the impermeable layer. Subsequent kneading and scouring action by traffic in the presence of the water causes rapid failure of the overlay (Brown et al., 2001).

2.4 Waste Tires Rubber

2.4.1. Chemical Properties of Waste Tire Rubber

The chemical characteristics of rubber waste tire. Rubbers determine its chemical composition, granules are analyzed using X-ray fluorescence. To order to determine their suitability as an aggregate replacement in the blend, thermogravimetry, and differential gravimetric analysis was conducted to analyze the relationship between temperature and mineralogical composition of the rubber granules.

2.4.2. Chemical and Physical features.

Two-particle sizes of rubber granules (i.e. 1 mm to 4 mm and 5 mm to 8 mm) have been used as partial replacements for both fine and coarse aggregates in this analysis. Indonesian companies in the tire industry produced the recycled rubber tire samples By the mechanical shredding process (Figure. 2.3). The XRF tool was used to determine the tire rubber granules ' chemical composition as shown in Table 2.3.

Figure 2.3 Rubber Granules.

Table 2.3 Rubber chemical composition

Chemical composition	Percentage [%]
SBR	48.0
Carbon black	47.0
Extender oil	1.9
Zinc oxide	1.1
Stearic acid	0.5
Sulfur	0.8
Accelerator	0.7

(Jusli et al., 2014)

2.4.3. Tests related to waste tire

1. Thermogravimetric Analysis (TGA).

The TGA uses the method of decomposition to quantify changes in samples or products by weight. Thermal Differential Analysis (DTA) senses temperature changes and apply them to different phases of the content, or the sample's thermal decomposition. The TGA slope changes are defined by a designated point within the DTA. The TGA and DTA have been used to examine the reactions and modifications that occur during sample heat treatment.

2. X-Ray Fluorescence (XRF)

Using XRF the chemical composition of the rubber tires has been determined, usually used to identify the sample elements or components by irradiating the ASTM D5381-93 monochromatic X-ray test sample.

3. Fourier Transform Infra-Red (FTIR).

The specimens are described in the Perkin Elmer 100 FT-IR spectrum before we evaluate, the samples are prepared in powder form. The FTIR study was carried out on a spectrometer using the pellet method of potassium bromide (KBr) (1 mg sample per 100 mg KBr) with 32 scans per sample collected at 32 cm-1 resolution from 4000 to 650 cm-1.

4. Scanning Electron Microscope (SEM).

The samples in this study are characterized by the Zeiss Supra 35 VP, a ground emission scanning electron microscope. To describe the morphology of the specimen, the specimens are cut into small sizes (except for those in powdered form). For surface examination, the samples were first placed horizontally on the substratum holder (180 °) and then positioned vertically (90 °) for a cross-sectional representation (thickness). Magnifications of 5, 10, 20 , and 50 kV have been used to determine the microstructure of the 3 and 5 kV working energy samples.

Table 2.4 Sample of waste tire and type of vehicles:

Types of vehicles	**Car**	**Motorcycle**	**Track**	**Bicycle**
Number of sample	4	4	4	4

2.5 Various Tests

2.5.1. Parameter of Marshall Test

Research related to the performance of local materials for construction materials has been performed. They evaluated the performance of local materials based on the parameters of the Marshall and has included that some material in East Kalimantan is good enough for road pavement materials, particularly for base materials (Djakfar et al., 2010).

Studied assessed the physical characteristics of the aggregate of Bulungan, Kutai, and Banjar in Borneo, Indonesia, and evaluated its performance when used in Hot mastic asphalt (HMA) mixture using Marshall. The results showed that mixture specimens using Banjar materials performed better than those from Kutai and Bulungan in terms of Marshall Characteristics. Besides, their performance fell below mixture specimens prepared from Java material(Djakfar et al., 2010).

Marshall Test is used for the asphalt mix design. Two things are of primary concern in an asphalt mix. It is called the aggregate gradation and mix design requirements. Hence for various individual mixes, a separate Marshall Mix design needs to be carried out to find out the optimum bitumen content value. The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method (Shuler et al., 1986).

2.5.2. Unconfined Compressive and Creep Test

Extensive studies were conducted using the unconfined creep test (also known as simple creep test or uniaxial creep test) as a basis for predicting permanent HMA deformation. The creep experiment is conducted at relatively low-stress levels (normally not approaching 30 psi (206.9 kPa) and low temperatures (normally not exceeding 104 ° F (40 ° C), otherwise the specimen fails prematurely. (Brown et al., 2001).

Hot-mixed asphalt (HMA) is defined as material dependent on time, temperature, and stress. A broad variety of constitutive models is used to describe HMA's mechanical behavior such as elasticity, viscoelasticity, plasticity, and creep. At low temperatures, though, HMA only acts elastically. To measure HMA's creep pressure, (Al-Qadi et al., 2009).proposed nonlinear time-hardening creep model could predict primary rutting damage in HMA and shear creep strains at the edge of the tire imprint caused by different tire configurations.

Buttlar (Buttlar, 2004) developed a technique to calibrate micro fabric discrete element modeling (MDEM) for predicting the asphalt mixture complex modulus in extension/compression across a range of test temperatures and load frequencies. Their approach provided accurate estimates of the modulus over a variety of test temperatures and frequencies relative to more conventional methods of calibration (Liu, 2005).

2.5.3. Indirect Tensile Test (ITS) and Indirect Tensile Stiffness Method (ITSM)

According to (Radziszewski, 2007) the compaction of asphalt concrete directly affects its strength and service life. Rubberized concrete pavement has high shear strength and resistance to rutting (Lee et al., 2007). The tensile strength ratio is the average static indirect tensile strength of the conditioned specimens expressed as a percentage of the average static indirect tensile strength of unconditioned specimens and it is affected by moisture susceptibility (Palit et al., 2004).

2.5.4 Fatigue-related properties:

Fatigue cracking is one of the major distresses occurring in hot-mix asphalt (HMA) pavements, which is a consequence of the accumulation of damage under repeated load applications(Chapuis, 1992). HMA is predominantly composed of aggregates and asphalt binder, where the latter plays a significant role in the HMA fatigue performance. Superpave Performance Grade (PG) specification addresses the asphalt binder property related to HMA fatigue performance by measuring a parameter $G*\sin\delta$ at intermediate temperatures, where $G*$ and δ are the complex shear modulus and phase angle, respectively. However, this parameter was initially and primarily developed for non-modified asphalt binders(W. Mogawer2011).

2.5.5. Superpave Mix Design

The Superpave mix approach to growth has been a primary outcome of the Strategic Highway Research Program (SHRP). The design process for the Superpave combination was designed to replace Hveem and Marshall methods. The volumetric analysis that is specific to the Hveem and Marshall processes is the basis for the Superpave mixture development process. The Superpave network binds asphalt binder and aggregate choice to the mix design process and also takes into account traffic and weather.

A gyratory compactor has replaced the compaction tools from the Hveem and Marshall procedures, and the compaction operation in the mixing system is related to the planned traffic. Each chapter is a brief history of the process of developing the Superpave mix accompanied by a general outline of the actual method. The summary high lights the basic principles and reasoning for specific procedures.

2.6 Mix Specification

The bituminous mix in this research is the hot mix Hot asphalt (Laston) of Bina Marga year. The mix specification refers to that of Bina Marga 2010 as shown in Table 2.5

Table 2.5 Hot Mix Asphalt Specification Requisites

No.	Properties	Specification
1	Asphalt absorption (%)	1.5
2	Void in the mix (%)	3.5-6
3	Void in the aggregate (VMA) (%)	15

4	Void filled with asphalt (%)	65
5	Stability (kg)	800
6	Flow (mm)	3-5
7	Melting (mm)	3
8	Marshall quotient	250-350

Source: (Bina Marga, 2014)

2.6.1 Components of Road Construction

1) Asphalt

The binder used in this analysis is a form of asphalt binder rated 60/70. The bitumen content used in this research is 5.0, 5.5.6, 6.5, and 7%. by the weight of dense-graded asphalt and a mixture of HMA.The asphalt binder ratios are set to determine the impact of CR in the mixture are shown in Table 2.6.

Table 2.6 Specification Requisites for asphalt tests

No.	Aspects Examined	Ways of Examination	Requisites		Unit
			Min.	*Max.*	
1.	Penetration (25^{o}C, 5 seconds	PA.0301 – 76	60	79	0.1 mm
2.	Softening point	PA.0302 - 76	48	58	^{o}C
3.	Flash point	PA.0303 - 76	200	-	^{o}C
5.	Ductility (25^{o}C, 5 cm/minute)	PA.0306 - 76	100	-	cm
6.	Specific gravity	PA.0307 - 76	1	-	-

Source: BinaMarga, (2014)

2) Aggregate

The properties of the aggregate must be recognized before their application as the basic material of construction because they will influence the strength of construction. The properties of aggregate (Walker, 1971), generally viewed from granular size and gradation, cleanliness, density, granular form, granular surface, a chemical characteristic, and viscosity to asphalt. The aggregate used must fulfill the requisites stated in Table 2.7, and Table

Table 2.7 Requisites for Examination of Coarse Aggregate

No.	Aspects Examined	Requisites
1.	The Weariness of aggregate with Los Angeles machine	≤ 40%
2.	Viscosity to asphalt	≥ 95%
3.	Water absorption	≤ 3%
4.	The Specific gravity of coarse aggregate	2.5
5.	The dry specific gravity of the dry surface	2.5
6.	Durability	≤ 12%

Source: Bina Marga (2012)

Table 2. 8 Requisites for Examination of Fine Aggregate

No.	Aspects Examined	Requisites
1.	Value of sand equivalent	≥ 50%
2.	Water absorption	≤ 3%
3.	Specific gravity of fine aggregate	≥ 2.5%

Source: Bina Marga (2010)

3) Gradation

The gradation of aggregate is gained from the result of sieve analysis by using a set of sieving apparatus. The top sieve has the largest screen openings. Each lower sieve in the column has smaller openings than the one above, and at the base is a pan. The specification of mix gradation is presented in Table 2.1. Grading limits and maximum aggregate size are specified because these properties affect the amount of aggregate.

The dry process CR asphalt mixtures evaluated in this research are used for the surface layers of high-grade asphalt pavements. To obtain good texture and high-temperature stability of the CR mixture, the gradation design aims to achieve the densest skeleton structure of the coarse aggregate. Therefore, with the voids in the coarse aggregate in a dry process, the dense and gap skeleton gradation is designed by proper compaction of the coarse and fine aggregates, such a gradation completely omits the aggregate sizes of 2.36-4.75 mm, thus avoiding the interference of the fine aggregates to interlock the structure of the coarse aggregate skeleton. Meanwhile, it could accommodate larger volumetric deformation of crumb rubber (MARAIS et al., 2017).

4) Additive Material

The additive material used in the pavement mix of this research is Crumb rubber with the content variations of (o%, 2,5%,4.5%,6.5%,8.5%) toward the total mix This additive material functions to stabilize and retain the asphaltic properties, which may change due to the climate and traffic load during the road service period.

2.6.2. Test Asphalt

Asphalt is an aggregate binder of quality and the amount of which determines the success of an asphalt mixture which is the material of the road. One type of testing in determining asphalt quality requirements is asphalt penetration which is the asphalt rheological nature of asphalt hardness (RSNI 06-2456-1991). This test was designed to determine the penetration of hard or soft bitumen (solid or semi-solid) by inserting at a certain temperature a certain length, load , and time penetration needle into the bitumen (manual of hard-cover material, Institut Teknologi Sepuluh Nopember Transportation Engineering Laboratory). The results of this test can then be used in terms of asphalt or tar quality control for of development, upgrading , or maintenance of roads. This penetration test is strongly influenced by a total weight factor, angle size , and surface smoothness of needle, temperature , and time. It is, therefore, necessary to prepare in detail the size, requirements, and limitations of equipment, time , and loads used in the determination of bitumen penetration (RSNI 06-2456-1991).

2.6.3. Test course Aggregate

This test is intended to use a Los Angeles machine to determine the resistance or strength of the aggregate against wear and tear. The aggregate resistance or strength will limit the strength of the achievable concrete whenever the aggregate strength is less or approximately equal to the strength of the planned concrete. However, usually, most aggregates are available, the strength is still greater than the strength of the concrete. The value of aggregate wear is expressed by a comparison between the weight of the wear material through the number 12 by percent to its original weight. The standard parameters to be met by the rough aggregate materials used in concrete mixtures to check the results of rough aggregate testing in the laboratory or practical checks in the field. Good coarse aggregates for binding with cement paste and mortar are of fairly rough texture, numerous/cubical, not flat, or long.

2.6.4. Test Fine Aggregate

The aggregate wear test is to find out the wear rate of an aggregate, expressed by the ratio between the weight of the worn material that passes the sieve no. 12 (1.7 mm) to the initial weight, in percent (%), and also as a handle to determine the aggregate resistance to wear and tear using the Abrasion device in Los Angeles. This test can be used to determine the wear of rough aggregates. Test results of this material can generally be used in the planning and execution of pavement or concrete construction materials.

2.6.5. Marshal Test.

The Marshall Test method is used for determining the optimum bitumen and optimum waste crumb rubber content of Hot Mix Asphalt. Marshall test is performed to determine the stability, flow, VIM, percent VFB, percent VMA, and MQ that will be used to determine the OBC. The mix specification refers to that of Bina Marga 2014.

2.6.6. Unconfined Compressive Stress

The creep test (unconfined or confined) has been used to estimate the rutting potential of HMA mixtures. This test is conducted by applying a static load to an HMA specimen and measuring the resulting permanent deformation. Extensive studies using the unconfined creep test (also known as simple creep test or uniaxial creep test) as a basis of predicting permanent deformation in HMA has been conducted. It has been found that the creep test must be performed at relatively low-stress levels (cannot usually exceed 30 psi (206.9 kPa) and low temperature (cannot usually exceed 104°F (40°C), otherwise the sample fails prematurely (Brown et al., 2001).

$$F = \frac{P}{A} \qquad (2.7)$$

Where:

F = is compressive strength, lbs/in² (KN/m^2)

P = is the maximum load, lbf (KN)

A = is cross -sectional area, in² (m^2).

2.6.7 Indirect Tensile Test (ITS)

1. **Indirect Tensile Test (ITS)**

Prediction of asphalt concrete behavior under realistic repeated loading is essential to the design and analysis of asphalt concrete pavements. To model the fatigue behavior of asphalt concrete under repetitive loading with rest periods, both the progress of damage and the strong recovery due to crack growth, relaxation and healing must be considered. The difficulty in evaluating these mechanisms arises from the fact that they occur simultaneously.

The tensile strength of the compacted bituminous mixture is:

$$ITS = \frac{2F}{3.14-(h.d)} \quad \ldots\ldots(2.8)$$

Where:

ITS = Indirect tensile strength, (psi)

F = Total applied vertical load at failure, (lb).

h = Height of specimen, (in).

d = Diameter of specimen (in)

2. **Indirect Tensile Resilient Modulus (MR) Test**

The indirect tensile resilient modulus test is conducted at temperatures of 40 ºC According to the modified ASTM D4123 (10). It is a repeated load indirect tension test for determining the resilient modulus of the asphalt mixtures. The recoverable vertical deformation, δV, and horizontal deformation, δH were used to calculate the indirect tensile resilient modulus.

$$MR = \frac{P.(\mu+0.27)}{t.\delta H} \quad \ldots\ldots(2.9)$$

$$\mu = 3.59 \cdot \frac{\delta H}{\delta V} - 0.27 \quad \ldots\ldots(2.10)$$

Where:

MR = Resilient Modul

P = The vertical load applied, N

t = Thickness of sample, mm

μ = Poisson's ratio

δH = Deformation horizontal, mm, and
δV = Vertical distortion.

2.6.8. Permeability

The permeability of asphalt concrete mix can be measured by values, which is k value (cm) which indicates its permeability value or as permeability coefficient of k (cm/second). the value of permeability can be approached by using the empirical one of the hydraulic analysis, which has been widely used.

2.6.9. Indirect tensile fatigue test (ITFT)

Under controlled load test conditions, the ITFT characterizes the fatigue behavior of bituminous mixtures. ITFT is an experimental arrangement is similar to the one used for the ITSM but with slight crosshead modifications. In ITFT (Figure.2 4), displacement transducers are used to measure the vertical deformation over the horizontal diameter of the specimen rather than the deformation, as in the ITSM test. Repeated compressive pressure around the longitudinal diametric plane is subject to a cylindrical test specimen. The resulting horizontal tensile stress is calculated as follows Indirect tensile fatigue test (ITFT): x; max at the center of the model in (kPa)

$$\sigma_{x,max} = \frac{2.P_L}{\pi.d.t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.11)$$

Where PL is the vertically drawn loading line (kN), d is the test specimen diameter (m), and t is the test specimen thickness (m). The corresponding horizontal strain "x; max [in (strain)] at the middle of the specimen can then be measured using a Poisson ratio estimated as follows:

$$\varepsilon_{x,max} = \frac{\sigma_{x,max}.(1+3v)}{S_m}.1000 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.12)$$

Where x; max is the average tensile stress in the center of the specimen (kPa); is the Poisson ratio expected and Sm is the approximate tensile stiffness module obtained from the ITSM test on the same specimen (MPa).

The ITFT training was carried out with the following conditions:

(a) test temperature: 10 and 30 C°.

(b) Poisson’s ratio: 0.25 at 10 C and 0.45 at 30 C°.

(c) loading condition: controlled-stress

(d) loading rise-time: 120 ms

(e) failure indication: 9mm vertical deformation.

The breakdown of the bituminous mixture was determined in terms of the failure criterion, as the minimum amount of load operations occurred before the specimen was broken or a vertical deformation of 9 mm was achieved.

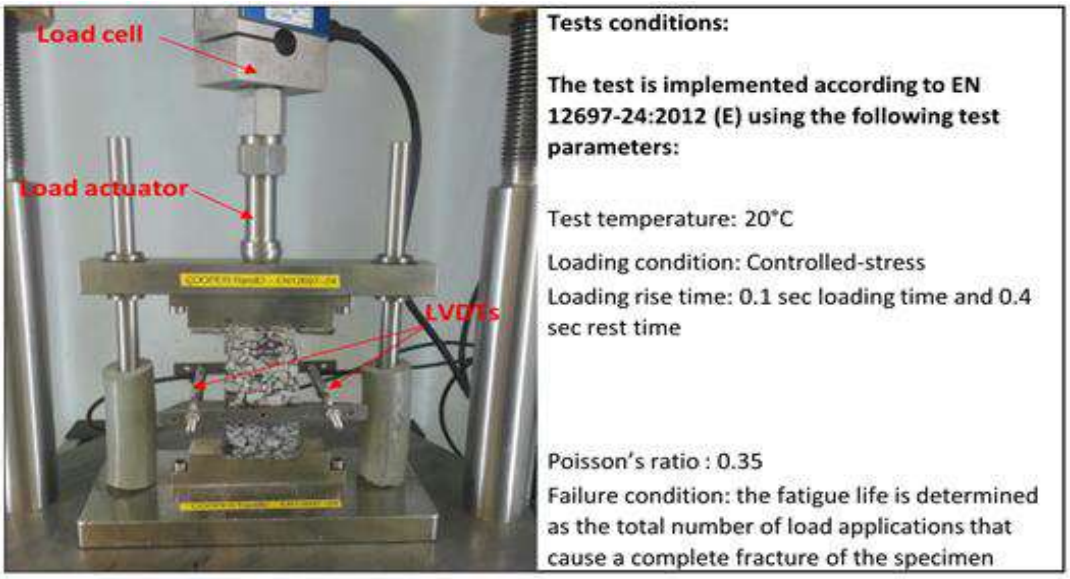


Figure 2. 4 ITFT testing configuration and test condition

The fatigue data for asphalt mixtures are generally recommending to plot against the strain criterion (Airey et al., 2006). The result is showing in the terms of the relationship between the resilient strain at the 100th load application fatigue life (NF)in the logarithm scale.

1. Two-point bending cantilever test

The fatigue test for the two-point cantilever bending beam was done using an electromagnetic actuator. This study can be carried out in two modes of control: 'Controlled stress (displacement)' and 'Controlled stress (load). For this analysis, all the experiments were performed under stable stress conditions, as this is the control mode used for the ITFT.

Testing program:

Two types of fatigue tests were used in the test program. The first component of the system involved measuring the fatigue of the asphalt mixture with 20 mm DBM using the two-point bending fatigue apparatus. In the following conditions, trapezoidal specimens were examined :

(a) loading mode: controlled load

(b) temperature: 10 and 30 C

(c) frequency: 10 Hz;

The second part of the testing program aimed at characterizing the 20 mm DBM's ITFT fatigue behavior and comparing those results were obtained from the bending experiments of two points. In the following test conditions, this was done by conducting indirect tensile tests.

(a) loading mode: controlled load

(b) temperatures: 10 and 30 C° respectively.

(c) Flow rate: 40 pulses per min.

In the ITSM test, this ITFT cylindrical model was previously tested to determine, Stiffness sensor and Poisson ratio at the test temperature. The specimens were then tested at different stress levels (100 to 2500 kPa) to provide approximately three magnitude levels to disperse the stiffness module at the test temperature and the Poisson ratio. Finally, similarities were made between the effects of fatigue obtained from the two different tests which were carried out at two temperatures on the same substance.

2.6.10. Superpave Mix Design:

Superpave ProcedureThe Superpave mix design method consists of 7 basic steps :

1. **Selection of aggregates**

Superpave has two ways to specify aggregate. First, using wide control points, it places restrictions on aggregate gradation. Secondly, it puts it “consensus requirements” Angularity, smooth and elongated grains and clay material of coarse and fine aggregate. Other aggregate requirements that the Institute of Asphalt has (2001) Calls "source properties" (since they are deemed unique to the source). In

L.A. Superpave uses abrasion, soundness, and liquid absorption, but they aren't discussed here because Superpave didn't change them.

2. Gradation and Size

The aggregate gradation affects core HMA parameters like rigidity, strength, durability, permeability, fatigue resistance, friction, and moisture resistance. (Roberts et al., 1991). The total cumulative size can also be important in the determination of compaction and lift thickness. Superpave mix system defines control points through which typical gradations will migrate. Such checkpoints are very popular and are a starting point for an equation of mix layout.

3.Aggregate Blending

It is difficult from a single aggregate stockpile to achieve the desired aggregate gradation. Superpave combination models are therefore typically based on multiple different stock aggregates, and mix them in a ratio that gives the final blended gradation acceptable. It is very popular to see a Superpave mix model using 3 or 4 separate stock aggregates. The Superpave gyratory compactor sets three different numbers of gyration: initial. The number of gyrations used as a measure of the compactness of the mixture during construction. Mixes that compress too fast (Initial air voids are too low) can be tendered during construction and unstable when exposed to traffic. This is often a good indication of aggregate value – HMA will often fail to meet the initial requirement with excess natural sand. At Initial, a mixture of more than or equal to 3 million ESALs with a 4% air vacuum should have at least an 11% air vacuum.

a. Design

This is the number of gyrations required to produce the same density sample as predicted in the field after the specified volume of traffic. In the design of the mix, a mixture with 4% air voids is desired.

b. Nmax

The number of gyrations required to produce laboratory densities that should never be exceeded in the field. The field mixture under traffic can compact too much if the Nmax air vacuum is too low, excessively low air vacuum and possible rutting can occur Nmax air gap should never be less than 2%.

$$\frac{P_{0.075}}{P_{be}}$$

where: $P_{0.075}$ = mass of particles passing the 0.075 mm (No. 200) sieve

P_{be} = effective binder content = the total asphalt binder content of a paving mixture less the portion of asphalt binder that is lost by absorption into the aggregate particles.

…………………………………………………………………….…………(2.13)

Figure 2.6 Gyratory compactor

2.6.11. Performance testing

The Superpave mix was originally planned for the development process was to send the different test mix configurations to performance test batteries equivalent to the Hveem. The system with the stability meter and consistency meter or the stability and flow check Marshall method. Such reliability measures, which make up the Superpave mixture analysis section, are still being developed and tested and have not yet been implemented Confined Dynamic Modulus Test is the more probable, the Simple Quality Test (SPT) test.

2.7 Hypothes

The hypothesis of this research is the modification of hot mix asphalt with crumb rubber expected to have lower temperature susceptibility and increased durability and strength as compared to mixes. Therefore, it is expected that this study will increase the resistance of asphalt at high temperatures. This study will make us get rid of large amounts of tire wastes in the future and to take advantage of them in the Roads and Transport Services is also expected not to have any effect on the Marshal properties stability, MQ, Indirect tensile strength, Indirect Tensile Strength Modulus, permeability, and the Unconfined Compressive Strength values at hot mix asphalt (HMA). At certain CR mixtures show the higher performance of stiffness, fatigue life, cracking with the regular mixture from different percentages of CR. The hypothesis in this research as follows:

H1: There is the impact of percentages for crumb rubber to the high durability of flexible pavement in HMA properties by using crumb rubber that comes from sources of tires wastes that will give good quality to mix design.

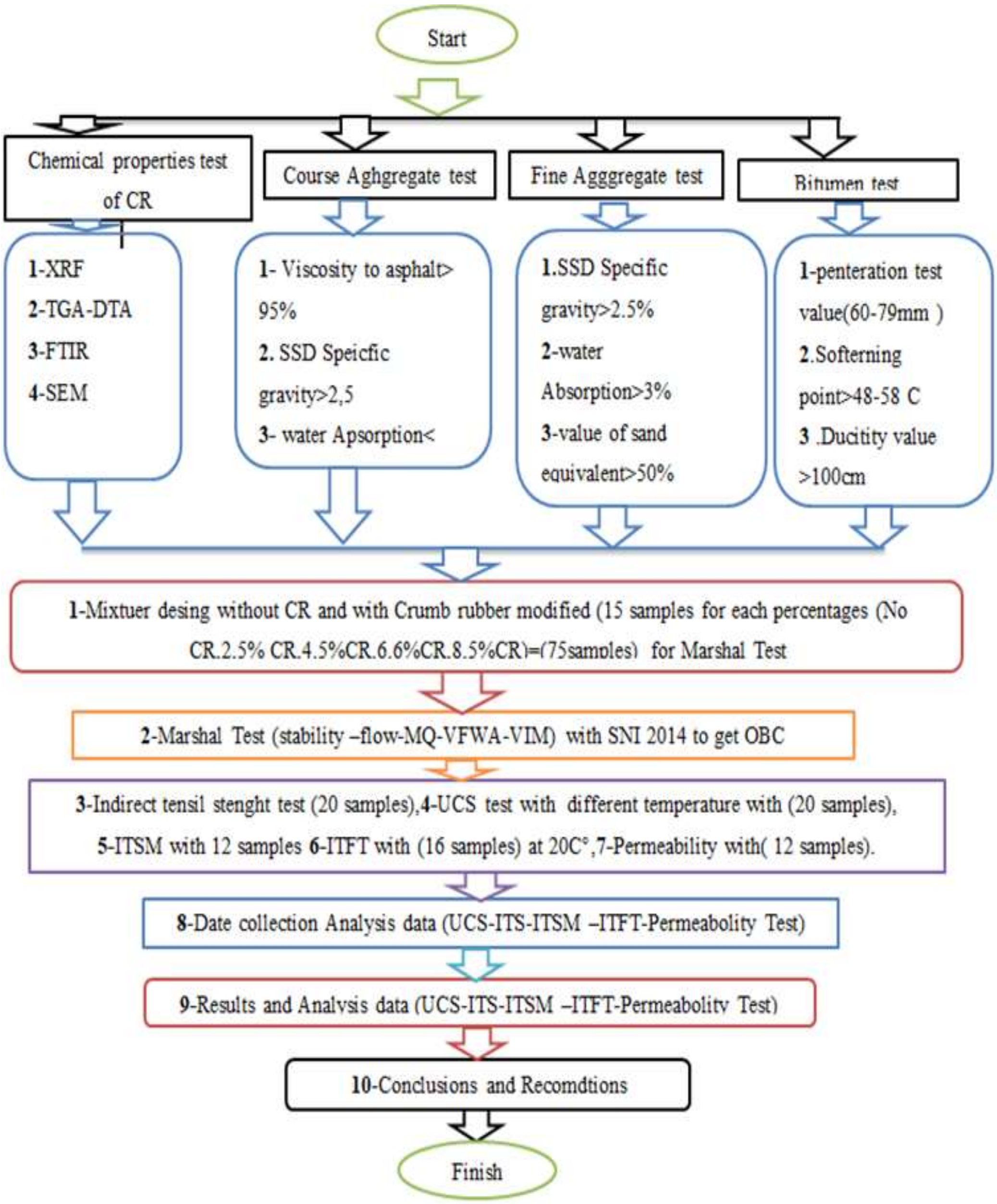
H2: There is the impact of high temperature on the durability of flexible pavement in HMA properties by using crumb rubber that comes sources of tire wastes that will give good quality to mix design.

H3: There is the impact of mechanical properties of flexible pavement in HMA properties by using crumb rubber that comes from sources of tire wastes.

H4: There is the impact of chemical properties of flexible pavement in HMA properties by using crumb rubber that comes from sources of tire wastes.

CHAPTER 3
RESEARCH METHOD

3.1. Flow chart of research work/methodology



Figuer 3.1. Concept of framework

3.2 Introduction

This chapter discusses the mixed design of hot mix asphalt concrete with crumb rubber and several tests that will be conducted in achieving the objectives of the research. First, to reach the graduation mark, the dry sieve, and mixed quarry aggregates. The washed-snow analysis that mixing types are the HMA crumb rubber, the laboratory works can be divided into several stages, starting with cumulative preparation and delivery through sieve analysis of different particle sizes. Fine crumb rubber (grinding from truck tires) is applied to this work in a powder form in which the thickness varies from 0.6 mm to 0.3 mm. The percentage of crumb-rubber that are applied to the blends is shown. For both HMA designs, the second stage will be performing the Marshall sample. The dry process method will be used to prepare modified asphalt mixes for rubber. Marshall Specimens with both modified and unmodified specimens will be ready to integrate CRM into a blend. Also will use SNI and ASTM standard manual test, besides that research program.

3.3 Location and Time

This section addresses multiple experiments to be carried out to achieve the study's objectives. The research was conducted at will be Civil Engineering laboratory of Institut Teknologi Sepuluh Nopember in 2019 also will be in Civil Engineering Laboratory in UII (University Islamic Yogjakarta), University Gajah Mada (UGM) at Yogjakarta, and University Udayana at Denpasar, Bali.

3.4 Variables and Parameters

Variables and parameters of this research are dependent Variables, Strength of bituminous material (Y): the predicted variables are magnitude and rate of change Independent Variable, Variation Different proportion of CR (X). The crumb rubber is added into HMA in this research with different temperatures The crumb rubber is added into HMA in this research with different temperatures. The Parameters that we use in the research are asphalt concrete, aggregate gradation is all as shown in. Also, how can we use crumb rubber to the high durability of pavement?

PARAMETERS:

1.Properties of asphalt AC 60/70:

a. Penetration (mm);
b. Asphalt solubility in TCE (tri chlore enthelyn)/CCL;
c. Ductility (cm);
d. Softening point;
e. Flashpoint and fire point;
f. The Specific gravity of asphalt.

2. Coarse and fine aggregate properties:

a. Specific gravity for bulk coarse and fine aggregate;
b. SSD specific gravity of coarse and fine aggregate;
c. Apparent specify gravity of coarse and fine aggregate;
d. Water absorption of coarse and fine aggregate;
e. Abrasion Value of sand equivalent.

3. Variables:

a. Asphalt concert modified crumb rubber: size, shape, density gravity, dense, gap graded with a different percentage 2.5. %, 4.5%,6%.5and8.5 % CR).

b. Bitumen content: to get Optimum Bitumen Content (from 5 to 7%).

c. Waste tires: from different sources of tire waste (cars, trucks, motorcycles, bicycles) with different (surplus content, size, a diameter of crumb rubber on the chemical content, crumb rubber from the source of the tire.)

d. Temperatures: start from 10 C°20°C, 30C°,40°C, 60°C.

3.5 Data

3.5.1. Type of data

The type of data used in this study is two data, primary data, and secondary data. Primary data is data collected directly through a series of experiments conducted themselves concerning to the existing manual instructions, for example by conducting research/testing directly.

The data included in primary data are as follows:

a. Data Examination Asphalt, Aggregate, Crumb Rubber.
b. Data Marshall Properties Test

Secondary data is data obtained indirectly (derived from research or other sources) for the material /same type. In many ways, the researcher must receive secondary data according to what it is. Secondary data used in this study, namely:

a. Examination of Asphalt, Aggregate, Fine Aggregate, Crumb Rubber.
b. Testing Marshall of HMA in previous studies.
c. UCS Test
d. ITS Test,
e. ITSM Test ,
f. ITFT Test.
g. Permeability Test.

3.5.2. Data Collection Method

Data collection methods implemented with an experimental method to several test specimens tested in the laboratory. The data of the research were obtained through the Marshall Test. Stability, flow, Marshall Quotient (MQ), Void in Total Mix (VITM), Void Filled with Asphalt (VFWA) , and VIM for optimum asphalt content were included in the results. Before the execution of penetration index, Marshall Bina Marga 2012, Bina Marga 2014, also measured ITS, UCS with ASTM D1074 and AASHTO T167, ITSM with BS DD1231993 Britch standard, ITFT with standard BSN 12697 and Pereamblity Test with Bina Marga 2012, Bina Marga 2014.

3.6 Preparing the Aggregate Samples.

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are an essential ingredient in concrete. Aggregate is used in this study consist of coarse and fine aggregates, coarse aggregate is characterized as the aggregate that exceeds the sieve size of 4.75 mm. Where fine aggregate is the aggregate whose size is less than 4.75 mm, for example, sand is used as a fine aggregate in the preparation of HMA. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 3/8-inch sieve.

3.6.1. Aggregate Impact Value (Los Angloes).

Los Angeles aggregate abrasion test is a measure of aggregate resilience and abrasion resistance, such as smashing, crushing, and decay AASHTO T 396 executes the test. Resistance to degradation by Abrasion and Impact of Small-Size Coarse Aggregate in Los Angeles Machine. The aggregate used in the highway pavements ' surface course is subjected to wear due to traffic movement. The soil particles present between the pneumatic tires and the road surface cause road aggregates to be abrasive when vehicles move on the road. The steel-rimmed wheels of animal-driven vehicles are also producing severe ground surface abrasion. Hence road aggregates should be difficult enough to withstand abrasion. Resistance to aggregate abrasion is determined by the Los Angeles testing machine at the laboratory.

The principle of the Los Angeles abrasion test is to produce abrasive action by using standard steel balls which also affect aggregates when mixed with aggregates and rotated in a drum for a certain number of revolutions.'

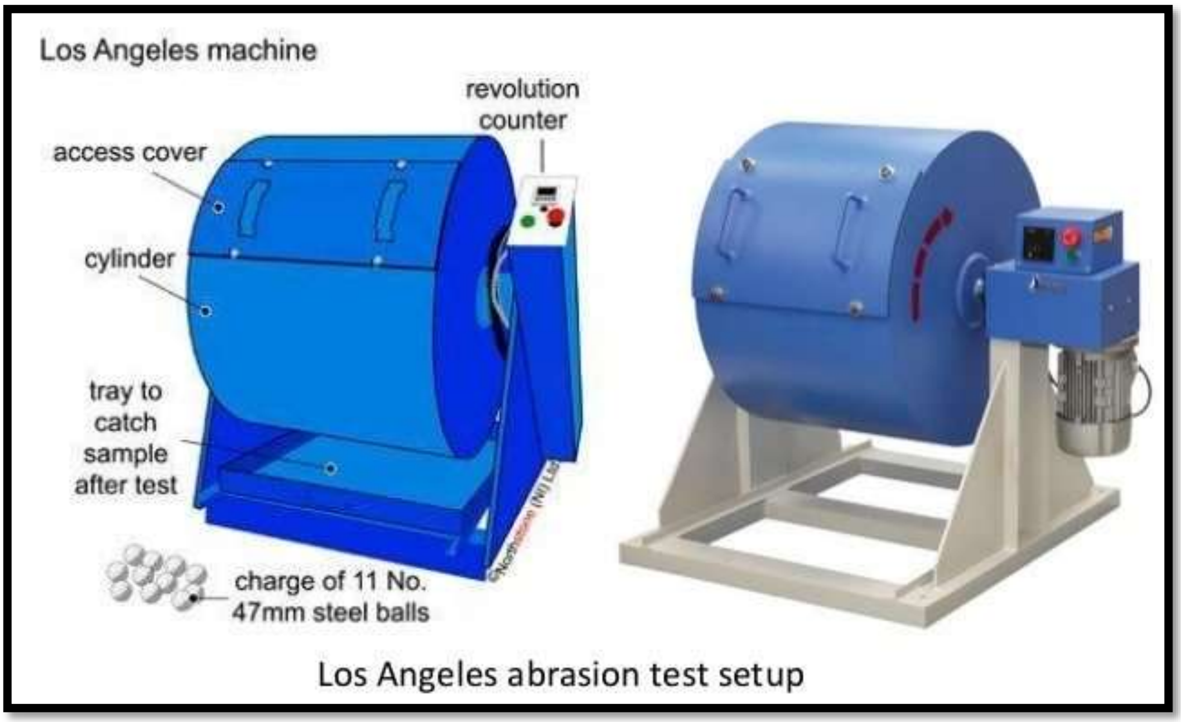


Figure 3.2 Los Angeles Abrasion test set up

1. **Determination of Los Angeles Abrasion Value**

The Los Angeles abrasion test on aggregates is performed with the following purposes:

a. Determine the Los Angeles abrasion factor.
b. Consideration of the appropriateness of the aggregates for road construction applications.

2. **Apparatus for Los Angeles Test**

The device according to IS: 2386 (Part IV) – 1963 consists of :

a. Los Angeles Machine.
b. Abrasive charging: cast iron or steel balls, about 48 mm in diameter and weighing between 390 and 445 g each; it requires six to twelve balls.
c. Sieve: 1.70, 2.36, 4.75, 6.3, 10, 12.5, 20, 25, 40, 50, 63, 80 mm IS Sieves.
d. Capacity balance 5 kg or 10 kg.
e. Dry oven.
f. Miscellaneous like a tray.

3. **Procedure for Los Angeles Test**

The test sample is made up of hard, dried aggregates in an oven at 105 ° - 110 ° C. The sample must correspond to any of the grades shown in steps:

1-Select the grading to be used in the evaluation to the maximum extent possible so that it conforms to the grading to be used in the building.

2-Take a sample of 5 kg for grades A, B, C & D, and 10 kg for gradations E, F & G.

3-Choose the abrasive charge as shown in Table 2 according to the aggregate gradation.

4-Place on the cap the aggregates and the abrasive charge and repair the seal.

5-Wheel the machine at 30 to 33 revolutions per minute. The number of revolutions for grades A, B, C & D is 500 and for gradations E, F & G is 1000. The machine should be balanced and driven such that there is uniform peripheral speed.

6- After the required number of revolutions the unit is stopped and the substance is discharged into a tray.

7- All stone dust is sieved to a sieve of 1.70 mm IS.

8-Material measuring up to 1.7 mm is right to one gram.

Aggregate impact value is a relative measure of the resistance of an aggregate to a sudden shock or an impact, which in some aggregates differs from it, is resistance to a slow compressive load. When determining the aggregate impact value, the test sample should conform to the following grading passing through 12.5 mm Sieve 100% and Retention on 10 mm Sieve 100%

1). Sieve Analysis of Fine and Coarse Aggregate

Sieve processing is the method of sorting dry aggregates into different sizes using a collection with sieves of increasingly smaller openings for particle size distribution. Aggregates will be used for producing HMA samples with ASTM C136.

2). Specific Gravity of Aggregates

The aggregate specific gravity is useful for weight-volume conversions and for weighing the empty product in a lightweight liquid mixture. A basic gravity experiment was carried out to determine the level of absorption of the aggregate and the amount of water in the aggregate. This experiment was performed for fine aggregate and coarse aggregate in two phases. The coarse aggregate is defined as the aggregate retained in sieve size 4.75 mm whereas the fine aggregate is defined as the aggregate passing sieve size 4.75 mm and retained in sieve size 75 mm.

3). Aggregate Gradation

The percentages required for sieve sizes will be based on Indonesian standards The preserved samples were then measured using the proportion that passed for sample size.

Table.3.1 Gradation limits for wearing course.

Sieve size		**OPPER LIMIT SPECS (∅)**	**LOWER LIMIT SPECS (∅)**
Mm	**Mm**		
¾	19.1	100	100
½	12.5	90	100
3/8	9.5	72	90
#4	4.76	43	82
#8	2.38	28	64
#16	1.18	19	49

#30	0.59	13	38
#50	0.279	9	28
#100	0.149	6	20
#200	0.074	4	13
PAN		0	0

Source: (Indonesian standards, 2014).

Table.3.2 Gradation limits for wearing course with AC 5%

Sieve Size (inch)	Sieve Size (mm)	Gradation Limit(∅	Percentage Passing (∅)	Weight (gr)
25	1"	100	100	0
19	3/4 "	100	98	22.32
12.5	1/2"	90	88	111.6
9.5	3/8"	82	80	89.28
4.75	# 4	64	60	223.2
2.36	# 8	49	45	167.4
1.18	# 16	38	35	111.6
0.6	# 30	28	25	111.6
0.3	# 50	20	16	100.44
0.15	# 100	13	10	66.96
0.075	# 200	8	5	55.8
Pan		0	0	55.8

Source: (Indonesian standards, 2014).

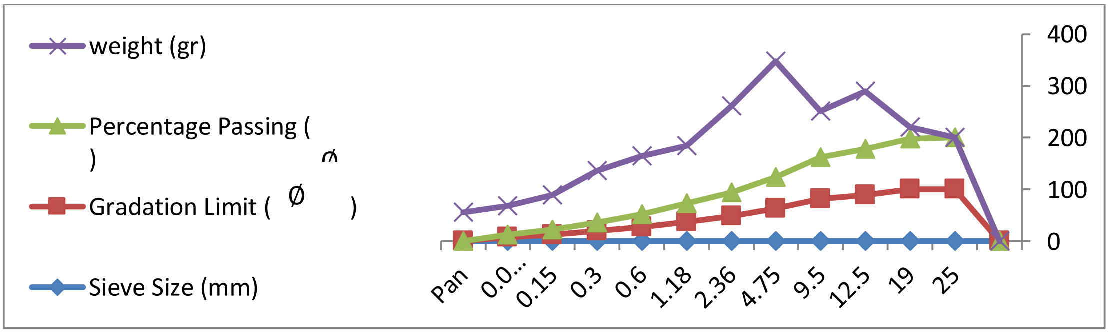


Figure 3.3 Gradation limit for asphalt concrete AC 5.0 %

The percentages of aggregates needed for sieve sizes shall be based on Indonesian standards. The remaining specimens were then measured using the sample size proportion. Table 3.2, and Figure 3.1 summarize the upper and lower limit according to Indonesian standards, and the weight of samples starts from (0 to 232.2 gr)pass sieve size 4.75mm when using Asphalt Content 5%.

Table.3.3 Gradation limits for wearing course with AC 5.5%

Sieve Size (inch)	**Sieve Size (mm)**	**Gradation Limit**	**Percentage Passing**	**Weight (gr)**
25	1"	100	100	0
19	3/4 "	100	98	22.68
12.5	1/2"	90	88	113.4
9.5	3/8"	82	80	90.72
4.75	# 4	64	60	226.8
2.36	# 8	49	45	170.1
1.18	# 16	38	35	113.4
0.6	# 30	28	25	113.4
0.3	# 50	20	16	102.06
0.15	# 100	13	10	68.04
0.075	# 200	8	5	56.7
Pan		0	0	56.7

Source: (Indonesian standards, 2014).

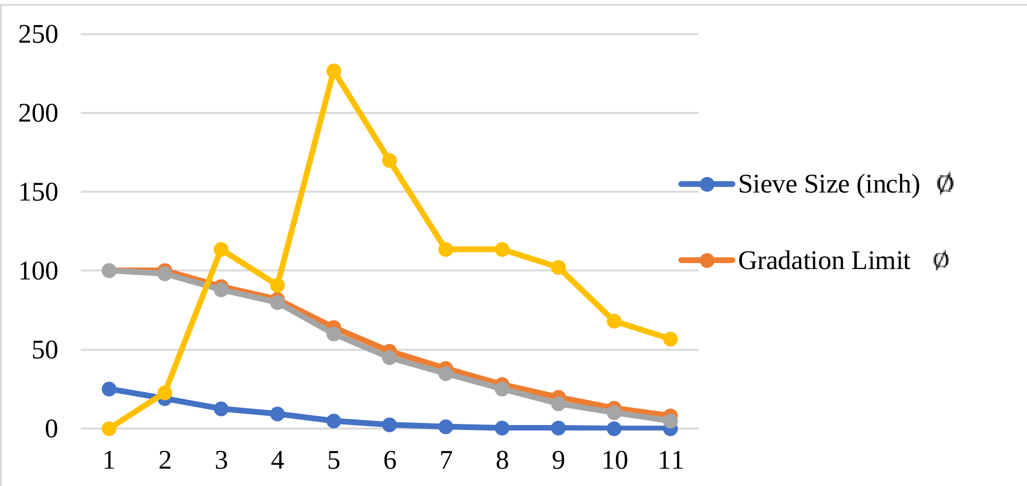


Figure 3.4 Gradation limit for asphalt concrete AC 5.5%

Table.3.4 Gradation limits for wearing course with AC 6.0%

Sieve Size (inch)	Sieve Size (mm)	Gradation Limit	Percentage Passing	weight (gr)
25	1"	100	100	0
19	3/4 "	100	98	22.56
12.5	1/2"	90	88	112.8
9.5	3/8"	82	80	90.24
4.75	# 4	64	60	225.6
2.36	# 8	49	45	169.2
1.18	# 16	38	35	112.8
0.6	# 30	28	25	112.8
0.3	# 50	20	16	101.52
0.15	# 100	13	10	67.68
0.075	# 200	8	5	56.4
Pan		0	0	56.4

Source: (Indonesian standards, 2014).

The percentages of aggregates needed for measurements of sieves will be based on Indonesian norms. The specimens held were then determined using the sample size proportion. Table 3.3, and Figure 3.2 summarize the upper and lower limit according to Indonesian standards, and the weight of samples starts from (0 to 226.8 gr)pass sieve size 4.75mm when using Asphalt Content 5.5%

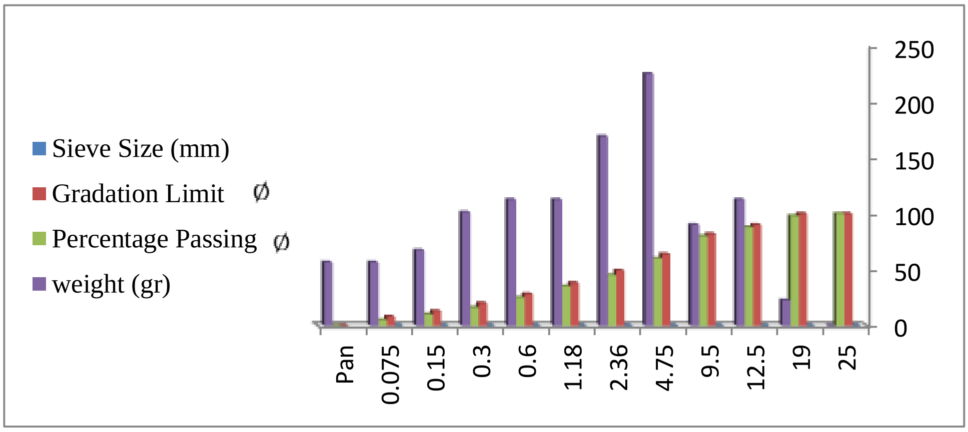


Figure 3.5 Gradation limit for asphalt concrete AC 6.0%

Table.3.5 Gradation limits for wearing course with AC 6.5%

Sieve Size (inch)	Sieve Size (mm)	Gradation Limit	Percentage Passing	Weight (gr)
25	1"	100	100	0
19	3/4 "	100	98	22.44
12.5	1/2"	90	88	112.2
9.5	3/8"	82	80	89.76
4.75	# 4	64	60	224.4
2.36	# 8	49	45	168.3
1.18	# 16	38	35	112.2
0.6	# 30	28	25	112.2
0.3	# 50	20	16	100.98
0.15	# 100	13	10	67.32
0.075	# 200	8	5	56.1

'Source: (Indonesian standards, 2014).

The percentages of aggregates that are required to calculate sieves will be based on Indonesian norms. The remaining specimens were then measured using the percentage of the sample size Table 3.4, and Figure 3.3 summarizes the upper and lower limit according to Indonesian standards, and the weight of samples starts from (0 to 225.9 gr) pass sieve size 4.75mm when using Asphalt Content 6%.

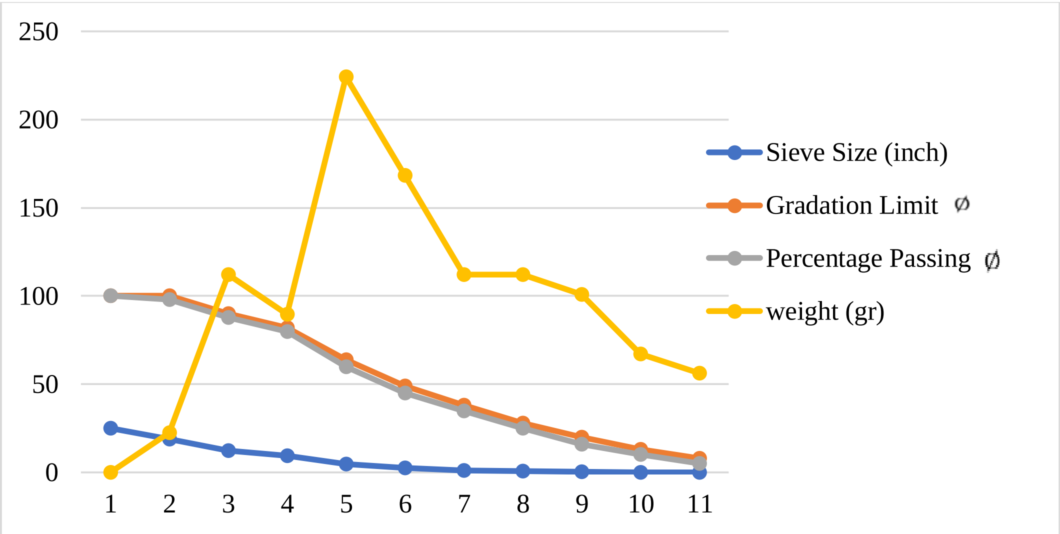


Figure 3.6 Gradation limit for asphalt concrete AC 6.5%

Table.3.6 Gradation limits for wearing course\ with AC 7.0%

Sieve Size (inch)	Sieve Size (mm)	Gradation Limit	Percentage Passing	Weight (gr)
25	1"	100	100	0
19	3/4 "	100	98	22.32
12.5	1/2"	90	88	111.6
9.5	3/8"	82	80	89.28
4.75	# 4	64	60	223.2
2.36	# 8	49	45	167.4
1.18	# 16	38	35	111.6
0.6	# 30	28	25	111.6
0.3	# 50	20	16	100.44
0.15	# 100	13	10	66.96
0.075	# 200	8	5	55.8
Pan		0	0	55.8

Source: (Indonesian standards, 2014).

The percentages of aggregates needed for sieve sizes shall be based on Indonesian standards. The remaining specimens were then measured using the percentage of the sample size. Table 3.5, and Figure 3.4 summarizes the upper and lower limit according to Indonesian standards, and the weight of samples starts from (0 to 224.4 gr)pass sieve size 4.75mm when using Asphalt Content 6.5%.

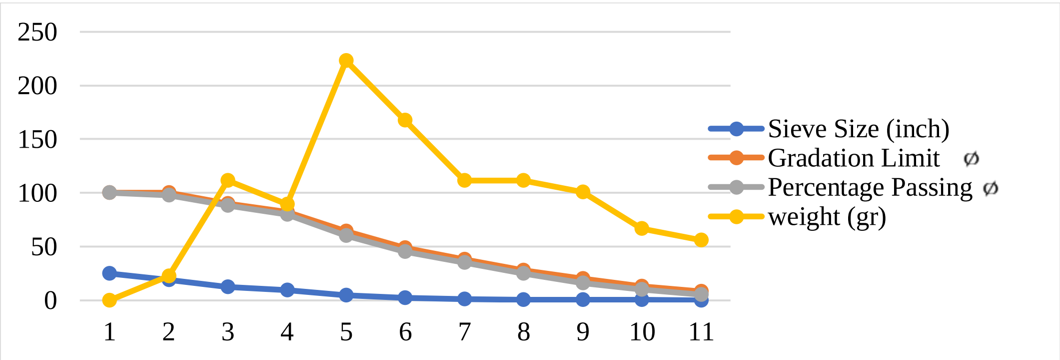


Figure 3.7 Gradation limit for asphalt concrete AC 7%

The percentages of aggregates necessary for measuring sieves will be based on Indonesian standards. Then the samples retained were calculated using the percent passing for sample size. Table 3.5, and Figure 3.4 summarizes the upper and lower limit according to Indonesian standards, and the weight of samples starts from (0 to 224.4 gr) pass sieve size 4.75mm when using Asphalt Content 6.5%.

3.7 Bituminous binder

Bitumen with penetration grade 60/70 PEN was utilized for this study. The bitumen content for these samples ranged from JKR / SPJ / rev/2005, and JKR / SPJ/1988.

Table 3.7 Design bitumen contents

Mix type	**Bitumen content**
HMA	5-7%

1. Preparing The Bitumen Samples.

This study will use one type of bitumen: Asphalt 60/70 pen and crumb rubber. The bitumen contents for these samples will be ranged as (5% to 7% of the total weight according to ASTM 96. It has been made the tests for bitumen to know the physical properties of bitumen with crumb rubber (CR).

2. Test for Bitumen

a. Penetration Test

The Penetration Test It is an empirical test the measures the consistency (hardness) of asphalt at a specified test condition. In the standard test condition, a standard needle of a total load of 100 gr is applied to the surface of the temperature of an asphalt sample at 25 ° C for 5 seconds. The amount of penetration of the needle at the end of 5 seconds is measured in units of 0.1 mm or penetration unit).

b. Softening Point Test

The ring and ball softening point test measures the temperature at which asphalt reaches a certain softness. When asphalt is at its softening point temperature, it has approximately a penetration of 800 or an absolute viscosity of this conversion is only approximate and can vary from asphalt to 13,000 poises.

c. Ductility Test

The ductility test measures the distance a standard asphalt sample will stretch without breaking under a standard testing condition (5 cm min at 25 ° C). It is generally considered that asphalt with a very low ductility will have poor adhesive properties and thus poor performance in service. Specifications for asphalt cement normally contain requirements for minimum ductility (ASTM 1992).

3.8 ASPHALT RUBBER PRODUCTION

There are two processes for producing asphalt-rubber, known as the wet process and the dry process.

1. The wet process, called asphalt-rubber, in the wet process, a straight binder is initially preheated to around 160Cº, then crumb rubber is added. The digestion process, which is the incorporation of rubber in the conventional binder, continues for a period of (1 to 4) hours, at a temperature of (160) Cº. The process is facilitated by a mechanical agitation produced by a horizontal shaft.
2. The dry process, called aggregate-rubber, in the dry process, particles of crumb rubber are added to preheated aggregates before the addition of the straight bituminous binder. Aggregates are heated to temperatures of approximately (200) Cº, then crumb rubber is added and mixed for about (15) seconds until a homogeneous mixture is obtained.

The straight binder is then added to a conventional mixing plant. And the main differences between these processes are:

1. size of rubber: the dry process rubber is much coarser than wet process rubber.
2. The volume of rubber: the dry process uses (2 to 4) times as much as the wet process.
3. Rubber function: the rubber acts more like an aggregate in the dry process, but it behaves more like a binder in the wet process.
4. Easy mixing: no special equipment is required in the dry process, while special mixing chambers are required in the wet process., reaction and blending tanks, and oversized pumps are required (Roberts et al., 1989).

3.9 Crumb Rubber Modified

Fine crumb rubber (truck grinding, car types) The analysis will be performed in powder form where the size ranges from 0.3 mm to 0.6 mm. The quantity of crumb-rubber modifiers applied to the blends is reflected in the different percentages from 0%, 2.5%, 4.5%, 6.5% , and 8.5% CR of the total weight of aggregates.

3.10 Analysis

3.10.1. Marshall Properties

To analysis the Marshall properties with finding Marshall properties value of HMA (60/70) and Marshall properties value of HMA with crumb rubber. Then compare the value of the Marshall properties between HMA (60/70) and HMA with crumb rubber: stability, flow, Marshall Quotient, Void In Total Mix, Void Filled with Asphalt, and Air Void. The value of Marshall properties find with the use of formula stability, flow, Marshall Quotient, Void In Total Mix, Void Filled With Asphalt, and Air Void. Bruce Marshall, formerly Bituminous Engineer with the Mississippi State Highway Department, formulated the concept of the Marshall method of designing paving mixtures. The American Society for Testing Materials has standardized the Marshall Design procedure (Roberts et al., 1991). The Marshall Model procedure begins with the preparation of test samples. In this Marshall Sample, both AC mix models are prepared. In essence, Marshall Design practices are as follows:

1. Aggregate and asphalt selection.
2. Select the form of gradation.
3. Aggregate mixture.
4. Specific gravity determination for mixed aggregate.
5. Mixing and compaction temperature determination
6. Compact sample preparation with specific bitumen materials.
7. Determination of compacted samples ' mass-specific gravity.
8. In the preparation of modified asphalt blends of tires, the dry process approach was used.

This method is applied to hot asphalt mixtures containing cement asphalt and aggregates with no more than 25 mm. This method gives economical asphalt mixtures with the following properties:

1. Asphalt ratio is sufficient to ensure the durability and elasticity of the mixture.
2. Air spaces sufficient to accommodate the asphalt.
3. Sufficient force to resist traffic without any deformities in the class.
4. Ease of handling.

The steps of this method are summarized in the following processes:

1. Sufficient quantities of aggregates are prepared to prepare 3 samples. The weight of each quantity shall be within the limits of g1200.
2. Check the aggregates and determine the desired gradient for the mixture.
3. Check the asphalt and determine its properties and extent of conformity to specifications.
4. Asphalt and aggregates are heated to the optimal 160-165c ° temperature separately.
5. Mix the quantities of aggregates with different percentages of cement (5%, 5.5%, 6%, 6.5%, 7%).
6. Each mixture is cast in a cylindrical mold of 101.6 mm and a height of 76.2 mm and hammered with a hammer weighing 4.53 Kg falling from a height of 45.8 cm, and the number of strikes 35, 50 or 75 hits according to the quality of traffic.
7. The samples are first weighed in the air and second and are immersed in water. From these data, the volumetric density can be calculated.
8. The sample shall be placed in a 60 ° C water bath for 30 minutes, then lifted and placed on its side in the crushing heat of the Marshall machine and loaded onto its outer perimeter until the collapse occurs. The maximum load is recorded as the value of the stability, the amount of movement to the maximum load , and the value of elongation.

3.10.2. HMA with CR Mix Design

Table 3.8 Individual components of HMA with crumb rubber

Components	Percent/amount
CRM %	0%, 2.5%, 4.5%, 6.5%, 8.5 %
Bitumen	60/70
Fine Aggregate	0.075-0.5 mm
Coarse Aggregate	1-4mm

3.10.3. Marshal Test for OBC

The Individual stability test values, the flow, rigidity, VIM, and VFWA at the OBC. Then, the smooth curves are determined plotted and compared to the required design criteria. It Should any of the values fail to meet the criteria, the protocols for mix design are repeated until all design requirements are fulfilled.
The indirect tensile stiffness modulus is shown in Table 3.9.

Table.3.9 The indirect tensile stiffness modulus

ASPHALT TYPE		5%	5.5%	6%	6.5%	7%
HMA asphalt (60/70) pen		3	3	3	3	3
HMA crumb rubber	NO CR %	3	3	3	3	3
	2,.5%	3	3	3	3	3
	4..5%	3	3	3	3	3
	6.5 %	3	3	3	3	3
	8.5%	3	3	3	3	3

Total of samples =75

3.10.4. Unconfined Compressive Test

This laboratory was designed to evaluate the unconfined compressive strength of the asphalt concrete sample as presented in Table 3.10**.** The unconfined compression test is by far the most popular method of shear testing and it is one of the fastest and cheapest methods of measuring shear strength.

Table.3.10 Unconfined Compressive Test Samples

Percent of Crumb rubber	**Number of Samples At each Temperature ^{0}C**			
	24^{0}C	**30^{0}C**	**40^{0}C**	**60^{0}C**
Without CRM %	1	1	1	1
2.5%	1	1	1	1
4.5%	1	1	1	1
6.5%	1	1	1	1

Total of samples =20

3.10.5. Indirect Tensile Strength Test

1. **Indirect Tensile Strength Test**

The standard indirect tensile test is used to test the crumbs under wet conditions for this research purpose. The ITS will be determined by measuring the ultimate load to failure of a specimen which is subjected to a constant deformation rate of 50.8 mm/minute. The ITS of asphalt concrete sample it shows in Table 3.11.

Table 3.11 Indirect Tensile Strength (ITS) Samples

Percent of Crumb rubber	**Number of Samples At each Temperature ^{0}C**			
	10^{0}C	**20^{0}C**	**40^{0}C**	**60^{0}C**
Without CRM %	1	1	1	1
2.5%	1	1	1	1
4.5%	1	1	1	1
6. 5%	1	1	1	1

Total of samples =20

2. **Indirect Tensile Strength Modulus Test (ITSM**

Stiffness is one of the important mechanical properties, defined as uniaxial stress divided by the corresponding strain. A base layer behaving high stiffness can protect the soil foundation by decreasing soil shear stress; although this brings a risk that the base layer itself may crack (Brown,1994). The ITSM of asphalt concrete sample as presented in Table 3.12.

Table 3.12 Shows the distribution and number of samples for ISTM.

Percent of Crumb rubber	Number of Samples for ITSM
Without CR %	3
2.5%	3
4.5%	3
6.5%	3

Total of samples =12

3. Test procedures

In the experimental system two types of fatigue testing were used, ITFT a double-point bending test of a cantilever. Additionally, indirect modulus tensile stiffness (ITSM) experiments were carried out to assess the ITFT cylindrical specimens ' stiffness module prior to fatigue testing. The stiffness module for calculating the initial horizontal strain in the ITFT was used**,** the ITSM of asphalt concrete sample as presented in Table 3.13

Table 3.13 Shows the distribution and number of samples for ITFTI.

Percent of Crumb rubber	Number of Samples for ITFT
Without CR %	4
2..5%	4
4.5%	4
6.5%	4

Total of samples =16

3.11 Permeability Test

Table 3.14 Show the distribution and number of samples for Permeability

CR percent in modified Ac	Total Sample
NO CR %	3
2.5%	3
4.5%	3
6.5%	3

Total of samples =12

3.12 Data Collection Techniques

Primary and secondary data collection techniques will be used in this research experiment. Primary data will be collected directly from laboratory experiments. All the data will be recorded on a daily basis until the research is completed. The primary data to be collected include results from:

a. Asphalt examination.

b. Bitumen and aggregate standardization test.

c. Marshall properties test data.

Secondary data will be used for the sake of comparison and standardization of the research. The secondary data will be collected from the previous test was done on:

a. Testing ITS of HMA.

b. Testing UCS of HMA

c. Testing ITSM of HMA

d. .Test ITFT of HMA

e. Permeability

3.13 Data Analysis

Determining the maximum quality of bitumen (OBC) all Marshall Samples will be analyzed at HMA without CR, HMA added with 2.5% CR, HMA added with 4.5% CR, HMA added with 6..5% CRM and HMA added with 8.5% crumb rubber CR. The following volumetric composition will be subjected to each compacted sample. Hot mix asphalt concert of UCS ITS, ITSM, ITSM, and ITFT.The data collected from the laboratory experiments will be presented in different forms like tables, charts, diagrams, etc. The analysis of the Marshall test results in Figures and tables showed that modified with 0%, 2.5%, 4.5.0%, 6.5%, and 8.5% crumb rubber have a correlation between Stability, flow, MQ, VIM, air void, and asphalt content, will show a comparison of, stability, flow, MQ, air void, VFWA, VMA test for asphalt Content (%) with CR and without CR to get OBC, also for ITS, ITFT to analysis data this relationship between the ITS, ITFT, UCS, permeability is shown in Figure, table and chart by using diagrams to compare the results with previous studies.

CHAPTER 4
CHEMICAL PROPERTIES OF CRUMB RUBBER

4.1 Introduction

The petroleum asphalt chemistry at the molecular and intermolecular concentrations has been an important topic and interesting to be discussed, as well as a mixture of understanding and conjecture on how quality features in roadways can be explained by chemical information. At the rate of molecules, previous Studies have shown that in any specific asphalt there are at least hundreds of thousands of distinct molecular kinds. Asphalts are considered to include molecular species whose polarity and molecular weight differ extensively. The main goal of this part of the job is to clarify asphalt cognitive features in aspects of chemistry. To accomplish this objective, three specific parameters, including economic variables, traffic flow, and asphalt mixture, should be taken into account by developers (Peralta2009).

The chemical composition in the mixed asphalt has its characteristics, so it is important to conduct research focusing on the effect of chemical properties of crumb rubber with a different waste tire in mix design asphalt. The waste tire is produced each year, and it threatens the environment due to the pollution of litter, mosquitoes insects, snakes, and rats. Tire waste mostly comes from the automobile industry such as truck, car, bicycle, motor etc which are manufactured by numerous tire companies like MICHELIN, PIRELLI, COOPER, GOODYEAR, MAXXIS, IRELL, KUMHU, CORNELL, DUNLOP, BFGOODRICH, BRIDGESTONE @ CONTINENTALS, UNIROYAL, FURIA, DEND, GAJAH TUNGGAL, and IRC TUNGGAL, etc.

Table 4.1 shows the statistic of the tire waste production in world.

	The number of scarp tire (Million)
USA	266(*270)
Japan	102
France	44.3
Germany	28.2
G.Britain	23.4
Canada	20
Australia	17
Italy	12.1

Date 1998

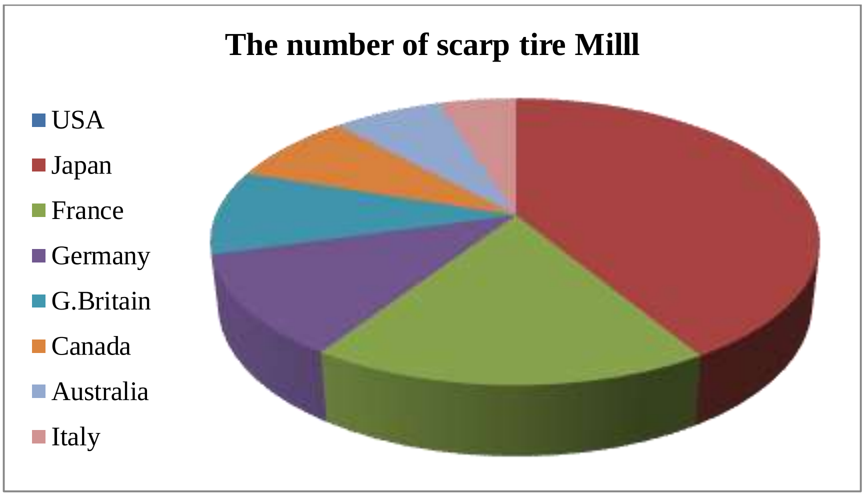


Figure 4.1 The number of scrap tire generated annually

1. **The number of scrap tire stockpiled (in metric tone)**

USA(1996):800 million.

USA (1998):5000 million.

Europe (1990):161 million.

2. **The contents of scarp tire (number %).**

Passenger tire (PS tire):84%

Truck and bus tire (TB tire):15%

Off the road,Air plane and Heavy equipement the (OR/AP tire):1%

The weight range of the TB tire :40-10.000lb.

The avarge weight of PS tire :20lb.

*scarp tire usually has 90% of original weight.

3. Typical tire compostions (wt%):

a. Rubber :85%

b. steel : 12%

c. Fiber :3%.

Average life : 80000 km (50000 miles)

* Today's radial tire lasts twice as long as that of 20 years ago.

Rubber particulate decomposed naturally over 27 years. The tire decomposed naturally over 80 years.

See Also : Anatomy of Tire (MSW in 1996)

. Densities of Shredded and Whole Tires

Approximate Densities		
Loosely Packed		**Densely Packed**
100/10yd^3 (App. 200 Lbs/Yd^3)	Whole Tires (Passenger/Light Truck)	500/10yd^3 (App. 1000 Lbs/Yd^3)
550-600 Lbs/Yd^3	Single Pass	1220-1,300 Lbs/Yd^3
850-950 Lbs/Yd^3	2" Shred	1,350-1,450 Lbs/Yd^3
1,000-1,100 Lbs/Yd^3	1 1/2" Shred	1,500-1,600 Lbs/Yd^3
10 Mesh - 29 Lbs/Ft^3		
20 Mesh - 28 Lbs/Ft^3		
30 Mesh - 28 Lbs/Ft^3		
40 Mesh - 27 Lbs/Ft^3		
80 esh - 25-26 Lbs/Ft^3		

4. Scrap Tire in The Municipal Solid Waste Stream (MSW in 1996)

	Generated (mil. tons/year)	Percent Occuping in Total MSW (wt%)	Recovered Rate (wt%)
Paper and Paperboard	79.93	38.1	40.8
Glass	12.35	5.9	35.7
Plastics	19.76	9.4	5.4
Aluminum	2.98	1.4	34.2
Steel	11.83	5.6	38.0
Tire tires	3.17 (266 mil.	1.6	18.6

4.2 Literature Review

4.2.1. Waste Tire Rubber

The chemical properties of waste tires, there were rubber granules evaluated to determine their chemical composition using X-ray fluorescence. Thermogravimetric and thermogravimetric differential analysis conducted to explore the connection.The temperature and mineralogical characteristics for rubber granules to assess their suitability in the asphalt mixture as an aggregate substitute. (Chen 2011).

4.2.2. Chemical Properties of Waste Tire Rubber

Thermogravimetric TGA (Analysis) the TGA utilizes the decomposition method to assess weight adjustments in samples or equipment. Differential thermal analysis (DTA) detects heat adjustments and refers them to various stages of fabric or sample thermal decomposition. The TGA path modifications are depicted in the DTA by a defined maximum. The TGA and the DTA were used to check the responses and modifications that happen during the heat treatment of the samples (Djakfar, 2011).TGA just to know mechanical properties for thermal strength.

X-Ray Fluorescence (XRF) is a chemical composition element analysis within the particle, more accurate than SEM-EDS / EDAX. X-ray (XRF). The chemical compositions of the rubber tires "Infra-Red Transform Fourier (FTIR). The PerkinElmer Spectrum 100 FT-IR characterized the samples. Before the screening, the samples were in paste form ready. The FTIR assessment was performed with 32 images per sample (1 mg test per 100 mg KBr) on a spectrometer using the magnesium bromide (KBr) pellet method) gathered at 32 cm-1 sizes from 4000 to 650 cm-1 (Hainin, 2012). FTIR plays a role in chemical interaction between anion and action. SEM with EDS/EDAX to confirm the surface morphology, pore structure , and also chemical component inside the particle.

4. 3 Result and Discussion Chemical Properties of Crumb Rubber

Within this analysis, the chemical properties of rubber crumbs are discussed, and the result of chemical properties tire waste from various sources compared to content crumb rubber and impact chemical properties of crumb rubber in the mix design. Also, analyze every chemical property in which sources of tire wastes measure by TGA, XRF, SEM, and FTIR.

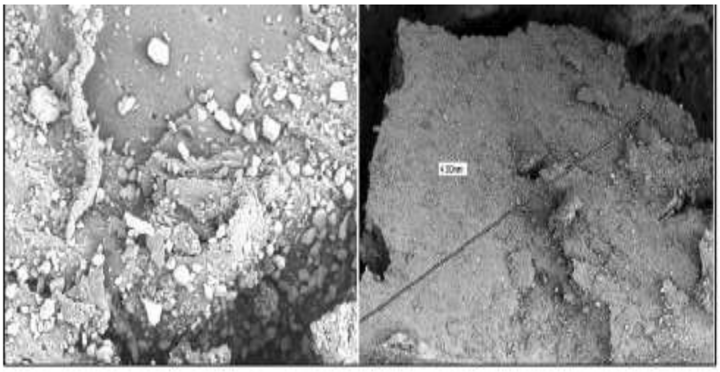


Figure. 4.2. Thermogravimetric Analysis Crumb Rubber

4.3.1. Thermogravimetric Analysis (TGA).

From the Figure above the derived weight (mg / min) can be said to decrease along with several samples temperature, and the lowest was during the temperature 400°C and after that increased again until the temperature 1000°C. From the graph above, it can be said that the derivative weight (%/min) decreases along with the temperature of the number samples, and the lowest was at the temperature of 580.59 °C is the maximum degradation temperature of the sample with the residue is 34.23%. Plastic rubber asphalt (PRA) mix with asphalt styrene-butadiene (SBS) mix has comparable performance in high temperatures, low temperatures, and water durability. Plastic Rubber Asphalt (PRA) mixture is more environmentally-friendly.

However, mixtures containing these binders are more prone to cracking at low temperatures. Comparing the described technologies and providing justifications and suggestions toward the widespread use of Recycled Tire Rubber Modified Bitumen (RTR-MBs) (Chen S2011). Changed crumb rubber binders and crumb rubber features are more widely recognized. It is, therefore, possible to estimate the ground effectiveness of crumb rubber modifier pavements more properly. Crumb rubber modifier performance was revealed to depend on multiple factors such as crumb rubber, mixing circumstances, mixing variables, overall gradation, and compaction method used (Wanga2012). This thesis addresses the application of asphalt crumb rubber hot mix (Dry Process), and its impact on bituminous mixture bearing capacity and cohesion.

From Figure 4.3. illustrates the TGA and DTA of a waste car tire. it can be said that the maximum decomposition temperature (Td) of waste tire care was at 507.59°C which was indicated by the highest weight reduction rate of 5.23 wt%/ min in DTA. There were 32.5 wt% residues at the end of the heating process.

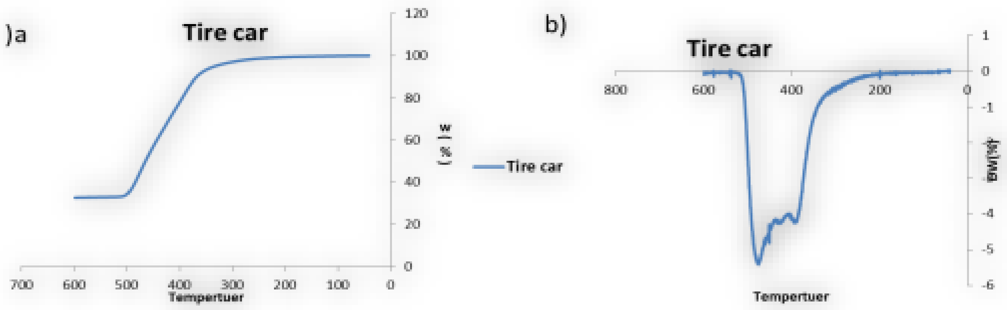


Figure 4.3 TGA (a) and DTA (b) Curve of car tire wastes (by Co. Dunlop 2016**)**

Figure 4.4 illustrates the TGA and DTA of the truck tire wastes. it can be said that the maximum decomposition temperature (Td) of the truck tire wastes was at 507.98°C which was indicated by the highest weight reduction rate of 7.02 wt%/ min in DTA. There were 31.17 wt% residues at the end of the heating process

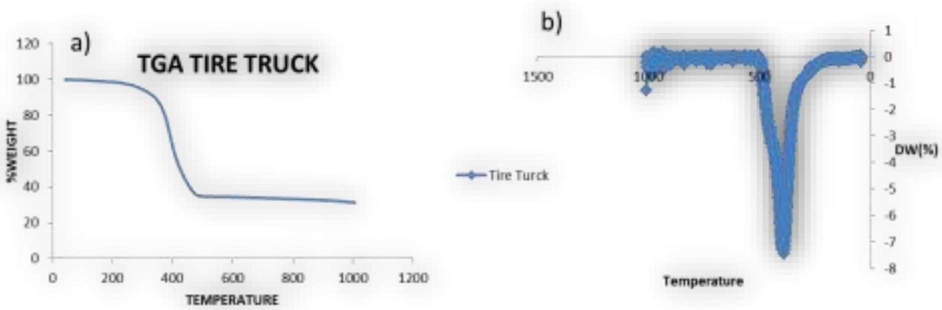


Figure 4.4 TGA (a) and DTA (b) Curve of truck tire wastes (by Co. Gajah Tunggal 2016

Figure 4.5 illustrates the TGA and DTA of the motorcycle tire wastes. It can be said that the maximum decomposition temperature (Td) of waste tire motor was at 507.98°C which was indicated by the highest weight reduction rate of 4.72 wt% min in DTA. There were 32.11 wt% residues at the end of the heating process.

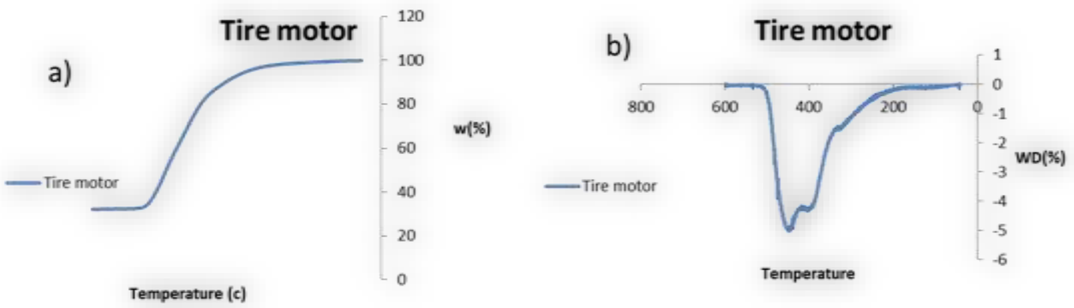


Figure 4.5 TGA and DTA Curve of motorcycle tire wastes (by Co.IRC2017).

Figure 4.6. illustrates the TGA and DTA of the bicycle tire wastes. it can be said that the maximum decomposition temperature (Td) of the waste tire Bicycle was at 507.92°C which was indicated by the highest weight reduction rate of 4.22 wt% min in DTA. There were 39.19 wt% residues at the end of the heating process.

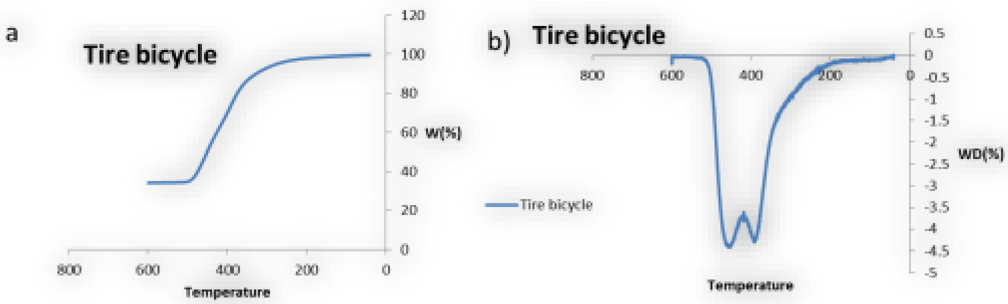


Figure 4.6 TGA and DTA Curve of the bicycle tire wastes (by Co.Dend 2011)

Based on the TGA study, it was revealed that the truck and motorcycle exhibit the highest decomposition temperature as compared to other waste tires T_d of 507.98°C followed by the bicycle waste with T_d of 507.92°C. On the other hand, the bicycle has the highest residue of 39.19 wt%. It is expected the bicycle waste tire consists of high metal content. Thus, bicycle waste tire is suitable to be used as an asphalt additive to improve the thermal resistance due to high degradation temperature and residue.

4.3.2. Fourier Transform Infra-Red (FTIR).

"In many nations, the building is limited to summer months as the compact foundation cools the asphalt too much during the winter before it can be filled to the necessary density. Hot mix asphalt (HMA) is the most common type of asphalt used in high-speed roads, such as those on main roads, roads, and airports. Using used car tires on road pavement building is a method that can enhance the efficiency of Hot Mix Asphalt (HMA) and address the issue of trash for sustainable development. (Wanga,2015). Over four centuries of Caltrans expertise, asphalt rubber goods can be lasting and stretch the service life of the pavement if correctly intended, produced , and built (Pasetto, 2012).

The entire sample showing a similar FTIR spectrum as can be seen in Figure 6. The peak at 1000 cm¬-1 corresponds to refer to C-H from vinyl groups. The peak at 1600 cm¬-1 corresponds to refers to conjugated C=C. The peak at 1500 cm¬-1 corresponds to refers to C=C aromatic groups. The peak at 2900 cm¬-1 corresponds to refer to C-H methylene groups. The peak at 2850 cm¬-1 corresponds to refer to C-H methylene groups. The peak at broad peak 3400 cm¬-1 corresponds to refer to hydrogen bonding of O-H. The result strengthens the assumption that all the tires were manufactured using the same chemical compound of polystyrene which also reported previously.

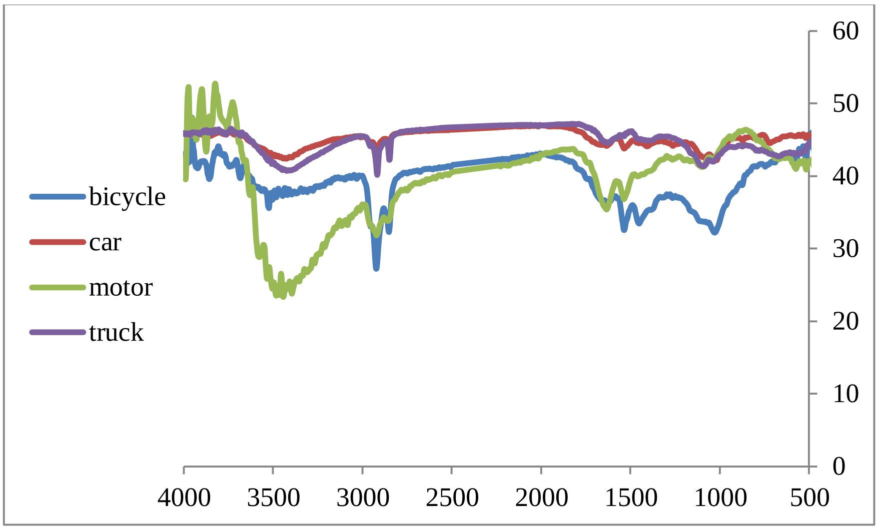


Figure 4.7 Fourier Transform Infra-Red with different type of tire wastes

Hot-mixed asphalt is classified as a constant thick graded blend of crude and heavy aggregates, mineral filler , and blended crop. It is supplied, distributed, and compacted while still warm. It is necessary to pave and compact while the asphalt is sufficiently hot. In many nations, the building is limited to summer months because the compact foundation cools the asphalt too much during the winter (Ramez, 2016). Using a waste tire in asphalt pavement is extremely common in the latest years. A significant amount of waste tires can be consumed by Crumb Rubber Modified (CRM) pavement. Besides, the addition of crumb rubber to asphalt can enhance its efficiency (ZY,2013). Many surveys have shown that pavement with CRMA improves life paving by improving cracking and rotting resistance, reducing traffic noise, and general maintenance cost reduction. Moreover, some scientists have discovered that the use of crumb rubber in asphalt binders can increase the strength of fatigue (Wei,2016). From here, it is possible to complete previous studies to know the new percentage of crumb rubber also to conduct experiments on temperature variations.

Materials such as crumb rubber, plastic, rubbers, fly ash, bagasse ash, and tire waste pose to become environmental pollution in the nearby locality because many of them are non-biodegradable. It is vital to know the products engaged in sidewalk building in an attempt to improve pavement efficiency to improve hot mix asphalt (HMA) performance, crumb rubber could, therefore, be an alternative material (Martínez2013).

Asphalt pavement also faces multiple types of stress. Chemical or chemical stress such as traffic loading, moisture damage, and oxidative aging) can eventually lead to pavement cracking. Therefore, a better understanding of asphalt performance and improvement of pavement durability affecting pavement durability (Wei, 2016). Asphalt absorption will reduce the effective binder content in the pavement, while oxidative hardening of asphalt will eventually lead to pavement fatigue and cracking. A better understanding of these two properties in asphalt pavements can help minimize the maintenance of pavement and improve its performance to reach a successful HMA pavement design. The disposal of tire scrap has posed severe pollution issues due to the global rise in the number of cars A tire does not decompose and can stay 80 to 100 years in a landfill (Shu, 2014).

Rubber and plastic wastes are accumulating heavily in China and causing significant environmental issues. The advantage in bonding properties leads to an advantage in mixed field performance where use pavement rubber. These benefits include enhanced abrasion resistance, enhanced durability, enhanced fatigue life, enhanced constructive cracking strength, enhanced rutting strength, noise reduction, reduced construction time, energy , and resource-saving.

However, standard asphalt's vibrant characteristics and durability are deficient in preventing pavement distress. The job of existing asphalt scientists and technicians is to search for various forms of polymer-modified asphalt, including crumb rubber (Qiu 2016), the term 'reinforced pavements' refers to the use of one or more pavement construction strengthening components.

The use of strengthening components in asphalt is another implementation of pavement strengthening. Asphalt overlays to provide the asphalt coating with appropriate tensile strength and to stop pavement errors such as thermal splitting (Wei,2016.).

4.3.3.Result of XRF with the X-ray Fluorescence method.

Figure 4.7 is Figure indicates of components of bicycle waste tire Based on the graph above, it can be said that the Silica is higher than the phosphor Silica with 4.1% while phpshore with 1.5%, but Sulfur is higher with 20.6%, while the Potassium (P) is lower than Sulfur with 1.3%. The lowest is Mn with.13% and Chromium with.14% with, but the highest is Zinc. Based on the graph above, it can be said that the Silica is higher than the phosphor, but Sulfur is higher, meanwhile, the Iron content (Fe) is lower than Sulfur with 7.73%. The lowest is Copper (Cu) with 1.47%and Rubidium (Rb) with 0.1%, but the highest is Zinc (Zn) with 54.2% of the sample weight.

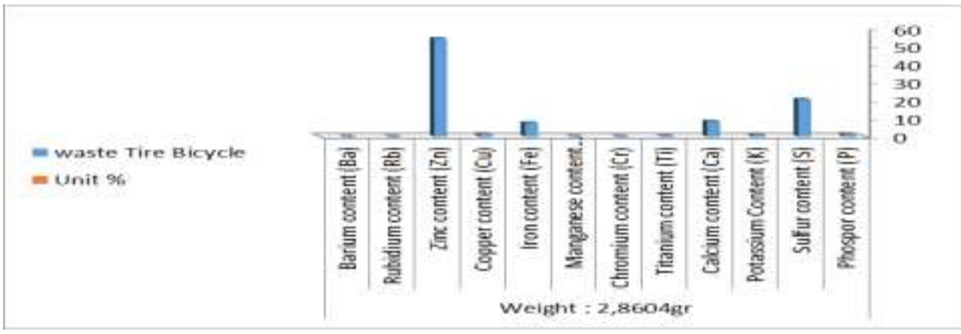


Figure 4.8 bicycle tire wastes from CO. Dend, 2011

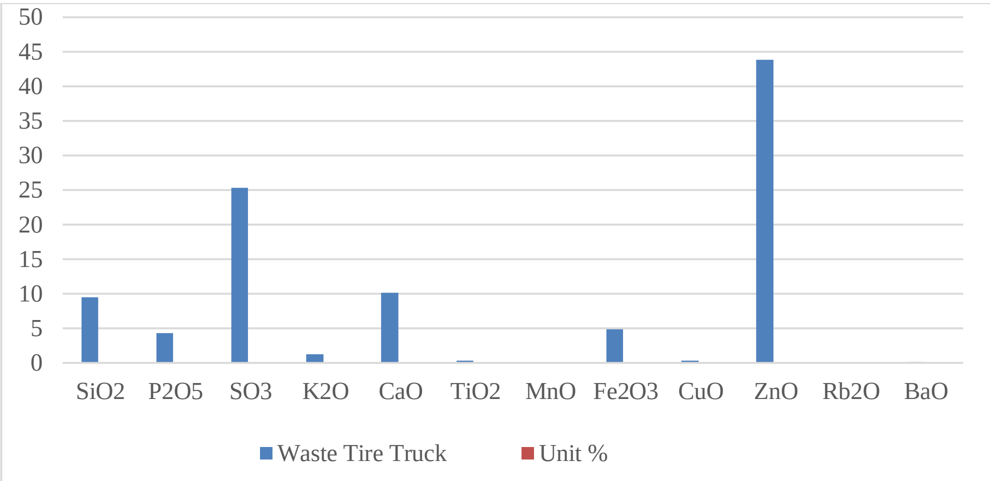


Figure 4.9 Truck tire wastes from CO.Gajah Tunggal Years 2016

Based on the graph above, it can be said that the Sulfur content (S) is higher than the Calcium content (Ca) with 15.9% while Ca with 10.9%, but both Sulfur and calcium are higher. Meanwhile, Iron content (Fe) is higher than Silica with 5.23%. The lowest is Rubidium (Rb) with 0.06 %, while Mn with o.1 and the highest is Zn with 57.4% of the sample weight.

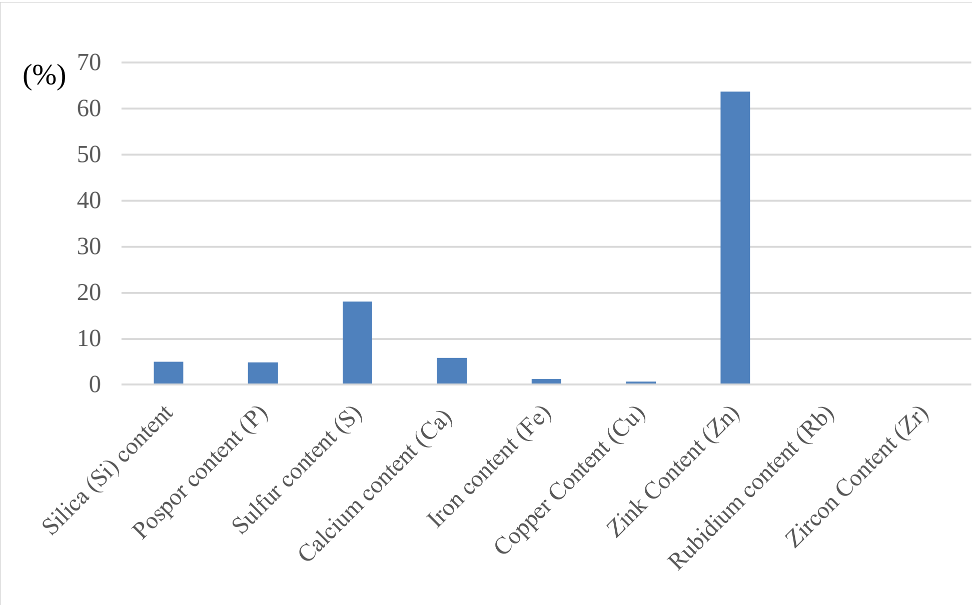


Figure 4.10 Car tire wastes from CO.Dunlop Tunggal Years 2016

Based on the graph above, it can be said that the Sulfur content (S) is higher than the phosphor content (P) with 18.1 while (P) with 4.9, but both Sulfur and phosphor are higher. Meanwhile, Silica is higher than Iron content (Fe) with 5% while (Fe) with 1.3%. The lowest is Zirconia content (Zr) with 0.06%, Rubidium (Rb) with 0.10% and, the highest is Zn with 63.7% of the sample weight.

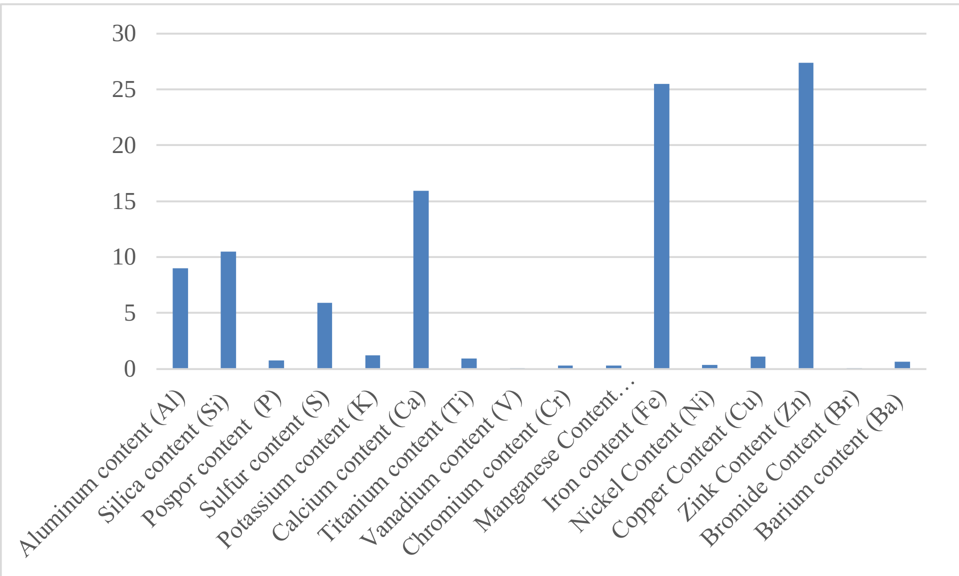


Figure4. 11 Motorcycle tire wastes From CP.IRC Tunggal Years 2017

Based on the graph above, it can be said that the Iron content (Fe) with 25 % is higher than the Calcium content (Ca) %. Meanwhile, Iron content is higher after Zink content (Zn). The lowest is Bromide content (Br) with 0.09% and Vanadium content (V) with 0.01, the highest is Zn with 27.4% of the sample weight. To understand the heavy element composition of all waste tire, the FNS analysis was conducted at a temperature of 22.6°C and 55% humidity (Figure 9). As can be seen in Figure 9, all the waste tire consisting of similar heavy elements such as silica, sulfur, chromium, zinc, etc. Elements such as Silica, Sulphur, Chromium, Zinc, and Copper have dominant presences in all tire waste. Intestinally, the bicycle tire the highest Zinc, and Sulphur content which is considered as toxic to the environment (The results show that the introduction of LDHs improves the UV aging resistance of asphalt. By comparison, Zn-Mg-Al LDHs are superior to Mg-Al LDHs in improving the aging performance of asphalt, which is due to the more outstanding UV shielding of Zn-Mg-Al LDHs in comparison with Mg-Al LDHs, leading to a beneficial effect in improving UV aging performance of asphalt (Xu, 2015).

The compatibility between bitumen and nano-ZnO is improved by surface modification of nano-ZnO. As a result of UV aging, the viscosity aging index of bitumen is decreased with the addition of nano-ZnO and KH-560-nano-ZnO. The carbonyl indices of nano-ZnO and KH-560-nano-ZnO modified bitumens are decreased more remarkably in comparison with that of unmodified bitumen after ultraviolet (UV) aging such a result suggests that nano-ZnO can be effectively used as a modifier to improve the ultraviolet (UV) aging resistance of bitumen. On the other hand, the highest valuable metal content such as Chromium and Copper was a presence in car and truck tire waste respectively. The highest silica content was observed in the motorcycle tire waste.

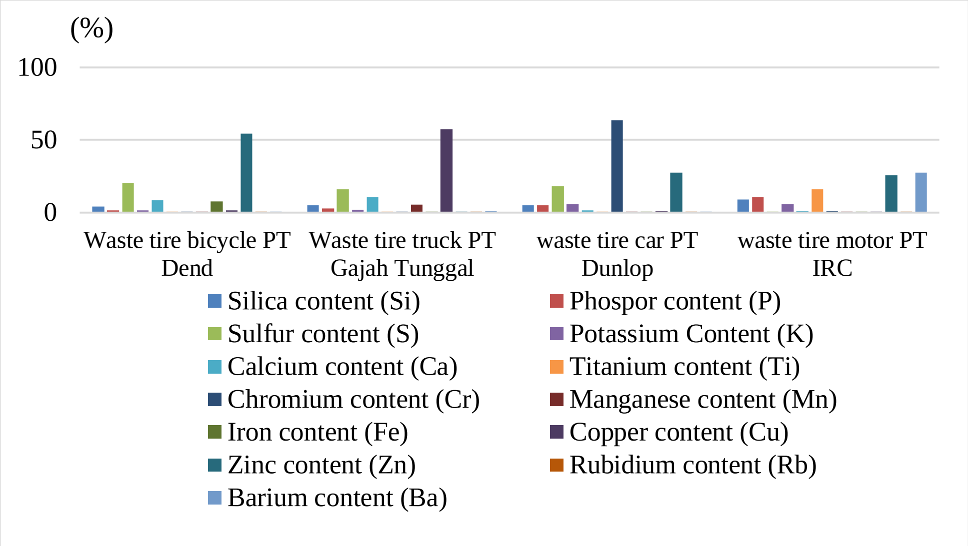


Figure 4.12 FNS Analysis

The FNS analysis was done at a temperature of 22.6°C and 55% humidity. The result showed that the bicycle has the largest Cr element and the largest Cu element of the truck waste tire. Meanwhile, the largest element of Cr and Zn is the vehicle tire wastes. Finally, the largest element of Cr and Ba is the motorcycle tire wastes.

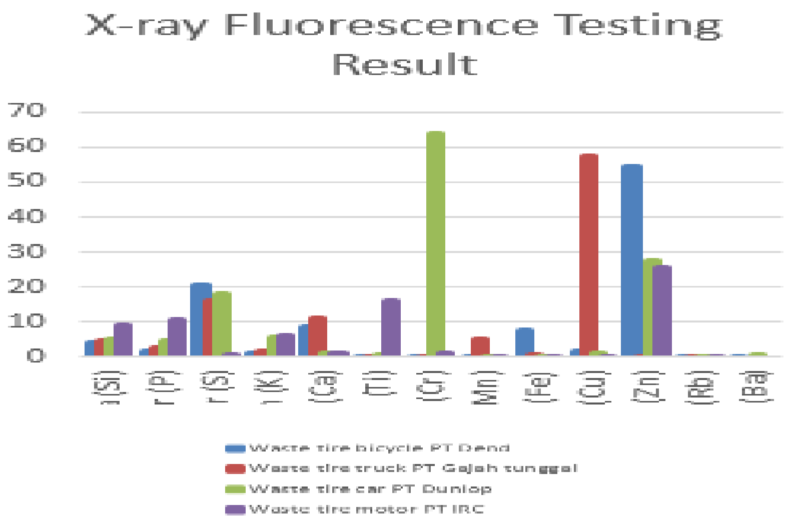


Figure 4.13 X-ray Fluorescence Result

Based on the graph, it can be seen that S, P, Cr, Zn are higher compared to other compositions in the wastes of bicycle, car, truck, and motorcycle tire. Meanwhile, the highest in the waste tire of motorcycle and the lowest in the waste tire of a bicycle. The highest content during the X-ray fluorescence experiment is

Chromium (Cr) material and Barium (Br) concentration is the smallest. X-ray fluorescence spectrometer (XRF) is an X-ray machine used regularly, chemical rocks, fossils, sediments , and liquids relatively non-destructive.

It operates on an electron microprobe-like wavelength-dispersive spectroscopic theory. However; XRF generally cannot assess a small location sort typical of EPMA (2-5 microns) work. Therefore, normally used to evaluate most fractions bigger than geological components. Ease of cost and relatively low preparation of samples and stabilization and convenience of using one of the most commonly used tools are X-ray spectrometers analyzing key components and residues in stones, minerals, and sediments (ASTM D5381).

The XRF method relies on the fundamental values prevalent to several other techniques of instruments involving relationships between the electron beam and the sample X-ray is X-ray included microscopy (E.g. SEM-EDS), X-ray and dispersive diffraction (XRD) detection of the spectrum (WDS microprobe). A review of the primary components and residues of X-ray fluorescence in geological products is rendered feasible by the conduct of atoms when interacting with radiation (Qiu,2016).

The result shows that bicycle the waste tire has the largest Cr element and the largest Cu element of the truck waste tire. Meanwhile, car the largest element of the waste tire is Cr and Zn. Finally, motorcycle waste pneumatics has the largest Cr and Ba element. The chemical composition of the crumb rubber mix with all tire wastes shows in Table 4.2.

Table 4.2 chemical composition of crumb rubber.

Chemical composition	**Percentage [%]%**
Si	5.8
S	12.8
K	0.82
Ca	9.09
Ti	0.62
V	0.02
Mn	0.16
Fe	9.4
Cu	0.39
Zn	60.1
Br	0.88

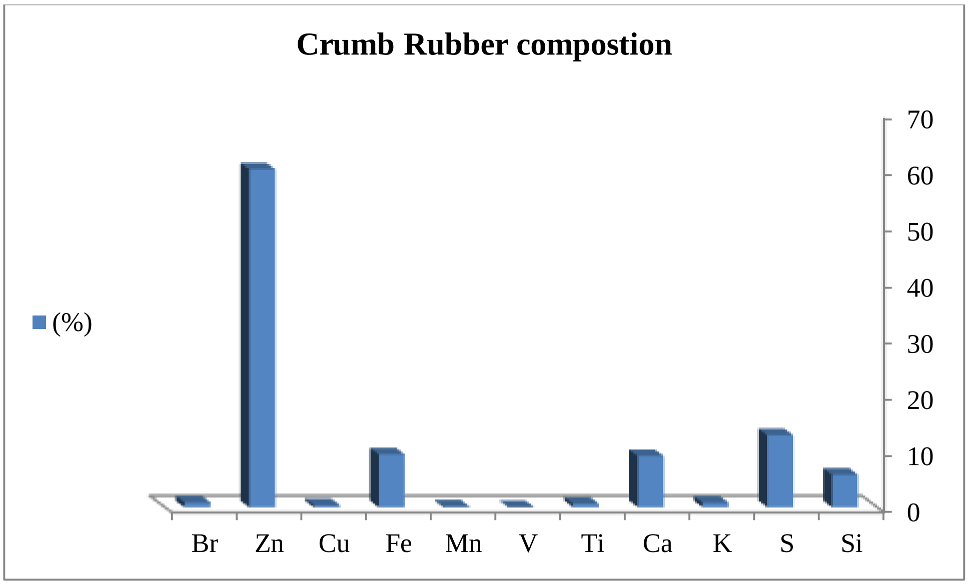


Figure 4.14 XRF for crumb rubber content

Based on the graph above, it can be said that the sulfur (So3) with 12.8% is higher than the Silica content (Si) with 5.8%. Meanwhile, sulfur content is higher after Zink content (Zn). The lowest is Manganese content (Mn) with 0.16% and Vanadium content (V) with 0.02%, the highest is Zn with 60.1% of the sample weight. Overall, it can be seen that the crumb rubber chemical composition was similar to the truck and car waste tire.

From the results, there is a convergence in the components of crumb rubber, and components of bicycle, truck, car, and motorcycle from the sulfur content, which is very important in mix design for a beneficial effect in improving ultraviolet (UV) aging performance of asphalt. Three surface modifiers increase the dispersion stability of the nano-zinc oxide in bitumen. APTS-nano-zinc oxide modified bitumen displays the lowest VAI values and carbonyl index after ultraviolet (UV) aging compared with MTS and EPTMS, showing its high resistance to UV aging. (Liu,2014).

The results of sulfur components were as follow for crumb rubber, bicycle, truck, car, and motorcycle the grade as follows (12.8%, 20.6%, 15.9%, 18.1%, 5.9%). The higher is the bicycle and the lower is a motorcycle. Sulfur is a bright, tasteless non-metallic element. Sulfur hardness ranges from 1.5 to 2.5 on a banana scale, which is brittle and easily breaks. Sulfur is present in several forms called allotropes.

While the results there is a convergence in the components of crumb rubber, and components of bicycle, truck, car, and motorcycle from the Zinc content, which is very important in mix design for strength, toughness, ductility and conductivity properties. The results of sulfur components were as follow for crumb rubber, bicycle, truck, car, and motorcycle the grade as follows (12.8%20.6%,15.9%,18.1%,5.9%). The higher is the bicycle, and the lower is a motorcycle.

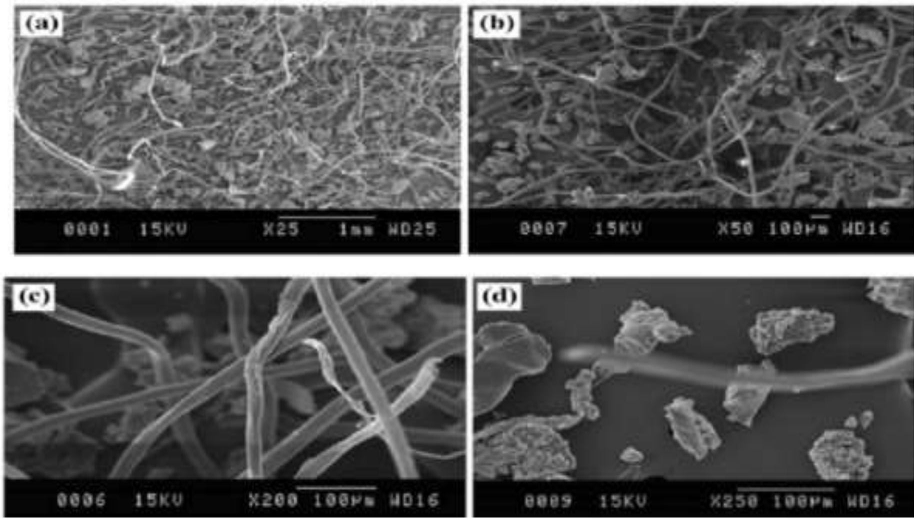


Figure 4.15 Typical SEM images of the RTF mixed with GTR at different magnifications. a) 25x, b) 50x, c) 200x, d) 250. SEM: scanning electron microscope; RTF: recycled tire fiber; GTR: ground tire rubber'.

When high-energy, short-wavelength radiation (e.g. X-rays) excites ingredients, it can become ionized. If enough radiation energy to remove an electron in a meeting is held, the atom becomes unstable and the external electron replaces the internal electron lost. The released radiation is less powerful than the primary incidence of X-rays and is called neon radiation. According to the energy of the photons released in a particular case, the element is the characteristic of the transition between specific electrons orbitals, fluorescent X-rays can be used to detect the abundance of elements in the sample.

The use of petroleum asphalt as a pavement mixer, although it meets the requirements of the specification, often shows a decrease in service behavior due to rutting, fracture, and other forms of damage. Fractures from or on the sidewalk ease water to enter and it can damage the paving structure due to the movement of air and water on the sidewalk causing oxidation and evaporation to occur in the binder. As a result, sidewalks have relatively low durability.

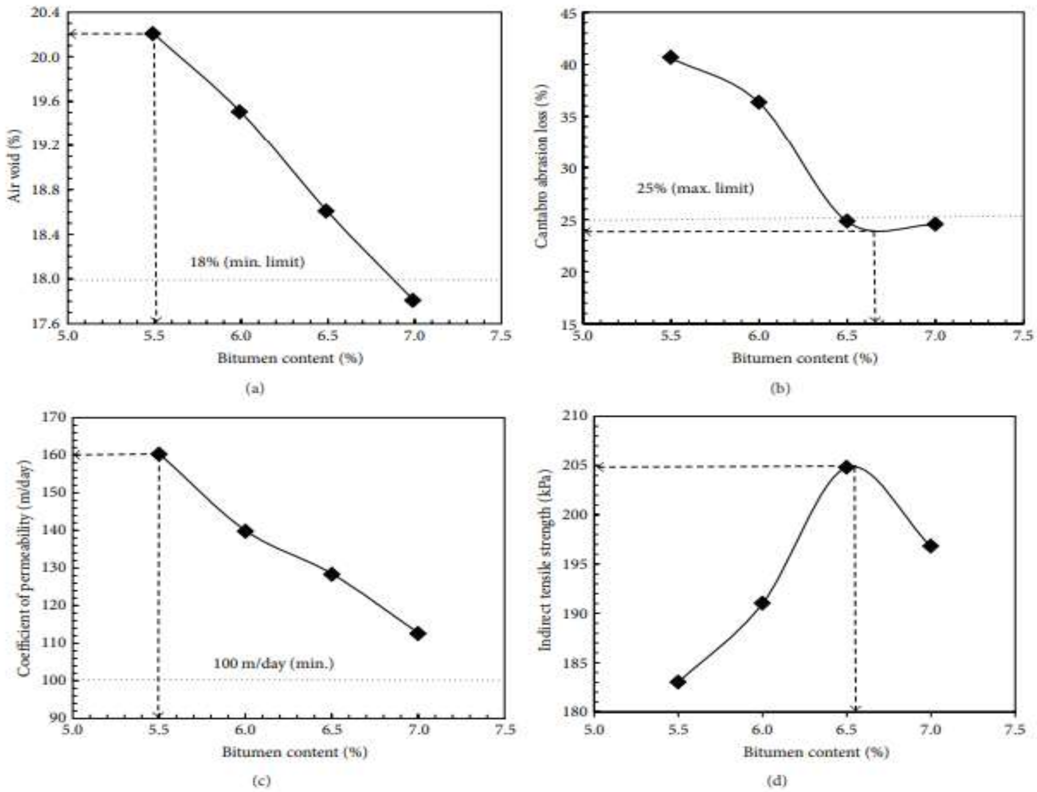


Figure 4.16 Bitumen Content

In pavement, asphalt is absorbed by the porous aggregates, illustrating a typical asphalt absorption status. Asphalt absorption needs to be correctly estimated for a successful pavement mixture design since it affects the effective binder content. Asphalt oxidation can significantly increase pavement stiffness.

Unless correctly reused and/or rejected, waste tires present important safety and environmental concerns. Recycling waste tires in civil engineering apps over the years, particularly in building mixtures of asphalt has been done (Xiang,2013). Mixing synthetic rubber, natural rubber, white wood, vitamins, fillers, and cold concrete oils. The disposal tire has been one of the biggest issues in the nation, there are no significant economic issues with correctly treated scrap tires or disposal tires. However, waste tires can be a danger to the atmosphere if treated incorrectly. Tires subjected to the components can retain water and be a testing ground for disease-carrying mosquitoes. Tire stacks can also be fired by incendiary or accident.

These flames are hard to carry out and generate heavy smoke and rivers toxic run-off. Other vermin, such as rats and snakes, may also harbor tire stacks. Because of the growing amount of scrap waste tires, some overseas nations have grown up with the concept of using it again and since then several applications have been found, including in building materials Crumb rubber is produced by buffing tires or peeling tires. Tire buffing and tire peeling are the tires recapping the industry's disposal commodity. A used tire is buffed with residual dust or the material is removed from the tire to create a soft, standardized texture for assembly of the fresh tread (Lhwaint, et al, 2017).

Characteristics of aggregate inputs to bitumen blend characteristics would be gradation, the surface texture of solids, the structure of fibers, cleanliness, and chemical composition. The increase varies the rubber type used and the process by which the rubber is incorporated into the bitumen. Pre-blending bitumen with rubber is, therefore, a needed move to create an effective rubberized bitumen binder, likely owing to appropriate and effective bitumen dispersions. Controlled-strain flexural fatigue analysis shows that their fatigue resistance can be enhanced by incorporating CRM in combinations.

The degree and sort of rubber alteration appear to rely on the magnitude of the enhancement (Xin,2014). The increased fatigue conduct of CRM combinations was also stated by multilayer elastic assessment coupled with fatigue sample outcomes for typical Alaskan circumstances. Mixed waste is waste containing a component of hazardous waste and radioactive material. The impact on the rigidity of the asphalt binder requires to be assessed, as the inclusion of nanoscale powders significantly enhances the binder, as Cr and Zn in asphalt design. The crumb rubber is produced by shredding waste tire, a specific fiber- and steel-free fabric. The particle of rubber is graded in many sizes and shapes. The rubber crumb is described or assessed during the manufacturing stage by the mesh screen or sieve magnitude it passes through.

Generally speaking, it is essential to decrease the volume of the tires to generate crumb rubber. There are two crumb gum production methods: atmospheric milling and cryogenic method (Takallou,2014). It is possible to divide the environmental processing method into two techniques: granulation and cracker factories. The environment defines the temperature when the rubber of the disposal wheels is decreased in volume. The product is packed at ambient temperature in the chip factory or granulator. Cryogenic grinding is a slower, mildly quicker procedure this outcome in a decent production of the mesh size. The elevated price of this method is a drawback owing to the additional expense of liquid nitrogen**.**

While the results there is a convergence in the components of crumb rubber, and components of the bicycle, truck, car, and motorcycle from the Zinc content as follows (60.1%, 54.2%, 57.4%, 63.7%, and 27.4%), which is very important in mix design for tensile strength, compressive strength ductility and conductivity properties. The results of sulfur components were as follow for crumb rubber, bicycle, truck, car, and motorcycle the grade as follows (12.8%, 20.6%, 15.9%, 18.1%, 5.9%). The higher is the bicycle, and the lower is a motorcycle. Characteristics of aggregate inputs to bitumen blend characteristics would be gradation, the surface texture of solids, the structure of fibers, cleanliness, and chemical composition.

The increase varies the rubber type used and the process by which the rubber is incorporated into the bitumen. Pre-blending bitumen with crumb rubber is, therefore, a needed move to create an effective rubberized bitumen binder, likely owing to appropriate and effective bitumen dispersions. Controlled-strain flexural fatigue analysis shows that their fatigue resistance can be enhanced by incorporating CR in combinations. Overall, it can be stated that Zn content dominated in all tire waste and accompanied by the other elements such as Ca, and Si. The noticeable difference between car-based and the motorcycle-based tire was the Fe Iron content, where the cycle-based tire exhibits higher Fe compare to a crumb rubber composition.

It is recommended that the bicycle, car, and truck tires waste is the most applicable candidates as an asphalt additive due to high Zn content. The chemical composition of these tire wastes similar elements on the crumb rubber, thus they very promising to be used as an asphalt additive. Moreover, all of the tire waste exhibits similar thermal degradation at ~507°C.

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CHAPTER 5
THE RESULTS OF MARSHALL, MECHANICAL AND DURABILITY PROPERTIES ON CRUMB RUBBER AGGREGATE REPLACEMENT FOR HOT MIXTURE ASPHALT CONCRETE

5.1 Introduction

The purpose of this analysis is to realize the feasibility of using crumb rubber as an additive in modified hot mix asphalt with some contrast to improve the quality of asphalt and learn the properties of crumb rubber asphalt. Comparing the two types of properties of the hot mix asphalt (without and with CR). Comparing the two types of the hot mix asphalt materials (without and with crumb rubber) to the Marshall properties (stability, flow, MQ, VITM, VFWA, and air void for optimum asphalt contact, ISTM, ITFT and UCS at different test temperatures of 24C°, 30 C°,40 C°, and 60 C° ITS at different test temperatures of 10°C, 25°C, 40°C, and 60°C, and permeability test.

Chapter 3 presented the approaches used for this research. This chapter describes the outcomes of each method for evaluating the properties and will be further examined and discussed in detail.

5.2 Materials and properties

The primary materials used in this analysis are: coarse aggregate asphalt AC 60/70, fine aggregate, and CR All the key properties of the materials used were tested for further research; multiple experiments were carried out to determine their properties in compliance with the AASHTO, and Bina Marga 2014, Britsh standard conditions referred to as standard AASHTO and Bina Marga specifications.

5.2.1.Asphalt

Asphalt Properties Test AC 60/70 produced by CO. PERTAMINA. The table presents the results of properties test asphalt AC 60/70, Table 4.1 shows some properties of the bitumen 60/70. This test was conducted according to (Bina Marga, 2010) presents the properties test results for each form of 60/70 asphalt.

Table 5.1 Result of properties test of asphalt 60/70

No	Characteristics	Result	Specification (Bina Marga |2014)
1	The Specific gravity of asphalt	1.035	Min.1
2	Penetration (mm)	64.3	60-79
3	Ductility (cm)	142	Min. 100
4	Flashpoint and fire point ©	328 -399	Min. 200
5	Softening point (c)	52.5	48 - 58
6	Asphalt solubility in TCE (tri chlore enthelyn)/CCL	99.115	MIN.99

*Summarized results from detailed tests in Appendix C

5.2.2. Aggregate

The mixture used as the ingredients for the hot mix asphalt. The analysis as a Table is based on the properties testing of coarse aggregate and fine aggregate**.**

1. **A.Properties of Aggregates.**

At the preliminary stage, the aggregate was sieved following Indonesian standards and separated on the selected aggregate gradation according to the size of sieves. The total weight needed for aggregates was 1200 grams. Table 5.2 and Figure 5.1 show the aggregate gradation specification for HMAand the gradation used in this study.

Based on Figure 5.1, it can be concluded that the selected aggregate gradation used in this study can meet Bina Marga's graduation requirement. (2014). Similar to hot mix asphalt, aggregate products need to be tested to determine whether the requirements are met by their properties. In this analysis, many aggregate properties have been evaluated, specific gravity, abrasion, flakiness and elongation indices, and so on, to ensure that the aggregates used in asphalt mixtures can be used.

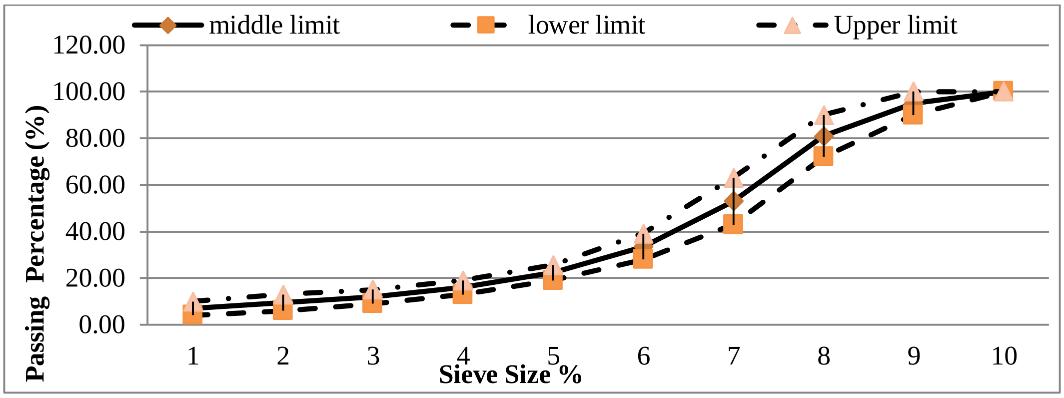

Figure 5.1 Gradation limit for Hot Mix Asphalt Concrete

Table 5.2 Properties of coarse aggregate

No	Properties	Result	Specification (Bina Marga2014)
1	The Bulk specific gravity of coarse aggregate	2.64	≥ 2.5
2	SSD specific gravity of coarse aggregate	2.67	≥ 2.5
3	Apparent specific gravity of coarse aggregate	2.714	≥ 2.5
4	Water absorption of coarse aggregate	1.02	≤ 3
5	Abrasion	24.08	≤ 40
6	Adhesiveness	92.15	≥ 95

*Summarized results from detailed tests in Appendix C

Table 5.3 Properties of fine aggregate

No	Properties	Result from Fine aggregate	Specification (Bina Marga 2014)
1	The Bulk specific gravity of fine aggregate	2.52	≥ 2.5
2	SSD specific gravity of fine aggregate	2.59	≥ 2.5
3	Apparent specific gravity of fine aggregate	2.723	≥ 2.5
4	Water absorption of fine aggregate	2.94	≤ 3

5.3 Marshall Properties Test Results.

The test is conducted to have the optimum results of the hot mix asphalt with crumb rubber. The tests here were performed for various types of mix with CR composition of 0% (without CR), 2.5%, 4.5%, 6.5%, and 8.5% CR. In every CR content, the results from Marshall Stability tests are presented. The test results include the following Marshall Properties, which are: Marshall Stability (in Kg), Flow (in mm), Void (containing air) in Mix, VIM (in %), Marshall Quotient, MQ (in Kg/mm), (Total) Void in Mineral Aggregates, VMA (in %), and Void Filled with Asphalt, VFWA (in %).

For the gradation of aggregates used in this study, the following specification is used to determine the optimum bitumen content to be used in the field (Bina Marga, Indonesia, 2017):

- Marshall Stability, minimum value = 800 Kg.
- Marshall Flow, minimum value = 3 mm to maximum value = 5 mm.
- MQ, minimum value =250 Kg/mm to maximum value = 350 Kg/mm.
- VIM, minimum value = 3.5% to maximum value = 6%.
- VMA, minimum value = 15%, no maximum value.
- VFWA, minimum value = 65%, no maximum value.

The above specification will determine the optimum asphalt content to be prescribed for the actual design AC mixture in the field.

5.3.1. Mixture without Crumb Rubber Content (0% CR)

Summary of the results of complete Marshall Tests for hot AC mixture with 0% CR can be given in Table 5.4, while the Stability correlations are given in Figure 5.2.

Table 5.4 Results of Marshall Properties of Hot Mix Asphaltic Concrete without crumb rubber (0% CR)*

AC (%)	Stablity (Kg)	Flow (mm)	VIM (%)	Mq (kg/mm)	VMA (%)	VFWA (%)
5.0	1685.49	4.45	1.06	378.76	9.24	52.67
5.5	1813.50	4.90	7.67	370.10	17.28	55.63
6.0	1621.48	4.92	5.22	329.57	17.01	66.43
6.5	1173.44	4.97	4.99	236.10	16.95	70.58
7.0	803.63	5.73	1.05	140.25	16.57	93.64

*Summarized results from detailed tests in Appendix E

The figure indicates this relationship between the stability and the HMA

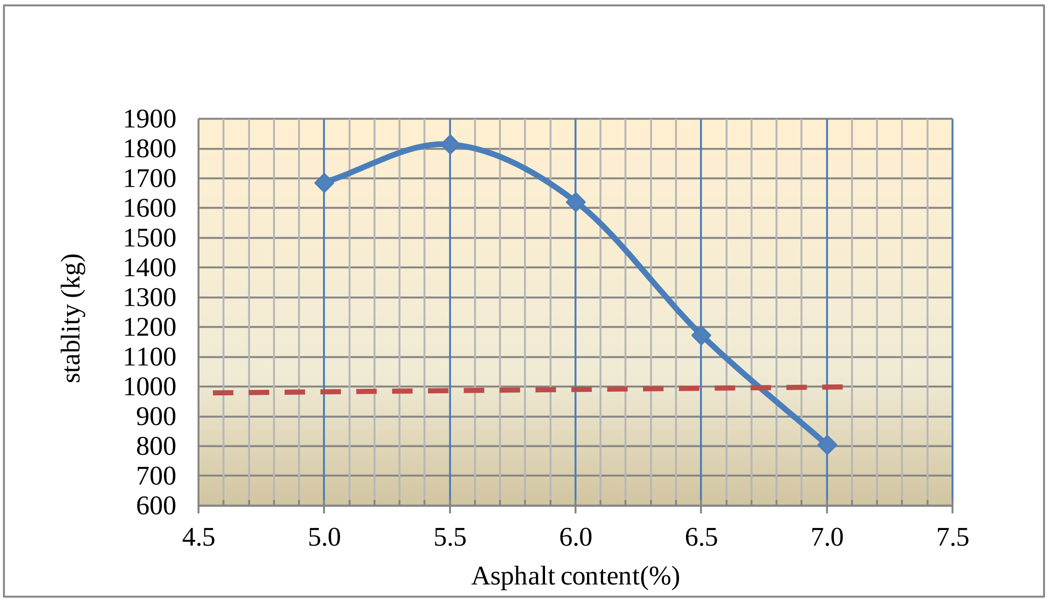

Figure 5.2. Correlation between Stability and asphalt content for mixtures with 0% CR.

From Figure 5.2 it is apparent that for the range of the prescribed asphalt contents from 5% to 7% all the specimens tested are meeting the minimum Stability value of 800 Kg. The highest Stability value is 1813.5 Kg for asphalt content 5.5%.

From Table 5.2, correlations between the flows and the asphalt contents can be drawn in Figure 5.3.

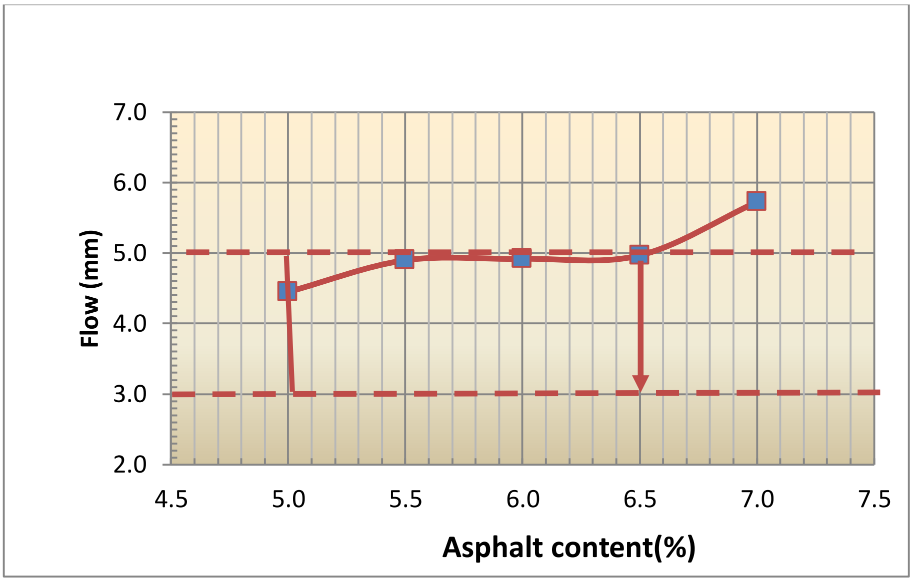

Figure 5.3. Correlated between Flows and asphalt content for mixtures with 0% CR

From Figure 5.3. it is shown that the AC mixtures meeting the Specification for Flow are only those having asphalt content between 5% to 6.5%. In general, the higher asphalt content should cause higher Flow, and this is a common practice.

The relation between the MQ and asphalt content from Table 5.4 can be drawn in Figure 5.4. It is obvious that the AC mixtures meeting the requirement of MQ between 250 – 350 Kg/mm are only those with asphalt content between 5.8% - 6.5%.

This relation between the MQ and asphalt content is shown in Figure 5.4.

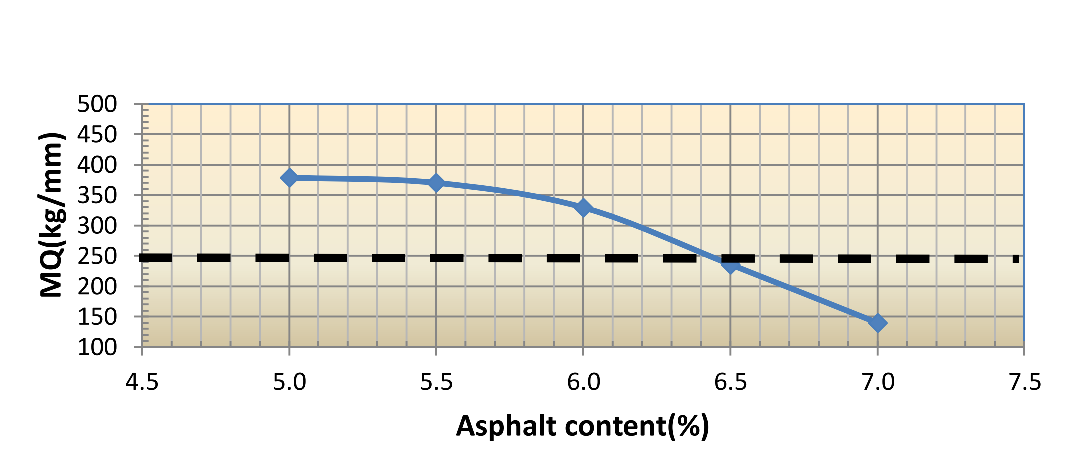

Figure 5.4 Correlation between MQ and asphalt content for AC mixture with 0% CR

CR In general, the values of Marshal Quotient, MQ, decrease with a higher value of the asphalt contents. Marshall Quotient can be considered as representing the AC mixture's rigidity. The higher the value of MQ the more rigid the pavement. However, AC pavement with MQ > 350 Kg/mm is not allowed, because the pavement is considered too rigid; so that the pavement is said to become too brittle and is easily cracked under heavy truck traffic. Whereas, AC pavement is not allowed to have MQ values < 250 Kg/mm, for the pavement becomes too soft and more prone to rutting.

The values of VIM can be drawn in Figure 5.5. It is apparent that the specimens of AC mixtures meeting the Specification are only of those with asphalt contents between 5.15% - 5.3% and between 5.9% - 6.8%. Lower VIM values from 3.5 % are not allowed to prevent the AC mixture from bleeding after subjected to heavy truck traffic. Higher VIM values from 6% are also not recommended, because the pavement could become easily penetrated by water (rainwater) so that the pavement becomes less durable and it is more prone to premature deterioration.\

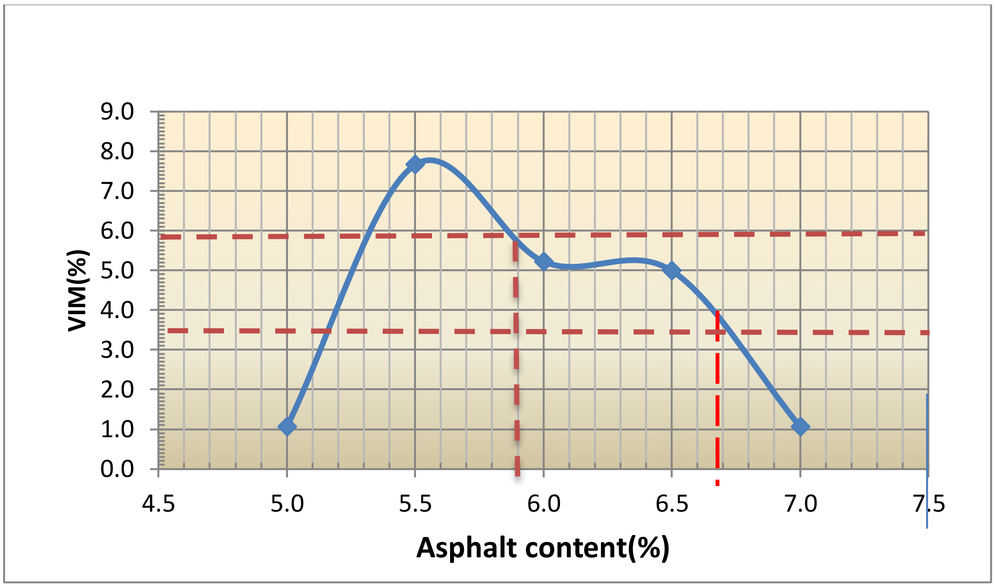

Figure 5.5. Correlation between VIM and asphalt content for AC mixture with 0% CR

Figure 5.6 shows the relationship between the VFWA and the asphalt content. The asphalt specimens meeting the specification are those with asphalt contents between 5.95% to 7.0%. It is also apparent that higher asphalt content will increase the percentage of asphalt filling the voids between mineral aggregates.

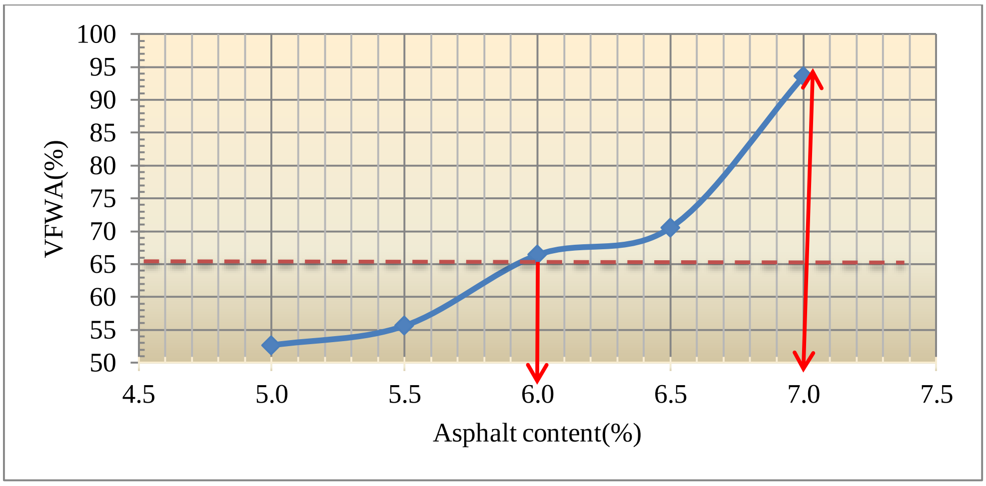

Figure 5.6 Correlation of VFWA and asphalt content for AC mixture with 0% CR

The relationship between VMA and asphalt content is shown in Figure 5.7. The asphalt specimens meeting the specification are of those with asphalt content between 5.3% - 7.0%.

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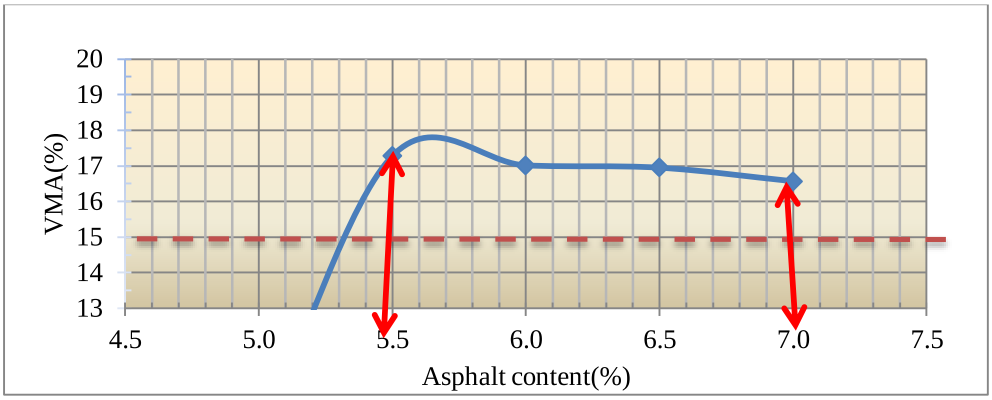

Figure 5.7 Correlation of VMA and asphalt content for mixture with 0% CR

The minimum value of VMA ,in this case, is 16%, which primarily depends on the maximum diameter of the aggregate used in the mixtures. In this study, the maximum diameter of the aggregate is 1 inch (= 2.5 cm).

From all the test results shown in Figure 5.2. to 5.7., the results can be summarized in Figure 5.8 by plotting only the asphalt contents that are meeting the specification of each Marshall parameters. The range of asphalt contents that are meeting all the parameters are those between 5.9 % - 6.30 %, and this narrow percentage of the range is the number of asphalt contents to be specified for application of AC mixture with 0% CR.

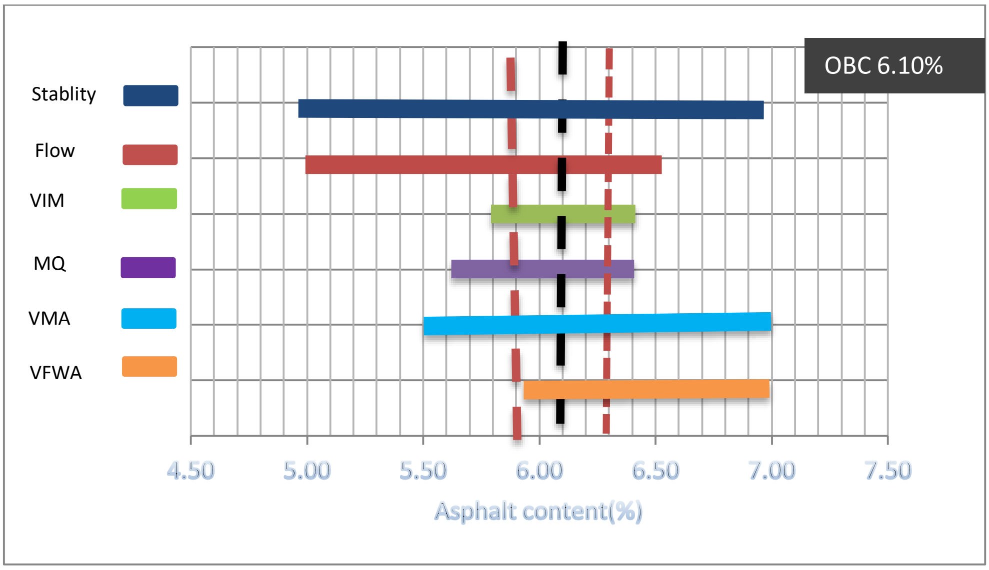

Figure 5.8. Summary of Optimum Bitument Content, OBM, for Marshall Properties for AC mixtures with 0% CR. (CR = crumb rubber).

5.3.2. Mixtures with Crumb Rubber Content of 2.5%.

The results of the complete Marshall Test for hot AC mixture with 2.5% CR can be given in Table 5.5, while the Stability correlation is given in Figure 5.9. The percentage of crumb rubber here is a percentage of weight. Therefore, for each hot mix specimen with a total weight of 1200 grams, the 2.5% CR represents the weight of a 30-gram crumb rubber.

Table 5.5. Results of Marshall Properties of Hot Mix AC with 2.5% CR*

Table 5.5 Hot Mix Asphalt Concrete of crumb rubber at 2.5 %

AC (%)	Stability (kg)	Flow (mm)	VIM (%)	Mq (kg/mm)	VMA (%)	VFWA (%)
5.0	576.05	3.00	4.34	192.02	15.23	66.53
5.5	917.42	3.15	4.94	291.24	15.84	68.80
6.0	1322.79	3.80	4.83	348.10	16.78	71.22
6.5	960.09	4.20	3.15	228.59	17.95	82.43
7.0	853.41	4.90	2.07	174.17	18.05	88.52

Summarized results from detailed tests in Appendix E

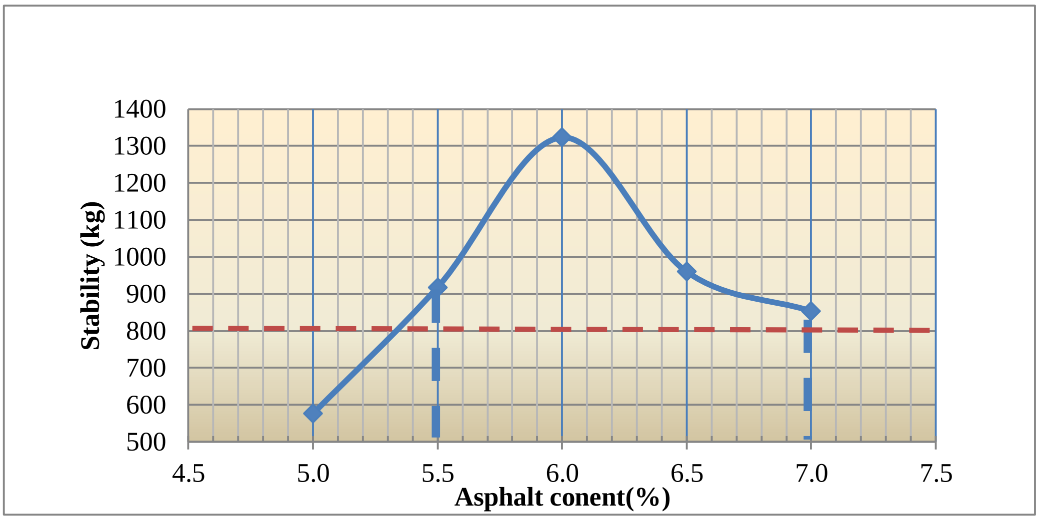

Figure 5.9. Correlation of Stability and asphalt content for mixtures with 2.5% CR.

From Figure 5.9 it is apparent that only the specimens with asphalt contents from 5.3 % to 7% are meeting the minimum Stability value of 800 Kg. The highest Stability value is 1322.8 Kg for asphalt content 6.0%.

Figure 5.10. shows the correlation between the flow and asphalt content for 2.5 % CR.

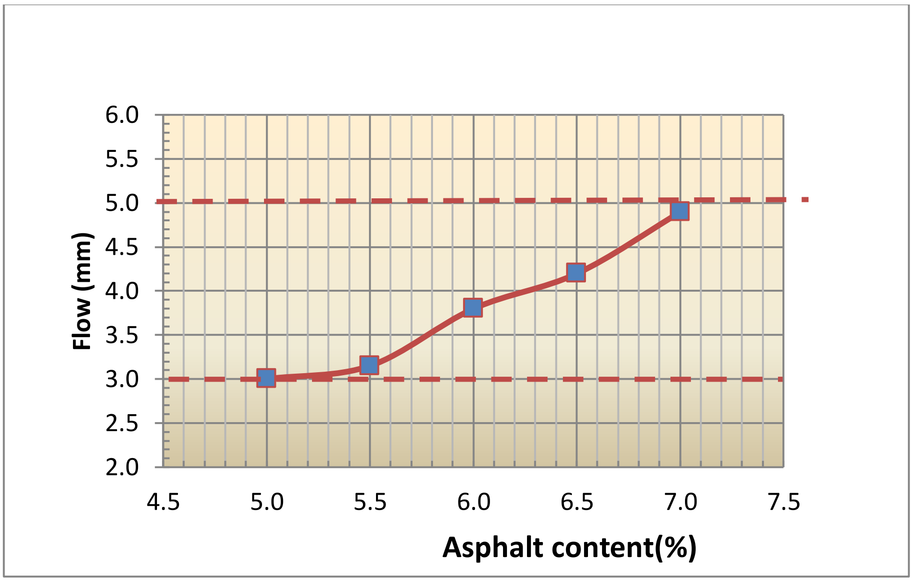

Figure 5.10 Correlated of Flows and asphalt content for mixtures with 2.5 % CR

From Figure 5.10. it is shown that all specimens tested with 5% - 7% asphalt contents in this study are meeting the Specification for Flow. This is similar to those in 0% CR, the higher asphalt content should cause higher Flow.

The relation between the MQ , and the AC with 2.5% CR from Table 5.5. can be drawn in Figure 5.11.

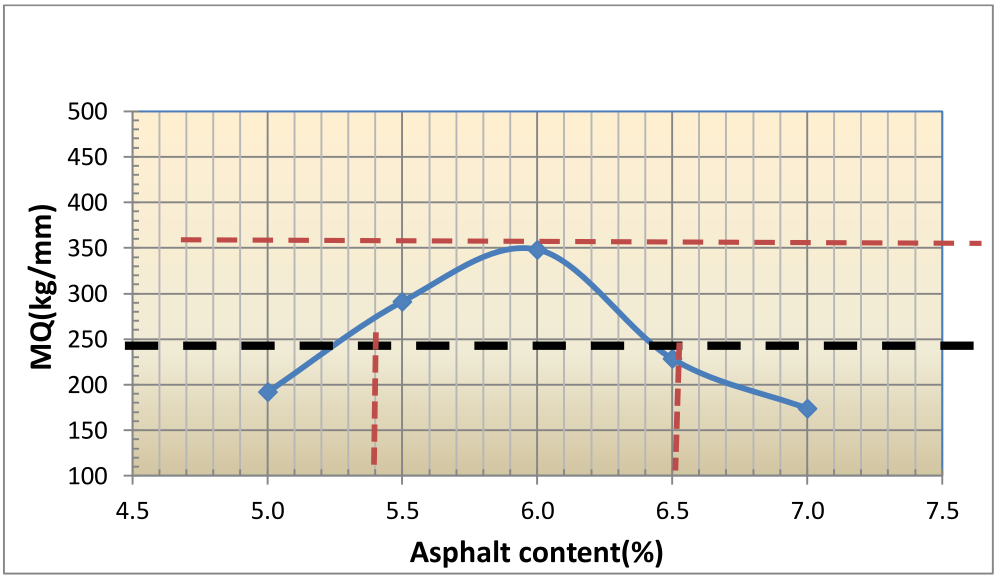

Figure 5.11. Correlation of MQ and asphalt content for mixtures with 2.5 % CR

The AC mixtures meeting the requirement of MQ between 250 – 350 Kg/mm are of those with asphalt content between 5.3% - 6.4%.

Figure 5.12 shows the relationship between the VIM with asphalt content for 2.5 % CR. The asphalt specimens meeting the Specification are of those with asphalt contents between 5.0% - 6.4%. Furthermore, Comparing Figure 5.5. and Figure 5.12., it is apparent that adding 2.5% CR to the mixtures will cause VIM to decrease.

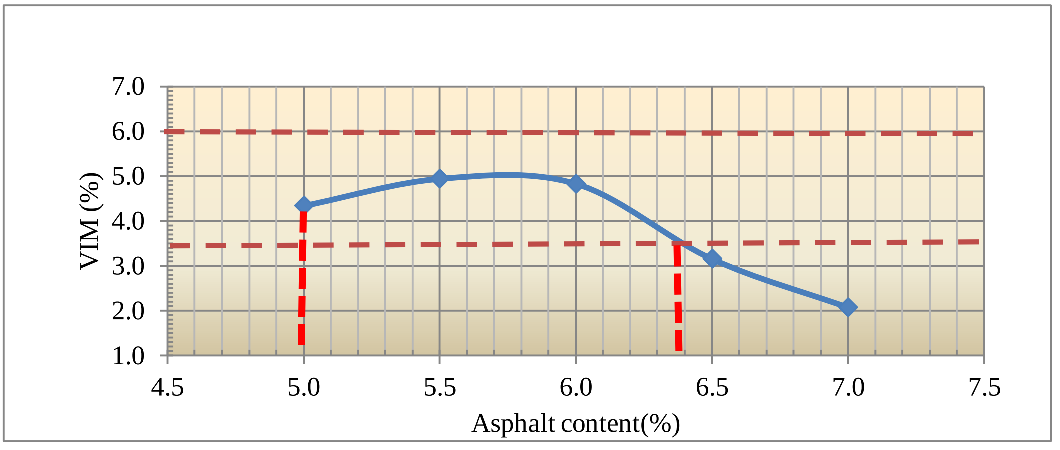

Figure 5.12 Correlation of VIM and asphalt content for mixtures with 2.5 % CR

The following observations were obtained by way of the examination of the VIM test results in Table 5.5 and Figure 5.12. that the VIM value of HMA with CR reaches the highest level of 2.5 % at 5.5 % with 4.9%; while the lowest level of asphalt content at is7.0% by 2.07%, 6.5% by 3.15%, 6.0% by 4.83%, and 5.0 % by 4.34 %. Therefore, it can be concluded that 2.5% CR with % bitumen decreases VIM.

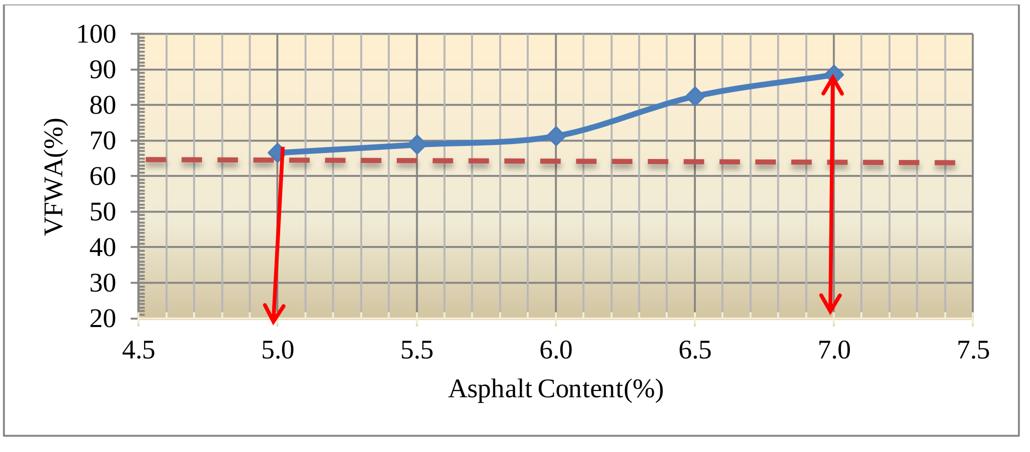

Figure 5.13 Correlation of VFWA and asphalt content for mixtures with 2.5 % CR

From Figure 5.13., all the asphalt specimens used in this study are meeting the Specification. Adding crumb rubber into the mixture will increase VFWA.

Figure 5.14 shows the relationship between the VMA and the asphalt content for 2.5% CR. All the asphalt specimens used in this study meet the Specification for VMA.

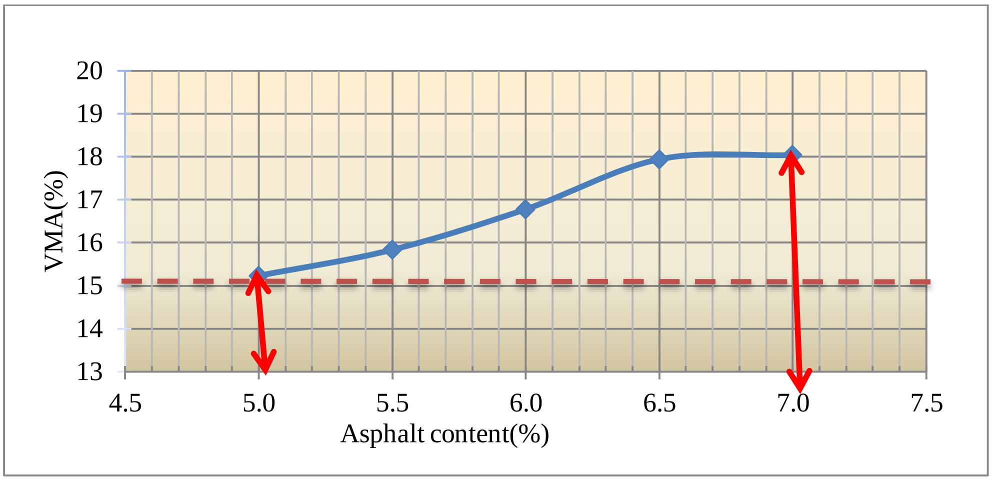

Figure 5.14 Correlation VMA and HMA with 2.5% CR toward asphalt content

The following findings were obtained from the analysis of the VMA results in Table 5.5 and Figure 5.14 regarding. The VMA value of HMA with 2.5% CR, it reaches the highest level of 7.0% by 18.05%, while the lowest level of 5% asphalt content is at by 15.23%, 5.5% by 15.84%, 6% by 16.78%, and 6.5% by 17.95%. Therefore, it can be concluded that 2.5% CR with % bitumen increases VMA The findings of the Marshall Properties test are analyzed in Table 5.9 were obtained the following observations that the OBC when added 2.5% crumb rubber is 6.20% bitumen, which is shown in Figure 5.15.

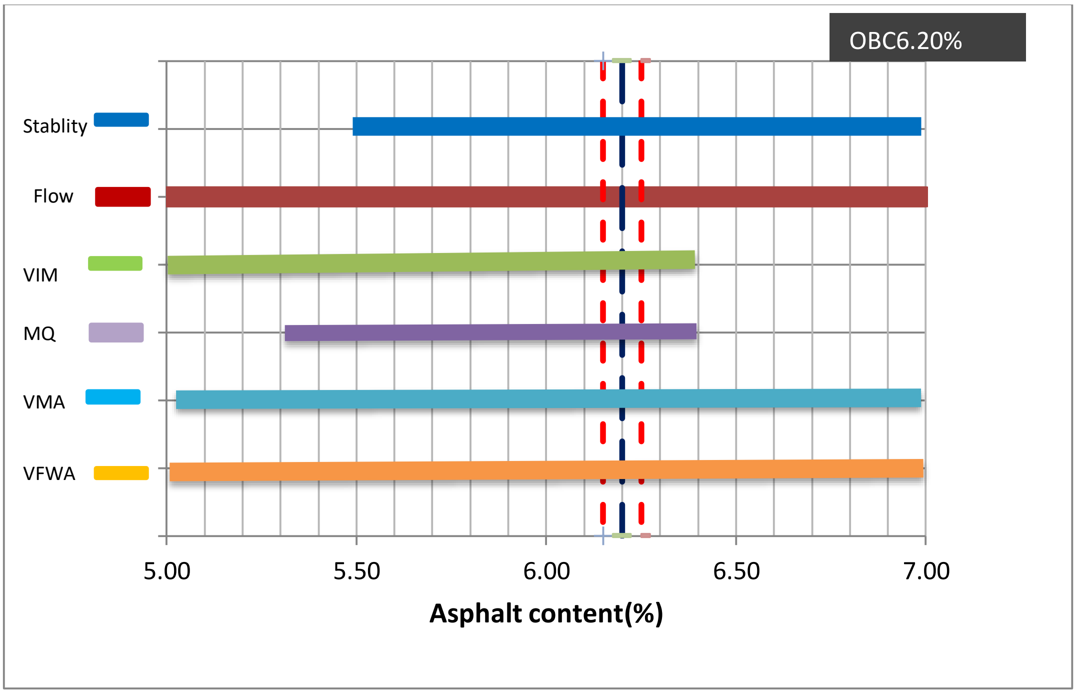

Figure 5.15 Summary of Optimum Bitumen Content, OBM, for Marshall Properties for AC mixtures with 2.5% CR. (CR = crumb rubber).

5.3.3. Mixtures with Crumb Rubber Content of 4.5%.

The results of the complete Marshall Test for hot AC mixture with 4.5% CR can be given in Table 5.6 and the Stability correlations are given in Figure 5.16. The percentage of crumb rubber here is by weight. Therefore, for each hot mix specimen with a total weight of 1200 grams, the 4.5% CR represents the weight of 54-gram crumb rubber.

Table 5.6. Results of Marshall Properties of Hot Mix AC with 4.5% CR*

AC(%)	Stability (Kg)	Flow (mm)	VIM (%)	Mq (Kg/mm)	VMA (%)	VFWA (%)
5.0	426.71	3.10	4.30	137.65	13.20	67.42
5.5	533.38	3.20	3.48	166.68	13.52	74.30
6.0	746.73	3.35	4.63	222.91	24.45	73.18
6.5	1066.76	3.40	5.36	313.75	21.64	67.14
7.0	917.42	3.45	7.60	265.92	22.22	65.78

Summarized results from detailed tests in Appendix E

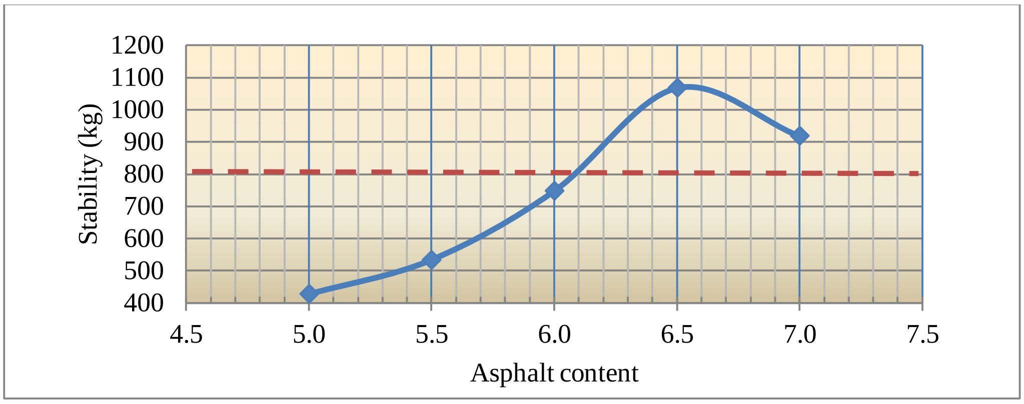

Figure 5.16 Correlation of Stability and asphalt content for AC mixtures with 4.5% CR.

From Figure 5.16 only the specimens with asphalt contents from 6.1 % to 7% are meeting the minimum Stability value of 800 Kg. The highest Stability value is 1066.8 Kg for asphalt content 6.5%.

Figure 5.17. indicates this connection between the flows and asphalt contents for 4.5% CR. The flow values are all meeting the Specification and only show a slight increase toward a variation of asphalt content from 5% - 7%. This means the existence of more crumb rubber content will make the AC mixtures to become stiffer and more resistant against deformation.

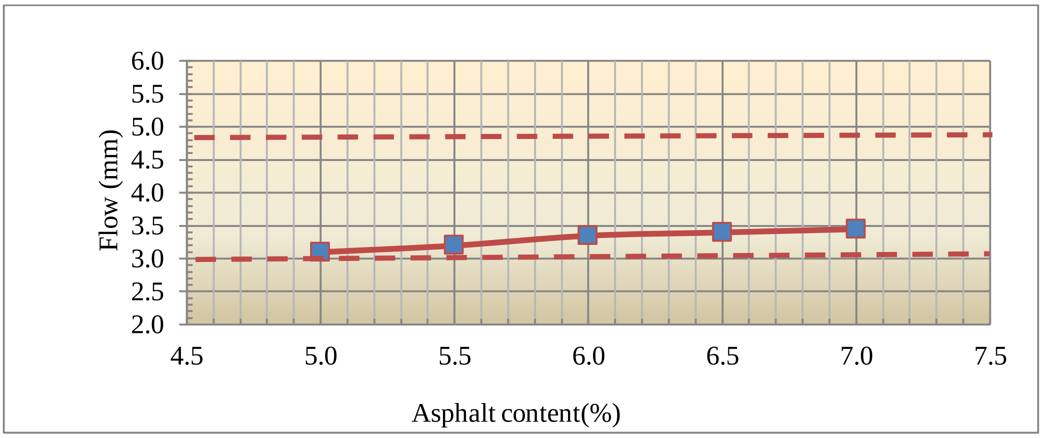

Figure 5.17 Relationship between flows and asphalt content for 4.5% CR

Figure 5.18 shows the correlation between the Marshal Quotients, MQ, and asphalt contents for 4.5% CR. In this figure, the AC specimens that are meeting the Specification are only those with asphalt content between 6.15% - 7%.

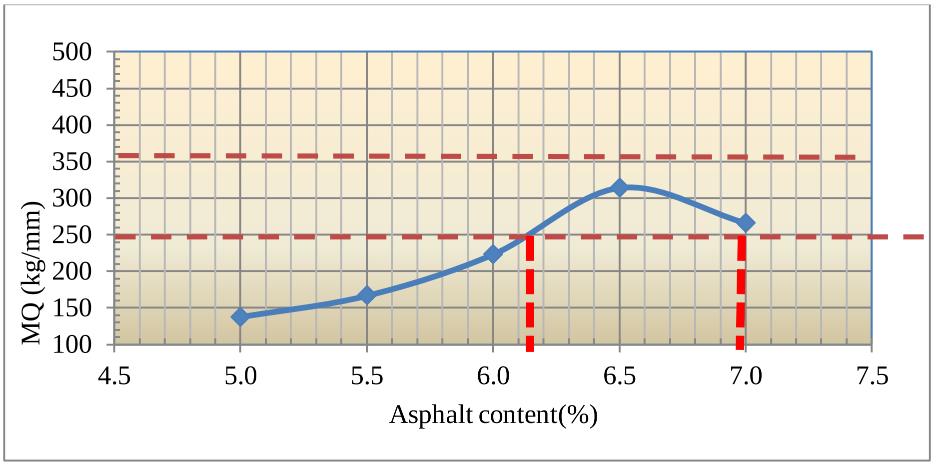

Figure 5.18 Relationship between MQ and asphalt content for 4.5% CR

The following observations were obtained by analyzing the MQ check findings in Table 5.6, and Figure 5.18. The table and the figure show that the MQ value of HMA with CR of 4.5 % reaches the highest value of 313.75 mm at 6.5 %, and the lowest level of asphalt content at 5% by 137.65 mm. Therefore, it could be inferred that the 4.5% CR with % % bitumen increases Marshall Quotient (kg/mm).

Figure 5.19 shows this relationship between VIM and asphalt content of 4.5 %CR.

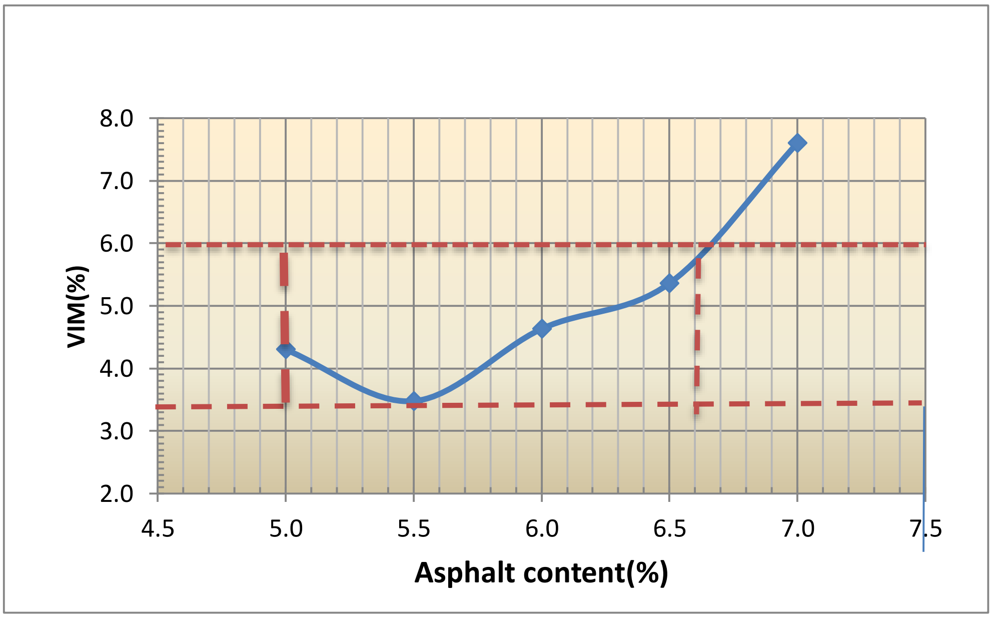

Figure 5.19 Relationship between VIM and asphalt content for 4.5% CR .

In Figure 5.19. the specimens meeting the Specification for VIM are those with asphalt contents between 5.0% - 6.6%. Contrary to the previous CR contents, where the values of VIM commonly decrease with the increase of asphalt content, in this 4.5% CR the VIM values increase with higher asphalt content. The more content of CR in AC mixtures will cause more voids to form inside the specimens.

This relationship can be drawn between the VFWA and asphalt content in Figure 5.20. All the specimens tested to meet the Specification for VFWA.

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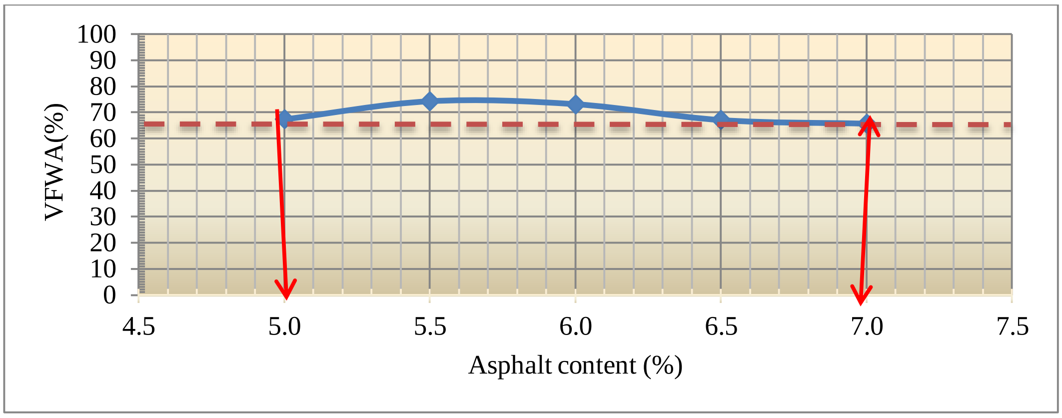

Figure 5.20 Correlation of VFWA and asphalt content for 4.5% CR

This relationship can be drawn in Figure 5.21 between the VMA and asphalt content for 4.5 % CR. The specimens tested that meet that the Specification is those only with asphalt content between 5.6% - 7%.

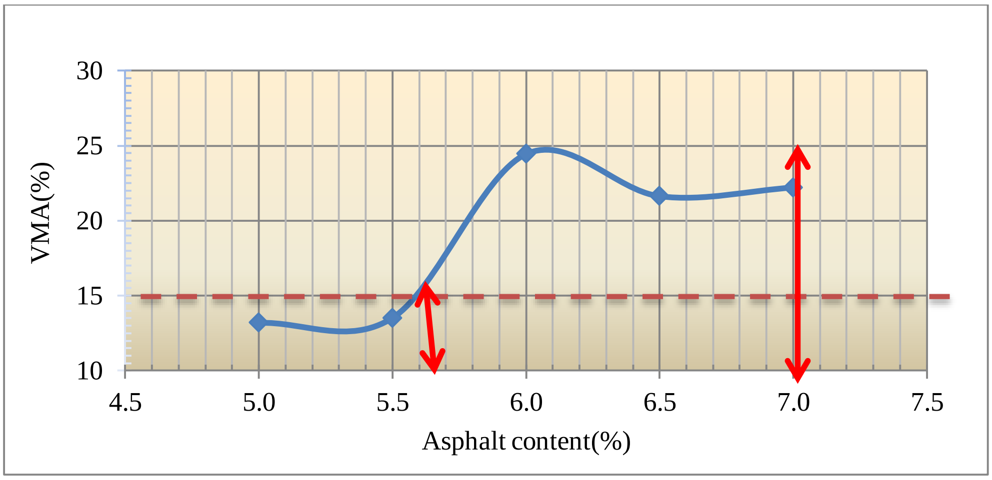

Figure 5.21 Correlation of VMA and asphalt content for 4.5% CR

From all the test results shown in Figure 5.15. to 5.21., the data can be summarized in Figure 5.22 by plotting only the asphalt contents that are meeting the specification of each Marshall parameters. The range of asphalt contents meeting all the paremeters is those between 6.1 % - 6.40%. with the OBC = 6.25%. This is the asphalt content specified for application of AC mixture with 4.5% CR

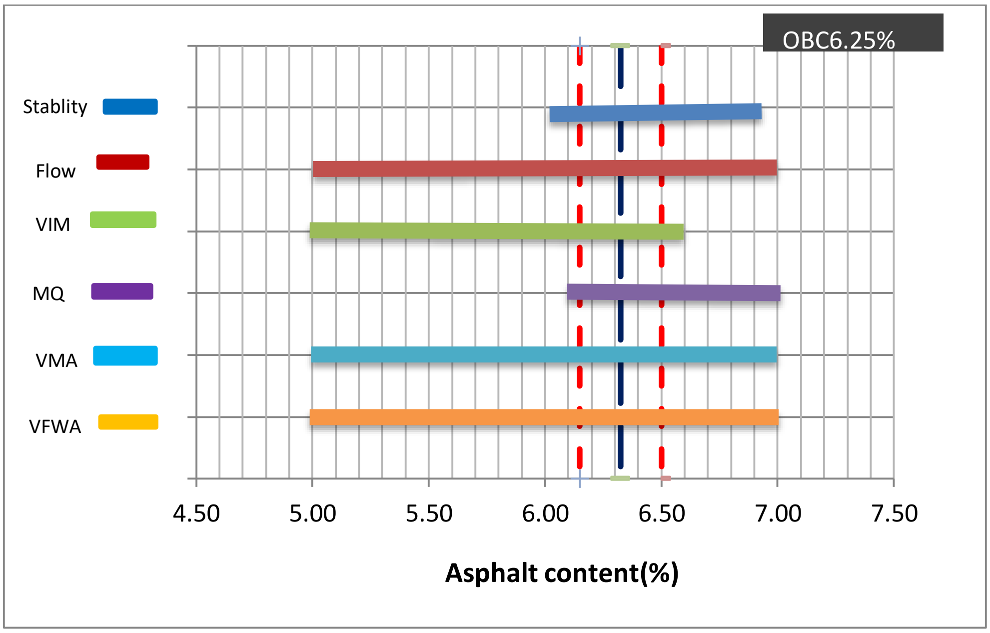

Figure 5.22 Summary of Optimum Bitument Content, OBM, for Marshall Properties for AC mixtures with 4.5% CR. (CR = crumb rubber).

5.3.4. Mixtures with Crumb Rubber Content of 6.5%.

The results of the complete Marshall Test for hot AC mixture with 6.5% CR can be given in Table 5.7. and the Stability correlations are given in Figure 5.23. The percentage of crumb rubber here is by weight. Therefore, for each hot mix specimen with a total weight of 1200 grams, the 6.5% CR represents the weight of 78-gram crumb rubber.

Table 5.7. Results of Marshall Properties of Hot Mix AC with 6.5% CR*

AC(%)	Stability (Kg)	Flow (mm)	VIM (%)	Mq (kg/mm)	VMA (%)	VFWA (%)
5.0	1280.12	3.20	5.23	400.04	14.04	62.77
5.5	1429.46	3.45	5.03	414.34	14.91	66.29
6.0	1280.12	3.66	5.42	349.76	16.31	66.74
6.5	960.09	3.70	5.77	259.48	17.63	67.29
7.0	746.73	3.80	3.66	196.51	18.82	80.54

Summarized results from detailed tests in Appendix E

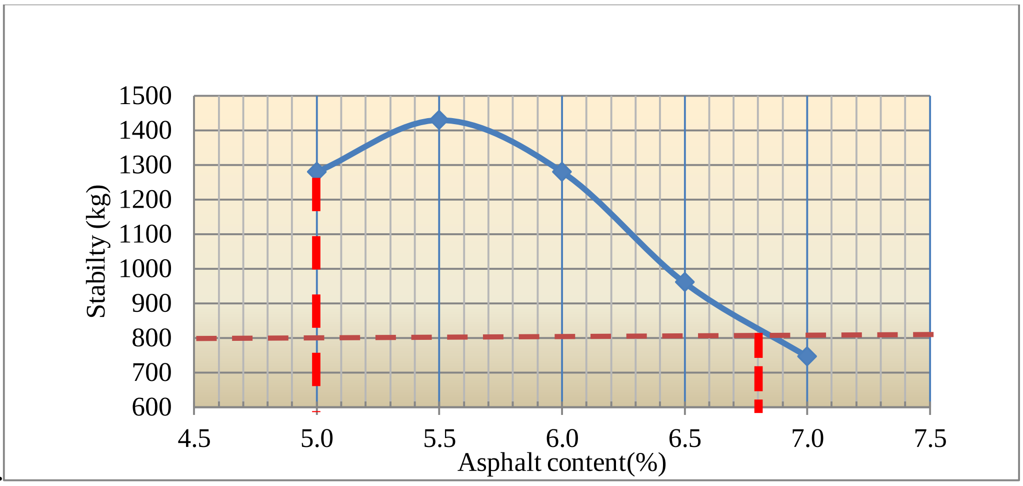

Figure 5.23 Correlation stability and HMA with 6.5% CR toward asphalt content

The following findings were made by analysis of the effects of the stability test in Table 5.7 and Figure 5.23. The table and the figure shows that the stability value of HMA with 6.5 % crumb rubber reaches the highest value of AC at 5.5 % by 1429.46 kg and has the lowest value with an asphalt content of 7 %by 746.73 with the additional 6.5 % crumb rubber effect at the cohesion and the bonding. Therefore, the stability value of HMA without crumb rubber is higher than HMA with crumb rubber. Also, the stability value of HMA with crumb rubber 6.5% is higher than HMA with crumb rubber 2.5% and 4.5% crumb rubber. However, the stability increases along with the decrease of crumb rubber content up to a certain extent (optimum) and decreases after it passes the optimum limit. This result happens because the asphalt as the binding material between the aggregate limit become a lubricant after reaching the optimum limit.

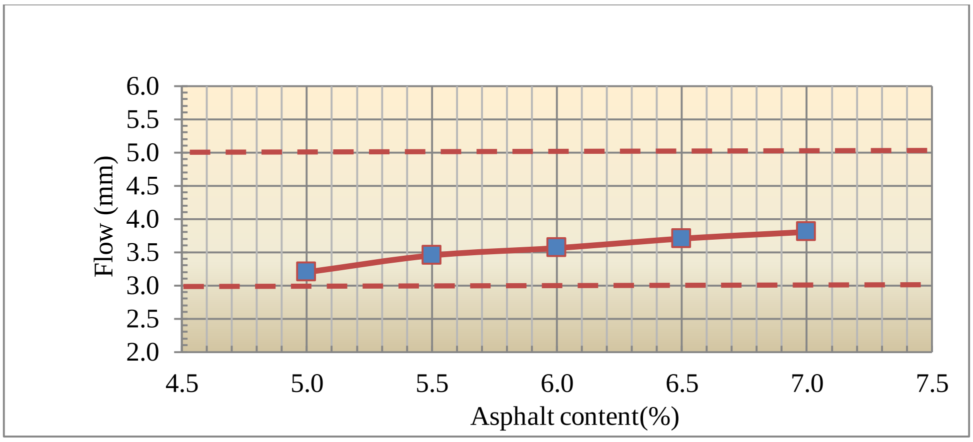

Figure 5.24 Correlation flows and HMA with 6.5% CR toward AC

The following findings were made by analyzing the test results for the flow in Table 5.7 and Figure 5.24. The table and the figure show the value of the flow of HMA with CR reaches the largest value of 6.5% asphalt content at 7 % by 3.80 mm and 5.0 % smallest with AC by 3.20 mm. Therefore, it can be concluded that the flow can reach a higher level that causes the content of asphalt increases. The mixes become less flexible with the addition of the asphalt content, and the deformation resistance decreases which results in a high flow value.

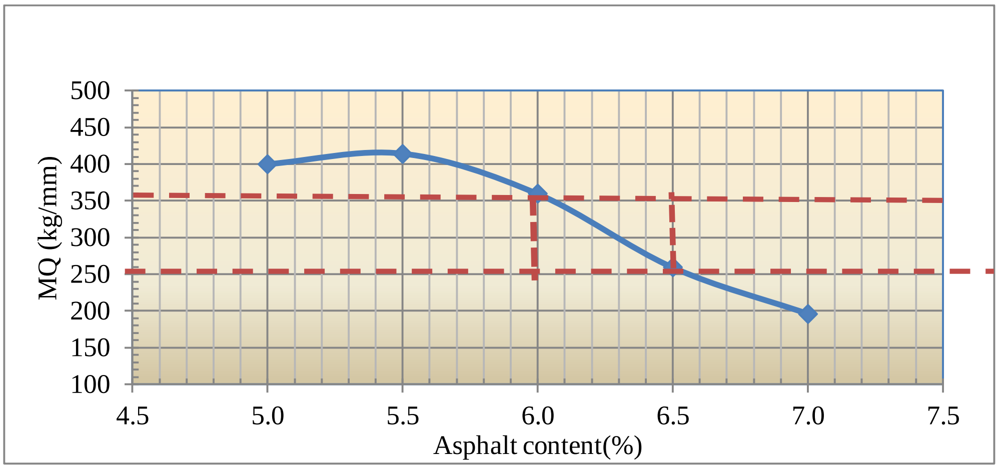

Figure 5.25 Correlation MQ and HMA with 6.5% CR toward asphalt content

The following observations were obtained by reviewing the test results for the MQ in Table 5.7 and Figure 5.2. The table and the figure shows that the MQ value of HMA with 6.5 % CR reaches the highest value at 414.34 mm at 5.5 % and the smallest value of 7.0 at 196.51 mm at HMA. Accordingly, it may be concluded that the 6.5% CR with % % bitumen increases MQ(kg/mm). Figure 5.26, shows this relationship between the VIM and 6.5 % CR toward asphalt content.

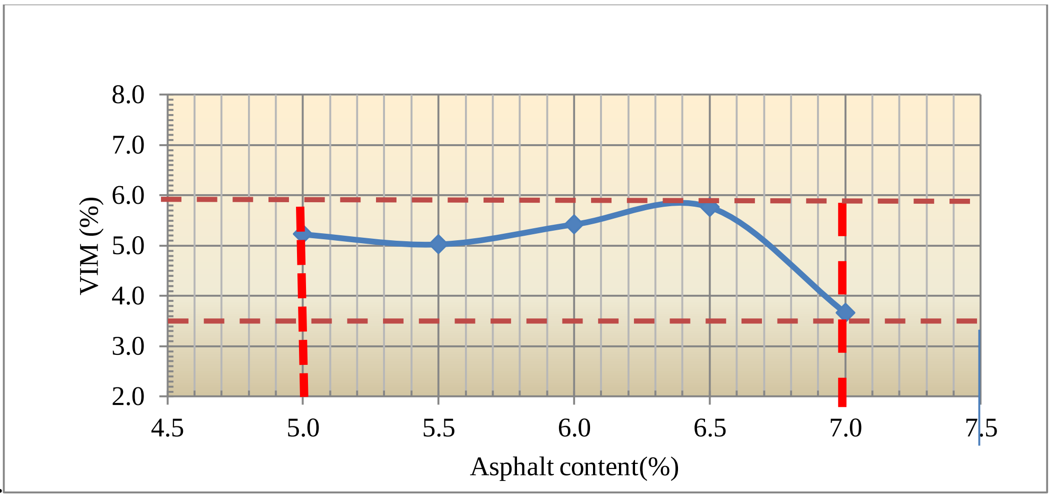

Figure 5.26 Correlation VIM and HMA with6.5% CR toward asphalt content

The following observations were obtained by reviewing the test results for the VIM in Table 5.7 and Figure 5.26. The table and the figure show that the VIM value of HMA with 6.5 % crumb rubber reaches the highest value of 5.77% at 6.5% and the lowest value at 5.5 % with asphalt content at 3.45 %. It can be inferred from this result that 6.5 % crumb rubber with % bitumen decreases the VIM %).

Figure 5.27 shows this relationship between the VFWA and 6.5 % crumb rubber asphalt content.

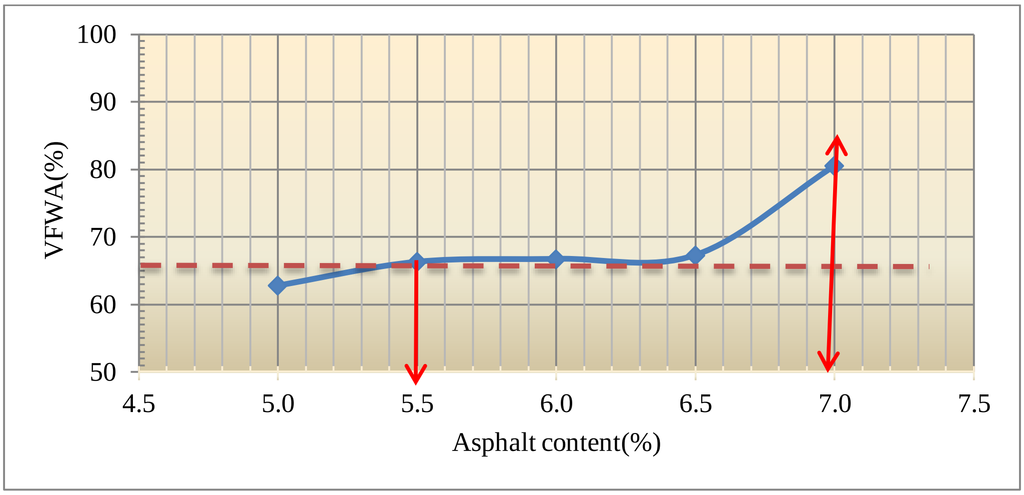

Figure 5.27 Correlation VFWA and HMA with 6.5% CR toward asphalt content

The following conclusions were reached by examining the VFWA findings in Table 5.7 and Figure 5.27. The table and the figure show that the VFWA value of HMA with 6.5 % crumb rubber reaches the highest value of 80.54 % at

7.0 %, and the lowest value of 5.0 % at HMA by 62.77 %. Therefore, it may be inferred that the 6.5% crumb rubber with % bitumen increases VMA. Figure 5.28 shows this relationship between VMA and crumb rubber 6.5 % asphalt content.

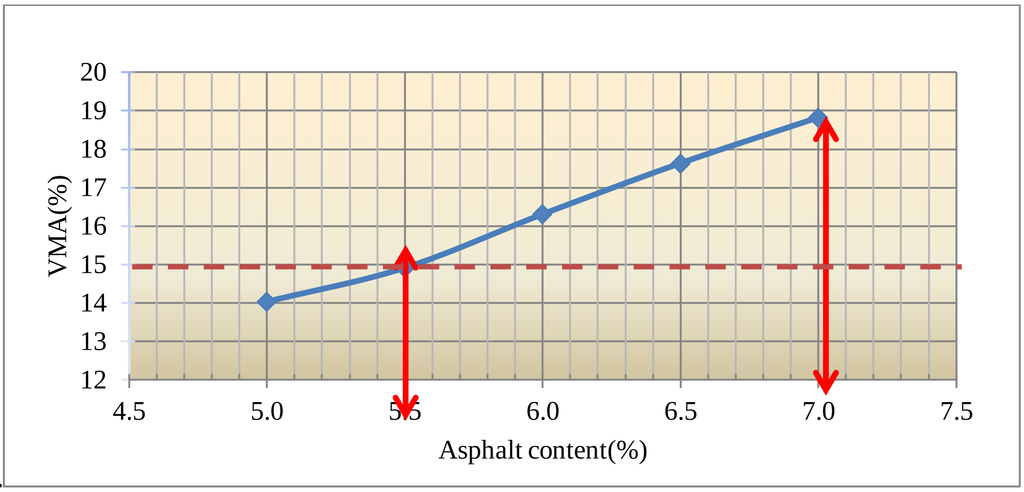

Figure 5.28 Correlation VMA and HMA with 6.5% CR toward asphalt content

The following findings were made by the analysis of the VMA results in Table 5.7 and Figure 5.28. The table and the figure show that the VMA value of HMA with 6.5 % CR reaches the highest value of 7 % by 18.82, and the lowest value of asphalt content at 5% by 14.04%. Therefore, it could be inferred that the 6.5% crumb rubber with % bitumen increases VMA.

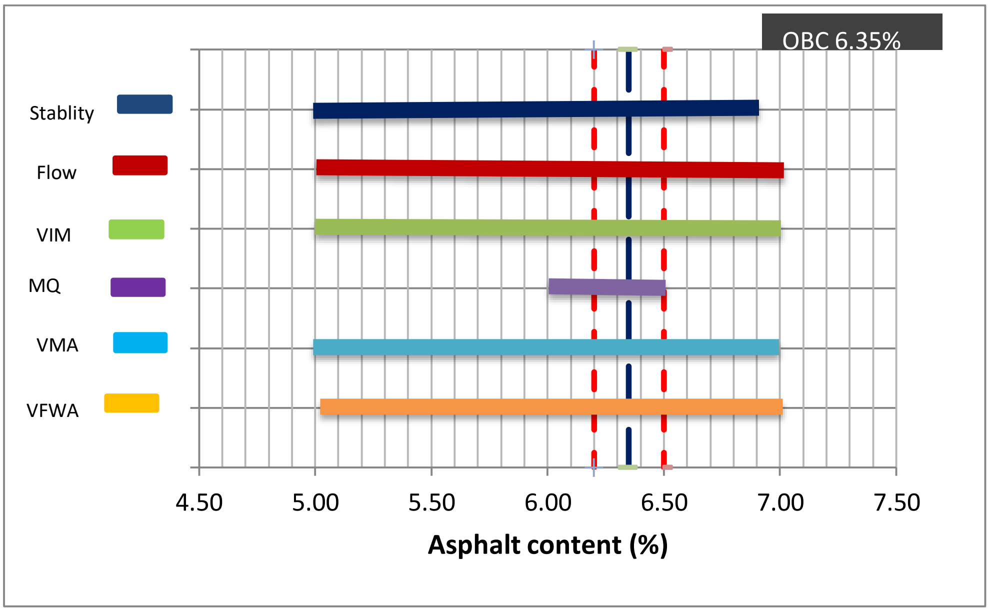

Figure 5.29. Summary of Optimum Bitument Content, OBM, for Marshall Properties for AC mixtures with 6.5% CR. (CR = crumb rubber).

5.3.5. Mixtures with Crumb Rubber Content of 8.5%.

The results of the complete Marshall Test for hot AC mixture with 8.5% CR can be given in Table 5.8. and the Stability correlations are given in Figure 5.30. The percentage of crumb rubber here is by weight. Therefore, for each hot mix specimen with a total weight of 1200 grams, the 8.5% CR represents the weight of 102-gram crumb rubber.

Table 5.8. Results of Marshall Properties of Hot Mix AC with 8.5% CR*.

Asphalt Content (%)	Stability Kg	Flow mm	VFWA (%)	VMA (%)	MQ (kg/mm)	VIM (%)
5.0	810.74	3.35	34.97	11.84	242.01	14.74
5.5	1216.11	3.70	48.14	11.46	328.68	11.05
6.0	597.39	3.90	42.58	9.77	153.18	11.60
6.5	469.38	4.10	52.31	10.10	114.48	12.42
7.0	256.02	4.20	50.06	11.02	60.96	14.27

*Summarized results from detailed tests in Appendix E

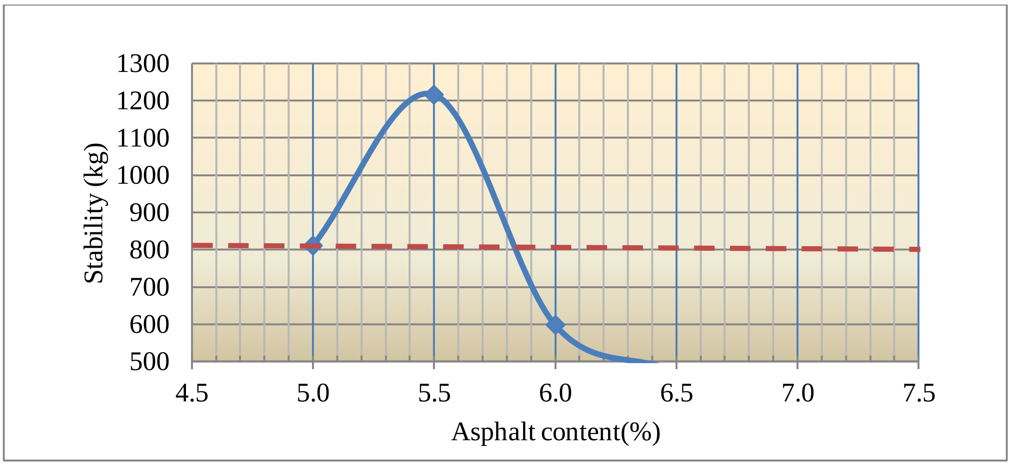

Figure 5.30 Correlation stability and HMA with 8.5 % CR toward asphalt content

The following observations were obtained through the test results for the stability in Table 5.8 and Figure 5.30. The table and the figure shows that the stability value of HMA with 8.5 % crumb rubber reaches the highest value of 5.5 % asphalt content by 1216 kg and the lowest value of 7 % asphalt content by 256.02 with the additional crumb rubber cohesion effect at 8.5 %; it causes the bonding stability of the bitumen decreases. Therefore, the stability value of HMA without crumb rubber is higher than HMA with crumb rubber, while the stability value of HMA with 6.5 % crumb rubber is higher than HMA with 8.5 % CR. However, the stability increases along with the decrease in crumb rubber content up to a certain extent (optimum) and decreases after it passes the optimum limit.

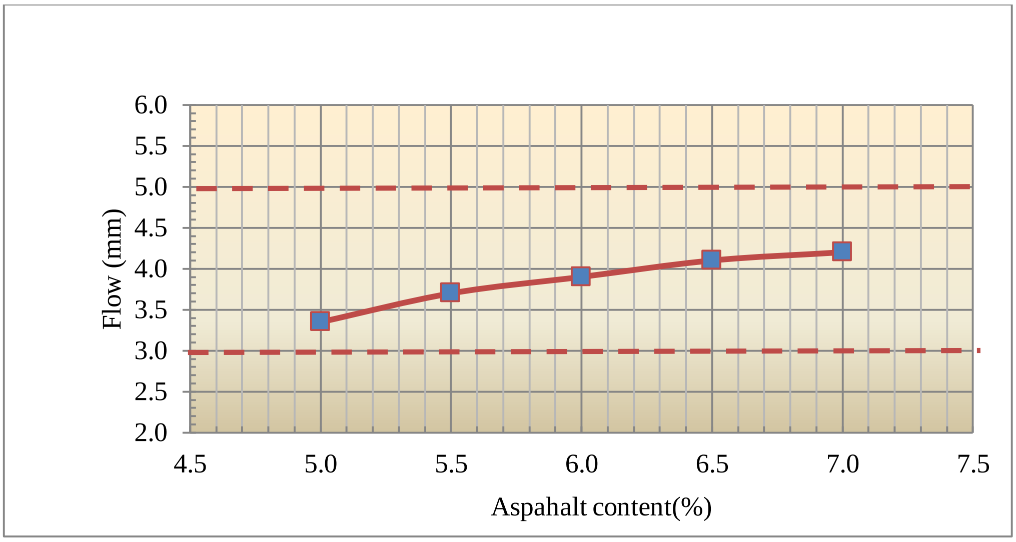

Figure 5.31 Correlation Flows and HMA with 8.5% CR toward asphalt content

The following observations were obtained by reviewing the flow test results in Table 5.8, and Figure 5.31. The table and the figure show that HMA with crumb rubber flow value reaches the highest value of 8.5 % at 7% asphalt content by 4.2 mm and the smallest value of 5.0% asphalt content by 3.35 mm. Therefore, it can be inferred that the flow increases along with the increase of HMA. When adding the asphalt, the substance of the mixtures becomes less stable, and deformation resistance decreases which result in a high flow value.

This relationship between the MQ and the 8.5 % CR asphalt content is shown in Figure 5.32.

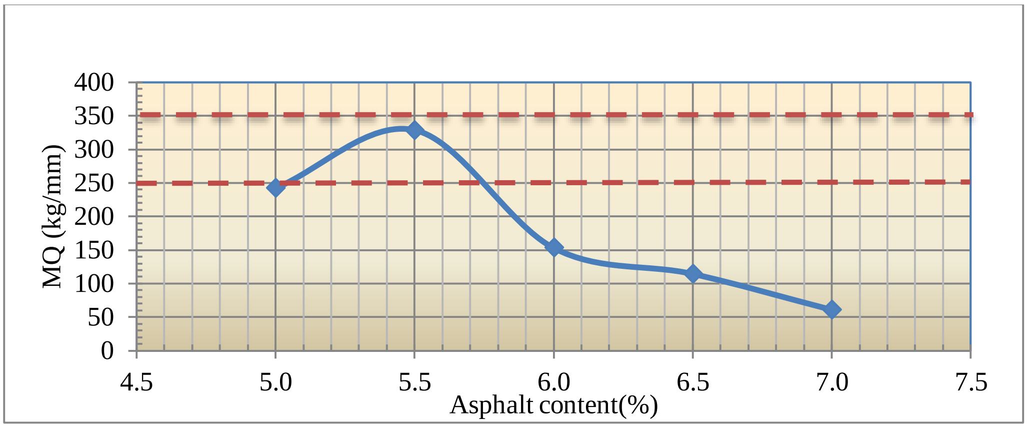

Figure 5.32 Correlation MQ and HMA with 8.5% CR toward AC

The following findings were made from the check of the test results for the MQ in Table 5.8, and Figure 5.32. The table and the figure shows that the MQ value of HMA with crumb rubber reaches the highest value of 8.5 % at 5.5% with 328.68 mm and the lowest value of 7% asphalt content with 60.90 mm. Therefore, it can be inferred that the 8.5 % crumb rubber with bitumen reduces the Marshall Quotient. Figure 5.33 shows this relationship between VIM and 8.5 % CR asphalt content.

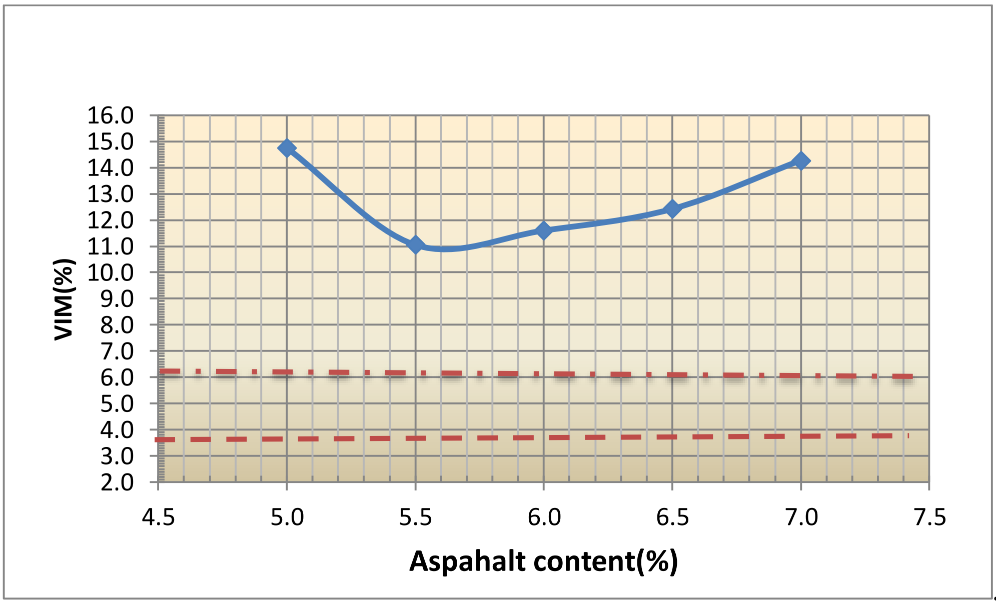

Figure 5.33 Correlation VIM and HMA with 8.5% CR toward AC

The following findings were made by checking the study findings for the VIM in Table 5.8, and Figure 5.33. The table and the figure show that the VIM value of HMA with crumb rubber reaches the highest value of 8.5 % at 5 % by 14.74 % and the lowest value of 5,5% asphalt content by 11.08 %. Therefore, it can be concluded that the VIM decreases at 8.5 % crumb rubber with % bitumen. Figure 5.34 shows the correlation between the VFWA and asphalt content is at 8.5% CR.

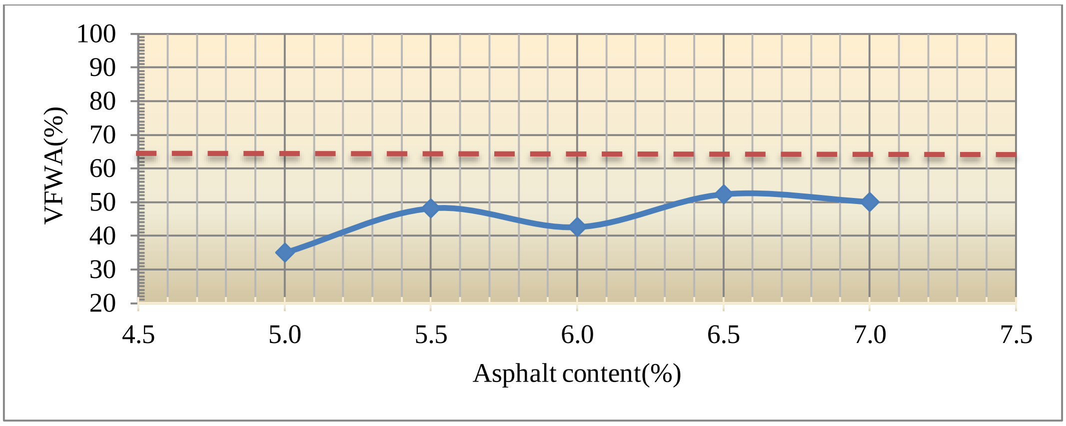

Figure 5.34 correlation VFWA and HMA with 8.5% CR toward AC.

The following findings were made through the analysis of the VFWA results in Table 5.8, and Figure 5.34. The table and the figure show that the VFWA value of HMA with CR reaches the highest value of 8.5 % at 52.31 % by 6. %, and 5 % lowest value of 34.97 % asphalt content. Therefore, it may be concluded that VFWA is increased by 8.5% CR with% bitumen.

Figure 5.35 illustrates this relationship between the VMA and the 8.5% CR

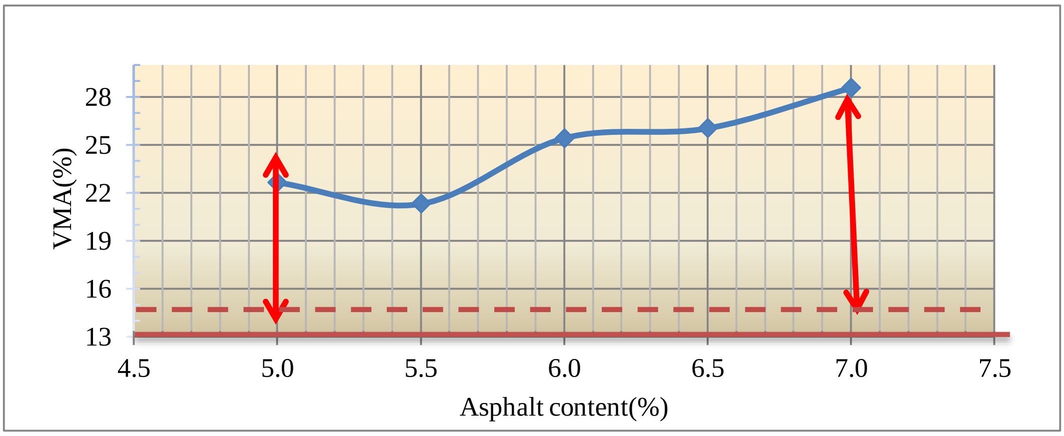

Figure 5.35 Correlation VMA and HMAwith 8.5% CR toward AC

The following findings were obtained through the analysis of the VMA results in Table 5.8, and Figure 5.35. The table and the figure show that the VMA value of HMA with crumb rubber reaches the highest value of 8.5 % at 5.5 % by

11.46%, and the lowest value at 6.0 % by 9.1 % with HMA. Therefore, it can be concluded that the 8.5 % crumb rubber with bitumen increases the aggregate of the void.

5.4. Analysis of the Marshall Properties for Different CR content.

The analysis here is performed by comparing the results of the Marshall Properties in Section 5.3.1 to 5.3.5. to find the best CR content based on for the following rationales:

1. Marshall Stability

Marshall Stability represents the strength of the AC mixture against compressive and shear stresses caused by the repetition of vehicle tire passing, especially for heavy truck tires. The higher Stability means the stronger the AC mixture against damages due to heavy truck traffic.

2. Flow

The flow values represent the resistance of asphaltic pavement against permanent deformation under the repetitive load of heavy truck traffic. The higher flow means the pavement is more vulnerable to rutting, while lower flow means the pavement is more rigid and less vulnerable to permanent deformation or rutting. However, the flow values are limited to certain upper and lower limits (in this case is 5% and 3%, respectively). Too high value of flow means softer asphaltic pavement that is more easily to undergo permanent deformation; yet, too low value of flow means the pavement is too brittle. Therefore, the better AC mixtures are those with lower flow, providing that the values are still within the corridor of the specified upper and lower limits.

3. Marshall Quotient (MQ)

Marshall Quotient (MQ), also represents the strength of asphaltic mixture against tire-induced stresses, especially heavy truck traffic. The higher MQ also means the stronger pavement against tire stresses. Yet, the MQ values are restricted to certain upper and lower limits (in this case is 350 Kg/mm and 250 Kg/mm, respectively). Too high MQ also means the pavement is too rigid and too brittle, so that it may be more prone to cracking. Whereas, too low MQ means the pavement is more easily to undergo permanent deformation under repetitive loading of heavy truck traffic. Therefore, MQ is the reflection of the toughness and resilience of the mixture against stress and deformation. Because MQ = Stability/flow, the same Stability of specimen tested but with the lower flow will yield higher MQ. This means, even if the Stability values are the same, the AC pavement with higher MQ will have more resistance to deformation after subjected to repetitive loading than those with lower MQ. Therefore, higher MQ values mean better AC mixtures, providing that the values are still within the corridors of the specified upper and lower limits.

4. VIM

VIM represents the amount of air still remains inside the AC mixture after the mixture is compacted to become pavement. The amount, in this case, is limited to 3.5% to 6%. The lower limit, 3.5%. is the minimum air still needed inside the mix so that bleeding will not occur in the pavement after the pavement is subjected to many years of repetitive heavy truck traffic. Repetition of truck traffic will cause the pavement will become further densified, so that when no more enough void of air remaining inside the pavement, bitumen binder will be forced to flow outside to the surface of the pavement and to cause bleeding. Bleeding is not permitted in the asphaltic pavement because it may cause the pavement more slippery and hazardous to the traffic. On the opposite side, the higher limit of VIM, 6%, is the limit for the pavement not to become too porous so that water may enter the pavement and dwell inside the pavement. This condition has been known to cause the pavement to deteriorate and crumble more easily so that the pavement is more likely to be damaged prematurely. Therefore, the better quality of AC mixtures are those with VIM values closer to the average value of the specification, which is (3.5 + 6)/2 = 4.75%.

To find the better quality of the AC mixtures with different content of CR, each of the results of the Marshall Properties should be given scores. The score is 1 for the best one, 2 for the second one, 3 for the third, etc. The scores are finally accumulated by just simple addition and the CR content with the least value is chosen as the best AC mixtures for all the Marshall properties describes above.

It should be noted here that the VMA and the VFWA are not included in the qualitative analysis, because the VMA and VFWA are only for the initial condition for the aggregates and gradation; they are not related to the asphalt content or CR content. Therefore, as long as the VMA and VFWA specifications are already met according to the specification, the other Marshall properties should be used as the determining factors.

Table.5.9 Comparison of Marshall tests of HMA with CR and without CR

	%Crumb Rubber content in mix			
	%CR	2.5%CR	4.5%CR	6.5%CR
optiumum biltumen content for design mix(OBC)	6.10	6.20	6.25	6.35
Marshall stablity (kg)	1621.48	1322.79	1066.76	1280.12
Flow (mm)	4.92	3.80	3.40	3.66
Marshall Quotient (kg/mm)	329.56	377.94	313.75	349.76
VIM (%)	5.22	4.83	5.36	5.42
VMA(%)	17.01	16.78	21.64	16.31
VFWA(%)	66.43	71.22	67.14	66.54

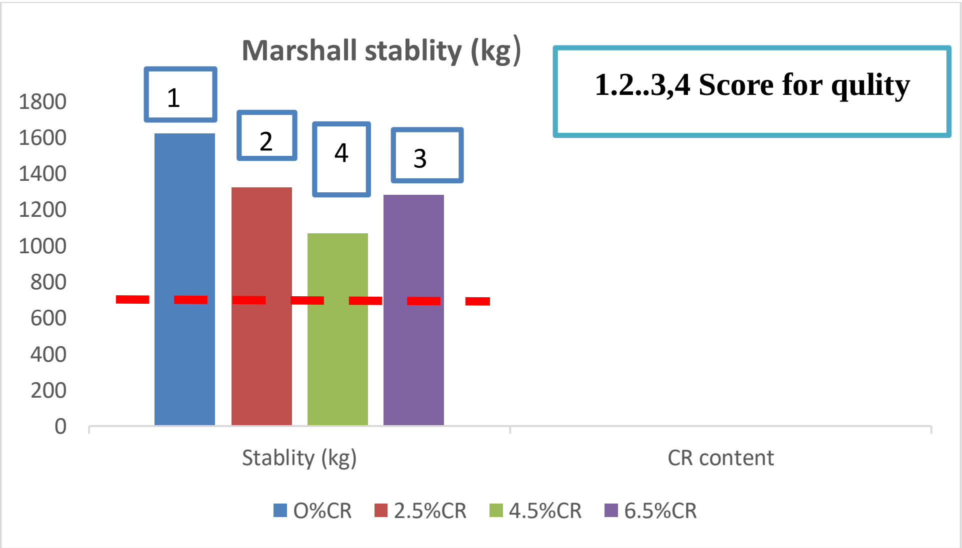

Figure 5.36 Comparison of cases Stability test for HMA with and without CR

5.4.1 The Marshall Stability

When comparing the test results for Stability in Table 5.9 and Figure 5.36 optimal stability. The results in stability tests respectively without CR at AC 6.0% was 1621.48 kg, with 2,5% CR at AC 6% was 1322.79kg, with 4.5%CR at AC 6.0% was 1066.76kg, with 6.5%CR at AC6 % was 1280.12kg.

Therefore, it can be inferred that a higher proportion of CR improves stability by 2.5 % CR. Further injection of CR into the mixture resulted in an increase in the consistency factor since extensive crumb rubber application reduces the coarse aggregate point of contact within the mixture. The use of crumb rubber can result in higher density or more porous bitumen. Consequently, the mixture becomes more flaccid to lead to a drop in the stability value. The resilience of aggregates reduces as the crumb rubber content increases (Mashaan et al. 2013). Increasing crumb rubber has been found to reduce HMA stability, with a higher percentage of crumb rubber yielding the lowest stability value.

Table.5.10 Comparison of Flow (mm) of Hot Mix Asphalt Concrete with CR and

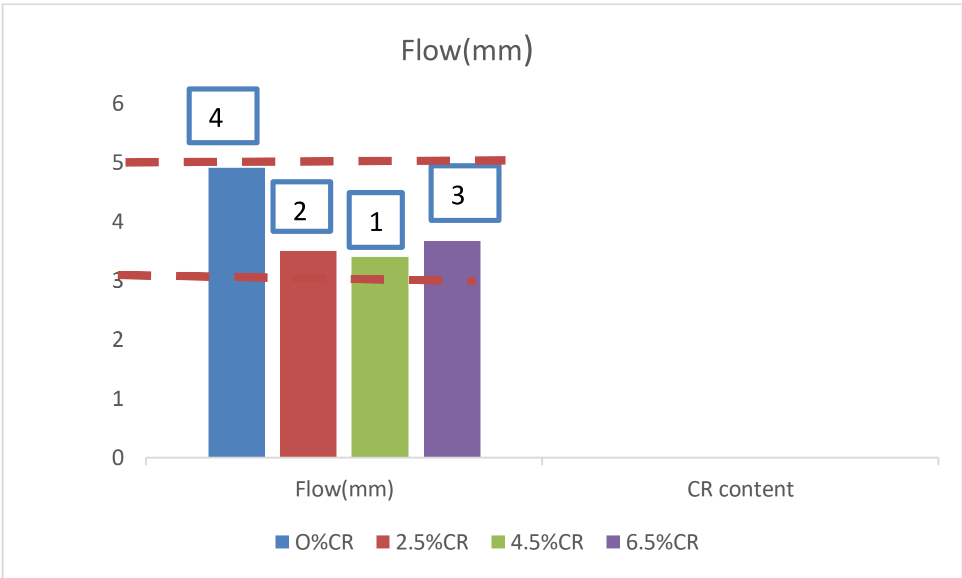

Figure 5.37 Comparison of cases flow test for HMA with and without CR

5.4.2 The Marshall Flow

Comparing the outcome of the Flows check-in Table 5.9 Figure 5.37, the hot mix asphalt concrete flow test volume improved as the CR quality rose from 5% to

7%. Higher flow values can be associated with increased air void (more compaction required) by using more CR in the mixture, resulting in a more versatile mix. Therefore, it can be inferred that the lower amount of crumb rubber increases the flow but the higher volume of asphalt reduces the flow. The mixtures are more stable with the inclusion of asphalt content; while the resistance to deformation decreases, it can result in a high flow value (Mashaan et al. 2013). It has been stated that applying crumb rubber additive to asphalt concrete increases the mixture flow before maximum crumb rubber content is obtained. Crumb rubber with additional content is good at higher temperatures with high flow. while very low permeability and more rigidity in small flow. Asphalt content with additional crumb rubber can lead to high flow value, This means that good against rutting, and permeability .

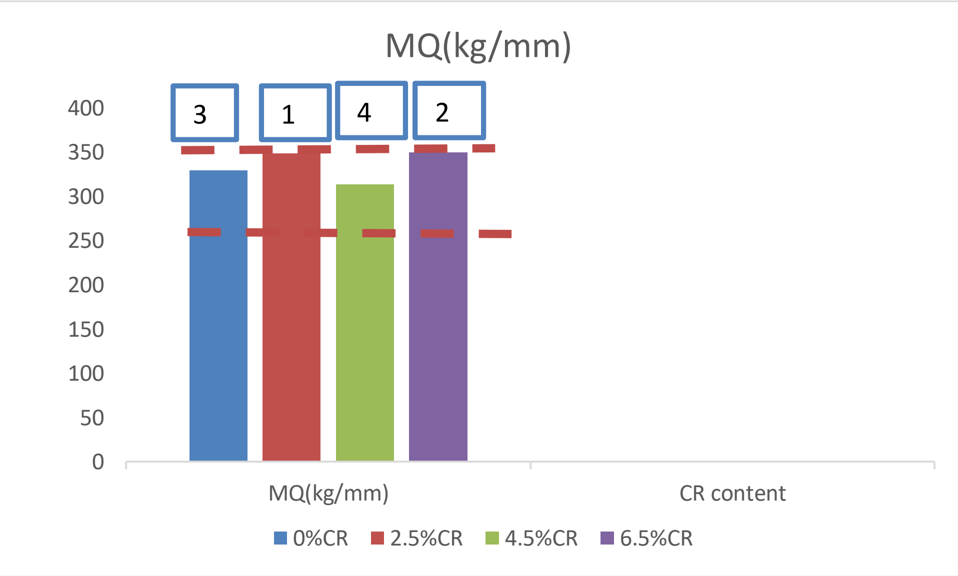

Figure 5.38 Comparison of cases of MQ test for HMA with and without CR

5.4.3 Marshall Quotient (MQ)

The MQ test results evaluated in Figure 5.40 show that HMA without crumb rubber, 2.5%, 4.5%, and 6.5% CR have maximum MQ values of 303.01, 348.10, 313.75, and 349.76 kg/mm, accordingly at AC 6%. Therefore, it can be inferred that MQ can improve by increasing the percentage of crumb rubber content. This is because voids have space within the compacted mix to transfer the HMA. The combination of asphalt construction and rubberized HMA mixtures is a trade-off in high binder quality to boost long-term longevity and efficiency.

Moreover, enough space in place can prevent rutting, instability, flushing, and bleeding. The details can be seen in Table 5.9 the MQ.

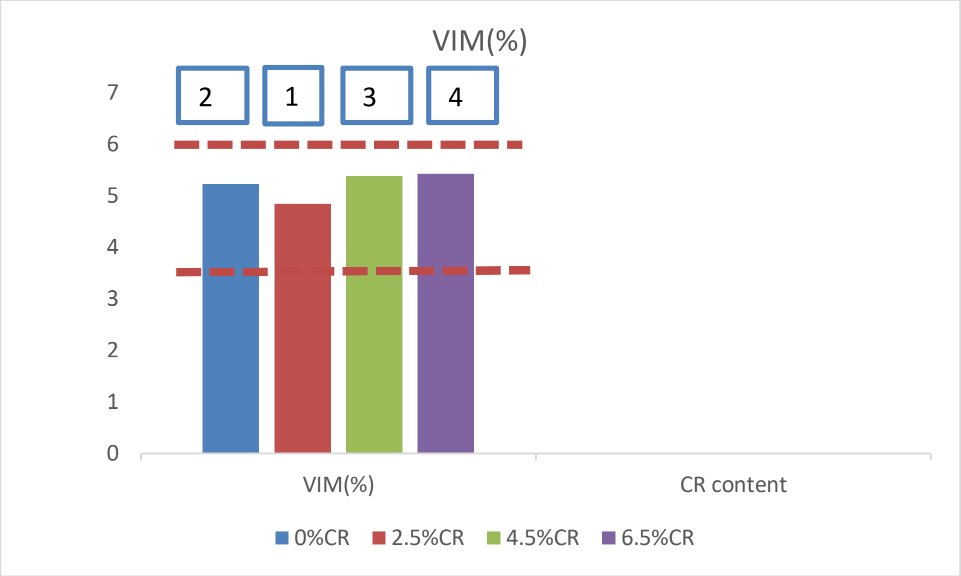

Figure 5.39 Comparison of cases VIM test for HMA with and without CR

5.4.4 Void in Mix (VIM)

The VIM test results analyzed in Figure 5.41 showed that HMA without crumb rubber,2.5%, 4.5%,6.5%, CR have maximum. The VIM has the values of 5.22, 4.83, 6.36, and 5.77 respectively. Therefore, it can be inferred that an increase in the amount of crumb rubber content can increase the VIM.

Al-Azri et al. (2006) concluded that The use of petroleum asphalt as a pavement mixture although it meets the requirements of the specification, often shows a decrease in service behavior due to rutting, fracture, and other forms of damage. Fractures from or on the sidewalk make water easy to enter so that it can damage the paving structure due to the movement of air and water on the sidewalk, causing oxidation and evaporation to occur in the binder. As a result, sidewalks have relatively low durability. There is strong evidence that asphalt oxidation happens in the whole depth of pavement, dramatically affecting pavement durability. Shu and Huang (2014) stated that an increased amount of crumb rubber in the mixture of asphalt concrete would reduce the strength of Marshall. Nevertheless, this was not always accompanied by enough flow; thus, as expressed by the Marshall Quotient parameter, it resulted in less versatility. Waste tires pose significant health and environmental concerns if not recycled and/or discarded properly. Over the years, recycling waste tires into civil engineering applications, especially into asphalt paving mixtures. Crumb rubber or waste rubber is a mixture of natural rubber synthetic rubber, black carbon, antioxidants, fillers and extender form of oils that are soluble in warm paving grade.

	Scores for quality of Marshall properties			
	%CR	2.5%CR	4.5%CR	6.5%CR
Marshall stablity (kg)	1	2	4	3
Flow (mm)	4	2	1	3
Marshall Quotient (kg/mm)	3	1	4	2
VIM (%)	2	1	3	4
Σ score	10	6	12	12
Ranking of overall quality	2	1	4	3*

* Having total scores = 12 similar to 4.5% CR, but it selected as no.3 because of the more amount of CR used as more desirable for environmental concern.

As for the conclusion of this Chapter, the best CRMA mixture for overall condition according to the criteria of the Marshall Test is the one with the CR content = 2.5%. This 2.5% CR will exhibit the best mixture for hot mix asphalt concrete against fatigue cracking and rutting.

5.5 The Mechanical Properties

5.5.1 The Indirect Tensile Strength Properties (ITS)

The stress test was used to classify the pressure and tensile strength of the mixture of specimens. Specimens were monotonically primed to fail at a constant rate of 3 in / min (76.2 mm / min) along the vertical diametric axis. Another method of tensile strength test used for stable materials is the indirect tensile strength test. This test involves driving a compressive filled cylindrical model together with two opposite generators. This results in a relatively uniform tensile stress, working perpendicularly. In line with the demurral plan of the load applied, it has a result of splitting failure that normally occurs along with the diametric plans. The three samples were measured at temperatures at 10°C, 25°C, 40°C, and 60°C for each type of HMA without and with CR. Figure 5.46 and Table 5.10 shows a summary of the indirect tensile strength test result for each type of HMA without and with crumb rubber in OBC. Calculate the tensile strength of the compacted bituminous mixture:

$$ITS = \frac{2F}{3.14(h.d)} \quad \ldots\ldots \quad (5.1)$$

Where:

ITS = Indirect tensile strength, psi
F = Total applied vertical load at failure,
h = Height of the specimen, in.
d = Diameter of the specimen.

Table 5.10 Comparison of indirect tensile strength test at OBC

CR%	OBC	ITS@ 10C°	ITS@ 25C°	ITS@ 40C°	ITS@ 60C°
without CR	6.10	210.810	71.757	23.977	13.147
2.5% CR	6.20	217.90	87.274	27.024	15.028
4.5% CR	6.25	154.60	54.294	20.881	7.955
6.5% CR	6.35	125.041	45.222	24.334	5.791

Summarized results from detailed tests in Appendix F

This relationship is shown in Figure 5.42 between the ITS and the various temperatures

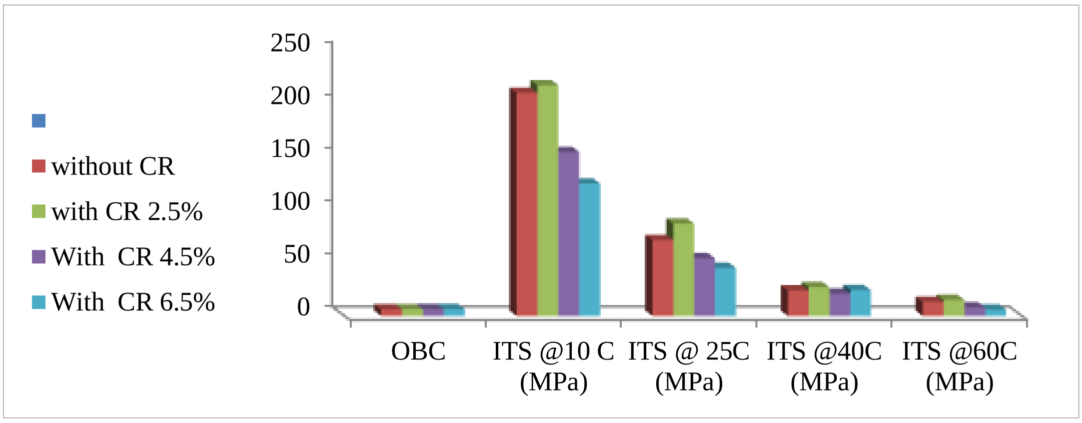

Figure 5.40 Results of the ITS each and HMA Concrete without and with CR

1.At 10C° temperature.

The ITS value of HMA with2.5% CR is higher than HMA without CR by 217.90MPa. HMA without CR is higher than HMA with 4.5% CR by 210.81MPa, and HMA with 4.5% CR is higher than HMA with 6.5% CR by 154.60 MPa. The least ITS value at a temperature 10˚C was obtained for AC modified with 6.5% CR by 125.041MPa. Therefore, it can be inferred that HMAwith crumb rubber is better to change the temperature on ITS tests comparison by using CR or without using CR. The optimum result in the Indirect tensile strength test at 10C° with 2.5%CR has the result at 217.90MPa.

2.At 25C°temperature.

The ITS value of HMA with 2.5 % CR is higher than HMA without crumb rubber by 87.274MPa. HMA without CR is higher than HMA with 4.5% by 71.757MPa. The hot mix asphalt with 4.5% CR is higher than hot mix asphalt with 6.5% CR by 54.29MPa. The least value of ITS at a temperature of 25 C° was obtained for HMA with 6.5% CR by 45.22MPa. It may be concluded that hot mix asphalt with crumb rubber is better to change in temperature by using ITS tests compared to AC without CR. The optimum result in the Indirect tensile strength test at 25 C° was with 2.5% CR, which the result was 87.274 MPa

3.At 40C° temperature.

The ITS value of HMA with 2.5% CR is higher than HMA without crumb rubber by 27.024MPa. HMA 6.5% CR is higher than HMA without CR by 24.334MPa. hot mix asphalt without CR is higher than hot mix asphalt with 4.5% CR by 23.977MPa. The least ITS value at a temperature 40˚C was obtained for hot mix asphalt with 4.5% CR by 20.881MPa. Therefore, it could be concluded that CR hot mix asphalt is better to change the temperature by using ITS tests compared to hot mixed-asphalt without crumb rubber. The optimum result in the Indirect tensile strength test at 40 C° with 2.5% CR was 27.024MPa.

4.At 60C°temperature.

The ITS value of hot mix asphalt with 2.5 %CR is higher than hot mix asphalt without crumb rubber by 15.028 MPa. hot mix asphalt without CR is higher than hot mix asphalt with 4.5% by 13.147MPa. hot mix asphalt with 4.5% CR is higher than hot mix asphalt with 6.5% CR by 7.995MPa. The least ITS value at a temperature 60˚C was obtained for HMA with 6.5% CR by 5.791MPa. The optimum result in the Indirect tensile strength test at 60C° with 2.5% CR was 15.028 MPa. It may be concluded that hot mix asphalt with crumb rubber is better to change the temperature by using ITS tests compared to HMA without CR.

From the above observations for hot mix asphalt is not stronger than the hot mix asphalt with crumb rubber. The hot mix asphalt with 2.5% crumb rubber is stronger than the hot mix asphalt with 4.5% and 6.5% crumb rubber. There is a lot of filler composition of the asphalt that can fill cavities in the mixed-aggregated asphalt. This makes the asphalt surrounds thicker than using asphalt without crumb rubber. The ITS results for asphalt samples with 2.5% CR content are the highest result among those other samples tested at all temperature conditions.

5.5.2 The Unconfined Strength Properties

This method was used to assess the tolerance to irreversible deformation of the bitumen mixture at 24C°, 30C°,40°C, and 60C° and loads. A continuous load is applied to a specimen using OBC and then the actual load is calculated. This approach has been used to assess the permanent deformation of hot mix asphalt without crumb rubber, and hot mix asphalt with three percentages of crumb rubber is rendered with UTM (Universal Testing Machine) for a strong push from the Kg machine. The unconfined compression test is by far the most common shear test method, as it is one of the easiest and cheapest methods for measuring shear strength. The results of the unconfined compressive strength test give inTable 5.11 and Figure 5.47.

Table.5.11. Comparison of the Unconfined compressive strength test at OBC at different temperatures °C

CR %	OBC	UCS @24 C°	UCS @ 30C°	UCS @40C°	UCS @60C°
without CR	6.10	5060	3990	2280	1620
with CR 2.5%	6.20	3030	2770	2470	1080
With CR 4.5%	6.25	2010	3170	1900	1100
With CR 6.5	6.35	2465	1400	2790	1730

Summarized results from detailed tests in Appendix F

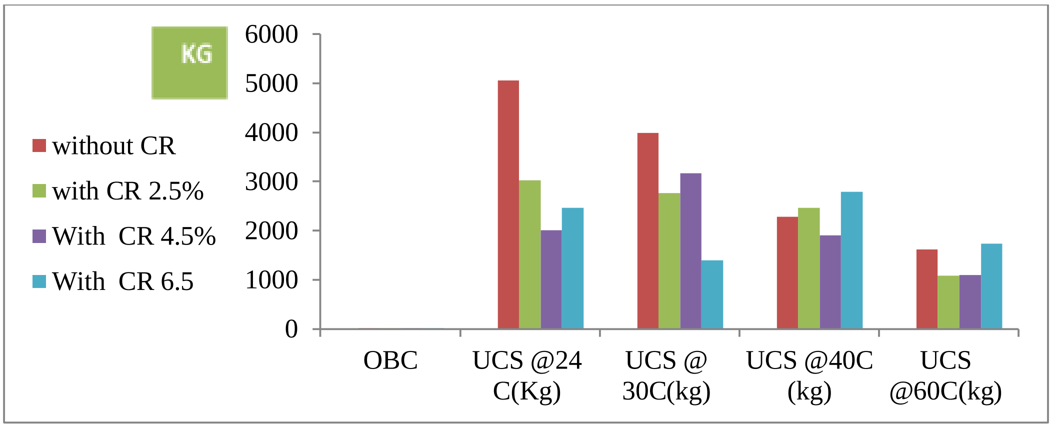

Figure 5.41. Results of the UCS each and HMA concrete without and with CR at different temperatures °C

1. At 24C° temperature.

The UCS value of hot mix asphalt is higher than that of crumb rubber hot mix asphalt with 2.5% CR by 5060kg. hot mix asphalt with 2.5% crumb rubber is higher than hot mix asphalt with 6.5% by 3030kg. Hot mixed-asphalt with 6.5% CR is higher than hot mix asphalt with 4.5% CR by 2465kg. The least UCS value at a temperature 30˚C was obtained for HMA with 4.5% crumb rubber by 2010kg. This is due to the addition of the hot mix asphalt that modified the mixture with crumb rubber decrease adhesion of asphalt to aggregate more resistant to the destruction. This destruction would affect the decrease in UCS value. However, HMA without CR is higher than HMA with 4.5% CR at a temperature of 30°C. The asphalt with crumb rubber is less sensitive to temperature changes by using the test compared to hot mix asphalt without crumb rubber. Through the study of the relationship between the value of UCS and temperature change, it is found that the optimum result in the Unconfined Compressive Strength Test at 24C° without CR was 5060kg.

2. **At 30C° temperature.**

The UCS value of hot mix asphalt is higher than that of crumb rubber hot mixed-asphalt with crumb rubber 4.5 % CR by 3990kg. hot mix asphalt with 4.5% crumb rubber is higher than hot mix asphalt with 2.5% by 3170. hot mix asphalt with 2.5% CR is higher than hot mix asphalt with 6.5% CR by 2770 kg. The least UCS value at a temperature of 30C° was obtained for HMA with 6.5% CR by 1400kg. From this result, it can be inferred that hot mix asphalt with CR is good to change the temperature by using the UCS test compared to hot mix asphalt without crumb rubber. The optimum result in the Unconfined Compressive Strength Test at 30C° without CR was 3990kg.

3-At 40C° temperature.

The UCS value of hot mix asphalt with 6.5% CR is higher than HMA with 2.5% CR by 2790kg. HMA with 2.5% CR is higher than hot mix asphalt with 4.5% by 11620kg. hot mix asphalt with 4.5% CR is higher than HMA without CR by 2470kg. The least UCS value at a temperature of 40˚C was obtained for HMA with 4.5% CR by 1900kg. Therefore, it can be concluded that hot mix asphalt with crumb rubber is better to change the temperature by using the UCS test compared to hot mix asphalt without crumb rubber. The optimum result in the Unconfined Compressive Strength Test at 40C° with 6.5% CR was 2790kg.

3. **At 60C° temperature.**

The UCS value of hot mixed-asphalt with CR 6.5% CR is higher than HMA without CR by 1730kg. HMA without CR is higher than hot mix asphalt with 4.5% CR by 11620kg. hot mix asphalt with 4.5% CR is higher than HMA with 2.5% CR by 1100. The least UCS value at a temperature of 60C° was obtained for HMA with 2.5% CR by 1080kg. Therefore, it can be concluded that hot mix asphalt with crumb rubber is better to change in the temperature using the UCS tests relative to hot mix asphalt without crumb rubber. The optimum result in the Unconfined Compressive

Strength Test at 60C° was 6.5% CR with 1730 kg. overall, the improvements in the UCS test results due to the addition of CR were found at high test temperatures (40℃ and 60℃). The incorporating samples of 6.5% CR show a higher temperatures improvement overall

5.5.3 The Indirect Tensile Strength Modulus Properties

The ITSM test was conducted on both thin standard samples and hot mix asphalt using UMMATTAP'. The analysis was carried out at a temperature room, and the findings can be seen in Table 5.12 and Figure 5.48 (see also Appendix). For every mixture with CR and without CR, three samples were tested. The sample was evaluated under three different conditions to obtain a stiffness modulus for a mixture and the mean value was adopted. Table 5.12 shows the Stiffness modulus of the mixtures Figure 5.44. Figure 5.44 shows this relation between ITSM and CR.

Table.5.12 Comparison of Indirect Tensile Strength Modulus test.

CR%	OBC	ITSM (MPa) @ 20C^0					Average (MPa)
No CR	6.10	2893	3071	2771	2801	2804	2868
2.5%	6.20	1652	1654	1658	1653	1679	1659
4.5%	6.25	1482	1484	1457	1444	1433	1460
6.5%	6.35	1103	1069	1031	921	474	920

*Summarized results from detailed tests in Appendix H

At the temperature of 20 C°, the ITSM value of HMA without CR is higher than HMA with 2.5% CR. The average is 2868Mpa, and hot mix asphalt with 2.5% CR is higher than hot mix asphalt with 4.5% CR with average 1659Mpa. The hot mix asphalt with 4.5% CR is higher than hot mix asphalt with 6.5% CR by1460Mpa. The least ITSM value at a temperature 20˚C was obtained for HMA with 6.5% CR by 920Mpa. Therefore, hot mix asphalt with CR can be concluded better to change in temperature using ITSM tests relative to HMA without crumb rubber. The result in Indirect Tensile Strength Modulus with 2.5% CR was 1659 MPa that was different from other results of 4.5% CR and 6.5% CR. In addition, it considered hot mix asphalt with 2.5% crumb rubber increased at Indirect tensile strength modulus that was different from other mixed-crumb rubber contents.

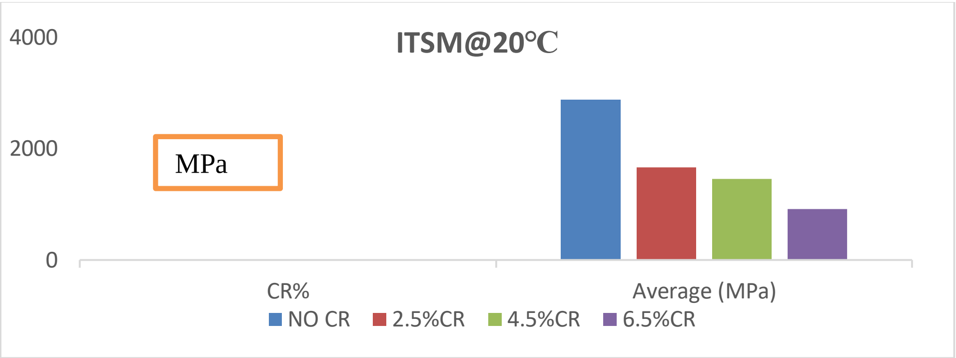

Figure 5.42 The results of ITSM each and HMA concrete without and with CR

5.5.4 The Indirect Tensile Fatigue Properties

Fatigue is one of the parameters of collapse in what mix in the concept of a mechanical method other than permanent deformation. As for the approach used to study this parameter is the imposition of cylindrical test specimens using the indirect tensile tests. This test method refers to BS EN 12697-24: 2012 with the pattern of haversine loading through a vertical diametric field. The concept of fatigue testing using the constant load method which is carried out at the optimum asphalt content of pavement mixture with a crumb rubber cycle until the failure condition is called fatigue age.

Tests are carried out at 5 different levels namely 300 KPa, 400 KPa, 500KPa, 600KPa, and 700 KPa. This large tensile sorting is based on the provisions of BS EN 12697-24: 201 which require a minimum voltage level of 250 KPa, this value is a practical voltage level that can be applied in almost every case; however, the operator can use a voltage level that matches the rigidity of the specimen. Before testing, a load calculation is performed to obtain the stress load desired to be inputted in an integrated application the desired stress load to be inputted in an application that is integrated with the testing tool by using the formula according to equation 2.11 the following calculation example:

$\sigma=\frac{2F}{\pi\times\tau\times\Omega}$ ……………………...…………………………………………..(5.2)

$\sigma=\frac{2\times4236}{3.14\times66.36\times101.6}$………………………………………………………..… (5.3)

σ=400 kpa(0.400Mpa)……………………………….…………………..(5.4) make bedan applied at a voltage level of 450 KPa is 4759N, the full load calculation can be seen in Table 5.13.

Table 5.13 Load calculation ITFT

No	σ		π	Thickness (mm)	Dimater (mm)	Force (N)
	Kpa=(kN/m^2)	(N/mm^2)=Mpa				
1	400	0.400	3.14	66.38	101.6	4236
2	500	0.500	3.14	62.00	101.6	4945
3	600	0.600	3.14	59.63	101.6	5707
4	700	0.700	3.14	58.88	101.6	6575

From table 5.13 based on the calculation, the F value is used as an input for the cyclic loading force or loading cycle. After that, when set up, the parameter set up is entered by following the testing standards in BS EN 12697-24: 201 The parameter set up can be seen in Table 5.14.

Table 5.19 standard set-up per meter for ITFT testing

No.	Parameters	Set up applied	Note
Test control parameter			
1	Seating Force (N)	10	
2	Cyclic loading force(N)	3 stresses level	Min 250kpa
3	Loading cycle width (ms)	100	
4	Load cycle repeat,s time (ms)	500	
5	Estimated poisson's ratio	0.35	
6	Target temperature deg C	20±1C°	
Test termination			
1	Max cycle count	50000 or more	Until failure
2	Total axial displacement (mm)	9	

Based on Table 5.14 there are several test control parameters and test terminations, including;

1. Seating force is the force applied by the loading system when the test object is placed into the testing instrument.

2. The Cyclic loading force is the determination of the load cycle force specification and is an additional seating force (the maximum force applied is the sum of the seating force and cyclic load force).
3. Load cycle width determines the width of the loading waveform in milliseconds with a minimum width of 20ms and the maximum cannot exceed the repetition of the load cycle.
4. Loading circle repeat time is data in determining the frequency of charging pulses and can range from 500 milliseconds (2Hz) to 10 seconds (0.1Hz)
5. Poisson ratio estimation is a constant of elasticity that is owned by each material used to calculate the modulus. a material that is one-way paraded or pressed, will change in shape in addition to changing shape in the direction of a given force, there is also a change in the shape of the direction perpendicular to the direction of the force. In the pavement, the estimated Poisson ratio of 0.35 is used.

The target temperature is used to determine the target temperature of the test which is equal to 20C°. According to reading (1997) on the ITFT loading method, due to the absence of voltage reversal, the accumulation of permanent deformation increases the likelihood that under high loads and/or high temperatures compressive or shear failure occurs in the specimens. Head and collop recommend that the test temperature be less than 30C°.

Table 5.15. The fatigue test results.

No	**Height(mm)**	**P(N)**	$\sigma x, \max = \sigma applied$ **(kPa=kN/mm2)**	**No of Cycles at failure (Nf)**
No CR				
1	66.38	4236	400	2281
2	62.00	4945	500	2691
3	59.63	5707	600	1601
4	58.88	6575	700	1141
2.5CR				
1	60.84	2915	300	4421

2	60.36	3852	400	1971
3	56.75	4527	500	731
4	68.50	6556	600	451
5	69.43	7753	700	151
4.5CR				
1	70.25	3362	300	4281
2	69.75	3895	350	951
3	70.13	4475	400	731
4	61.13	4388	450	621
5	62.75	5005	500	451
6.5CR				
1	74.75	2981	250	1471
2	65.75	3147	300	651
3	75.75	4229	350	601
4	73.75	4706	400	91

*Summarized results from detailed tests in Appendix I

Termination can be determined by the maximum number of load cycles of maximum actuator displacement, or when the maximum limit of the tool is reached Axial displacement or axial displacement is the holding of a specimen from the holder when tested, the fatigue life resulting from the tested sample must be in the range of 10^3-10^6 per number of load applications after the parameter set-up and testing is performed then the test results are seen. The fatigue test results can be seen in Table 5.15 and in full the fatigue test results are presented in the attachment to chapter 5orizontally (the specimen moves forward or backward more than the specified limit.

Based on Table 5.15 there is an average rate where the data is the high rate of the object which is measured using a sliding thrust then & (KPa) is a voltage level that has been determined based on literature studies and Nf which is the number of load repeats cycles. From this Table, it can be seen that the tensile stress applied to the test load consists of 4 variations of 400 KPa, 500 KPa, 600 KPa, and 700 kPa which the smaller the applied voltage make the greater the number of load repulses required to experience a loading collapse resulting in repetitive stresses against the load applied which causes the specimen to fail by splitting along the middle of the vertical diameter.

At the time of testing, samples gave a voltage level of 500,600 and 700 KPa load repetition occurred until the test object collapsed (failure). But it is different in testing with a voltage level of 400 KPa. when testing the sample, the tool stops giving a load up to 3560 cycles times the repetition of the load and there is no complete collapse because it is caused by a tool mechanism where if no different strains are detected at 2LVDT the loading will stop automatically. these conditions can occur if the applied load is too low. After getting the number of repetitions of the load at each voltage, make obtained the relationship between the voltage and the number of repetitions of the load, the relationship of the number of load repetitions Figure 5.45.

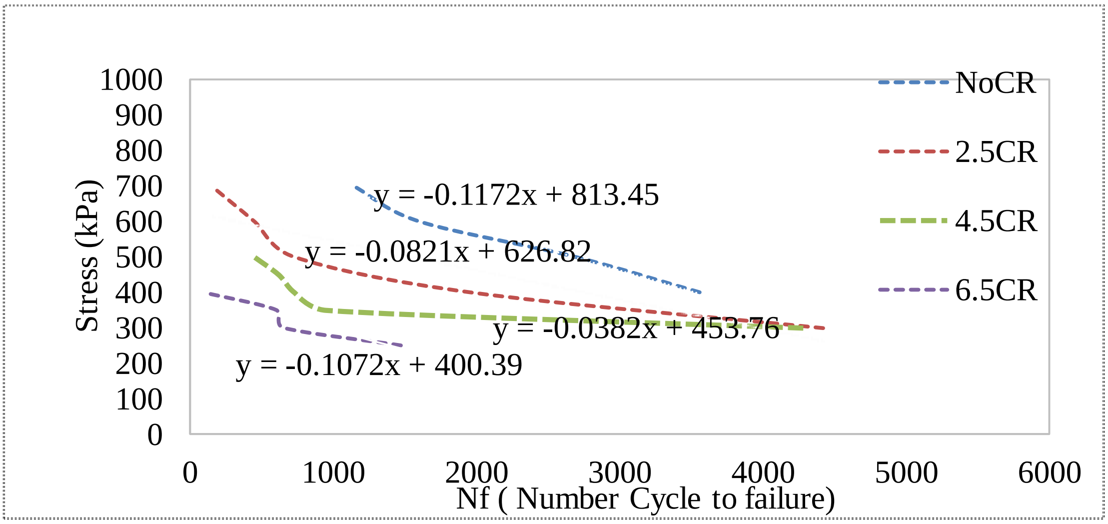

Figure 5.43 The relationship between the voltage and the number of load repetitions

In Figure 5.45 we can see the voltage data and its relationship to the number of repetitions of the load. The figure shows that if the line is extended then at a certain pressure, a stronger sample will collapse in a higher repetition load, the smaller the applied voltage the greater the number of repetitions of the load until the sample collapses. From generally when stress occurs there will be a strain on the elastic material. The Strain is a form of deformation which is described as the relative change of the particles in an object that is not a rigid. The tension can also be interpreted as a relative change in the size or shape of objects experiencing stress.

The fatigue test results that can be seen in the appendix to chapter 5 obtained the strain value. The Strain values are listed on the test results graph of strain values measured on the outside of the sample related to the application loading mechanism on the tool, so to get the strain that occurs in the middle or center of the sample, calculations are performed using the formula according to equation 2.12. The equation can be used to calculate the maximum horizontal tensile stress σ xmax) and the maximum initial stress-strain (ε max core tensile strain - ε xmax) in the middle of the sample. Examples of the calculation are as follows:

max $\frac{=\sigma x \max}{s\ mix}$ $1 + 3\nu$..(5.5)

=$\frac{700}{3058}$ $1 + 3(0.35)$..(5.6)

=469με

The strain that occurs in the middle of the sample obtained at a voltage of 700 KPa is 469με. The complete calculation results can be seen in table 5.16.

Table 5.16 calculation of strain values

No	**Height (mm)**	**P (N)**	**(kPa=kN/mm2)**	**S mix = ITSM (MPa)**	**ex, max * (micro strain)**	**No of Cycles at failure (Nf)**
No CR						
1	66.38	4236	400	3058	268	2281
2	62.00	4945	500	3058	335	2691
3	59.63	5707	600	3058	402	1601
4	58.88	6575	700	3058	469	1141
2.5CR						
1	60.84	2915	300	1752	351	4421
2	60.36	3852	400	1752	468	1971
3	56.75	4527	500	1752	585	731
4	68.50	6556	600	1752	702	451
5	69.43	7753	700	1752	819	151

4.5CR						
1	70.25	3362	300	1539	400	4281
2	69.75	3895	350	1539	466	951
3	70.13	4475	400	1539	533	731
4	61.13	4388	450	1539	599	621
5	62.75	5005	500	1539	666	451
6.5CR						
1	74.75	2981	250	953	538	1471
2	65.75	3147	300	953	645	651
3	75.75	4229	350	953	753	601
4	73.75	4706	400	953	860	91

Summarized results from detailed tests in Appendix K

From Table 5.16 there is the value of s max where the value is obtained directly from the testing of indirect tensile stiffness modulus (ITSM) on one CR of the mixed δmix gradation specimens which is the sensitivity modulus is the stress and strain relationship which shows the rigidity of material so that when under load, the ability of the material in holding the strain is affected by the modulus of rigidity. A linear relationship occurs between stress and strain where the greater the strain generated, the greater the strain. ITSM test results can be seen in Chapter 5 while εx max is the maximum horizontal tensile strain in the middle of the specimen (initial strain). The relationship between the number of repetitions of load with strain can be seen in Figure 5.50.

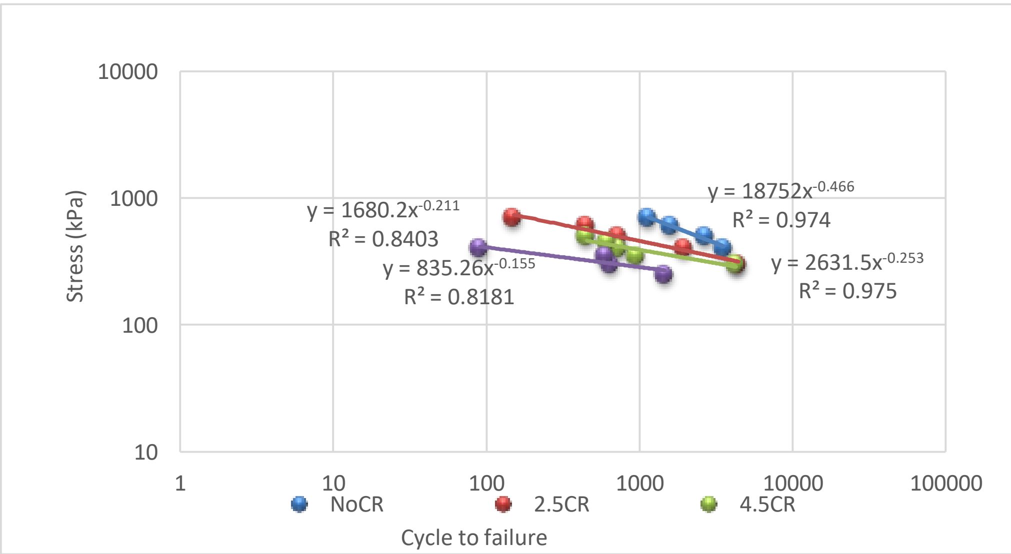

Figure 5.44 The relationship of the number of repetitions of load with stress(Kpa)

In Figure 5.46, there are 4 strains in samples 1, 2,3 , and 4.They are 400 KPa, 500KPa, 600 KPa, and 700 KPa for HMA without CR, and with 3 various CR values starting from 2.5 % CR, 4.5 %CR, and 6.5%CR. There are 5 stretches, they are at 1,2,3,4 and 5 voltages of 300 KPa, 400 KPa, 500 KPa, 600 KPa, and 700 KPa which each CR has several repetitions of the load until the sample experiences failure. First of all, the research results from HMA without CR found that the value of the repetition of the body in each loading cycle will be used to calculate the amount of strain. However, the collapse in a specimen with voltage levels of 400 KPa, 500 KPa, 600 KPa, and 700 KPa respectively occurred at 3560,2691,1601and 1141 cycles. It can be seen that when the target of a pavement collapses longer or the fatigue life value is longer, then the material's ability to withstand the strain is smaller.

From the research results for HMA with2.5% CR, it is found that the value of repetition of the body in each loading cycle will be used to calculate the amount of strain. Meanwhile, the collapse in a specimen with voltage levels of 300 KPa, 400 KPa, 500 KPa,600 KPa, and 700 KPa respectively occurred at 4421, 1971, 731, 451 and 151 cycles. It can be seen that when the target of a pavement collapses longer or the fatigue life value is longer, then the material's ability to withstand the strain is smaller

Besides that, the research results for HMA with 4.5% CR, it is found that the value of repetition of the body in each loading cycle will calculate the value of the strain. Meanwhile, the collapse in a specimen with voltage levels of 300 KPa, 350KPa,400KPa,450Kpa, and500KPa respectively occurred at 4281,951,731,621, and 451 cycles. It can be seen that the longer the target of a pavement collapses or the longer the fatigue life value is, the smaller the material's ability to withstand the strain.

After that, the research results for HMA with 6.5% CR, it is found that the value of repetition of the body in each loading cycle will calculate the value of the strain Meanwhile, the collapse in a specimen with voltage levels of 250kpa, 300kPa, 350kPa, and 400kPa respectively occurred at 538,651, and 601,91cycles. It can be seen that the longer the target of a pavement collapses or the longer the fatigue life value is, the smaller the material's ability to withstand the strain. It was the optimum result in the Indirect Tensile Fatigue Test was with 2.5% CR the result was fatigue life longer compare to other results with 4.5% CR, and 6.5% CR. Based on the test results, after the pressure level is converted to a unit of wheel pressure, the voltage level of 600kPa is equal to 1750mpa which at that level produces a load repetition cycle that is equal to 541 times equal to 702 microstrains. With the collapse value, it can be concluded that the mixture of pavement with a gradation (CR) can be used in agricultural roads, forests road, between residential neighborhoods, small streets, and alleys road. And also can use on small airport runways or airport runways which only serve aircraft types classified as small aircraft.

5.6 The Durability Properties

Testing permeability is essential because one of the key principles is the robust architecture of concrete pavement (asphalt concrete) for modern pavement and the pavement must be impermeable. The foundation of this design approach is to reduce the absorption of moisture and thus maintain adequate protection from the unbound materials that underlie it. Table 5.17 shows the results of the OBC permeability check Figure 5.47 shows the findings outlined for each form of HMA in OBC. The calculations coefficient permeability by the following equation:

Where diameter (D) = 2.54*4 = 10.16 cm

Height (L) = 6.127 cm

Area (A) $= \frac{\pi \times D^2}{4} = \frac{\pi \times (10.16)^2}{4}$ = 79.756 cm^2..(5.7).

Pressure water (P)= 10Kg/cm^2

Volume of water leakage (V) = 1000 ml

Time leakage 1000ml = 194 sec @(10Kg/cm^2).

$\gamma = 1\ gr/cm^2$.

Coefficient permeability (k) = $\frac{V \times L \times \gamma}{A \times P \times T} = \frac{1000 \times 6.127 \times 1}{79.756 \times 10 \times 194}$ = 3.96E-07 cm/sec........(5.8)

Table 5.17 Comparison of Permeability Test at OBC.

CR %	Asphalt Content	Height (L) (cm)	Area (A) (cm2)	Pressure Water and N2 1 kg/cm2		Pressure Water and N2 2 kg/cm2	
				Time (T) sec	Permeability lt/sec	Time (T) sec	Permeability lt/sec
0	6.10	6.15	79.756	103	0.010	42	0.024
	6.10	6.316	79.756	78	0.013	31	0.032
	6.10	6.116	79.756	110	0.009	48	0.021
		Average			0.011		0.026
2.5	6.20	6.433	79.756	46	0.022	20	0.050
	6.20	6.283	79.756	88	0.011	43	0.023
	6.20	6.666	79.756	43	0.023	18	0.056
		Average			0.019		0.043
4.5	6.25	6.630	79.756	46	0.022	19	0.053
	6.25	6.583	79.756	43	0.023	22	0.045
	6.25	6.40	79.756	42	0.024	23	0.043
		Average			0.023		0.047
6.5	6.35	7.20	79.756	23	0.043	15	0.067
	6.35	6,766	79.756	40	0.025	24	0.042
	6.35	6.65	79.756	30	0.033	18	0.056
		Average			0.034		0.055

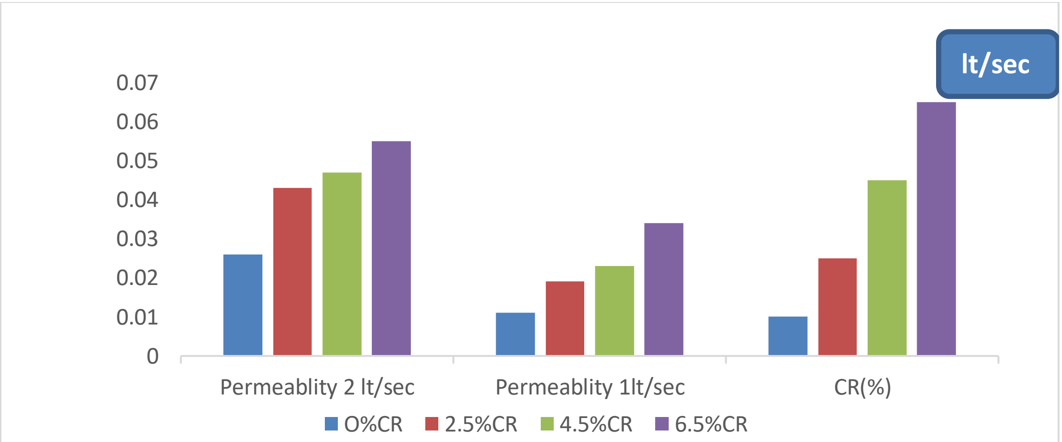

Figure 5.45 The results of the permeability test

The crumb rubber-type 0% on OBC 6.10% has the first permeability at 0.011 cm/sec and the second permeability at 0.026 cm/sec. Crumb Rubber content of 2.5% on OBC 6.20% has the first permeability at 0.019 cm/sec and the second permeability at 0.043 cm/sec. Crumb Rubber content of 4.5% at OBC 6.25% cm/sec has the first permeability at 0.023 lt/sec and the second permeability at 0.047 cm/sec. Crumb Rubber content of 6.5% at OBC 6.35% has the first permeability at 0.034 cm/sec and the second permeability at 0.055 lt/sec. The effect in using a different type of lowest crumb is when the optimum bitumen content is at 6.10%; while the highest is when the optimum bitumen content is at 6.35 in the fast water flow of samples. The following observations were obtained by reviewing the test results for permeability in Table 5.17 and Figure 5.49.

The concrete HMA with CR has the coefficient of permeability (K) at 6.5 % higher than the concrete HMA without CR (original) and with 2.5 %CR, and 4.5 % CR by 0.034 cm/sec at a water pressure of 10000 dyne / cm2 and by 0.055 cm/sec.

The findings of the permeability check demonstrate that HMA without crumb rubber is better than HMA concrete with crumb rubber, because the combination has the lowest coefficient of permeability and higher quality, as water escapes into the soil layer (base course) creating cracks and holes observed. That the association between the permeability coefficient and the water pressure is is opposite as the water pressure increases leading to a decrease in the permeability coefficient.

It was the optimum result in the permeability Test was with 2.5% CR the results were 0.019 cm/sec and the second permeability was 0.043 cm/sec compared to other results with 4.5% CR, and 6.5% CR. It can be said at certain permeability level the samples with higher CR content failed faster than samples with less CR, from here, 2.5% CR more durable compare to another mix with crumb rubber.

The validation of this result research compare with previous studies is consistent or supported has been done with asphalt concrete with crumb rubber by different authors shown the result compere to this research in Table 5.18.

Table 5.18 Result validation

No		
1	Author	Hmade et, al
	Year	2014
	The results	with the UCS test at OBC with 30℃ use only one temperature the results without CR, 2.5%,5%,7.5 %CR were respectively 5220.79kg,4097kg,3234.48kg, and 2619.05kg
	This research	In this research, Unconfined strength property was with different temperatures of 24℃,30℃,40℃, and 60℃ and loads, The samples incorporating 6.5% CR show a higher improvement overall.
2	Author	Hmade et, al
	Year	2014
	The results	Indirect Tensil strength modulus properties, the asphalt mixture with crumb rubber, and asphalt concrete modified with 2.5% crumb rubber were stronger than the asphalt concrete modified with 5.0% and 7.5% crumb rubber respectively by 669 MPa, 599.5 MPa,359 MPa, and 214 MPa
	This research	The results in this research without CR, 2.5% CR,4.5% CR,and 6.5% CR were respectively by 2868 MPa,1659 MPa,1460 MPa, and 920 MPa.
3	Author	Hmade et, al
	Year	2014
	The results	with asphalt concrete modified with 2.5% crumb rubber was stronger than the asphalt concrete modified with 5.0% and 7.5% crumb rubber, with 2.5 % CR the results with temperatures of 30℃,40℃, and 60℃ were respectively 144.45 MPa,76.03MPa, and 17.31MPa
	This research	This research was better than in previous studies. Theresults with 2.5 % CR with temperatures 10℃,25℃,40℃, and 60℃ were respectively 217.90 MPa,87.274 MPa,27.024MPa, and 15.028 MPa.
4	Author	Lhwaint et al,
	Year	2017

	The results	with different percentages without CR, 2.5% CR, 5% CR, 7.5% CR, and 10% CR the results of the stability were as follows: 1412kg,1181kg,962kg,901.33, and 774.43kg.
	This research	This research shows better result stability with hot mix asphalt with CR using different percentages without CR, 2.5% CR, 4.5% CR, 6.5%, and 8.5% CR. The resulting stability was as follows:1813.50 kg, 1322.79 kg, 1066.76 kg, 1429.46 kg, and 1216.11 kg
5	Author	Abusta
	Year	2014
	The results	stone mastic Asphalt modified with CR had been used with different percentages without CR, 2 % CR, 4% CR, 6%, The results of the stability were as follows:977.61kg, 893.87kg, 887.62kg, and 832.28kg
	This research	shows better result stability with hot mix asphalt with CR using different percentages of without CR, 2.5% CR, 4.5% CR, 6.5%, and 8.5% CR. The resulting stability were as follows :1813.50kg, 1322.79kg, 1066.76kg, 1429.46kg, and 1216.11kg.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Several measurable chemical properties are believed to be associated with the mechanical or organizational resistance of a pavement. From the result, the comparative outputs of the elastic and viscous behavior differed with the structure. The conclusion follows as follows:

1-The result of the TGA shows that the truck tire has the highest thermal resistance up to maximum degradation temperature at the temperature of 983.77 °C with the residue is 31.597%, the chemical analysis shows that all of the tire waste samples produced from the same precursor of polystyrene. Moreover, the chemical composition of crumb rubber was similar to the car and truck tire waste.

2- As for the conclusion of this Chapter, the best CRMA mixture for overall condition according to the criteria of the Marshall Test is the one with the CR content = 2.5%. This 2.5% CR will exhibit the best mixture for hot mix asphalt concrete against fatigue cracking and rutting.

3- The hot mix asphalt concrete samples with 2.5% CR content are the highest when compared against those for the other samples tested at all temperature conditions for the countries with very high-temperature variation throughout the year like Libya at ITS results, also samples with 6.5% CR are the recommended composition of crumb rubber inside the CRMA to produce the best performance of hot mix asphalt concrete with a very high-temperature variation at (40, and 60°C) as a basis for predicting permanent HMA deformation in UCS results.

4- The hot mix asphalt concrete with 2.5% CR the recommended proportion of the wet climate and high rainfall conditions of a tropical country like Indonesia, and the proportion of 2.5 % crumb rubber content recommended against rain-induced premature deterioration of hot mixture of asphalt concrete.

6.2 Recommendations

The following points were recommended for improving the results of this study and proposed future works:

1. The performance of fatigue in crumb rubber needs to be further investigated through the use of a mixture of tire waste, such as waste tire trucks with waste tire cars or a mixture of waste tire bicycles with waste tire cars, etc.

2. In further research, further attention should be paid to the reliability of diagnosis in the conduct of tests so that the values between the samples collected reflect the quality of the results. Also better to examine the effect of temperature in future studies by adjusting temperature variations at 20C° or lower temperature in fatigue testing using a hot mix asphalt concrete with crumb rubber.

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APPENDIX A: XRF (X-ray Fluorescence Result)

No.	Example Name	Test type	Results	Unit	Test Method
1	Waste Tire Bicycle From PT.Dend Years 2011. Weight : 2,8604gr	Silica content (Si)	4,1	%	*X-Ray Fluorescence*
		Phospor content (P)	1,5		
		Sulfur content (S)	20,6		
		Potassium Content (K)	1,3		
		Calcium content (Ca)	8,45		
		Titanium content (Ti)	0,32		
		Chromium content (Cr)	0,14		
		Manganese content (Mn)	0,13		
		Iron content (Fe)	7,73		
		Copper content (Cu)	1,47		
		Zinc content (Zn)	54,2		
		Rubidium content (Rb)	0,1		
		Barium content (Ba)	0,1		

No.	Example Name	Test type	Results	Unit	Test Method
2	Waste Tire Truck From PT.Gajah Tunggal Years 2016. Weight: 4,0893 gr	Silica content (Si)	4,9	%	*X-Ray Fluorescence*
		Pospor Content (P)	2,8		
		Sulfur content (S)	15,9		
		Potassium Content (K)	1,9		
		Calcium content (Ca)	10,9		
		Titanium content (Ti)	0,37		
		Manganese content (Mn)	0,1		
		Iron content (Fe)	5,23		
		Copper content (Cu)	0,49		
		Zinc content (Zn)	57,4		
		Rubidium content (Rb)	0,06		
		Barium content (Ba)	0,3		

No.	Example Name	Test type	Results	Unit	Test Method
3	Waste Tire Car From PT.Dunlop Tunggal Years 2016. Weight: 3,0147 gr	Silica content (Si)	5	%	*X-Ray Fluorescence*
		Pospor Content (P)	4,9		
		Sulfur content (S)	18,1		
		Calcium content (Ca)	5,8		
		Iron content (Fe)	1,3		
		Copper content (Cu)	0,73		
		Zinc content (Zn)	63,7		
		Rubidium content (Rb)	0,10		
		Zircon content (Zr)	0,06		

No.	Example Name	Test type	Results	Unit	Test Method
4	Waste Tire Motor From PT.IRC Tunggal Years 2017. Weight: 4,8456 gr	Aluminum content (Al)	9	%	*X-Ray Fluorescence*
		Silica content (Si)	10,5		
		Pospor Content (P)	0,75		
		Sulfur content (S)	5,9		
		Potassium content (K)	1,2		
		Calcium content (Ca)	15,9		
		Titanium content (Ti)	0,94		
		Vanadium content (V)	0,01		
		Chromium content (Cr)	0,27		
		Manganese content (Mn)	0,32		
		Iron content (Fe)	25,5		
		Nickel Content (Ni)	0,33		
		Copper content (Cu)	1,08		
		Zink content (Zn)	27,4		
		Bromide content (Br)	0,09		
		Barium content (Ba)	0,64		

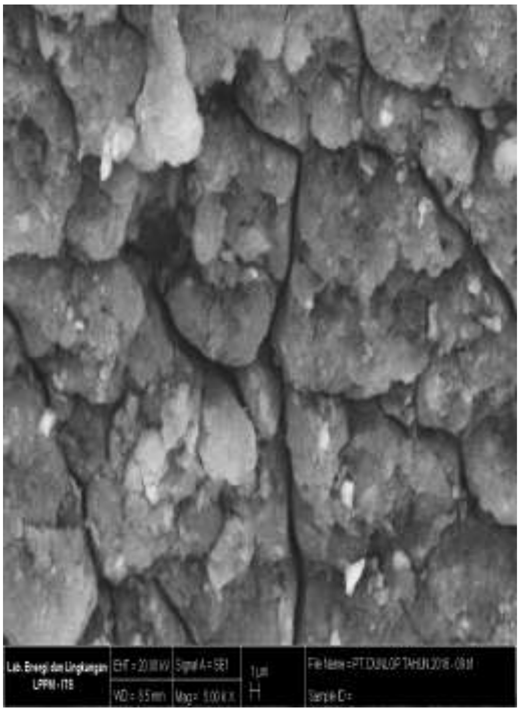
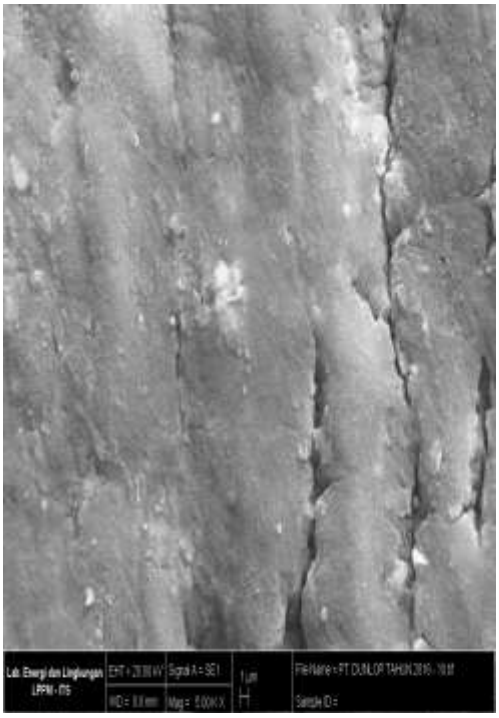
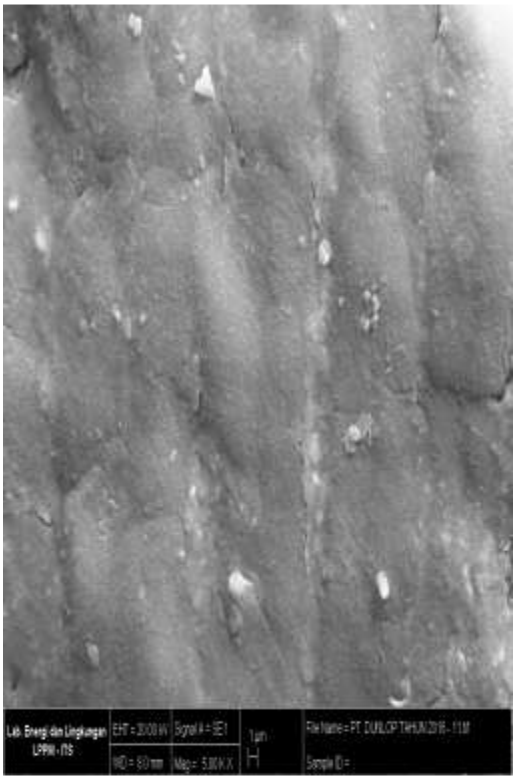
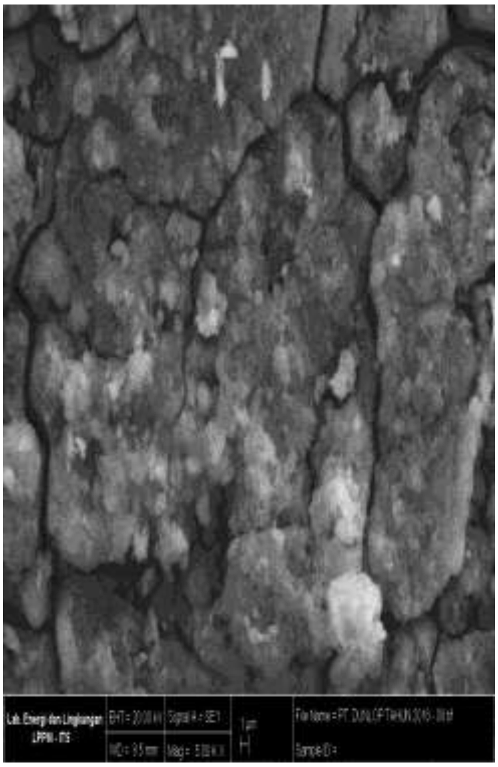
No	Example Name	Test type	Results	unit	Test method
5	Crumb rubber with different type tire wastes	Silica content (Si)	5.8	%	X-Ray Fluorescence
		Sulfur content (S)	12.8		
		Potassium content (K)	0.82		
		Calcium content (Ca)	9.09		
		Titanium content (Ti)	0.62		
		Vanadium content (V)	0.02		
		Manganese content (Mn)	0.16		
		Iron content (Fe)	9.4		
		Copper content (Cu)	0.39		
		Zink content (Zn)	60.1		
		Bromide content (Br)	0.88		

Temperature: 22.6 oC
Humidity: 55%
Analyst: NFS
Information :

1. The Test Results Report may not be duplicated in part, but must be duplicated in its entirety
2. The test results only apply to the example being tested.
3. The results of this test cannot be used as legal evidence

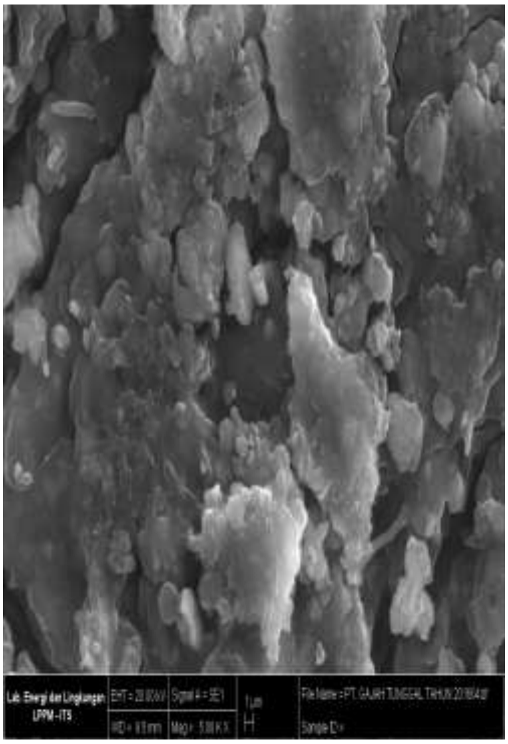
APPENDIX B: Scanning Electron Microscope

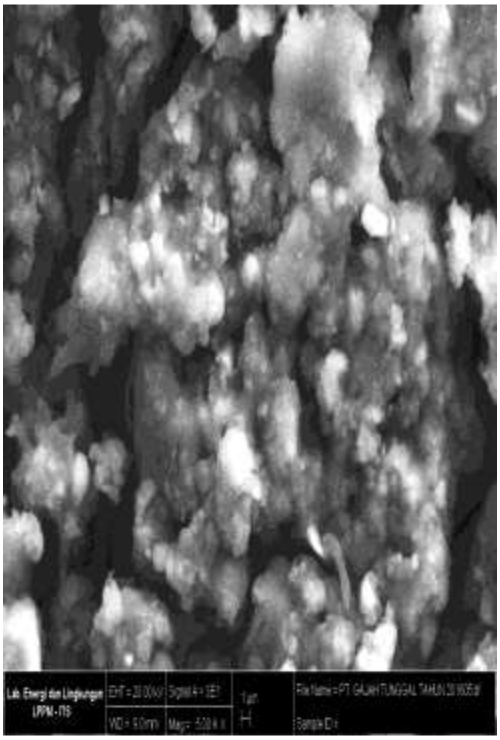
1-CO.DUNALOP Tire Waste CAR 2016

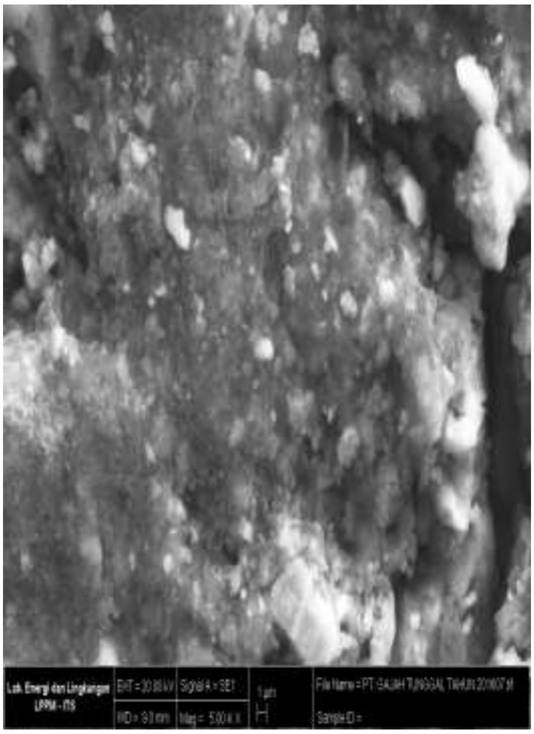





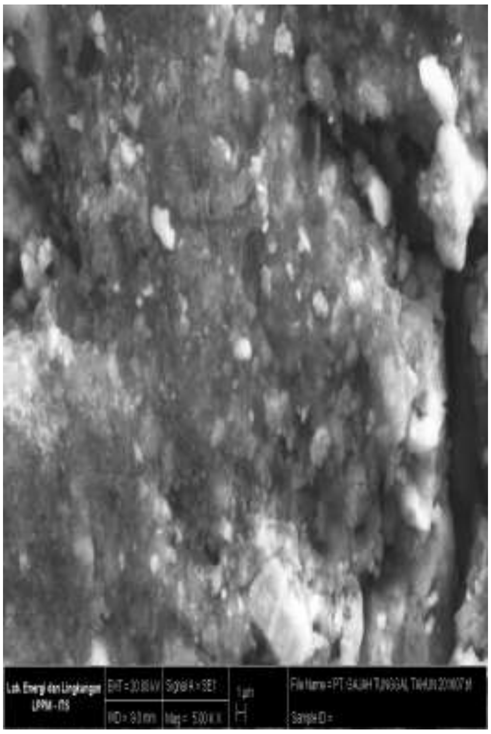
SEM

2- Tire Waste Truck from CO.Gajah Tungga 2016:

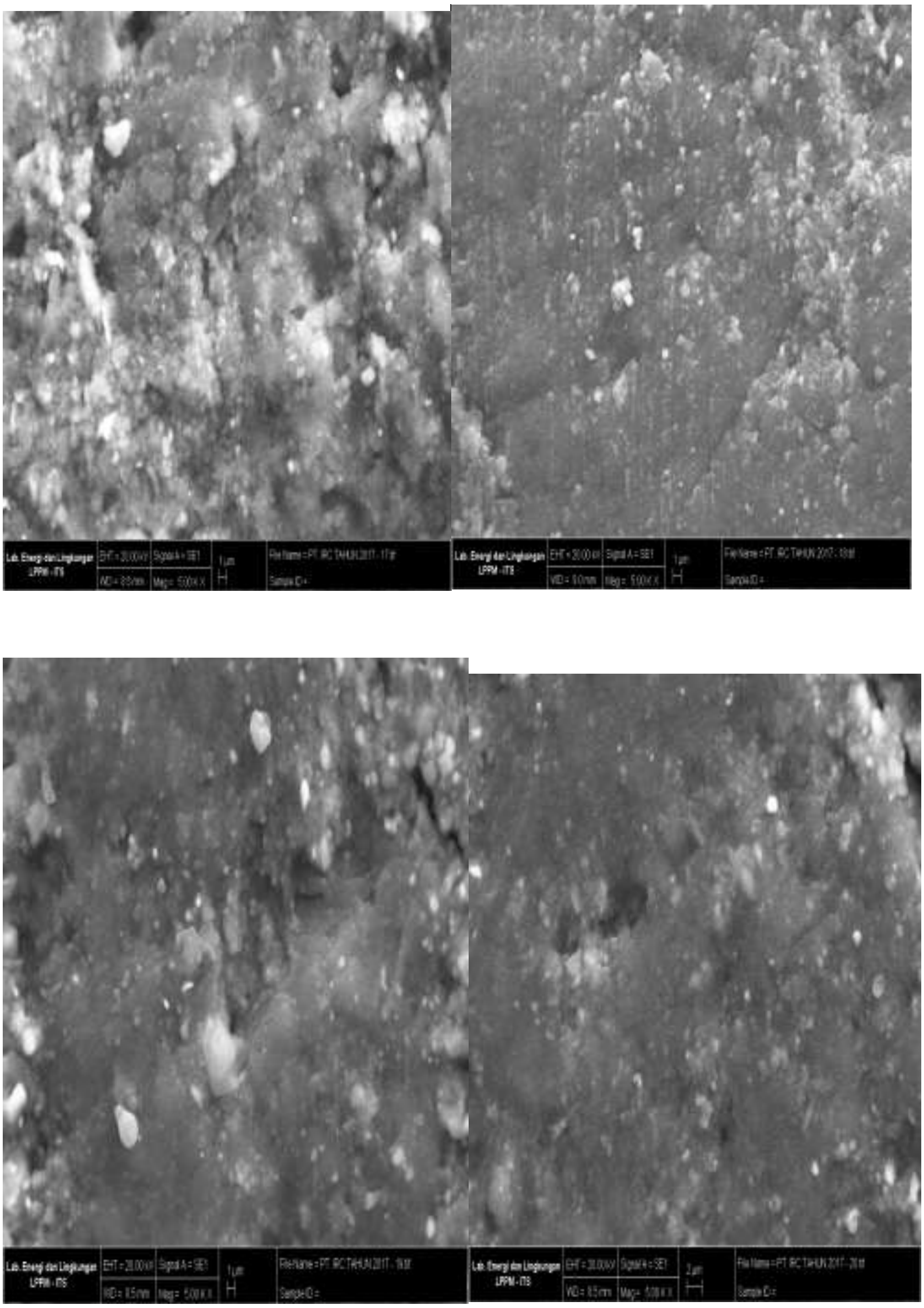




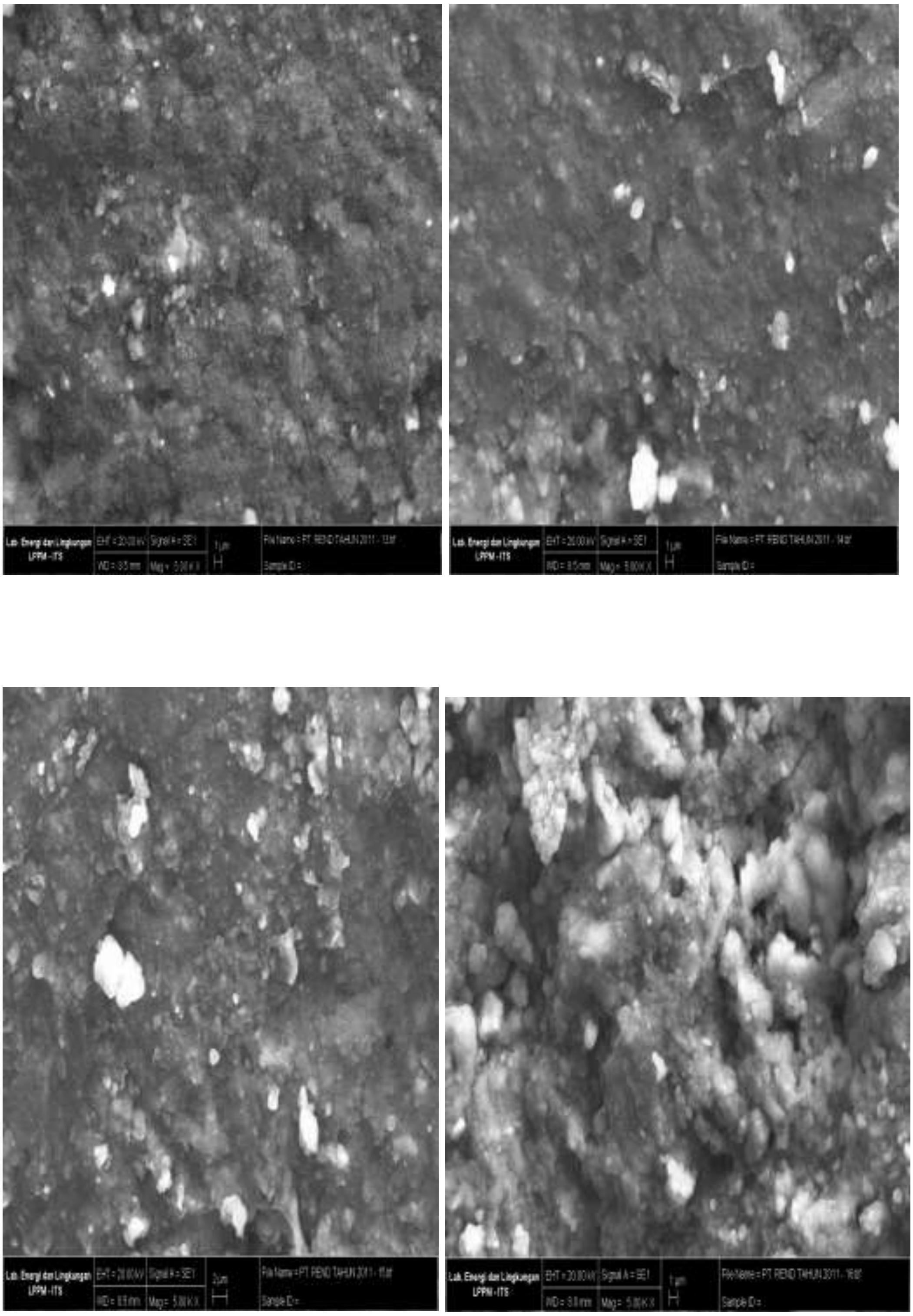




3 –SEM Tire Waste Motor From CO.IRC Tunggal Years 2017.



4-SEM Tire Waste Bicycle From CO.Dend Years 2011.



APPENDIX C:Experiment for materalis (Bitumen –Aggregate-Fine Aggregate-Crumb rubber)

softening point

Number : 1

Example : Asphalt Pen. 60/70 ex Pertamina

No	Temperature observed (°C)	Time (seconds)		Soft point (°C)		Average softening point (°C)
		a	b	a	b	
1	5	60	60	52	53	52.5
2	10	120	120			
3	15	180	180			
4	20	240	240			
5	25	300	300			
6	30	360	360			
7	35	450	450			
8	40	480	480			
9	45	540	540			
10	50	600	600			
11	55	660	660			

DUCTILITY CHECK

Number :2

Example : Asphalt Pen. 60/70 ex Pertamina

Ductility Check 25^{O}; 5 cm/minute

Observation of Test objects	Reader Measuring tool (cm)	Information
I	141.0	
II	143.0	
Average ductility	142.0 cm	

EXAMINATION
Specific Gravity of Asphalt

Number : 3

Example : Asphalt Pen. 60/70 ex Pertamina

Type of Testing	Test object		Information
	I	II	
Test bottle weight (A)	27.05	27.00	
Test bottle + water weight (B)	52.20	52.15	
Test bottle weight + sample (C)	34.20	32.50	
Test bottle + water weight + sample (D)	52.44	52.34	
Specific gravity = (C-A)/(B-A)-(D-C)	1.035	1.036	
Average Specific Gravity	1.035 gr/cc		

ASPHALT PENETRATION EXAMINATION

Number : 4

Example : Asphalt Pen. 60/70 ex Pertamina

Penetration on 25^{O}; 100 gr, 5 second, 0.1 mm

Number Testing	Test Example		Information
	I	II	
1	64	65	
2	65	64	
3	64	65	
4	63	64	
5	64	65	
Average	64.3 (0.1 mm)		

EXAMINATION
Flash Point

Number : 5

Example : Asphalt Pen. 60/70 ex Pertamina

No	°C below the flash point	Time (seconds)	Temperature °C	
1	56	60	285	
2	51	120	290	
3	46	180	295	
4	41	240	300	
5	36	300	310	
6	31	360	315	328°C Flash Point
7	26	420	320	
8	21	480	325	339°C Fuel Point
9	16	540	330	
10	11	600	335	
11	6	660	340	
12	1	720	345	

INVESTIGATIONS

SAND EQUIVALENT

AASHTO – T 176

Number : 6

Order : Abdallh A A Lhwaint

Example : Abu batu (0-0.5) mm

No Testing	Mud Scale Readings	Sand Scale Readings	SAND EQUIVALENT (%)
I	5.60	15.1 - 10.0	91.07
II	5.70	5.70	91.23
			91.15

EXAMINATIONSOUNDNESS

AASHTO T.104

Number : 7

Material Type : Aggregate (broken stone)

Test Solution : Sodium Sulfate

Filter number	weight before testing	weight after testing	Heavy Loss Due to being tasted
1 1/2 " - 3/4 "	2135.0	2116.8	0.852
3/4 " - 3/8 "	1754.8	1739.2	0.889
Total	3889.8	3856.0	0.869

LOS ANGELES ABRASION TEST

(SNI 03-2417-1991)

Number : 8

Material Type : Aggregate (broken stone)

Grading of sampel : A – 500 Revolution (AASHTO T – 96)

filter size				weight		weight	
Passed		restrained		After	before	After	before
3	in	2 1/2	in				
2 1/2	in	2	in				
2	in	1 1/2	in				
1 1/2	in	1	in	1250			
1	in	3/4	in	1250			
3/4	in	1/2	in	1250			
1/2	in	3/8	in	1250			
3/8	in	1/4	in				
1/4	in	No. 4					
No. 4		No. 8					
		No. 12			3796		
berat total				5000	3796		

The amount of wear material A :

a = 5000 gram
b = 3796 gram
c = 1204 gram
Abrasi c/a x 100% = 24.08

PEMERIKSAAN KEAUSAN AGREGAT (ABRASI TEST)
AASHTO T 96 - 77

Number :9
Jenis contoh : Agregat Kasar

No	JENIS GRADASI		B	
	SARINGAN		BENDA UJI (gram)	
	LOLOS	TERTAHAN	I	II
1	72.2 mm (3")	63.5 mm (2.5")		
2	63.5 mm (2.5")	50.8 mm (2")		
3	50.8 mm (2")	37.5 mm (1.5")		
4	37.5 mm (1.5")	25.4 mm (1")		
5	25.4 mm (1")	19.0 mm (3/4")		
6	19.0 mm (3/4")	12.5 mm (0.5")	2500.00	2500.00
7	12.5 mm (0.5")	09.5 mm (3/8")	2500.00	2500.00
8	09.5 mm (3/8")	06.3 mm (1/4")		
9	06.3 mm (1/4")	04.75 mm (4")		
10	04.75 mm (No.4)	02.36 mm (No.8)		
11	JUMLAH BENDA UJI (A)		5000.00	5000.00
12	JUMLAH TERTAHAN DI SIEVE 12(B)		3701.00	3710.00
13	KEAUSAN = $\frac{(A-B)}{A} \times 100\%$		25.980	25.800
14	Rata-rata Keausan			

PEMERIKSAAN BERAT JENIS AGREGAT KASAR

RUJUKAN AASHTO T - 85 - 81 ; ASTM C - 127 – 77

Number: 10

Jenis contoh : Agregat Kasar

No.	Keterangan	Benda uji		
		1	2	Rata-rata
1	Berat benda uji dalam keadaan basah jenuh (BJ) gr	1607.36	1606.15	
2	Berat benda uji dalam Air (BA) gr	1000.00	1000.00	
3	Berat benda uji dkering oven (BK) gr	1577.13	1576.06	
4	Berat jenis (Bulk) = $\frac{BK}{(BJ - BA}$	2.597	2.600	2.60
5	Berat jenis (SSD) = $\frac{BJ}{(BJ - BA}$	2.646	2.650	2.65
6	Berat jenis (Semu) = $\frac{BK}{(BK - BA)}$	2.733	2.736	2.73
7	Penyerapan air = $\frac{(BJ - BK)}{BK} \times 100\%$	1.917	1.909	1.91

PEMERIKSAAN SAND EQUIVALENT

Number : 11

Jenis contoh : Agregat Halus

No.	Keterangan		Benda uji		
			1	2	Rata-rata
1	Persiapan, dan perendaman benda uji dalam larutan $CaCl_2$ selama (± 10.1 menit).	Mulai	15.40	15.40	
		Selesai	15.50	15.50	
2	Waktu pengendapan (benda uji setelah digojok sebanyak 90x, dan di tambah larutan $CaCl_2$)	Mulai	15.55	15.55	
		Selesai	16.15	16.15	
4	Clay reading (Pembacaan Lumpur) Inchi		5.60	4.70	
5	Sand reading (Pembacaan Pasir)		2.40	2.50	
6	Sand Equivalent $= \frac{Sand\ Reading}{Clay\ Reading} \times 100$		42.86	53.19	
7					

EXAMINATION WEIGHT TYPE AND ABSORPTION OF THE FINE AGGREGATE (SNI 03-1970-1990)

Number : 12

Material Type : FINE AGGREGATE

TYPE OF TESTING	TRIAL	INFORMATION
Weight of saturated surface test specimen 9500) grams	500.0	
Weight picnometer + Water (mineral) gram (B)	649.8	
Weight of specimen + Water (mineral) + Picnometer gram (Bt)	960.8	
Weight oven gram dry test specimen (BK)	492.7	
Specific gravity (Bulk Specific Gravity) = BK (B + 500- Bt)	2.607	
All density (Apparent Specific Gravity) = BK B+ BK+ Bt	2.712	
Absorption = 500- BK x100% BK	1.482%	

PEMERIKSAAN BERAT JENIS AGREGAT HALUS
RUJUKAN AASHTO T - 84 - 74 ; ASTM C - 128 - 68

Number : 13

Jenis contoh : Agregat Halus

No.	Keterangan	Benda uji		
		1	2	Rata-rata
1	Berat benda uji dalam keadaan basah jenuh (BJ) gr	500.00	500.00	
2	Berat Vicnometer + Air (B) gr	656.12	657.00	
3	Berat Vicnometer + Air + benda uji (BT) gr	974.00	974.00	
4	Berat benda uji kering oven (BK)	492.25	491.33	
5	Berat jenis (Bulk) = $\frac{BK}{(B+500)-BT}$	2.703	2.685	2.69
6	Berat jenis (SSD) = $\frac{500}{(B+500)-BT}$	2.745	2.732	2.74
7	Berat jenis (Semu) = $\frac{BK}{(B+BK)-BT}$	2.823	2.818	2.82
8	Penyerapan air = $\frac{(500-BK)}{BK}\times 100\%$	1.574	1.765	1.67

PEMERIKSAAN BERAT JENIS ASPAL

RUJUKAN : AASHTO T - 228 - 68 ; ASTM D - 70 - 72

Number : 14

Jenis contoh : Crumb Rumbber

No.	Pemeiksaan	Sampel		
		1	2	3
1	Berat vicnometer kosong (gr)	20.96	16.04	
2	Berat vicnometer + Aquadest (gr)	44.40	42.55	
3	Berat Aquadest (2 - 1) (gr)	23.44	26.51	
4	Berat vicnometer + Crumb Rubber (gr)	24.97	22.63	
5	Berat Crumb Rubber (4 - 1) (gr)	4.01	6.59	
6	Berat vicnometer + Crumb Rumbber + Aquadest (gr)	45.11	42.93	
7	Berat Aquadest (6 - 4) (gr)	20.14	20.30	
8	Volume Crumb Rumbber (3 - 7) (gr)	3.30	6.21	
9	Berat Jenis Crumb Rubber = Berat / Vol (5/8)	1.215	1.061	
10	Rata-rata Crumb Rubber	1.138		

APPENDIX D: Figures for materials and equipments in Lab









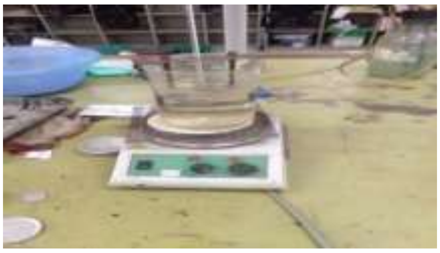












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APPENDIX E: PROPERTIES OF ASPHALT MIXES BY MARSHALL METHOD WITHOUT CR

Penetration of Bitumen = AC 60/70	Kalibrasi proving ring (Lbs) = 46.994	Temperature : 150	°C
Sp.Gr of Bitumen X = 1.047	Penambahan Karet = 0.00%	Compaction : 2 x 75	Blows

No.	Tinggi benda Uji	Bitumen Content	Bulk SP.GR Of Total Agg	Effective SP.GR Of Total Agg	Max Sp.gr Combine Mix	Weght (Gram) In Air	In Water	S.S.D	Volume Of Specimen	Bulk SpGr Combine Mix	Air Void (%)	Stability Meas	Adjust	Flow (mm)	Marshall Quotien (Kg/mm)	Absorbtion bitument	Void Mineral Agregat (VMA)	Void For With Aspal (VFWA)
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	R	S
	(mm)	% Bitument by weight of Mix	(% CA + % MA) x BJ Kasar + (% FA x Bj Halus)	$\frac{Bjbulk + BjAverent}{2}$	$\frac{100}{\frac{A}{X} + \frac{100-A}{C}}$	Timbangan LAB	Timbangan LAB	Timbangan LAB	G - F	$\frac{E}{H}$	$\frac{(D-I) \times 100}{D}$	LAB	LAB (Kg)	LAB	$\frac{L}{M}$	$A + \frac{X(100-A)}{B} - \frac{100 \times X}{D}$	$100 - \frac{(100-A) \times i}{B}$	$100 \times \frac{\frac{A \times I}{X}}{R}$
1	61.67	5.00	2.57	2.65	2.46	1162.49	698.79	1165.63	466.84	2.49	1.01	80	1706.82	4.65				
	62.00	5.00	2.57	2.65	2.46	1166.99	695.90	1168.81	472.91	2.47	1.31	78	1664.15	4.65				
	62.10	5.00	2.57	2.65	2.46	1175.04	694.39	1179.76	485.37	2.42	0.86	79	1685.49	4.05				
		Average	2.72						475.04	2.46	1.06	79	1685.49	4.45	378.761	1.040	9.24	52.67
2	64.23	5.50	2.57	2.65	2.44	1157.84	651.50	1165.26	513.76	2.25	7.67	85	1813.50	4.90				
	64.20	5.50	2.57	2.65	2.44	1010.11	585.5	1011.37	425.89	2.37	2.83	90	1920.17	5.00				
	64.30	5.50	2.57	2.65	2.44	1010.11	585.5	1011.37	425.89	2.37	2.83	81	1728.16	4.95				
									513.76	2.25	7.67	85	1813.50	4.90	370.102	1.035	17.28	55.63
3	63.86	6.00	2.57	2.65	2.42	1137.17	645.41	1145.73	500.32	2.27	6.22	76	1621.48	4.92				
	58.50	6.00	2.57	2.65	2.42	1142.87	664.36	1148.38	484.02	2.36	2.58	78	1664.15	4.92				
	57.93	6.00	2.57	2.65	2.42	1089.81	625.99	1097.23	471.24	2.31	4.58	80	1706.82	4.92				
									500.32	2.27	6.22	76	1621.48	4.92	329.569	1.029	17.01	66.43
4	62.33	6.50	2.57	2.65	2.41	1128.74	645.95	1139.53	493.58	2.29	4.99	55	1173.44	4.97				
	62.80	6.50	2.57	2.65	2.41	1111.81	634.67	1180.54	545.87	2.04	15.38	50	1066.76	4.99				
	62.46	6.50	2.57	2.65	2.41	1115.46	638.67	1128.71	490.04	2.28	5.43	45	960.09	5.95				
		Average							493.58	2.29	4.99	55	1173.44	4.97	236.105	1.024	16.95	70.58
5	55.93	7.00	2.57	2.65	2.39	1033.44	597.52	1035.68	438.16	2.36	1.32	40	853.41	5.65				
	53.80	7.00	2.57	2.65	2.39	1029.05	597.91	1031.83	433.92	2.37	0.78	38	810.74	5.81				
	58.30	7.00	2.57	2.65	2.39	1080.24	623.10	1082.40	459.30	2.35	1.60	35	746.73	5.67				
		Average							436.04	2.37	1.05	38	803.63	5.73	140.249	1.018	16.57	93.64

APPENDIX E: PROPERTIES OF ASPHALT MIXES BY MARSHALL METHOD @2.5CR

Penetration of Bitumen	= AC 60/70	Kalibrasi proving ring (Lbs) = 46.994	Temperature : 150	°C
Sp.Gr of Bitumen X	= 1.047	Penambahan Karet = 2.50%	Compaction : 2 x 75	Blows

No.	Tinggi benda Uji	Bitumen Content	Bulk SP.GR Of Total Agg	Effective SP.GR Of Total Agg	Max Sp.gr Combine Mix	Weght (Gram) In Air	In Water	S.S.D	Volume Of Specimen	Bulk SpGr Combine Mix	Air Void (%)	Stability Meas	Adjust (kg)	Flow (mm)	Marshall Quotien (Kg/mm)	Absorbtion bitument	Void Mineral Agregat (VMA)	Void For With Aspal (VFWA)
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	R	S
	(mm)	% Bitument by weight of Mix	(% CA + % MA) x BJ Kasar + (% FA x Bj Halus)	$\frac{Bjbulk + BjAverent}{2}$	$\frac{100}{\frac{A}{X} + \frac{100-A}{C}}$	Timbangan LAB	Timbangan LAB	Timbangan LAB	G - F	$\frac{E}{H}$	$\frac{(D-I)\times 100}{D}$	LAB	LAB (Kg)	LAB	$\frac{L}{M}$	$A + \frac{X(100-A)}{B} - \frac{100 \times X}{D}$	$100 - \frac{(100-A)\times i}{B}$	$\frac{100 \times \frac{A \times I}{X}}{R}$
1	61.67	5.00	2.57	2.65	2.46	866.77	499.60	868.21	368.61	2.35	4.34	27	576.05	3.00				
	62.00	5.00	2.57	2.65	2.46	866.77	499.60	868.21	368.61	2.35	4.34	27	576.05	3.00				
	62.10	5.00	2.57	2.65	2.46	866.77	499.60	868.21	368.61	2.35	4.34	27	576.05	3.00				
		Average							368.61	2.35	4.34	27	576.05	3.00	192.017	1.040	15.23	66.53
2	64.23	5.50	2.57	2.65	2.44	934.19	533.32	935.96	402.64	2.32	4.94	43	917.42	3.15				
	64.20	5.50	2.57	2.65	2.44	934.19	533.32	935.96	402.64	2.32	4.94	43	917.42	3.15				
	64.30	5.50	2.57	2.65	2.44	934.19	533.32	935.96	402.64	2.32	4.94	43	917.42	3.15				
									402.64	2.32	4.94	43	917.42	3.15	291.243	1.035	15.84	68.80
3	63.86	6.00	2.57	2.65	2.42	991.29	564.45	994.21	429.76	2.31	4.83	62	1322.79	3.80				
	58.50	6.00	2.57	2.65	2.42	991.29	564.45	994.21	429.76	2.31	4.83	62	1322.79	3.80				
	57.93	6.00	2.57	2.65	2.42	991.29	564.45	994.21	429.76	2.31	4.83	62	1322.79	3.80				
									429.76	2.31	4.83	62	1322.79	3.80	348.102	1.029	16.78	71.22
4	62.33	6.50	2.57	2.65	2.41	839.42	487.34	847.46	360.12	2.33	3.15	45	960.09	4.20				
	62.80	6.50	2.57	2.65	2.41	839.42	487.34	847.46	360.12	2.33	3.15	45	960.09	4.20				
	62.46	6.50	2.57	2.65	2.41	839.42	487.34	847.46	360.12	2.33	3.15	45	960.09	4.20				
		Average							360.12	2.33	3.15	45	960.09	4.20	228.592	1.024	17.95	82.43
5	55.93	7.00	2.57	2.65	2.39	967.77	555.18	968.63	413.45	2.34	2.07	40	853.41	4.90				
	53.80	7.00	2.57	2.65	2.39	967.77	555.18	968.63	413.45	2.34	2.07	40	853.41	4.90				
	58.30	7.00	2.57	2.65	2.39	967.77	555.18	968.63	413.45	2.34	2.07	40	853.41	4.90				
		Average							413.45	2.34	2.07	40	853.41	4.90	174.166	1.018	18.05	88.52

APPENDIX E: PROPERTIES OF ASPHALT MIXES BY MARSHALL METHOD @4.5CR

Penetration of Bitumen = AC 60/70	Kalibrasi proving ring (Lbs) = 46.994	Temperature : 150	°C
Sp.Gr of Bitumen X = 1.047	Penambahan Karet = 4.50%	Compaction : 2 x 75	Blows

No.	Tinggi benda Uji	Bitumen Content	Bulk SP.GR Of Total Agg	Effective SP.GR Of Total Agg	Max Sp.gr Combine Mix	Weght (Gram) In Air	In Water	S.S.D	Volume Of Specimen	Bulk SpGr Combine Mix	Air Void (%)	Stability Meas	Adjust	Flow (mm)	Marshall Quotien (Kg/mm)	Absorbtion bitument	Void Mineral Agregat (VMA)	Void For With Aspal (VFWA)
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	R	S
	(mm)	% Bitument by weight of Mix	(% CA + % MA) x BJ Kasar + (% FA x Bj Halus)	$\frac{Bjbulk + BjAverent}{2}$	$\frac{100}{\frac{A}{X} + \frac{100 - A}{C}}$	Timbangan LAB	Timbangan LAB	Timbangan LAB	G - F	$\frac{E}{H}$	$\frac{(D - I) \times 100}{D}$	LAB	LAB (Kg)	LAB	$\frac{L}{M}$	$A + \frac{X(100 - A)}{B} - \frac{100 \times X}{D}$	$100 - \frac{(100 - A) \times i}{B}$	$100 \times \frac{\frac{A \times I}{X}}{R}$
1	61.67	5.00	2.57	2.65	2.46	892.85	515.34	894.89	379.55	2.35	4.30	20	426.71	3.10				
	62.00	5.00	2.57	2.65	2.46	892.85	515.34	894.89	379.55	2.35	4.30	20	426.71	3.10				
	62.10	5.00	2.57	2.65	2.46	892.85	515.34	894.89	379.55	2.35	4.30	20	426.71	3.10				
		Average							379.55	2.35	4.30	20	426.71	3.10	137.647	1.040	13.20	67.42
2	64.23	5.50	2.57	2.65	2.44	813.03	478.60	823.70	345.10	2.36	3.48	25	533.38	3.20				
	64.20	5.50	2.57	2.65	2.44	813.03	478.60	823.70	345.10	2.36	3.48	25	533.38	3.20				
	64.30	5.50	2.57	2.65	2.44	813.03	478.60	823.70	345.10	2.36	3.48	25	533.38	3.20				
									345.10	2.36	3.48	25	533.38	3.20	166.682	1.035	13.52	74.30
3	63.86	6.00	2.57	2.65	2.42	948.21	496.62	954.88	458.26	2.07	4.43	35	746.73	3.35				
	58.50	6.00	2.57	2.65	2.42	948.21	506.62	958.88	452.26	2.10	4.62	35	746.73	3.35				
	57.93	6.00	2.57	2.65	2.42	948.21	506.62	958.88	452.26	2.10	4.63	35	746.73	3.35				
									458.26	2.07	4.63	35	746.73	3.35	222.906	1.029	24.45	73.18
4	62.33	6.50	2.57	2.65	2.41	956.73	523.04	966.47	443.43	2.16	5.35	50	1066.76	3.40				
	62.80	6.50	2.57	2.65	2.41	956.73	523.04	966.47	443.43	2.16	5.35	50	1066.76	3.40				
	62.46	6.50	2.57	2.65	2.41	956.73	523.04	966.47	443.43	2.16	5.35	50	1066.76	3.40				
		Average							443.43	2.16	5.35	50	1066.76	3.40	313.754	1.024	21.64	67.14
5	55.93	7.00	2.57	2.65	2.39	928.62	514.93	935.41	420.48	2.21	7.60	43	917.42	3.45				
	53.80	7.00	2.57	2.65	2.39	928.62	514.93	935.41	420.48	2.21	7.60	43	917.42	3.45				
	58.30	7.00	2.57	2.65	2.39	928.62	514.93	935.41	420.48	2.21	7.60	43	917.42	3.45				
		Average							420.48	2.21	7.60	43	917.42	3.45	265.918	1.018	22.22	65.78

APPENDIX E: PROPERTIES OF ASPHALT MIXES BY MARSHALL METHOD @6.5CR

Penetration of Bitumen = AC 60/70 | Kalibrasi proving ring (Lbs) = 46.994 | Temperature : 150 °C

Sp.Gr of Bitumen X = 1.047 | Penambahan Karet = 6.50% | Compaction : 2 x 75 Blows

No.	Tinggi benda Uji	Bitumen Content	Bulk SP.GR Of Total Agg	Effective SP.GR Of Total Agg	Max Sp.gr Combine Mix	Weght (Gram) In Air	In Water	S.S.D	Volume Of Specimen	Bulk SpGr Combine Mix	Air Void (%)	Stability Meas	Adjust	Flow (mm)	Marshall Quotien (Kg/mm)	Absorbtion bitument	Void Mineral Agregat (VMA)	Void For With Aspal (VFWA)
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	R	S
	(mm)	% Bitument by weight of Mix	(% CA + % MA) x BJ Kasar + (% FA x Bj Halus)	$\frac{Bjbulk + BjAverent}{2}$	$\frac{100}{\frac{A}{X} + \frac{100 - A}{C}}$	Timbangan LAB	Timbangan LAB	Timbangan LAB	G - F	$\frac{E}{H}$	$\frac{(D - I) \times 100}{D}$	LAB	LAB (Kg)	LAB	$\frac{L}{M}$	$A + \frac{X(100 - A)}{B} - \frac{100 \times X}{D}$	$100 - \frac{(100 - A) \times i}{B}$	$\frac{100 \times \frac{A \times I}{X}}{R}$
1	61.67	5.00	2.57	2.65	2.46	1080.13	618.62	1082.27	463.65	2.33	5.23	60	1280.12	3.20				
	62.00	5.00	2.57	2.65	2.46	1080.13	618.62	1082.27	463.65	2.33	5.23	60	1280.12	3.20				
	62.10	5.00	2.57	2.65	2.46	1080.13	618.62	1082.27	463.65	2.33	5.23	60	1280.12	3.20				
		Average							463.65	2.33	5.23	60	1280.12	3.20	400.036	1.040	14.04	62.77
2	64.23	5.50	2.57	2.65	2.44	969.41	554.34	972.54	418.20	2.32	5.03	67	1429.46	3.45				
	64.20	5.50	2.57	2.65	2.44	969.41	554.34	972.54	418.20	2.32	5.03	67	1429.46	3.45				
	64.30	5.50	2.57	2.65	2.44	969.41	554.34	972.54	418.20	2.32	5.03	67	1429.46	3.45				
									418.20	2.32	5.03	67	1429.46	3.45	414.337	1.035	14.91	66.29
3	63.86	6.00	2.57	2.65	2.42	965.02	549.62	970.62	421.00	2.29	5.42	60	1280.12	3.66				
	58.50	6.00	2.57	2.65	2.42	965.02	549.62	970.62	421.00	2.29	5.42	60	1280.12	3.66				
	57.93	6.00	2.57	2.65	2.42	965.02	549.62	970.62	421.00	2.29	5.42	60	1280.12	3.66				
									421.00	2.29	5.42	60	1280.12	3.66	349.759	1.029	16.31	66.74
4	62.33	6.50	2.57	2.65	2.41	980.00	557.01	989.10	432.09	2.27	5.77	45	960.09	3.70				
	62.80	6.50	2.57	2.65	2.41	980.00	557.01	989.10	432.09	2.27	5.77	45	960.09	3.70				
	62.46	6.50	2.57	2.65	2.41	980.00	557.01	989.10	432.09	2.27	5.77	45	960.09	3.70				
		Average							432.09	2.27	5.77	45	960.09	3.70	259.483	1.024	17.63	67.29
5	55.93	7.00	2.57	2.65	2.39	954.55	548.63	963.16	414.53	2.30	3.66	35	746.73	3.80				
	53.80	7.00	2.57	2.65	2.39	954.55	548.63	963.16	414.53	2.30	3.66	35	746.73	3.80				
	58.30	7.00	2.57	2.65	2.39	954.55	548.63	963.16	414.53	2.30	3.66	35	746.73	3.80				
		Average							414.53	2.30	3.66	35	746.73	3.80	196.509	1.018	18.82	80.54

APPENDIX F: Unconfined Compressive and Creep

Unconfined Compressive and Creep Test@24C°

No	AC Type	OBC	High(inch)	Diameter	Weight	Load (kg)	Temperature
1	Without CR	6.10	2.62	4.00	1148.27	5060	24 C°
2	With CR2.5%	6.20	2.58	4.00	1149.79	3030	24 C°
3	With CR4.5%	6.25	2.67	4.00	1198.04	2010	24 C°
4	With 6.5CR%	6.35	2.87	4.00	1096.83	2465	24 C°

Unconfined Compressive and Creep Test @30C°

No	AC Type	OBC	High (inch)	Diameter	Weight	Load (kg)	Temperature
1	Without CR	6.10	2.57	4.00	1103.57	3990	30 C°
2	With CR2.5%	6.20	2.64	4.00	1144.97	2770	30 C°
3	With CR4.5%	6.25	2.57	4.00	1119.8	3170	30 C°
4	With 6.5CR%	6.35	2.52	4.00	1049.21	1400	30 C°

Unconfined Compressive and Creep Test@40C°

No	AC Type	OBC	High (inch)	Diameter	Weight	Load (kg)	Temperature
1	Without CR	6.10	2.50	4.00	1136.49	2280	40 C°
2	With CR2.5%	6.20	2.42	4.00	1076.59	2470	40 C°
3	With CR4.5%	6.25	2.53	4.00	1088.69	1900	40 C°
4	With 6.5CR%	6.35	2.73	4.00	1047.70	2790	40 C°

Unconfined Compressive and Creep Test@60C°

No	AC Type	OBC	High (inch)	Diameter	Weight	Load (kg)	Temperature
1	Without CR	6.10	2.57	4.00	1139.25	1620	60 C°
2	With CR2.5%	6.20	2.64	4.00	1024.56	1080	60 C°
3	With CR4.5%	6.25	2.57	4.00	1084.41	1100	60 C°
4	With 6.5CR%	6.35	2.52	4.00	945.56	1730	60 C°

APPENDIX G: Indirect Tensile Test

Indirect Tensile Test @10C°

No	AC Type	OBC	High (inch)	Diameter	Weight	Load (kg)	ITS @10C°(Mpa)
1	Without CR	6.10	2.46	4.00	1031.7	3210	210 .810
2	With CR2.5%	6.20	2.40	4.00	1063.7	3285	217.954
3	With CR4.5%	6.25	2.57	4.00	1038.22	2496	154.125
4	With 6.5CR%	6.35	2.51	4.00	1079.72	1971	125.041

Indirect Tensile Test @25C°

No	AC Type	OBC	High (inch)	Diameter	Weight	Load (kg)	ITS 0C°(Mpa)25@
1	Without CR	6.10	2.62	4.00	1131.20	1182.60	71.757
2	With CR2.5%	6.20	2.32	4.00	1031.20	1270.20	87.274
3	With CR4.5%	6.25	2.70	4.00	1204.77	919.80	54.294
4	With 6.5CR%	6.35	2.78	4.00	1148.29	788.40	45.222

Indirect Tensile Test @40C°

No	AC Type	OBC	High (inch)	Diameter	Weight	Load (kg)	ITS @40C°(Mpa)
1	Without CR	6.10	2.62	4.00	1135.58	394.20	23.977
2	With CR2.5%	6.20	2.58	4.00	1160.62	438.00	27.024
3	With CR4.5%	6.25	2.67	4.00	1216.00	350.40	20.881
4	With 6.5CR%	6.35	2.87	4.00	1212.65	438.00	24.334

Indirect Tensile Test @60C°

No	AC Type	OBC	High (inch)	Diameter	Weight	Load (kg)	ITS @60C°(Mpa)
1	Without CR	6.10	2.65	4.00	1141.29	219.00	13.147
2	With CR2.5%	6.20	2.78	4.00	1207.28	255.20	15.028
3	With CR4.5%	6.25	2.63	4.00	1213.04	131.40	7.955
4	With 6.5CR%	6.35	2.41	4.00	1048.38	87.60	5.791

Indirect Tensile Test @80C°

No	AC Type	OBC	High (inch)	Diameter	Weight	Load (kg)	ITS @80C°(Mpa)
1	Without CR	6.10	2.60	4.00	1168.11	43.80	2.687
2	With CR2.5%	6.20	2.62	4.00	1142.93	21.90	1.332
3	With CR4.5%	6.25	2.67	4.00	1182.45	21.90	1.306
4	With 6.5CR%	6.35	2.55	4.00	1097.38	8.76	0.547

APPENDIX H: The Indirect Tensile Strength Modulus Properties

Indirect Tensile Modulus Test

Test method: BS DD213-1993 (British Standard - Draft for Development)
Data fileName: C:\UJI 2019\ITSM 2019\ITM Abdullah-ITS\NoCR1B.D003
Template file name: C:\IPCglobal UTS\003 IT Modulus Test\Templates\Template April 2016Adit.P003
Test date & time: 1/1/2013 5:09:45 AM
Project: -
Operator: Arya
Comments:

Setup Parameters

Target temperature (°C): 20
Loading pulse width (ms): 250
Pulse repetition period (ms): 3000
Conditioning pulse count: 5

Target deformation (µm): 5
Estimated Poisson's ratio: 0.35
Estimated modulus (MPa): 3000
Contact force (N): 20

Specimen Information

Identification: NoCR1B
Remarks...

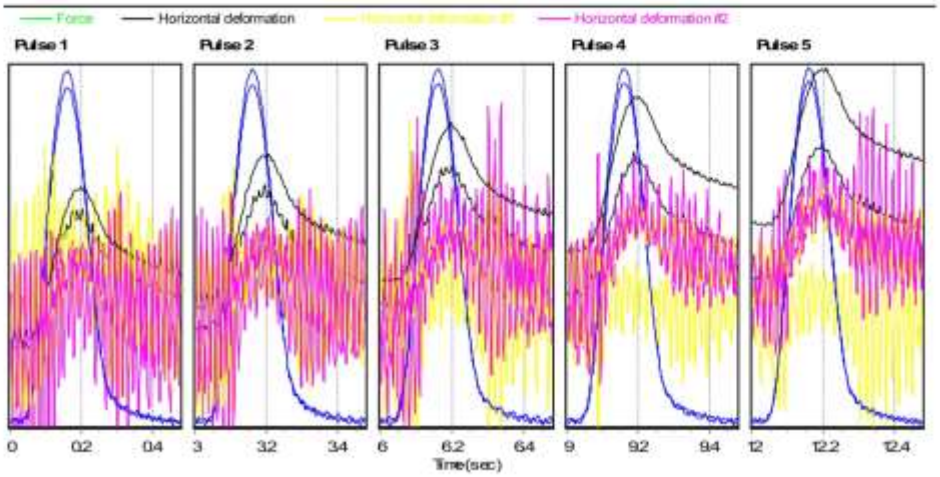
Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	66.5	66.0	66.0	67.0			66.4	0.5
Diameter (mm)	101.6	101.6	101.6	101.6			101.6	

Cross-sectional area (mm²): 8107.3

Test Results

Conditioning pulses: 5
Core temperature (°C): 21.0
Skin temperature (°C): 20.1

	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	Std. Dev	%CV
Stiffness modulus (MPa)	2883	3071	2771	2801	2804	2868	109.24	3.81
Adjusted stiffness modulus (MPa)	3100	3269	2937	3026	2957	3058	120.01	3.93
Peak horizontal deformation (µm)	4.80	4.55	5.06	4.97	5.01	4.88	0.19	3.81
Load area factor	0.55	0.55	0.53	0.57	0.52	0.54	0.02	2.95
Peak loading force (N)	1487	1495	1500	1490	1503	1495	6.01	0.40
Load rise time (ms)	113	108	115	109	109	110.9	2.69	2.43
Horizontal deformation #1 (µm)	2.25	3.65	0.71	1.38	1.66	1.93	0.99	51.57
Horizontal deformation #2 (µm)	2.55	0.89	4.35	3.59	3.35	2.95	1.18	39.90
Seating force (N)	13	13	11	19	11	14	2.96	21.78



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Indirect Tensile Modulus Test

Test method: BS DD213-1993 (British Standard - Draft for Development)
Data fileName: C:\UJI 2019\ITSM 2019\ITM Abdullah-ITS\2_5CR3C.D003
Template file name: C:\IPCglobal UTS\003 IT Modulus Test\Templates\Template April 2016Adit.P003
Test date & time: 1/1/2013 2:06:24 AM
Project: -
Operator: Arya
Comments: 8-10-19

Setup Parameters

Target temperature (°C): 20
Loading pulse width (ms): 250
Pulse repetition period (ms): 3000
Conditioning pulse count: 5

Target deformation (μm): 5
Estimated Poisson's ratio: 0.35
Estimated modulus (MPa): 3000
Contact force (N): 20

Specimen Information

Identification: 2.5CR3C
Remarks...

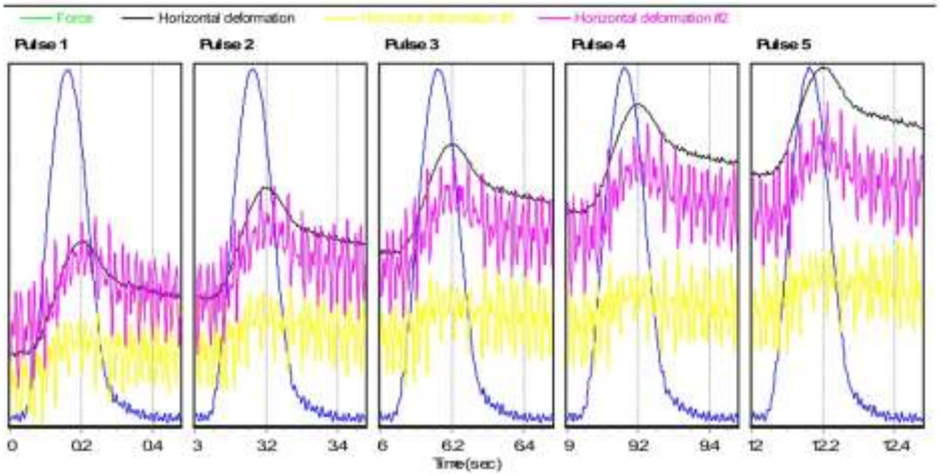
Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	57.0	56.0	57.0	57.0			56.8	0.5
Diameter (mm)	101.6	101.6	101.6	101.6			101.6	

Cross-sectional area (mm²): 8107.3

Test Results

Conditioning pulses: 5
Core temperature (°C): 20.8
Skin temperature (°C): 20.3

	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	Std. Dev.	%CV
Stiffness modulus (MPa)	1652	1654	1658	1653	1679	1659	10.19	0.61
Adjusted stiffness modulus (MPa)	1750	1733	1766	1758	1753	1752	10.98	0.63
Peak horizontal deformation (μm)	4.44	4.40	4.36	4.46	4.37	4.41	0.04	0.86
Load area factor	0.54	0.52	0.56	0.55	0.51	0.54	0.02	3.24
Peak loading force (N)	672	665	662	674	672	669	4.72	0.71
Load rise time (ms)	115	119	107	113	115	113.8	3.97	3.49
Horizontal deformation #1 (μm)	0.99	3.06	1.47	3.45	3.35	2.47	1.03	41.61
Horizontal deformation #2 (μm)	3.45	1.34	2.89	1.01	1.02	1.94	1.03	52.80
Seating force (N)	16	23	27	17	20	20	4.08	19.93



Industrial Process Controls Global Ltd UTS003 Ver:1.41 (1.41)   Printed 1/1/2013 2:10:10 AM

Indirect Tensile Modulus Test

Test method: BS DD213-1993 (British Standard - Draft for Development)
Data fileName: C:\UJI 2019\ITSM 2019\ITM Abdullah-ITS\4_5CR1B.D003
Template file name: C:\IPCglobal UTS\003 IT Modulus Test\Templates\Template April 2016\Adit.P003
Test date & time: 1/1/2013 2:36:50 AM
Project: -
Operator: Arya
Comments: 8-10-19

Setup Parameters

Target temperature (°C): 20
Loading pulse width (ms): 250
Pulse repetition period (ms): 3000
Conditioning pulse count: 5

Target deformation (μm): 5
Estimated Poisson's ratio: 0.35
Estimated modulus (MPa): 3000
Contact force (N): 20

Specimen Information

Identification: 4.5CR1B
Remarks...

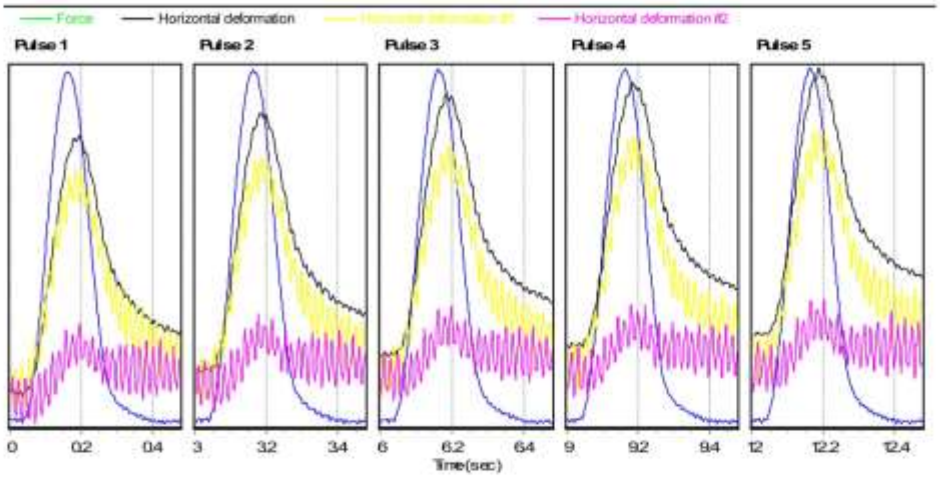
Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	63.0	62.5	63.0	64.5			63.3	0.9
Diameter (mm)	101.6	101.6	101.6	101.6			101.6	

Cross-sectional area (mm²): 8107.3

Test Results

Conditioning pulses: 5
Core temperature (°C): 20.8
Skin temperature (°C): 20.2

	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	Std. Dev.	%CV
Stiffness modulus (MPa)	1482	1484	1457	1444	1433	1460	20.13	1.38
Adjusted stiffness modulus (MPa)	1566	1566	1526	1529	1507	1539	23.28	1.51
Peak horizontal deformation (μm)	4.86	4.93	5.02	5.04	5.11	4.99	0.08	1.70
Load area factor	0.53	0.53	0.51	0.54	0.52	0.53	0.01	1.88
Peak loading force (N)	735	747	746	742	746	743	4.52	0.61
Load rise time (ms)	112	115	116	116	116	115.2	1.86	1.61
Horizontal deformation #1 (μm)	3.62	4.10	3.75	3.73	3.78	3.79	0.16	4.21
Horizontal deformation #2 (μm)	1.24	0.84	1.27	1.31	1.32	1.20	0.18	15.18
Seating force (N)	22	15	17	22	20	19	2.71	14.04



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Printed 1/1/2013 2:40:31 AM

Indirect Tensile Modulus Test

Test method: BS DD213-1993 (British Standard - Draft for Development)
Data fileName: C:\UJI 2019\ITSM 2019\ITM Abdullah-ITS\6_5CR1B.D003
Template file name: C:\IPCglobal UTS\003 IT Modulus Test\Templates\Template April 2016Adit.P003
Test date & time: 1/1/2013 4:43:28 AM
Project: -
Operator: Arya
Comments: 8-10-19

Setup Parameters

Target temperature (°C): 20
Loading pulse width (ms): 250
Pulse repetition period (ms): 3000
Conditioning pulse count: 5

Target deformation (µm): 5
Estimated Poisson's ratio: 0.35
Estimated modulus (MPa): 3000
Contact force (N): 20

Specimen Information

Identification: 6.5CR1B
Remarks...

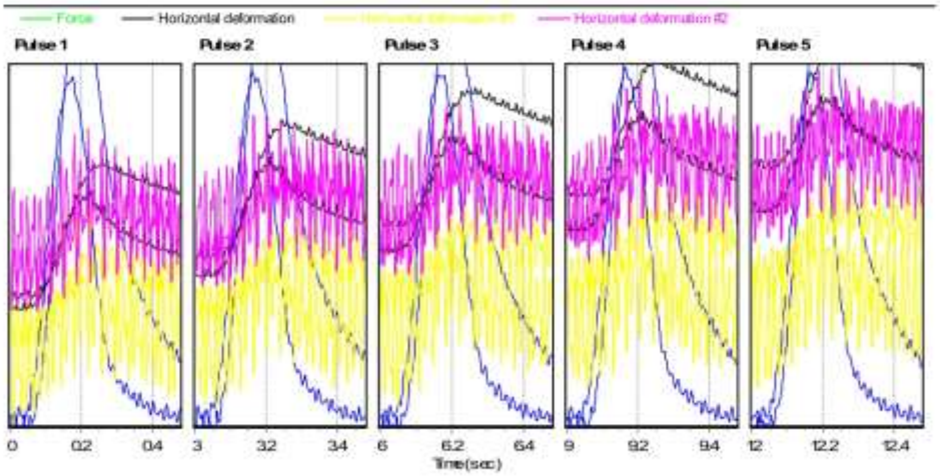
Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	51.0	53.0	54.0	53.0			52.8	1.3
Diameter (mm)	101.6	101.6	101.6	101.6			101.6	

Cross-sectional area (mm²): 8107.3

Test Results

Conditioning pulses: 5
Core temperature (°C): 20.8
Skin temperature (°C): 20.3

	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	Std. Dev.	%CV
Stiffness modulus (MPa)	1103	1069	1031	921	474	920	230.96	25.11
Adjusted stiffness modulus (MPa)	1195	1119	1094	890	466	953	263.34	27.63
Peak horizontal deformation (µm)	3.89	4.10	4.19	4.79	9.18	5.23	2.00	38.23
Load area factor	0.58	0.49	0.52	0.51	0.54	0.53	0.03	5.74
Peak loading force (N)	365	373	367	376	370	370	3.83	1.03
Load rise time (ms)	122	112	104	113	107	111.6	6.21	5.57
Horizontal deformation #1 (µm)	3.41	3.77	4.09	4.44	6.67	4.48	1.15	25.64
Horizontal deformation #2 (µm)	0.47	0.33	0.10	0.35	2.51	0.75	0.89	117.94
Seating force (N)	18	16	17	17	17	17	0.76	4.43



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APPENDIX I:The Indirect Tensile Fatigue Properties

Indirect Tensile Fatigue Test

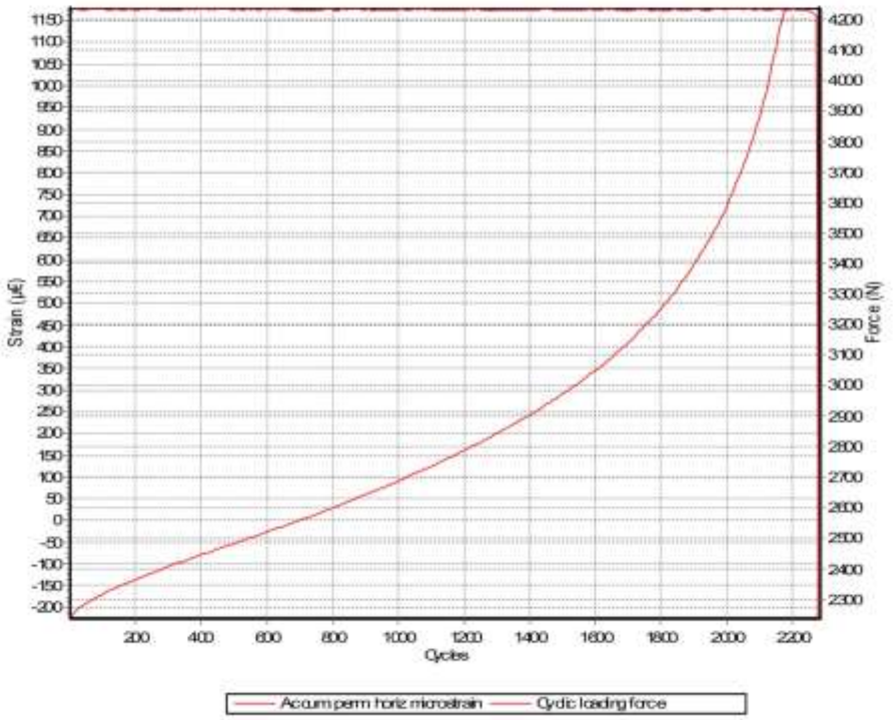
Data file name: C:\UJI 2019\TFT 2019\Mhs ITS, Abdullah\19-10-19.D013
Template file name: C:\IPCglobal UTS013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 12:33:06 AM
Project:
Operator: Arya
Comments: 19-10-19

Specimen Information
Identification: NoCR400
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	66.5	66.0	66.0	66.0	67.0		66.3	0.4
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

Cross-sectional area (mm²): 8107.3

Set up parameters
Transducer configuration: Std IT Jig
Cyclic loading force: 4236 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms
Poisson ratio: (calculated from data)
Target temperature: 20 °C
Termination cycle count: 100000
Termination max displacement: 9.0 mm



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Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\NoCR500a.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 12:23:25 AM
Project:
Operator: Arya
Comments: 22-10-19

Specimen Information

Identification: NoCR500a
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	61.0	61.0	61.5	61.5			61.3	0.3
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

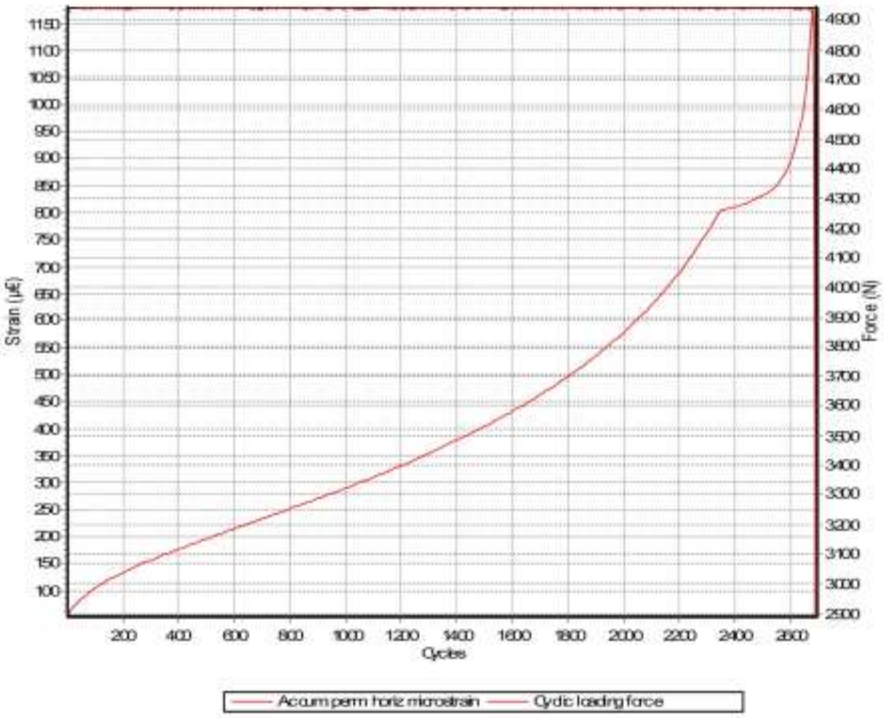
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 4945 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\NoCR600a.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 1:17:25 AM
Project:
Operator: Arya
Comments: 22-10-19

Specimen Information

Identification: NoCR600a
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	59.0	59.5	60.0	60.0			59.6	0.5
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

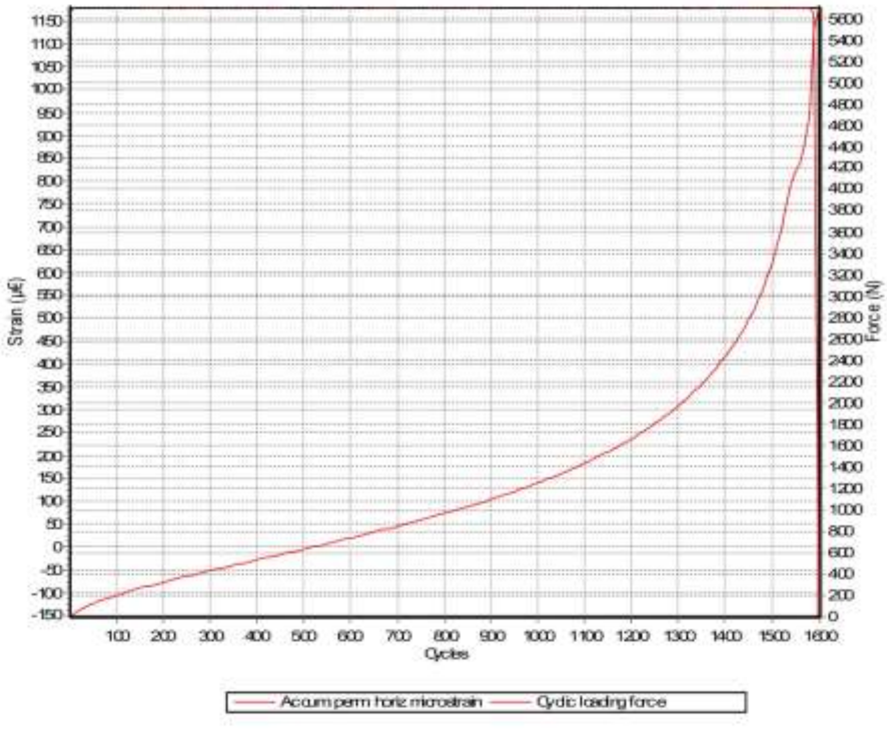
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 5707 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Industrial Process Controls Global Ltd UTS013 Ver:1.13 (1.13) Page: 1 Printed 1/1/2013 1:32:08 AM

Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\TFT 2019\Mhs ITS, Abdullah\NoCR700.D013
Template file name: C:\IPCglobal UTS013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 3:52:41 AM
Project:
Operator: Arya
Comments: 19-10-19

Specimen Information

Identification: NoCR500a
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	58.5	58.0	60.0	59.0			58.9	0.9
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

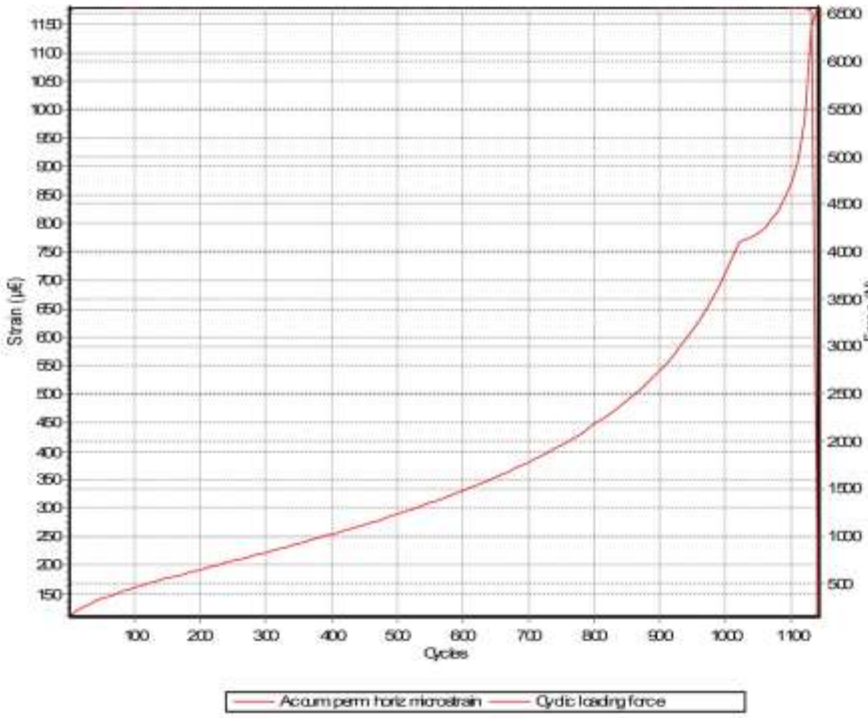
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 6575 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Industrial Process Controls Global Ltd UTS013 Ver:1.13 (1.13) Page: 1 Printed 1/1/2013 4:04:57 AM

Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\2.5CR300.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 3:51:06 AM
Project:
Operator: Arya
Comments: 27-10-1*9

Specimen Information

Identification: 2.5CR300
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	60.9	60.8	60.9	60.8			60.8	0.0
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

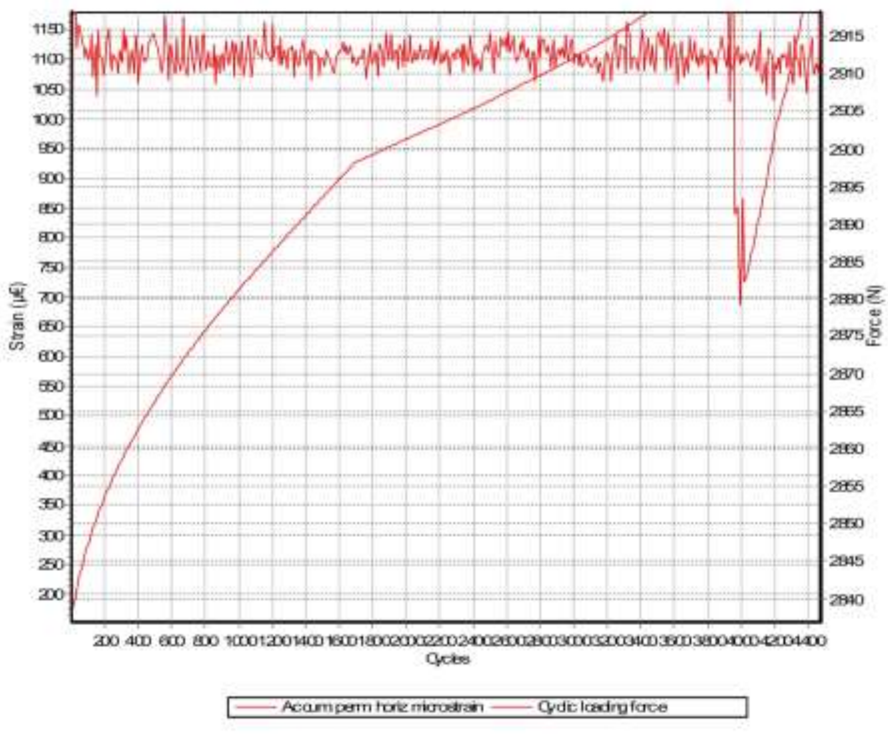
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 2915 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\2.5CR400b.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 3:10:50 AM
Project:
Operator: Arya
Comments: 27-10-19

Specimen Information

Identification: 2.5CR400b
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	60.3	60.4	60.4	60.4			60.4	0.0
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

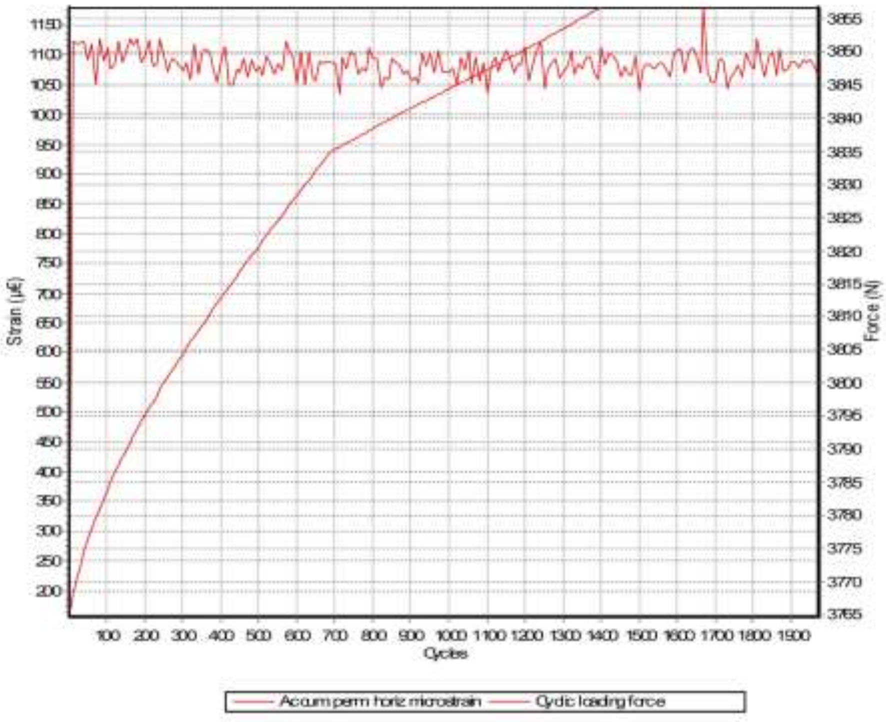
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 3852 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\2.5CR500.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 3:31:23 AM
Project:
Operator: Arya
Comments: 22-10-19

Specimen Information

Identification: 2.5CR500
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	57.0	56.0	57.0	57.0			56.8	0.5
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

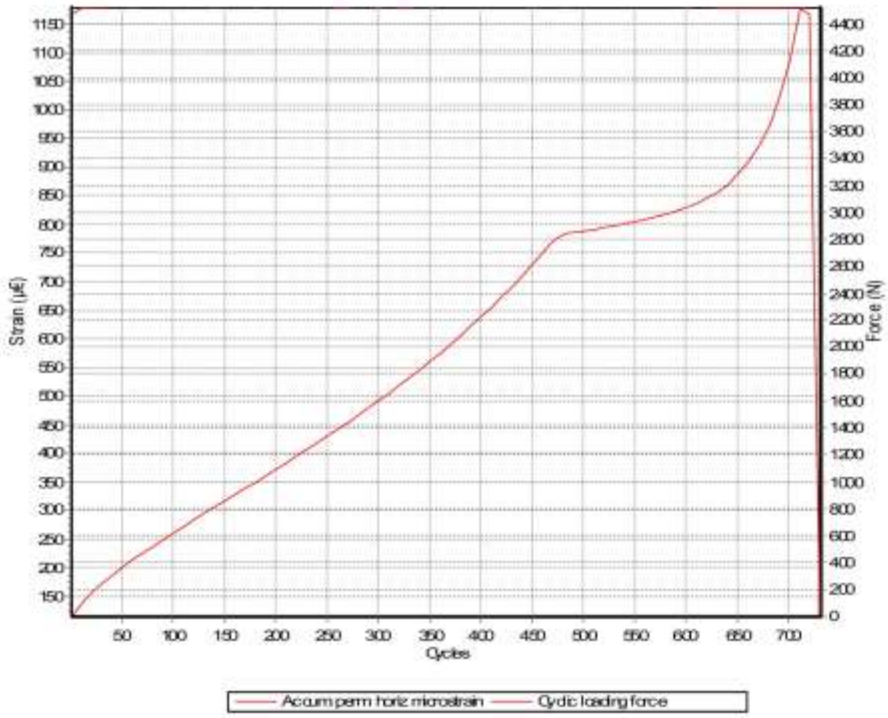
Cross-sectional area (mm^2): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 4527 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\2.5CR600.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 3:56:13 AM
Project:
Operator: Arya
Comments: 22-10-19

Specimen Information

Identification: 2.5CR600
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	68.5	68.5	68.0	69.0			68.5	0.4
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

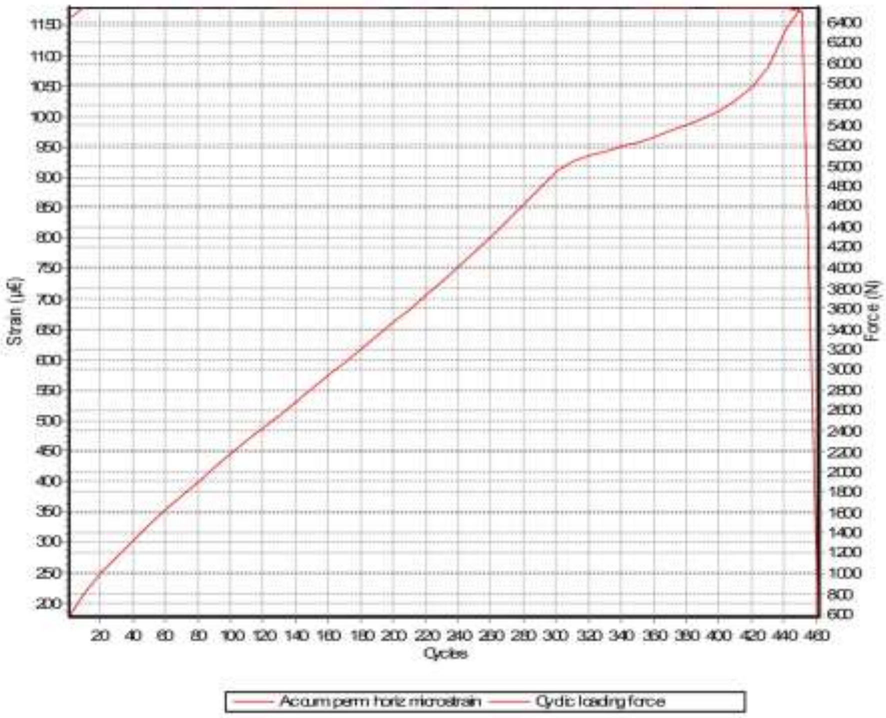
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 6556 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\2.5CR700.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 1:53:51 AM
Project:
Operator: Arya
Comments: 22-10-19

Specimen Information

Identification: 2.5CR700
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	69.3	68.6	70.1	69.7			69.4	0.6
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

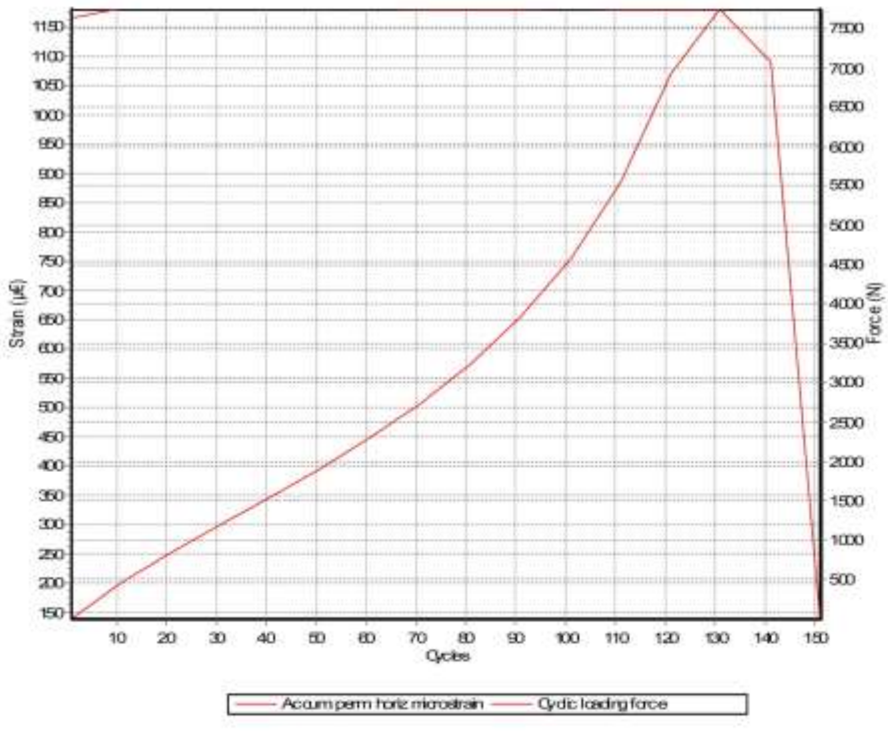
Cross-sectional area (mm²): 8107.7

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 7753 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Industrial Process Controls Global Ltd UTS013 Ver:1.13 (1.13)   Page: 1   Printed 1/1/2013 2:05:20 AM

Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\4.5CR3-300.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 1:03:43 AM
Project:
Operator: Arya
Comments: 1-11-19

Specimen Information

Identification: 4.5CR3-300
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	71.0	70.0	69.0	71.0			70.3	1.0
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

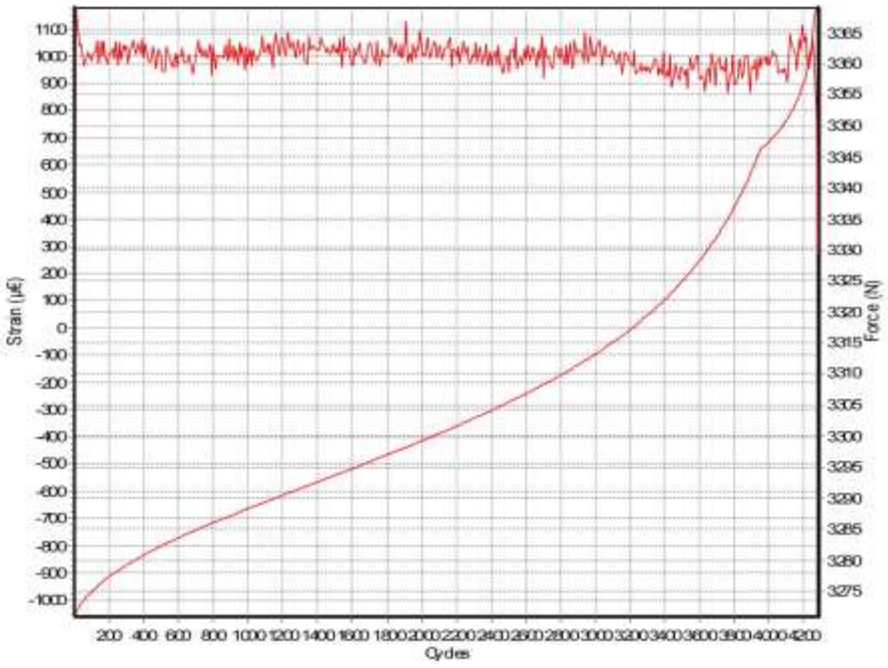
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 3362 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Industrial Process Controls Global Ltd UTS013 Ver:1.13 (1.13) Page: 1 Printed 1/1/2013 1:41:08 AM

Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\4.5CR2-350.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 12:36:21 AM
Project:
Operator: Arya
Comments: 1-11-19

Specimen Information

Identification: 4.5CR2-300
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	70.0	69.0	70.0	70.0			69.8	0.5
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

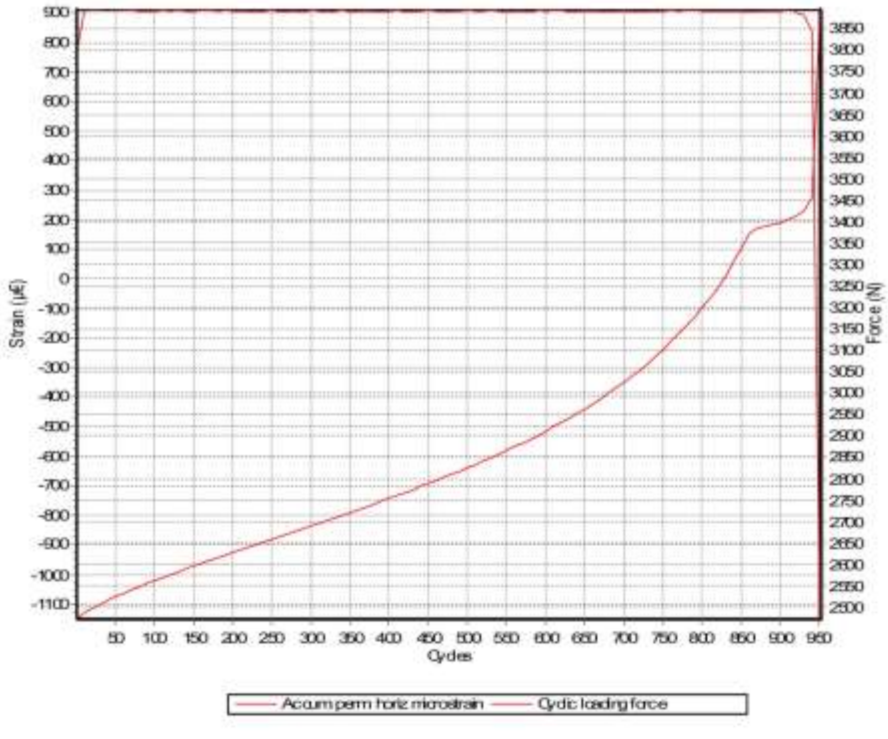
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 3895 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Industrial Process Controls Global Ltd UTS013 Ver:1.13 (1.13) Page: 1 Printed 1/1/2013 12:45:28 AM

Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\4.5CR1-400.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 12:20:18 AM
Project:
Operator: Arya
Comments: 1-11-19

Specimen Information

Identification: 4.5CR1-400
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	70.0	71.0	69.5	70.0			70.1	0.6
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

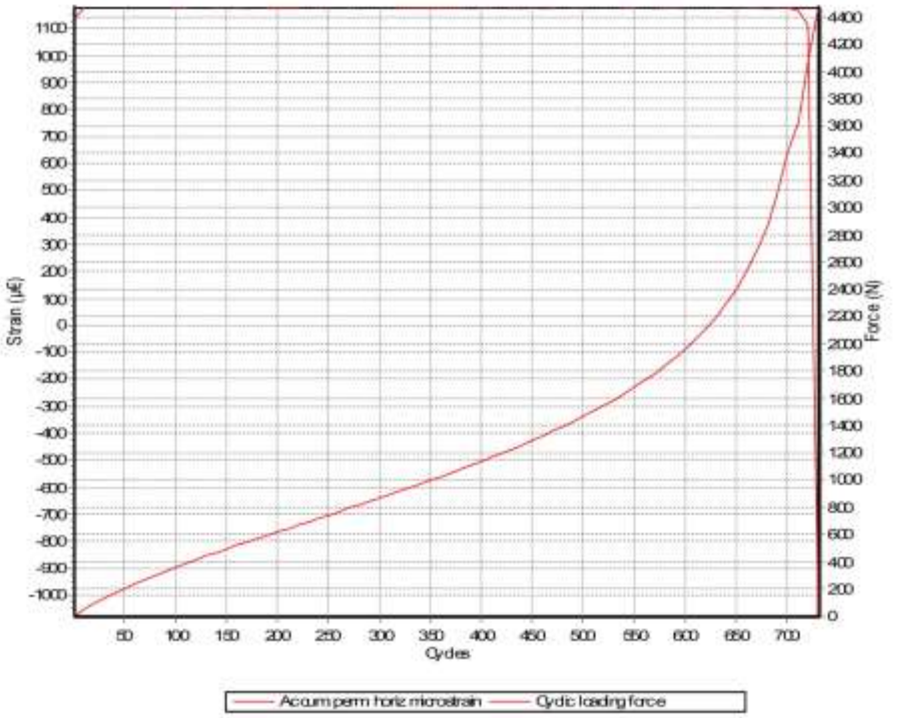
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 4475 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\4.5CR4-450.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 1:53:16 AM
Project:
Operator: Arya
Comments: 1-11-19

Specimen Information

Identification: 4.5CR4-450
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	61.0	60.0	61.5	62.0			61.1	0.9
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

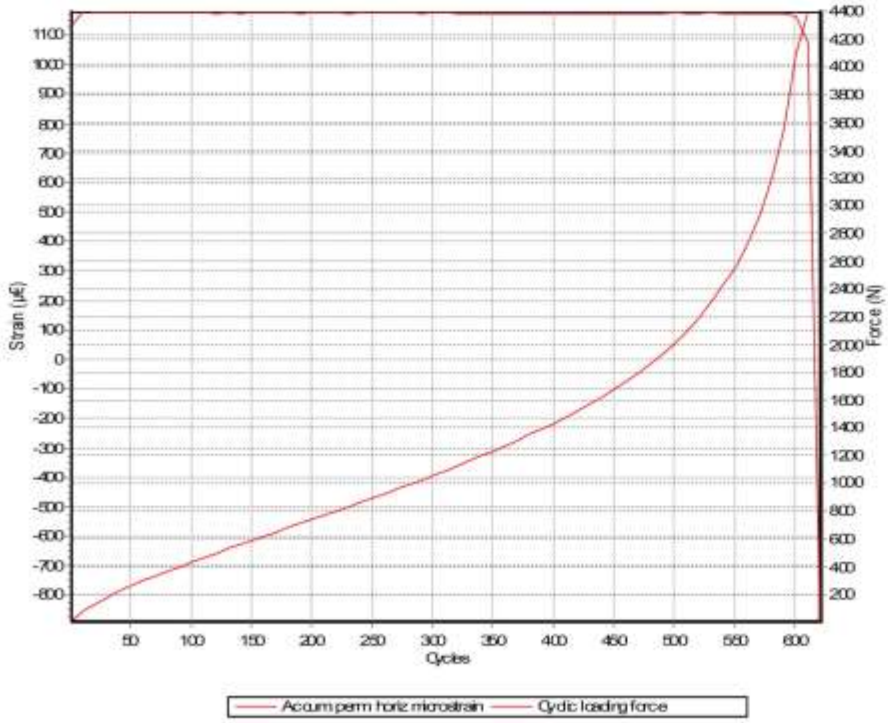
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 4388 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Industrial Process Controls Global Ltd UTS013 Ver:1.13 (1.13) Page: 1 Printed 1/1/2013 1:59:49 AM

Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\4.5CR5-500.D013
Template file name: C:\IPCglobal UTS013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 2:15:24 AM
Project:
Operator: Arya
Comments: 1-11-19

Specimen Information

Identification: 4.5CR5-500
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	63.0	62.0	63.0	63.0			62.8	0.5
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

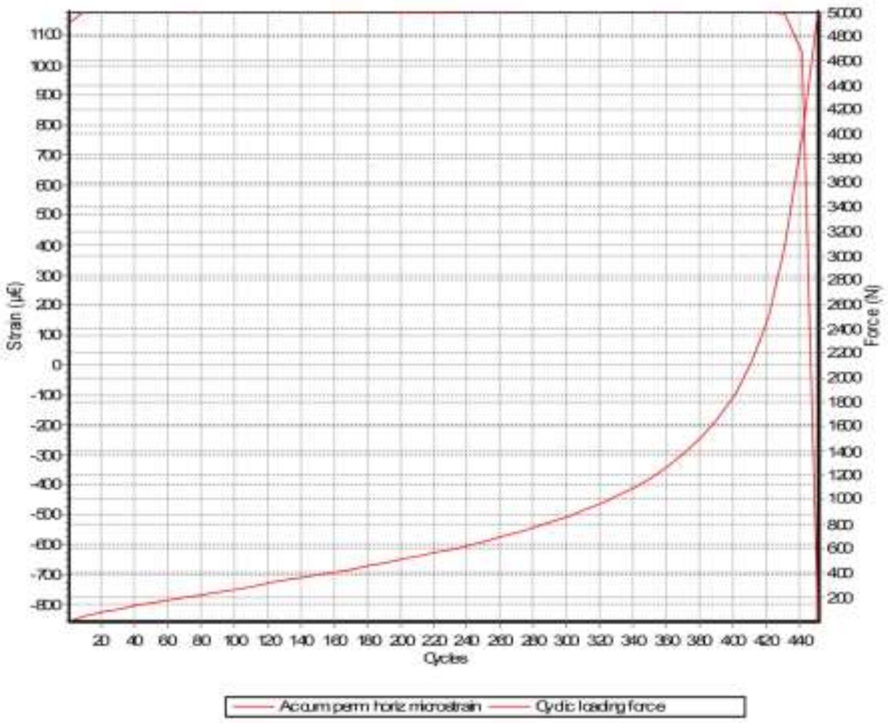
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 5005 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\6.5CR2-250.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adil S.P013
Test date & time: 1/1/2013 12:25:27 AM
Project:
Operator: Arya
Comments: 4-11-19

Specimen Information

Identification: 6.5CR2-250
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	75.0	75.0	75.0	74.0			74.8	0.5
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

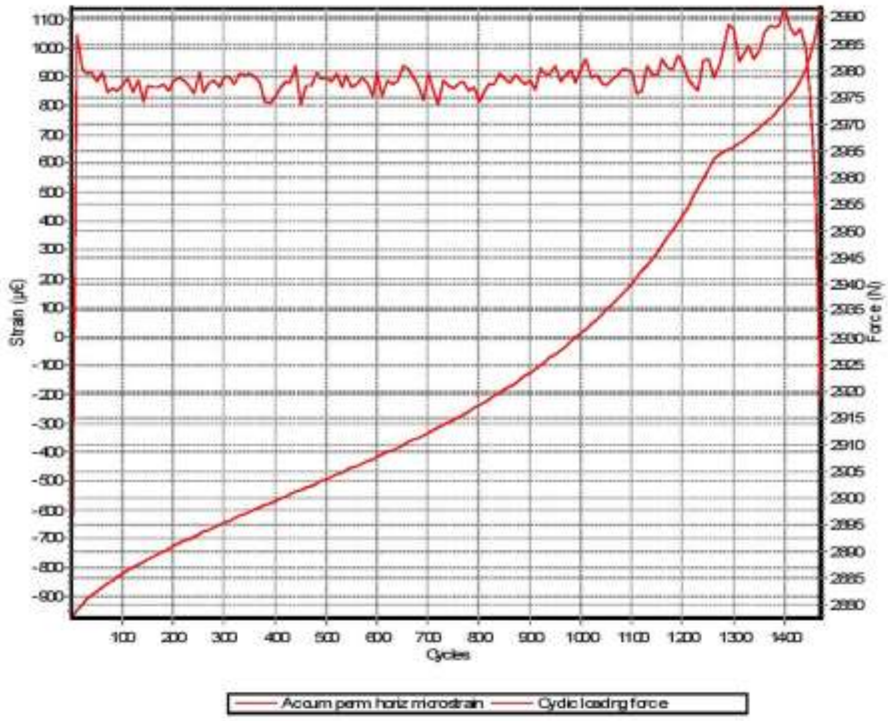
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 2981 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\6.5CR5-300.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 1:21:44 AM
Project:
Operator: Arya
Comments: 4-11-19

Specimen Information

Identification: 6.5CR5-300
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	66.0	65.5	65.5	66.0			65.8	0.3
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

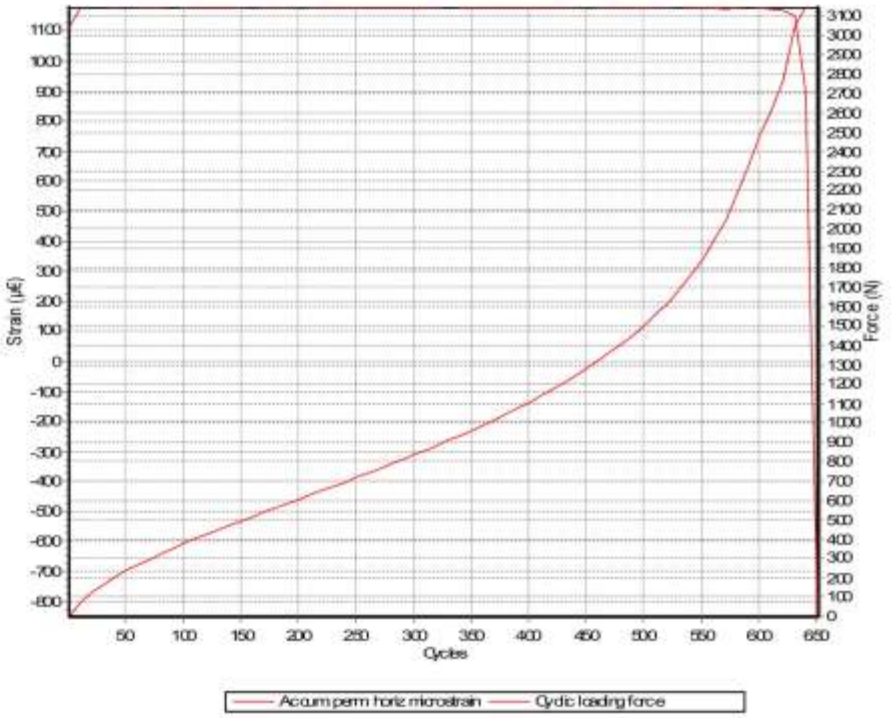
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 3147 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Industrial Process Controls Global Ltd UTS013 Ver:1.13 (1.13)   Page: 1   Printed 1/1/2013 2:48:15 AM

Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdulah\6.5CR3-350.D013
Template file name: C:\IPCglobal UTS\013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 12:49:54 AM
Project:
Operator: Arya
Comments: 4-11-19

Specimen Information

Identification: 6.5CR3-350
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	74.5	76.0	77.0	75.5			75.8	1.0
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

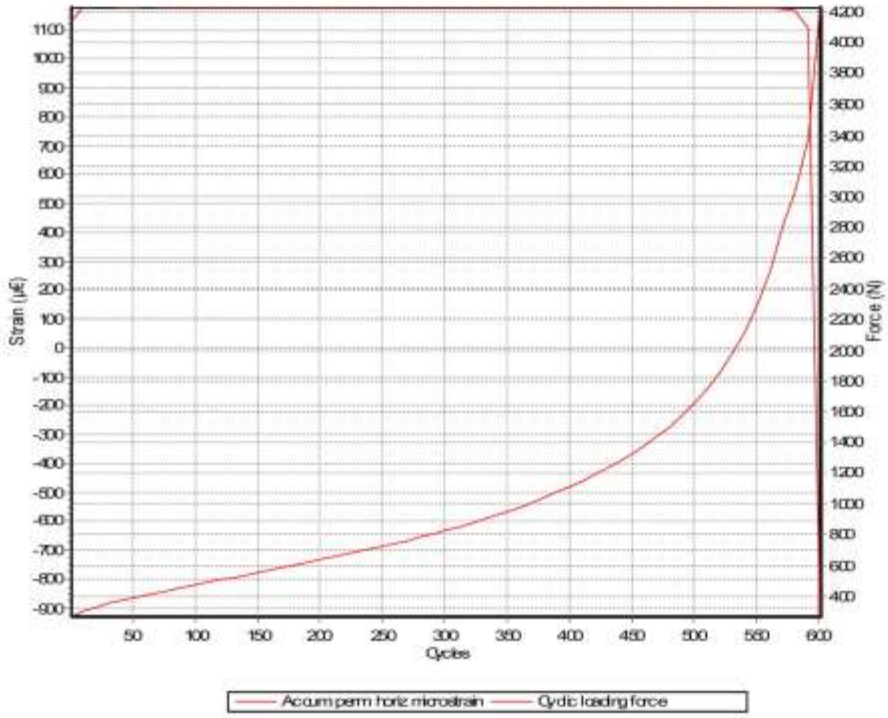
Cross-sectional area (mm²): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 4229 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



Industrial Process Controls Global Ltd UTS013 Ver:1.13 (1.13) Page: 1 Printed 1/1/2013 12:57:03 AM

Indirect Tensile Fatigue Test

Data file name: C:\UJI 2019\ITFT 2019\Mhs ITS, Abdullah\6.5CR4-400.D013
Template file name: C:\IPCglobal UTS013 IT Fatigue Test\Templates\Default\Adit S.P013
Test date & time: 1/1/2013 1:10:57 AM
Project:
Operator: Arya
Comments: 4-11-19

Specimen Information

Identification: 6.5CR4-400
Remarks...

Dimensions	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Average	Std Dev
Length (mm)	73.0	75.0	74.0	73.0			73.8	1.0
Width (mm)	100.0						100.0	
Thickness (mm)	80.0						80.0	

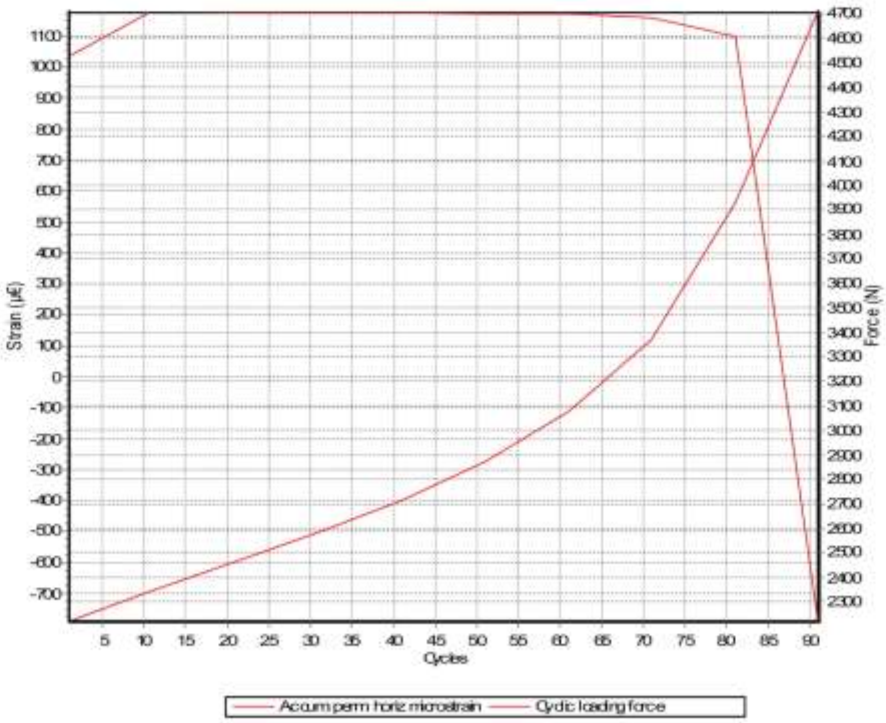
Cross-sectional area (mm^2): 8107.3

Set up parameters

Transducer configuration: Std IT Jig
Cyclic loading force: 4706 N
Seating force: 10 N
Cycle duration: 100 ms
Cycle repetition time: 500 ms

Poisson ratio: (calculated from data)
Target temperature: 20 °C

Termination cycle count: 100000
Termination max displacement: 9.0 mm



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1. kingergarten stage : Kingergarten Al-sawan Waddan, Libya (1989-1990).
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3. Junior high stage : Al-sawan shool Waddan, Libya (1997-1999).
4. Secondary stagev : Waddan secondary school Waddan .Libya (2000-2003).
5. S1 : Instuite Teknologi Tripoli, Libya (2003-2008).
6. S2 : Universtas Sebelas Maret, Solo, Indonesia (2013-2015).
7. S3 : Instuite Teknologi Sepuluh Nopember (ITS), Surabaya Indonesia (2015-2020).

C-EMPOLYOMENT RECORD:

1. Eshiblia Contracting Company, real estate and investment (Sirit –Libya): Location job: Algani flied Zalah, Libya (Jun2008-Jun2009).
2. A ssawaid Alarabiya Contracting Company, real estate and investment (Tripoli-Libya) Location job: Algani flied Zalah, Libya (Sep2009-Mar2010).
3. Aljmal Contracting Company, real estate and investment (Mistuta –Libya) Location Job: Sirit –Libya)(Jun 2010-Jun 2011).
4. Lectuer in HIGHWAY ENGINEERING in Civil Engineering Depertment at Collage Of Engineering Technology .Hoon.Libya (2016-2017).

D-JOURNAL PAPERS:

1. Abdallh. A. A. Lhwaint,Mohmed Alshekh A. M. Hmade, Ahyudanari, B.Mochtar, blash (2017). ANALYSING PROPERTIES OF ASPHALT CONCRETE MODIFIED WITH CRUMB RUBBER COMPARE TO OTHER MIXTURE. Regional Conference in Civil Engineering (RCCE) The Third International Conference on Civil Engineering Research (ICCER)August 1st-2nd 2017, Surabaya - Indonesia.

2. Abdallh. A. A. Lhwaint, Indrasurya B. Mochtar HOT MIX ASPHALT MODIFIEDWITH CRUMB RUBBER DESIGN AND DEVELOPMENT PROPERTIES FROM DIFFERENT SOURCES OF TIRE WASTES. International Journal of Civil Engineering and Technology (IJCIET) Volume 10, Issue 10, October 2019, pp. 289-304, Article ID: IJCIET_10_10_030 Available online http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=10&IType= 10 ISSN Print: 0976-6308 and ISSN Online: 0976-6316 © IAEME Publication.

3. Abdallh. A. A. Lhwaint .The Development of Rubberized Road For The Future Pavement Materials Construction . International Conference on Civil Engineering (ICCE),Madiun ,December ,2019 as Keynote Speakers.