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Evaluation and Improvement of Rutting Failure for Local Asphalt Base Course

A Thesis

Submitted to the Department of Civil Engineering, College of Engineering, University of Babylon in Partial Fulfilment of the Requirements for the Master Degree in Engineering / Civil Engineering / Transportation

By

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(B.Sc. in Civil Engineering 2018)

Supervised By

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2023 **1445**

بسم الله الرحمن الرحيم

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Fatima Muslim Hadi

2 / 6 / 2023

Dedication

Great thank to Almighty Allah for His blessings and all the achievements in my life. I am grateful to my family for their support and patience throughout my studies and provided me with motivation and financial support. Without them, none of this achievement would be possible.

To:

My Mom and Dad

My brothers and my sisters.

Every person supported me during my entire life.

Fatima Muslim Hadi

2/ 6/ 2023

Abstract

Rutting with in pavement structure is among the major deformations that appears on most Iraqi roads as a result of high temp changes and the enhance in axial excessive heavy vehicle load. The combination of these Two conditions has a substantial negative influence on the road's performance by shortening the service lifespan of the asphalt and increasing the number of accidents that occur. As a result. it has started utilizing the polymers as admixtures to increase the qualities of asphalt, which ultimately leads to the achievement of high-quality asphalt mixture. All of these enhancements are being made in order to forestall the production of rutting deformations in the asphalt pavement layers.

The aim of this study is to improve the asphalt mixtures by using two types of admixtures (High-Density Polyethylene (HDPE) and Crumb Rubber (CR)) to resist high traffic loads and extend the service life of the pavement section and avoid rutting failure. The statistical analysis using SPSS program was used to identify the variation between effect of 60 and 50 dedgree centigrade on both selected mixture asphalt layers that are produced due to the pressure of the wheels and the acceleration and deceleration of the movement of vehicles in a road section.

Through this study, two types of additives were examined: high-density polyethylene (HDPE) with a percentage of (4,6,8,10)% and CR rubber crumbs with a percentage of (5,10,15,20)%. It is found that the best percentage, was using (HDPE), is 8% and the best percentage, using (CR), is 15%.

Laboratory tests showed that the stability increased by 113% with HDPE and by 75% with CR, while the indirect tensile strength increased by 17% with HDPE and by 30% with CR,and the rutting depth decreased by 46% with HDPE, 27% with CR, and stiffness increased by 148% with HDPE and 61% with CR. While statistical analysis show that the corelation cofficient of using CR at 50 digree centigrade give better results than HDPE for similar temperature. However, increasing the temperature to 60 degree centigrade give opposite results.

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List of Abbreviations and Symbols

Abbreviations	Definition
AASHTO	American Association of State Highways and Transportation Officials
AASHO	American Association of State Highway Officials
AC	Asphalt cement
ASTM	American Society for Testing Materials
AMS	Aggregate max size
Av	Air void
Gmb	Bulk Density
Gmm	Theoretical Maximum Density
HMA	Hot mix asphalt
HWTT	Hamburg Wheel Truck Testing
HDPE	High - Density Polyethylene
CR	Crumb Rubber
MR	Resilient Modulus
NCHRP	National Cooperative Highway Research Program
OPC	Ordinary Portland Cement
WTA	Wheel Truck Aperture
ITS	Indirect Tensile Strength Test
VFA	voids filled with Asphalt

VMA	voids in mineral aggregate
UTM	Universal Testing Machine
SCRB	State Corporation of Roads and Bridges

Chapter One

Introduction

CHAPTER ONE

INTRODUCTION

1.1 Background

A road rut appears as a pavement depression, which contains part of the pavement surface area that is lower than the surrounding area. The depressions can be categorized by low, medium or high, starting at a low intensity pavement depression that is only visible after rain, to an easily observable depression that can cause hydroplaning. Roads play a major role in the development of all countries and societies by providing the essential links between different parts of the country to facilitate the movement of people and transport of goods. The importance of roads increases as the area of the country increases, especially in the absence of other means of transport such as railways and waterways, which is often occurred in developing countries **(O'Neill et al., 2017).**

Unacceptable surface rutting may be caused by an improper mix design or insufficient compaction of the asphalt layers, while a proper design mix should guarantee that traffic could be maintained for the whole design life. Under the heavy tire stress, the asphalt layers need to be rigid enough to prevent deformation and outward flow while yet staying flexible enough to avoid fatigue cracking **(Sun, 2016).**

The anticipated traffic loads, volume, and weather conditions must be considered in the asphalt mix-design. The aggregate (particle size and shape, and grading proportions) and the binder are the two elements of the mix design that have an impact on stiffness (the grade and composition of the bitumen used to bind the aggregate – which must be stiff enough to avoid rutting). The composition of the asphalt mix is also crucial; the amounts of aggregate, binder, and voids should all fall within acceptable bounds for a particular mix type. Surface rutting may result from poor compaction of the asphalt layers, which can happen even when employing current materials, equipment, and construction techniques. Problems may arise, however, if the asphalt is allowed to cool below ideal temperatures before compaction is finished, as can happen in distant locations owing to lengthy hauling durations.

The asphaltic paving mixture is subjected to various detrimental types of distresses during its service life. The cause of these stresses is the load (heavy traffic), bad asphalt properties, weathering (temperature, humidity, rain) and bad mixture designs **(Akinleye et al., 2021).**

Some of these serious distresses include permanent deformation, moving, stripping, and fatigue cracking as well as rutting, which to finish may lead to complete failure of roadway at the same time **(Shaikh et al., n.d.).** Such distresses will decrease the performance of asphalt road below the effect of dense traffic loading, in high temperatures and the cumulative number of vehicles and trucks with their dense traffic loading, specific condition is wanted to control the quality of highway materials in order to rise its durability. The best important property of the asphalt mix in the surface course design is its ability to attack moving and rutting below traffic. Therefore, strength must be high enough to handle traffic sufficiently, but not greater than the necessary traffic conditions**.** The lack of strength in a bitumen mix causes unraveling and movement of the highway surface **(Bhandari et al., 2022).** There are different ways to improve asphalt mixture properties in order to improve asphalt pavement stability and decrease rutting failure occurrence **(Hınıslıoğlu & Ağar, 2004):**

- First is building highway pavement with greater thickness.

- Second is using different kinds of additives as modifiers (e.g. different kinds of fibers and polymers) in bitumen mix constructing.

Increasing the pavement thickness in roadway will cause significantly higher construction cost due to increase the required materials for pavement. Thus, using additives might be a well solution to overcome the asphalt deterioration problem with lower maintenance cost **(Lateef & Mohmmed, 2018).**

Rutting of hot mix asphalt (HMA) pavement at or near intersection is very common both in cold and hot climates. Obviously, the problem is more acute in hot climates compared to cold climates because the stiffness of HMA decreases with increase in pavement temperature. In most cases, there is no significant rutting in the same asphalt pavement structure away from the intersections under fast moving traffic, which refer to an intersection with low traffic jam, while rutting issue appear in high traffic load **(Kandhal et al., 1998).**

The two primary mechanisms of rutting have been identified as shear failure (lateral movement) and densification (volume reduction). Shear failure (lateral movement) of the HMA courses occurs in the top 100 mm of the pavement surface, which results from the direct effect of the weather temperature and concentrated load from vehicles, and both effects are reduced with increasing the depth of pavement **(Yildirim, 2007)**; however, if the material is unsatisfactory, shear failure can occur deeper. Permanent deformation in pavement is usually created gradually with increasing numbers of load applications. Typically, it appears as longitudinal depressions in the wheel paths and sometimes occurs in conjunction with upheavals on the sides. It is caused by a combination of densification (decrease in volume and, hence, increase in density) and shear deformation can occur in any one or more of the HMA layers as well as in the unbound materials underneath the HMA **(Eisenmann & Hilmer, 1987; Lu & Harvey, 2006).**

In recent years, road pavements have been subjected to greater damage as result of increase in number and weight of vehicles passing on highways. One of the most common types of road damaging is rutting which has a noticeable impact on performance of road pavement during its service life. Rutting is defined as the accumulated permanent deformation of road pavement which occurs under applied loading **(Abdulshafi, 1988; Matthews & Monismith, 1992),** and in this case, asphalt layer has shown a prominent magnitude **(Khodaii & Mehrara, 2009).** Rutting is not only reducing the service life of asphalt mixture, but also influences basic vehicle handling maneuvers in a negative manner which can threat passengers' lives **(Fontes et al., 2010).**

1.2 Problem of Study

- very application of traffic load results in some degree of pavement distress. Distress of many kinds, including rutting, fatigue cracking, material disintegration, roughness, and bleeding, may occur and build up over time. The pavement is deemed to have failed when one or more of these distresses reaches a certain unacceptably high degree.
- Owing to Iraq's high summer temperatures and the impact of traffic loads, particularly for slow moving traffic, rutting damage may considerably worsen. This study examined how flexible pavement performed under the combined influences of traffic volume and temperature. One of the most significant environmental influences on flexible pavement degradation is thermal variables, which are one of them and are brought on by high pavement temp. Increased traffic volume and high overloading resulted in a significant issue with pavement rutting.

- Unsuitable mix-design or inadequate compaction of the asphalt layers can result in unacceptable road surface rutting, whereas correct design mix should ensure traffic can be supported for the full design life. The asphalt layers must be sufficiently stiff as to prevent deformation and outward flow under the high tire loading, whilst remaining flexible enough to prevent fatigue cracking.

1.3 Research aim and Objectives

The current study aims to find sustainable way to improve pavement resistance against rutting cracking in main roadways pavement layers by using two additive materials that apply in the mixing stages. However, the main objectives of study are:

- Evaluation effects of additive materials such as (crumb rubber waste and High - Density Polyethylene), temperatures condition on permanent deformation behavior of asphalt mixtures.
- Investigating the effect of additives materials on both indirect tensile strength and wheel track.
- Comparing the rutting values of asphalt mixture in construction of base course before and after using additives using SPSS Software.

1.4 The Structure of Thesis

To achieve the objective of this research, the study consists of the following:

2. **Chapter one** is an introductory chapter outlining the rutting pavement distress related problem and the objectives of the research work. The possibility of the study is clearly stated in this part as well as the structure layout of the thesis.

3. **Chapter two** deals with comprehensive literature review related to the approach of this study including information and definitions needed to provide good background knowledge about the subject.
4. **Chapter three** shows in detail the work required for this study with the information on material properties and the testing methods.
5. **Chapter four** presents the results of the experimental work and the analysis necessary discussions.
6. **Chapter Five** presents the conclusions and suggestions for more study works.

Chapter Two

Literature Review and

Basic Concepts

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Permanent deformation in the form of rutting is one of the most important distresses (failure) mechanisms in asphalt pavements. With the increase in truck tire pressure in recent years, rutting has become the dominant mode of flexible pavement failure. Pavement rutting, which results in a distorted pavement surface, is primarily caused by the accumulation of permanent deformation in all or a portion of the layers in the pavement structure. Rutting can also be caused by wear on the pavements resulting from the use of studded tires. Longitudinal variability in the magnitude of rutting causes roughness. Water may become trapped in ruts resulting in a reduced skid resistance, increased potential for hydroplaning and spray that reduces visibility. Progression of rutting can lead to cracking and eventually to complete disintegration or failure **(Garba, 2002).**

The scope of this study is focusing on flexible pavement. The surface of flexible pavement as shown in Figure 2.1 must be high quality and strong enough to resist large axle loads and high temperatures. Traffic load distribution of flexible pavement depends on the layered system over the subgrade. The layers of a flexible pavement structure basically consist of hot mix asphalt (HMA) at the pavement surface, with a stabilized base, base course gravel, and subbase course gravel **(Saltan & Fındık, 2008).**

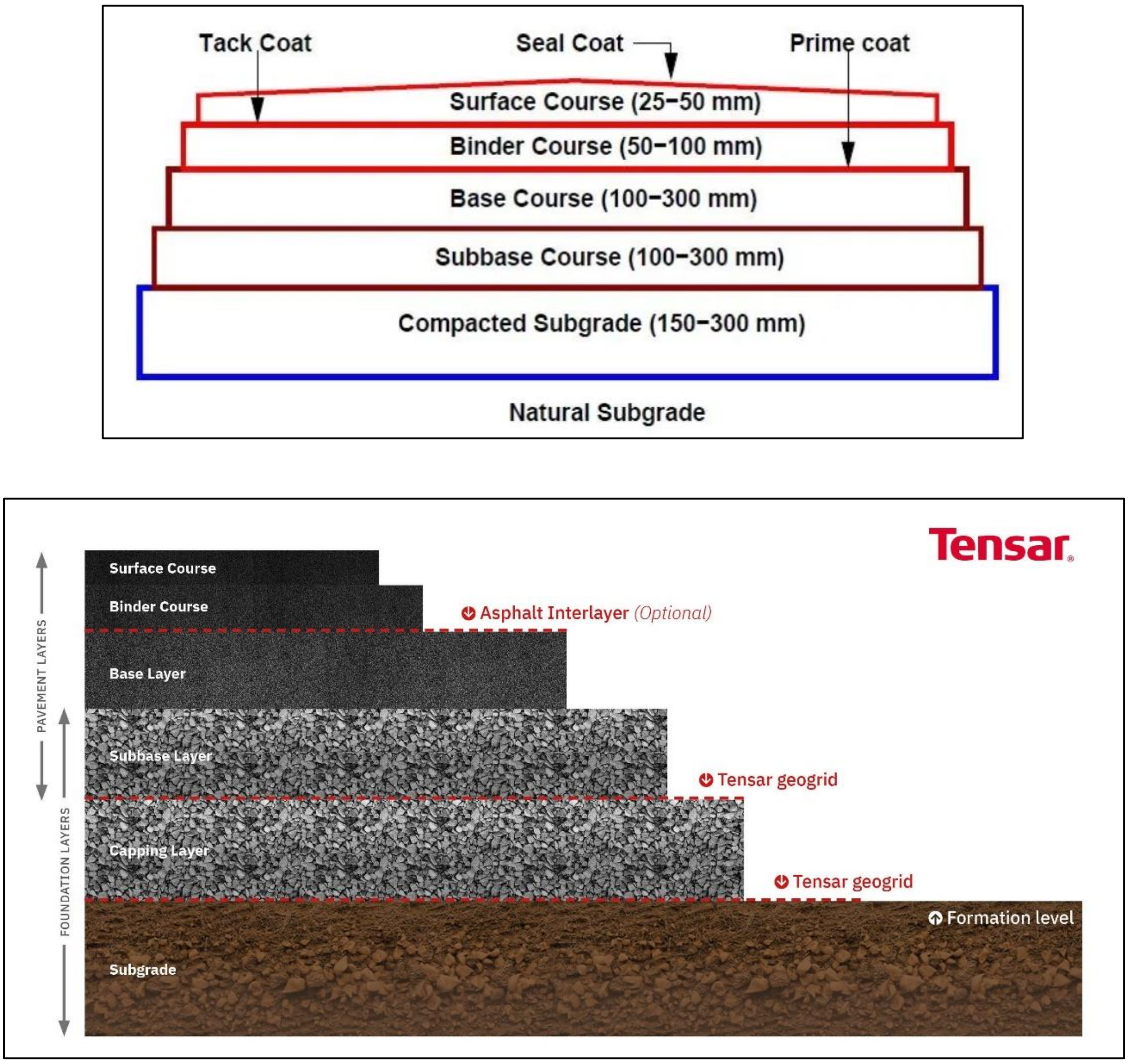


Figure 2.1. Flexible Pavement Cross Section (Tensar, 2021).

2.2. Hot Mix Asphalt

HMA is a common type of mix that broadly be used all over the world. Basic materials in HMA are a combination of asphalt binder and aggregates which is conducted through a specific design method such as Marshall, Hveem and Superpave. In addition, criteria of selecting the HMA mixtures are based on the different coefficient **(Hafeez et. al, 2010)**. The special procedure of HMA must be heated first before proceed to the next step. Besides that, in HMA mix design asphalt binder and aggregates are heated together in order to ensure that the asphalt in fluid form and the aggregates is totally dry during coating the aggregates. The newest method in designing HMA is called Superpave Mix design method.

Asphalt mixtures basically formed through the combination of asphalt cement, fine aggregates, coarse aggregates and other materials, which depend on the type of the mixtures. There are three types of asphalt mixtures that usually used in pavement construction which are hot-mix hot-laid asphalt mixture, hot-mix cold-laid asphalt mixture and cold-mix cold-laid asphalt mixture **(Masoudi et al., 2017; Zoorob et al., 2017).**

2.2.1. Asphalt

Asphalt is a thermoplastic viscoelastic adhesive which acts as a glue. It softens slowly and change the physical state from solid to liquid when heated. It is characterized by its consistency at certain temperatures (Mashaan et al., 2014)**.** Its relevant properties are its workability, strength, durability, imperviousness, and adhesion. Generally, the asphalt properties in terms of viscosity should be in specified fluid in order to allow it easily be conducted during the construction process and process of aggregates coat and wet (Koenders et al., 2000)**.** To avoid problems such as fracture and crack the viscosity of asphalt must restrain high temperature exposure so that it will not permanently deform through heavy traffic load and low pavement temperature. Factors need to be considered during selection of asphalt penetration grade and types are the climate of the construction area where the temperature of the atmosphere has to take into account the type of construction to be applied (M. Li et al., 2019)**.**

Asphalt can be classified into two, unmodified asphalt and modified asphalt. It is not recommended to use unmodified asphalt because it has a lower quality of resistance and formation of pavement distress can be easily formed when repetitive and heavy load is passed through the pavement (Moubark et al., 2017)**.**

Chemical composition of asphalt also affects the penetration grade of asphalt where the chemical percentage of pure asphalt is 80 to 88% of carbon (C), 0.5 to 10% of oxygen (O_2), 9 to 11% of hydrogen (H_2) and 0 to 1% of Nitrogen (N_2) **(Data, 2013).**

2.2.2. Modifying Asphalt Binder/Mixture

(Rodriguez-Fernandez et al., 2020) investigate the effect of adding crumb rubber to asphalt mixtures using the dry process by relating mechanical performances with microstructural characterizations. It was possible to observe the influence of conditioning process (time during which the asphalt mixture is kept at a high temperature after mixing) on the mechanical performance of the mixtures that depend primarily on the properties of the crumb rubber used. Specifically, it is shown that the conditioning time has an influence on the Marshall test results as well as the viscosity measurements. By using the Environmental Scanning Electron Microscope (ESEM), the distribution of the crumb rubber within the mixture has been investigated. In particular, the distribution of the crumb rubber by changing the conditioning time is of interest. The results showed that crumb rubber is well dispersed in the asphalt mixture when the conditioning time is increased. The effect of crumb rubber on the microstructure using Atomic Force Microscopy-Infrared Spectroscopy (AFM-IR) indicated that the main chemical change takes place in the para domain and catana or the so-called bee structures diminish on the CR modified bitumen because of more conditioning time.

(Lv et al., 2022) understand and quantify the PE and IE in terms of CRMA binder bonding performance. To do so, base asphalt, conventional CRMA and drained CRMA were evaluated. Drained CRMA were prepared by removing rubber particles from conventional CRMA via sieving. Asphalt binder bonding strength (BBS) test, tensile strength ratio (TSR) and Hamburg Wheel Tracking (HWT) tests were employed for performance evaluation. Furthermore, rheology master curves, Fourier Transform Infrared Spectroscopy (FTIR) and fluorescence microscopy were conducted to help reveal the influence of PE and IE. The results show that in terms of BBS testing, the PE and IE may vary with different CRMA formulas, but overall, a large negative PE with a small positive IE is seen, leading to inferior bonding strength of all CRMA samples. On the other hand, CRMA shows the best mixture performance (TSR, HWT) with both positive PE and IE. It is believed that even though the rubber particle is not favorable in terms of binder bonding performance, it is beneficial to the mixture water-resistance by improving the mixture elasticity.

(Zhang et al., 2021) evaluated the performances of TB/SBS composite modified asphalt with various modification formulas. Different rubber contents and SBS polymer contents were considered. Low temperature performance grading test, thermal stress master curve and low temperature Semi-Circular Bend (SCB) test were conducted for low-temperature performance evaluation. Multiple Stress Creep and Recovery (MSCR) and Hamburg Wheel Tracking (HWT) test were conducted for high-temperature performance evaluation. The results show that a 2% SBS addition can enhance the rutting resistance and moisture resistance of TBRA mixture without impairing its low-temperature performances. But more SBS introduction is not putting much extra value. Also, it is observed that with the presence of chemically active SBS polymer, rubber molecules from TB process also take part in the polymer crosslinking networking and strengthen the mixture. Based on both performance evaluation and cost analysis, a 10%TB plus 2%SBS formula is recommended in this study.

(Lee & Le, 2023) combined epoxy resin (ER) and crumb rubber powder (CRP) contents into conventional Styrene-butadiene-styrene (SBS)-modified asphalt binder to not only reduce the consumption of normal asphalt binder but also promote the usage of recycled waste material in practice. To cope with this research objective, the ER and CRP were designed at 3% and 5% by weight of asphalt binder, respectively. Various laboratory tests were performed to evaluate the performance of modified mixtures (ERCRP), including the Frequency Sweep Test, Multiple Stressed Creep and Recovery, Dynamic Modulus, Semi-Circular Bending (SCB), and Cantabro Durability Tests. Additionally, an assessment of the modified asphalt concrete pavement via field testbed was conducted through Falling Weight Deflectometer and Ground Penetrating Radar. Overall, by adding the ER and CRP, the strain value of the control reference mix can be reduced up to 31.8% and 28.3% at MSCR 0.1 and 3.1 kPa, respectively. Additionally, the dynamic modulus of the ERCRP-modified samples was approximately 32,267 and 189 MPa, while the value of the reference mixture was 28,730 and 105 MPa at the highest and lowest frequency, respectively, indicating an enhancement under repeated loads. Regarding the SCB test results at 0 °C, the peak stress of the ERCRP-modified mixture was 4.75 MPa, while the value of the reference specimens was only 4.2 MPa, noticing the improved stress-bearing capacity. Based on a full-scale testbed, the FLWD elastic modulus of reinforced pavement shows a novel improvement (6.75%) compared with the control pavement, suggesting a potential application of ERCRP-modified asphalt binder for sustainable development purposes.

2.3. Rutting in roads

A rut is a permanent, longitudinal surface depression that occurs in the wheel paths of a flexible pavement due to the passage of traffic. Ruts accumulate incrementally: every time a heavy vehicle passes a small, permanent deformation is caused. Further into the lifespan of the pavement, the surface deformation may be accompanied by heave, along each side of the rut as shown in figure 2.2.

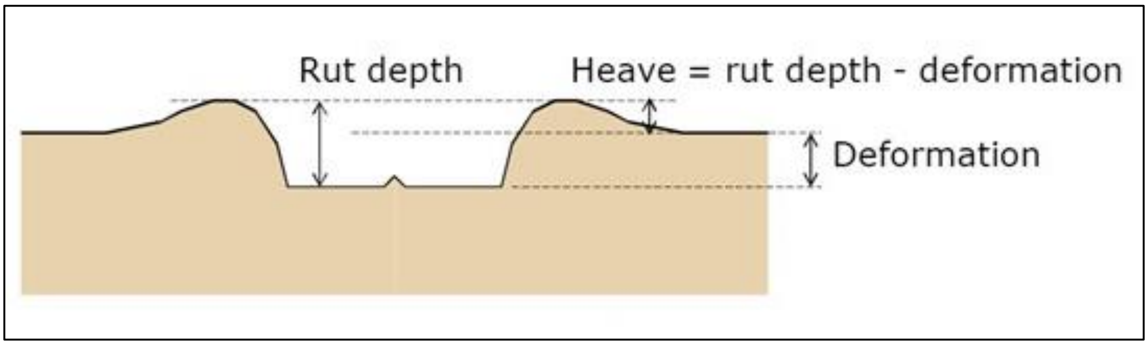


Figure 2.2. Rutting in Roads (Abdo, 2015)

The rut depth at any location is measured as the vertical distance between the top of the heave and the bottom of the depression. There are three basic types of rutting: mix rutting, subgrade rutting, and densification.

Mix rutting occurs when the subgrade does not rut yet the pavement surface exhibits wheel path depressions because of compaction/mix design problems as shown in figure 2.3 and 2.4. Rutting is confined to the HMA mixture. Loads push down the mixture and it flows away from the loading and up. Usually in mix rutting, there is a distinctive raised elevation on the edges of the wheel path. There is no rutting in the subgrade **(Al-Qadi et al., 2004).**

Mix rutting caused by improper mix design or manufacture (e.g., excessively high asphalt content, excessive mineral filler, insufficient amount of angular aggregate particles).

Figure 2.3. Severe Mix Rutting (Ahmed & Sabri, 2018)

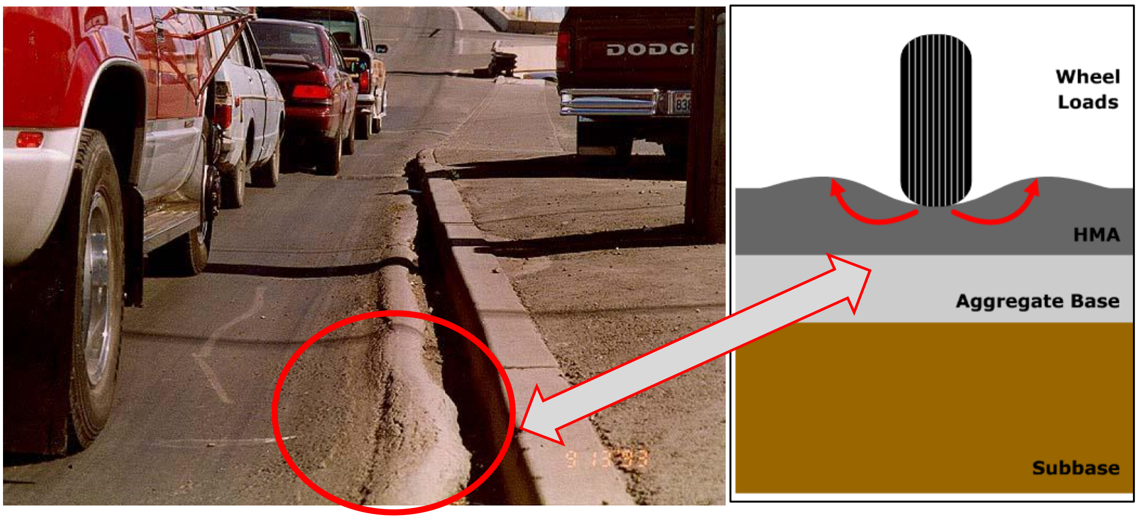


Figure 2.4. Mix Rutting (Von Quintus, 2012).

Subgrade rutting occurs when the subgrade exhibits wheel path depressions due to loading. In this case, the pavement settles into the subgrade ruts causing surface depressions in the wheel path as shown in figure 2.5. Rutting is confined to the subgrade. Loads are distributed through the pavement structure and push down on the subgrade. This further compacts the subgrade in the wheel paths and the pavement structure flexes down to accommodate the rutted subgrade. Usually, there is a distinctive lack of raised elevation on the rut edges, and the asphalt surface is cracked to allow it to flex into the subgrade rut **(Weng & Wang, 2011).**

Subgrade rutting caused by subgrade deforms under load. This is usually the result of one or both: inadequate subgrade preparation (e.g., compaction, replacement, etc.) and/or inadequate pavement structure (to reduce the loading on the subgrade to an acceptable level).

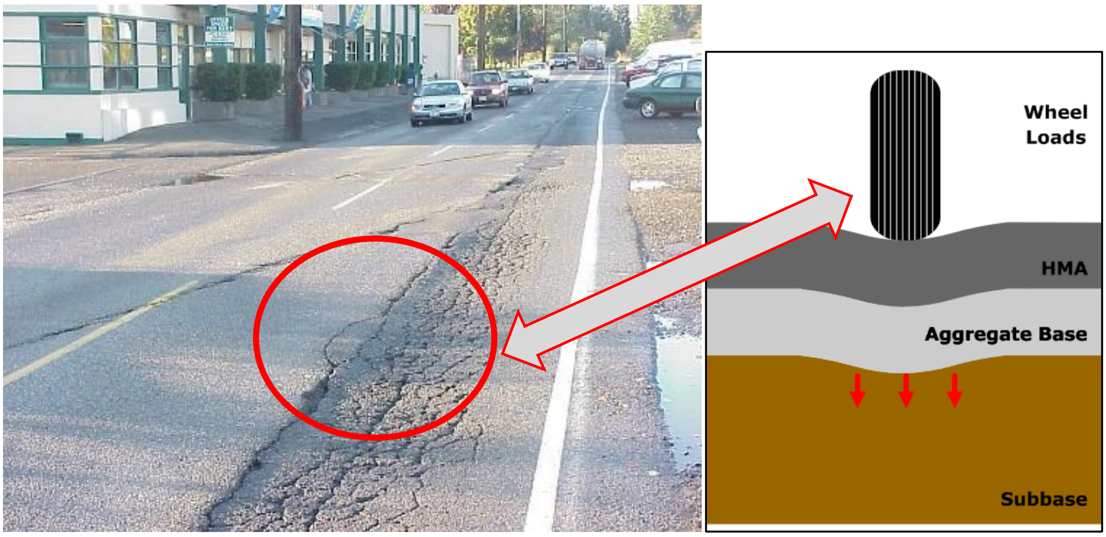


Figure 2.5. Outside Wheel Path Rutting as a Result of Subgrade Rutting (Onyango, 2009)

Densification occurs when there is insufficient compaction during construction and the pavement continues to compact under traffic loading as shown in figure 2.6. Rutting is confined to the HMA pavement that continues to compact under the traffic loading. This usually happens shortly after construction and will eventually subside. Ruts filled with water can cause vehicle hydroplaning, can be hazardous because ruts tend to pull a vehicle towards the rut path as it is steered across the rut **(Al Adili et al., n.d.).**

Densification caused by insufficient compaction of HMA layers during construction. If it is not compacted enough initially, HMA pavement may continue to densify under traffic loads.

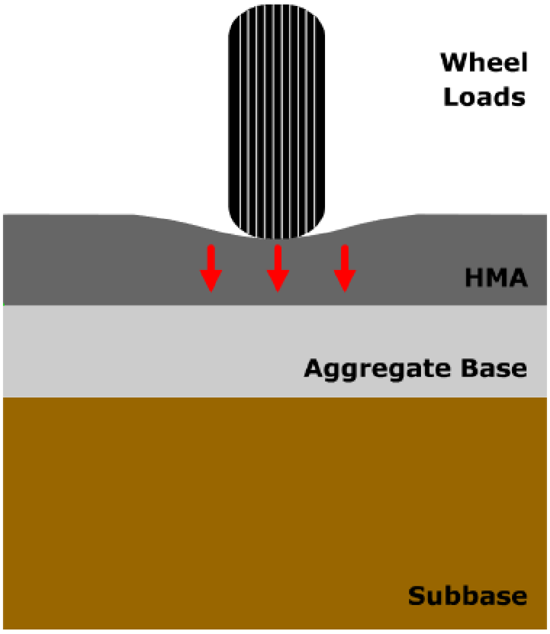


Figure 2.6. Densification Asphalt (Ogundipe, 2016).

2.4. The Problems Related to Rutting in Road Pavement

The two main concerns arising from rutting are the safety issue and the reduction in the life of the road. There are several safety considerations arising from rutting: steering can be affected by deep ruts, and rainwater pooling in them increases spray and visibility as well as the potential for aquaplaning. Additionally, drivers may maneuver to avoid ruts, leading to discomfort and even possible hazards **(Chan et al., 2010; Start et al., 1998; Zhou et al., 2019).**

A reduction in road life arises when the rutting produces surface cracking, allowing water ingress. In addition, the reduction in the thickness of the pavement weakens the pavement, increasing maintenance requirements and impacting the service life of the road **(Adlinge & Gupta, 2013).**

There are three primary causes of rutting in flexible pavements: asphalt layer problems, structural layer problems and weak subgrade problems.

2.4.1. Asphalt Layer Problems

Unsuitable mix-design or inadequate compaction of the asphalt layers can result in unacceptable surface rutting, whereas correct design mix should ensure traffic can be supported for the full design life. The asphalt layers must be sufficiently stiff as to prevent deformation and outward flow under the high tire loading, whilst remaining flexible enough to prevent fatigue cracking. The asphalt mix-design must allow for the expected traffic loads, volume and climatic conditions. The two mix-design components affecting stiffness are the aggregate (particle size and shape, and grading proportions) and the binder (the grade and composition of the bitumen used to bind the aggregate, which must be stiff enough to avoid rutting) **(D'Angelo & Anderson, 2003).**

Also the asphalt mix composition is important–aggregate, binder and voids content should be in allowable ranges for a given mix type. Poor compaction means the asphalt layers can compress under the action of traffic, causing surface rutting although this is rarely an issue using modern materials, plant and methods. However, problems can occur if the asphalt is allowed to cool below optimum levels before compaction is complete, for example in remote areas due to long haulage times **(Kim et al., 2017).**

2.4.2. Structural Layer Problems

The structural layers of the pavement are the subbase and base layers. They perform the essential function of distributing traffic loading onto the pavement foundation. The thickness of these layers determines their structural strength. If the structural layers are too thin (less than 3.15 in **(Jasim, 2015)**), the load on the subgrade may be excessive, resulting in subgrade failure and large pavement deformations, which show up as rutting at the surface. In some cases, particle movements within the unbound structural layers can occur under repeated traffic loading. The lateral movements away from the wheel path result in thinning of the base layer accompanied by rutting at the surface as shown in figure 2.7.

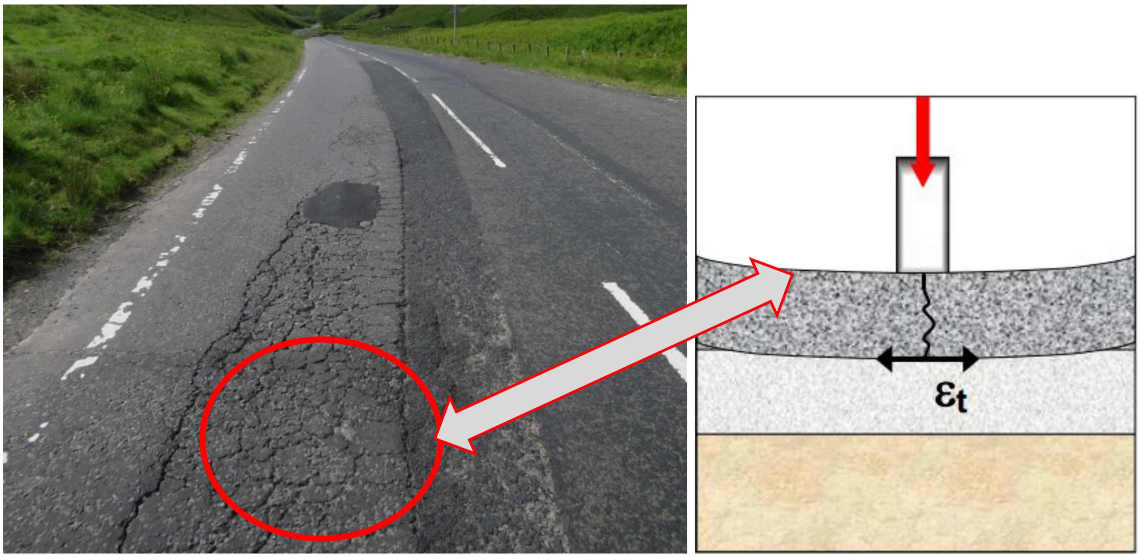


Figure 2.7. Asphalt Fatigue Due to Subgrade Failure (Sabouri et al., 2015)

2.4.3. Weak Subgrade Layer Problems

The pavement design is highly dependent upon the strength of the subgrade. If the subgrade is weaker than assumed in the design, the pavement structural strength is compromised, and rutting can result. The most likely cause of this is a rise in moisture content through a cracked pavement allowing surface ingress of rainwater through it or poor drainage – perhaps due to failed or inadequate side drains. Both issues can be solved with a maintenance regime, timely intervention and resurfacing if required **(Fifer Bizjak et al., 2014).**

Another reason for weak subgrade layer problems might be that the actual in-service strength of the subgrade is lower than assumed for the design. The most likely cause of this is if the subgrade was disturbed during construction: if the clay subgrade is rutted by construction traffic, remolding occurs that leads to a reduction in subgrade strength **(Borden, 2010).** Low subgrade strength might also have been due to an atypical subgrade condition at the time of the investigation due to a prolonged dry spell, for example. A final, possible reason for this would be inadequate site investigation prior to construction. The testing or interpretation of the results may be at fault but it is more likely that the amount of testing was insufficient to identify variability in the subgrade over the entire site **(Sowers & Royster, 1978).**

2.5. Factors Affecting Rutting

Permanent deformation or rutting is categorized as a longitudinal depression which is formed along the wheel paths. It happened due to the accumulation of minor deformations that caused by high temperature and repetitive heavy loads. Factors that contribute to deformations may be caused by too much continuous stress by tire being applied to the subgrade or by an unstable asphalt mixture where shear strength of the mixture is too low. In addition, rutting also considered as a structural problem **(Mashaan & Karim, 2013).**

It is generally the result happened because of wrong calculation during the pavement design or of properties in the subgrade that has been weakened due to the moisture intrusion **(McGennis et al., 1995).** In the other research study, the presence of rutting is due to the accumulated deformation happened in the asphalt surface layers rather than in the subgrade layer. Incorrect procedure in preparing the asphalt mixture also contributes to the permanent deformation **(Liu et al., 2021).**

It is explained that when a layer of asphalt pavement has inadequate shear strength it will cause shear deformation to occur every time a heavy load such as truck passes through the pavement **(Assogba et al., 2021).** A rut will then appear after the asphalt pavement achieves the maximum load where it can resist. This type of road distress can reduce the serviceability of the asphalt pavement and the road user was exposed to a safety hazard **(Newcomb & Hansen, 2006).**

2.6. Mechanisms of Rutting Accumulation

In general, the overall rutting depth is composed of three rutting modes, named loss of materials, densification and lateral plastic flow, respectively **(Ali et al., 2017).** Loss of materials, which usually occurs in low durable mixtures and presents ravelling along wheel paths, occupies a small percentage of the rutting depth as shown in figure 2.8 **(Huber, 1994),** while densification and plastic flow are the two primary deformation modes that control rutting accumulation **(Bonaquist & Mogawer, 1997).**

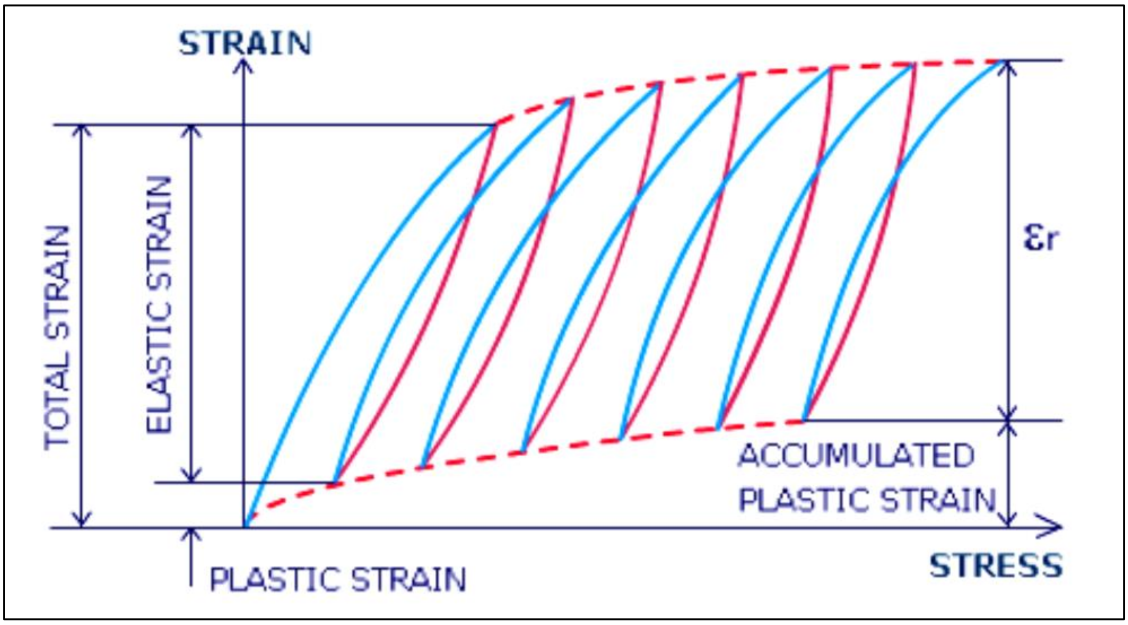


Figure 2.8. Accumulated Plastic Strains in Pavements (Huber, 1994)

As shown in Figure 2.9. usually three stages: decelerating, stationary and accelerating, of permanent strain vs loading cycle relationship were observed **(Witczak, 2002)**. The same phenomenon was also found in Hamburg wheel tracking test and field accelerated loading test **(Chaturabong & Bahia, 2017).**

In the decelerating stage, permanent strain accumulated rapidly but with a decreasing strain rate, leading to densification related rutting and strong aggregate skeleton. In the stationary stage, permanent strain accumulated with an approximately constant rate, and the skeleton became to deform with a plastic lateral flow of asphalt mixture, which could be characterized by a combination of densification and shear deformation. In the accelerating stage, aggregates accelerated to move to the side upheavals, indicating a shear failure of asphalt mixture structure.

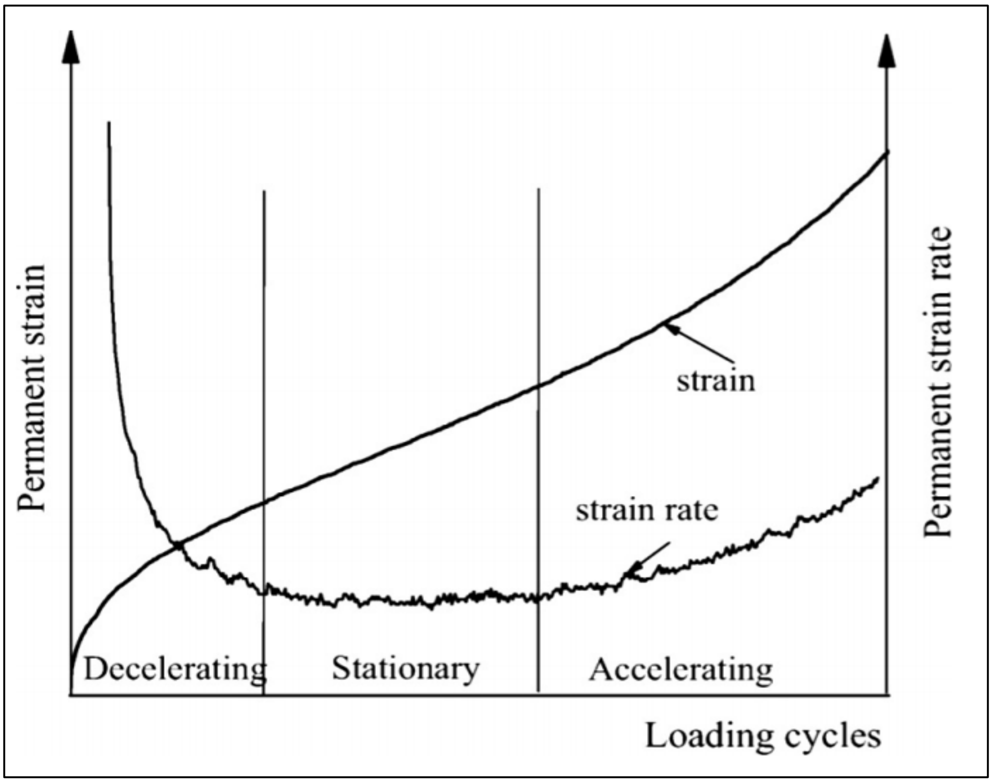


Figure 2.9. Permanent Strain vs Loading Cycle Relationship (Witczak, 2002).

To analysis the shear deformation principle, a theoretical analysis by **(Q. Li et al., 2015)** indicated that the maximum shear stress occurred at different locations/depths of asphalt layers with different layer thicknesses, as shown in Figure 2.10. The diversity of maximum shear stress led to some controversies on the individual layer contribution to the rutting depth. For asphalt pavement with two asphalt layers, **(Q. Li et al., 2015)** argued that more permanent deformation occurred in the bottom asphalt layer, while **(Hong & Chen, 2016)** indicated that the top layer contributed more to the rutting of two-layered asphalt pavement by using a ground-penetrating radar technology. For three layered asphalt layers, Tian et al. found that the deformation of the top asphalt layer occupied half of the observed rutting depth by using a laser profile scanning system.

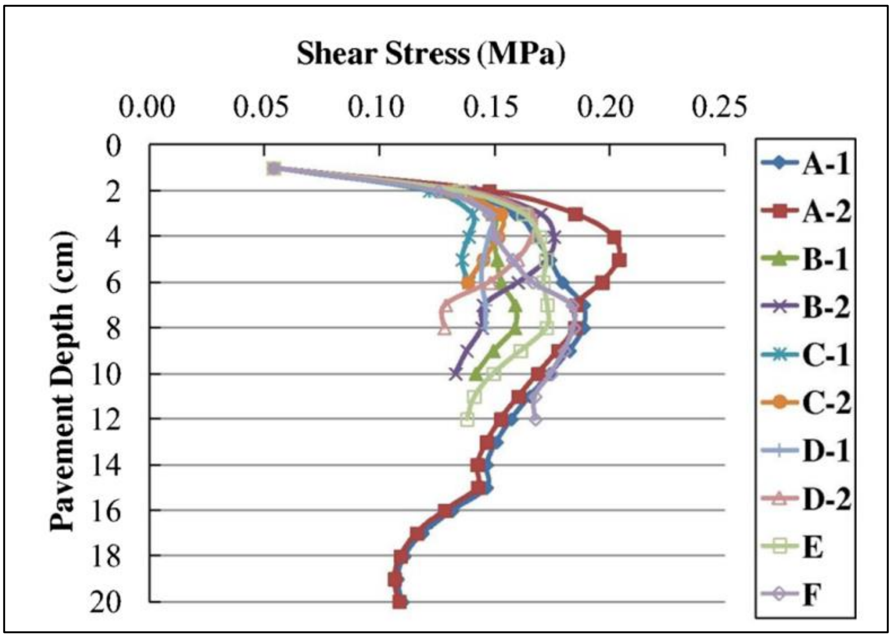


Figure 2.10. Distributions of the Shear Stress in Asphalt Layers Under the Outer Edge of Tire (Q. Li et al., 2015).

In contrast, by field investigations **(Wang et al., 2009; Xu & Huang, 2012)** reported that the middle asphalt layer produced the most permanent deformation, followed by the bottom and top asphalt layers, respectively. The thickness change of individual asphalt layer after rutting occurrence by Xu et al. shown in Figure 2.11.

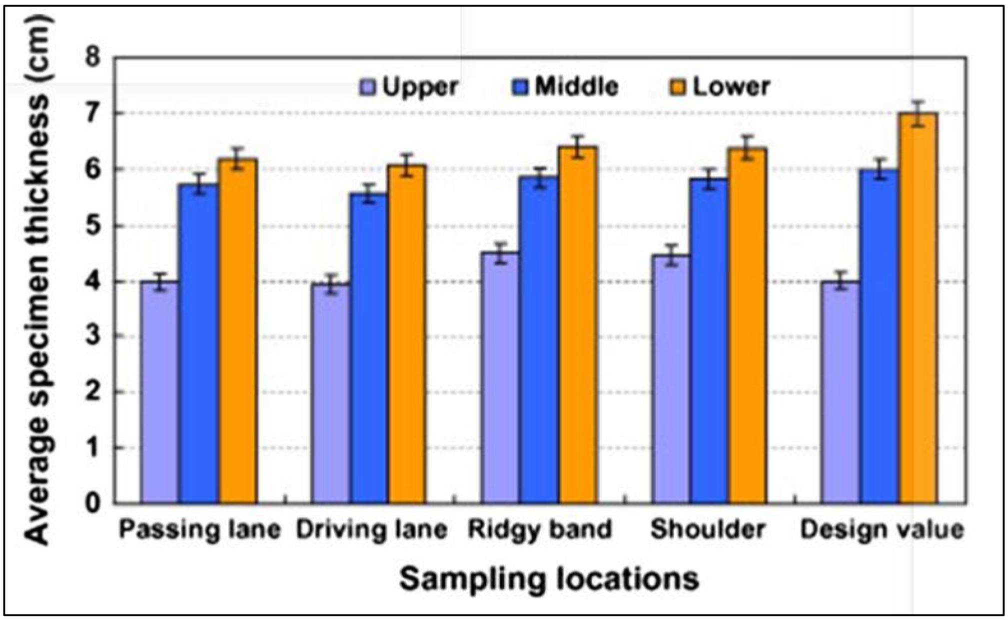


Figure 2.11. Thickness Change of Individual Asphalt Layer (Xu & Huang, 2012).

2.7. Solutions for Improving Rutting Resistance of Asphalt Pavement

Due to the high proportion of shear related rutting, most existing studies on improving the rutting resistance of asphalt pavement focused on increasing the shear strength of asphalt mixture, especially at high temperatures. The Mohr-Coulomb theory states that the shear strength (τ_f) is dependent on the normal stress (σ),internal friction angle (φ), and cohesion (C) in Eq. (2.1):

$$\tau_f = C + \sigma \tan \varphi \qquad (2.1)$$

In order to improve the shear strength of asphalt mixture, the efforts should be devoted to increase the cohesion of binder and the internal friction angle of aggregate. Apart from the cohesion properties of asphalt binders, the asphalt mixture with higher binder-to-aggregate adhesion, which was relevant to aggregate surface compositions, generally presented higher rutting resistance **(Singh et al., 2014, 2016).**

Chapter Three

Experimental Work

CHAPTER THREE

EXPERIMENTAL WORK

3.1. Introduction

This chapter deals with the laboratory work as well as office work, the selected materials are used widely in paving roads in Iraq. The asphalt cement binder from Al-Daurah refinery was used with two types of additives (HDPE, CR) as modifies to use in hot mix asphalt (HMA), and Full details of samples preparation, apparatus used, and testing procedure to perform the samples tests under moving load (wheel truck test) using roller compacter Machen to prepare the related samples and then the performance in terms of rutting failure using indirect tensile test. SPSS software program used too, in order to calculate vertical compressive strains (rutting) on the top of subgrade, generated from heavy vehicles especially trucks axial loads, which have significant impact of these parameters examined on different width of base course, however, the experimental work procedure has been shown in Figure 3.1.

3.2. Materials

Most of the materials that are supplied to this study are commonly utilized in most of Iraqi regions for purposes of paving. One type of aggregates and asphalt was utilized with two additives types. The aggregates and asphalt characteristics are based on the use of routine tests and the collected upshots are evaluated to the specification’s requirements.

3.2.1. Asphalt-Cement

The asphalt or (asphalt cement) utilized has a degree of penetration (40-50), usually from southwest Baghdad (Dura refinery). Tests are carried out on this type of asphalt cement and special knowledge compared in accordance to the State Corporation's specifications for Roads and Bridges (SCRB, 2003). The asphalt cement physical features are demonstrated in Table (3.1), which are conducted at the Civil Engineering Transport Laboratory at the Babylon and AL-Mustaqbal University, as demonstrated in Plate (3.1).

* Conducted at the Civil Engineering Transport Laboratory at the AL-Mustaqbal University

Plate 3.1: Mix Asphalt-Cement that is Used in the Current Study.

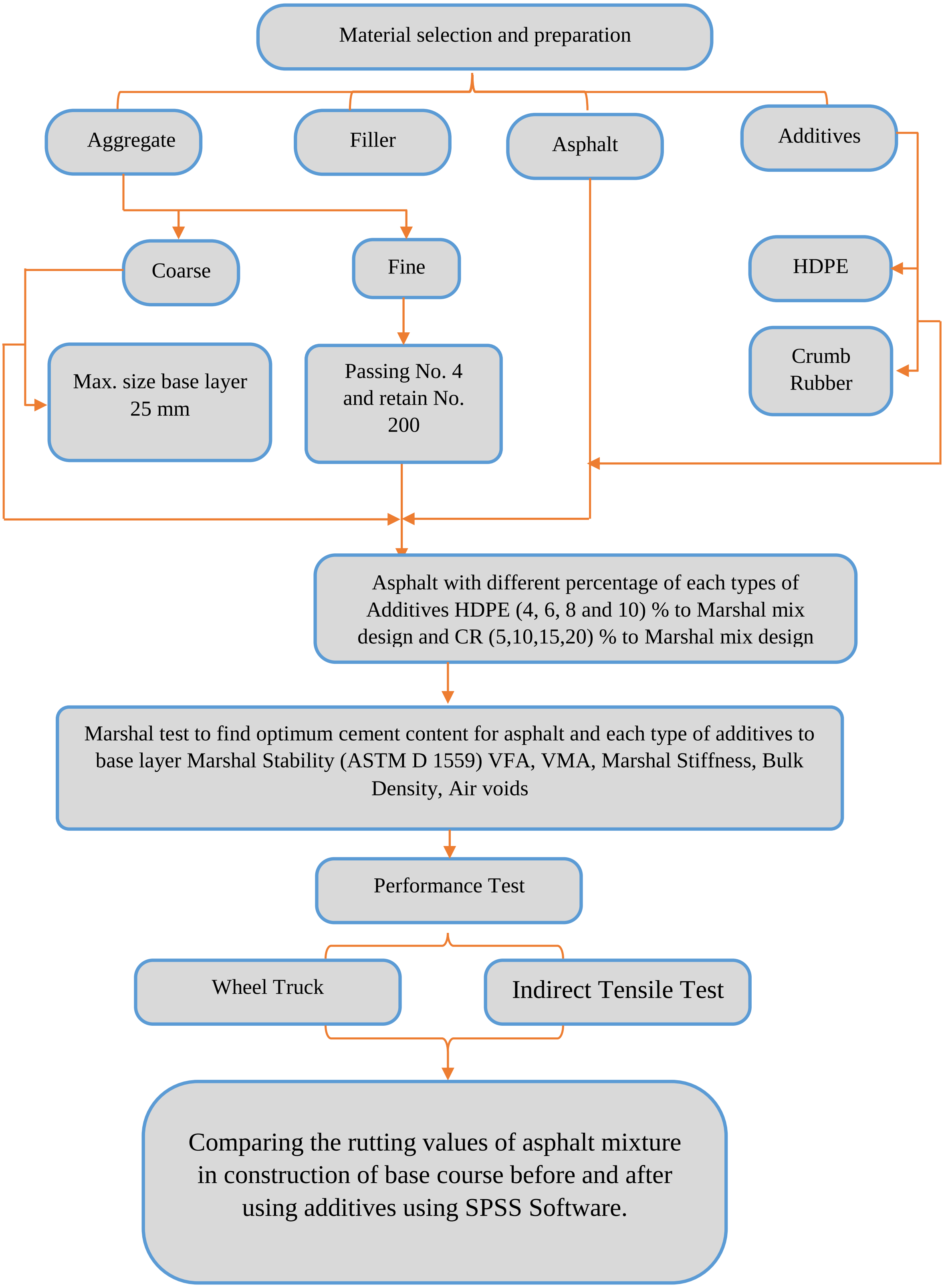


Figure 3.1. Experimental Work

Plate 3.2: Asphalt Cement Tests Implemented Through Current Study

*** Conducted at the Civil Engineering Transport Laboratory at the AL-Mustaqbal University**

Table 3.1: The Physical Properties and Tests of Asphalt Cement, According to ASTM Requirement with Iraqi Specifications (SCRB, R9, 2003).

Test	Unit	Specification	Value of test	SCRB 2003 Specification
Penetration (25 ºC- 100g-5sec)	1/10 mm	ASTM D5 (ASTM, 2013)	49	(40-50)
Ductility (25 ºC, 5cm/min)	Cm	(ASTM D113)	120	> 100

Flash Point (Cleave Land Open Cup)	ºC	(ASTM D92)	240	> 232
Softening Point	ºC	(ASTM D36)	54	(52-60)
Solubility in Trichloroethylene	%	(ASTM D2042)	99.9	> 99
Kinematics Viscosity at 135ºC	CST	(ASTM D2170)	480	>400
Specific Gravity at 25 ºC	…….	(ASTM D70)	1.02	(1.01-1.05)
After Thin-Film Oven Test				
Penetration of Residue (25 ºC-100g - 5sec)	%	(ASTM D1754)	56	>55
Ductility of Residue (25 ºC - 5 cm/min)	Cm	(ASTM D1754)	32	>25
Loss in Weight (163ºC-50gm-5hr.)	%	(ASTM D1754)	0.70	< 0.75

3.2.2. Coarse Aggregate

The coarse aggregate is brought from Al-Najaf province. It should be hard, strong, durable pieces and free of coherent coatings. The aggregates of different size were mixed together for obtaining the desired gradation defined by National Asphalt Pavement Association (NAPA**)**. The gradation of coarse aggregate ranges between passing 3/4 in (19.0 mm) and retains on No.4 sieve (4.75 mm), the physical compositions of the coarse aggregate are shown in Table (3.2).

3.2.3. Fine Aggregate

There are two types of fine aggregate, which are crusher sand whose rate is 75 % and river sand whose rate is 25 % by weight of fine aggregate. The aggregates of different size were mixed together for obtaining the desired gradation defined by (NAPA**)**. The gradation of fine aggregates ranges between passing No.4 sieve (4.75mm) and retains on No.200 sieve (0.075mm). It consists of tough grains, free amount of clay and loam or other deleterious substance. The physical composition of the fine aggregate is shown in Table (3.2), and Plat 3.3 ,3.4 Show the aggregates that used in the current study.

Plate 3.3: Aggregates that is Used in the Current Study.

Plate 3.4: Aggregate Intake Location.

Table 3.2: Physical Properties of the Aggregate.

Property of Aggregate	ASTM Test No.	Coarse Aggregate	Fine aggregate		SCRB
			crushed	Natural	
Bulk specific gravity	C-127 (ASTM, 2015c)	2.52	2.41	2.55	-------
Apparent specific gravity	C-127	2.6	2.51	2.76	-------
Water absorption%	C-127	1.26	1.63	1.75	-------
Percent wear by loss Angeles Abrasion%	C-131 (ASTM, 2014b)	27.86	-------	-------	30% max
Angularity	D-5821	92%	-------	-------	90% min

A) Los Angeles Machine **B) Sand Equivalent Device**

C) Drying of Sand. **D) Saturated Surface Dry.** **E) Specimen Weight**

*** Conducted at the Civil Engineering Transport Laboratory at the AL-Mustaqbal University**

Plate 3.5: Aggregate Tests Implemented Through Current Study.

Table 3.3: The limit Specification for Gradation of Aggregate.

Sieve Size	Sieve Opening (mm)	Specification limit [S.C.R.B]	Gradation
1" 1/2	37.5	100	100
1"	25	90-100	95
3/4"	19	76-90	83
1/2"	12.5	56-80	68
3/8"	9.5	48-74	61
No.4	4.75	29-59	44
No.8	2.36	19-45	32
No.50	0.3	5-17	11
No.200	0.075	2-8	5
Asphalt Cement (% by weight of total mix)		3-5.5	---

3.2.4. Mineral-Filler

In this study, Portland Cement (ordinary type) (OPC) is the only mineral filler type that is utilized. The physical characteristics of (OPC) are demonstrated in Table (3.3)

Table 3.3: Physical Characteristics of the Utilized Ordinary Portland Utilized Cement.

Property	Cement Filler
Specific Gravity (ASTM C128)	3.15
% Passing Sieve No. 200	97
Fineness (Blaine in m^2/kg) Min 230 m^2/kg according SCRB	340

* Conducted at the Civil Engineering Transport Laboratory at the AL-Mustaqbal University

3.2.5. Additives

The modified binder is manufactured in the blending of lab with the identified time for every content of admixture. Two kinds of additive are selected as Crumb Rubber (CR) and High-Density Poly-Ethylene (HDPE). Different additive contents (by weight) are investigated, for (CR) are (5, 10,15 and 20) % by weight of Asphalt cement with the High-Density Poly-Ethylene (HDPE) to be (4, 6, 8 and 10) % by total aggregate weight. These contents, of admixture are nominated depending on the reviewing of the literature in order to reach a significant increase.

3.2.5.1. Crumb Rubber (CR)

The rubber fracture material is originated from the factory of Najaf tires and can be defined as a granular shape black material with specific gravity (1.13), as demonstrated in Plate (3.6).

It can be utilized as asphalt modified rubber in two ways:

- Wet method - is made by blending the asphalt cement with the crumb rubber rate before it is incorporated into the asphalt concrete mixture.
- Dry method - mix the aggregates with the crumb rubber before loading the mixture with the asphalt machine.

In this study, the wet method is utilized by using blending machine with a speed of blending of 2620 rpm as demonstrated in Plate (3.7). The blending temperature in this work is in a range of (190-200) ^{0}C for 60-minutes blending time. The Characteristic of CR according to (SCTI, 2009) as demonstrated in Table (3.4).

Plate 3.6: Crumb Rubber.

Plate 3.7: The Blending Machine.

Table 3.4: Characteristic of CR (SCTI, 2009).

Feature	Unit	Requirement
Specific Gravity	---	1.13
Density	gm/m^3	1.320
Young Modulus	Mpa	2600-2900
Tensile Strength	Mpa	40-70
Elongation at Break	%	25-50
Melting Point	^{o}C	200

3.2.5.2. High-Density Poly-Ethylene (HDPE)

Polyethylene is manufactured in Iran, which is a white granule as shown in Plate (3.8) and used to produce plastic belts in the tires factory and another private factory in Iraq. High-Density Poly-Ethylene (HDPE) is a plastomers thermoplastic polymer material composed of carbon and hydrogen atoms joined together forming high molecular weight products is converted into ethylene, then, with the application of heat and pressure, converted into polyethylene. The polymer chain may be 500,000 to 1,000,000 carbon units long. Short and /or long side chain molecules existed with the polymer's long main chain molecules. The longer the main chain, the greater the number of atoms, and consequently, the greater the molecular weight. The molecular weight, the molecular weight distribution and the amount of branching determine many of the mechanical and chemical properties of the end product. The physical and mechanical properties of HDPE are presented in Table (3.6)

Table 3.5: Physical Characteristic of High-Density Poly-Ethylene (HDPE).

Physical Properties	Results
Tensile Strength	0.20 - 0.40 N/mm²
Notched Impact Strength	no break Kj/m²
Thermal Coefficient of expansion	100 - 220 x 10-6
Max Cont. Use Temp	65 Oc
Density	0.944 - 0.965 g/cm3

Table 3.6: Chemicals Characteristic of High-Density Poly-Ethylene (HDPE).

Resistance To Chemicals	Results
Dilute Acid	very good
Dilute Alkalis	very good
Oils and Greases	variable moderate
Aliphatic Hydrocarbons	Poor
Aromatic Hydrocarbons	Poor
Halogenated Hydrocarbons	Poor
Alcohols	very good

Plate 3.8: HDPE Used in the Study

3.3. The Experimental Tests

The experimental tests are divided into several phases; the preparation of the experimental test is shown below:

- Selecting one aggregate gradation and finding the optimum weight of Marshall specimen.
- Selecting of optimum asphalt content (OAC).
- Preparing of asphalt concrete mixtures, asphalt content (OAC±0.5%) .
- Preparing of Marshall specimens to abrasion loss test unaging and abrasion loss test aging, the temperature is fixed 25 °C for test condition **(ASTM D7064-04).**
- Group of uncompact bituminous mixes is evaluated using basket drainage test **(ASTM D6390-90, AASHTO T305, 2001)**

- Preparing of groups of Marshall specimens to study the effect of the strength, tested by indirect tensile test.
- Using SPSS approach to make model between the experimental works for simulation system phenomena.

Plate 3.9: Row Materials that is Used in the Current Study.

3.4. Mix Design and Evaluation Method

In the current study, the mixture is prepared in the following stages:

3.4.1. Preparation of Asphalt Concrete Mixture

The aggregate is first sieved, washed, and dried to a constant weight at 110 ºC. Coarse and fine aggregates are combining with mineral filler to meet the gradation; the combined aggregate is heated to a temperature of 160 ºC before mixing with asphalt cement. The asphalt cement is heated to a temperature of 150 ºC to produce a kinematic viscosity of (170±20) centistokes. Then, asphalt cement is added to the heated aggregate to achieve the desired amount and mixed thoroughly by hand using a spatula for two minutes until all aggregate particles are coated with asphalt cement.

Table 3.7: Mixtures Properties at Optimum Asphalt Content

Marshall Property	Base Layer	S.C.R.B Specification limits
Marshall Stability, KN	8.9	**5 min**
Marshall Flow, mm	3.5	**2-4**
Percent air voids	3.16	**3-6**
Percent VMA	13.53	**12 min**
Bulk density (mm)	2.31	**------**
Optimum asphalt content (%)	4.5	**4-6**

3.4.2. Preparation of Marshall Mold

According to **(ASTM D6927-06),** this method includes preparation of the cylindrical specimen of 4 inches (100 mm) in diameter and 2.5 ±0.05 in (63.5 mm) height. The Marshall mold, spatula and compaction hammer are prepared. The mold is not heated by a hot plate and still in room temperature, after that, mold is greased.

A piece of a nonabsorbent paper, cut to size is placed in the bottom of the mold before the mixture is introduced. The asphalt mixture is placed in this mold and spades vigorously with a heated spatula to level the surface around the perimeter and interior to remove air void inside it. Another piece of nonabsorbent paper cut to size is placed on the top of the mix.

The temperature of mixture immediately prior to compaction temperature is 150ºC. The mold assembly is placed on the compaction pedestal and 50 blows on the top and the bottom of specimen are applied with specified compaction hammer of 4.535 kg which sliding weight and a free fall in 18 in (457.2 mm). The specimen in mold are left to cool at the room temperature for 24 hours, then it is extracted from the mold using mechanical jack.

3.5. Optimum Asphalt Cement

Once the design gradation is determined according to NAPA, it is then used to prepare several specimens at various asphalt contents in order to determine the optimum asphalt content as shown in Figure 3. The optimum binder content for each gradation is found by the using asphalt contents which limits from (4.0 to 6.0) % (OAC±0.5%) by (Satyakumar et al., 2013)**.** The whole testing program is conducted on specimens at the optimum asphalt content whose range is above or below 0.5 %. Six asphalt contents are evaluated as (3, 3.5, 4.0, 4.5, 5.0 and 5.5) %. Their selection is based on engineering best practice after consulting with public and private sector experts. The specimens are evaluated depending on air void analysis and permeability in the laboratory. The results for each are utilized to determine the OAC.

$$\mathrm{OAC} = \frac{B_1+B_2+B_3}{3} \qquad (3.1)$$

OAC is the optimum asphalt cement content

B_1 is the ratio of asphalt content at maximum bulk Specific gravity

B_2 is the ratio of asphalt content at maximum Stability.

B₃ is the ratio of asphalt content at 4% of air voids in total mixture.

The optimum asphalt content ratio that has been obtained is 4.5% for the base layer.

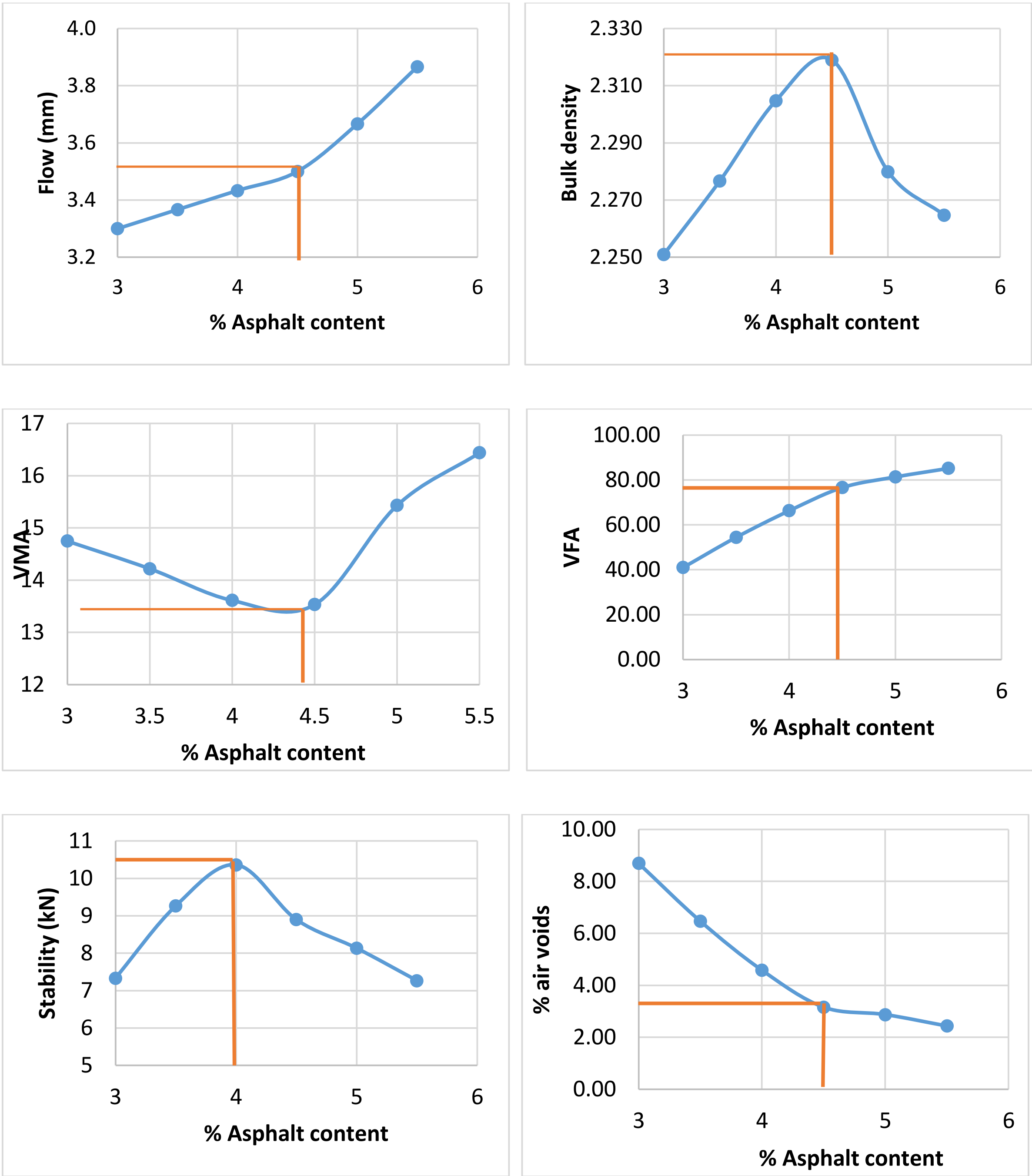


Figure 3.2. The Optimum Asphalt Content for Each Test.

3.6. Marshall Test

The results of standard Marshall test are: stability, flow, Marshall stiffness, theoretical maximum density (Gmm) and bulk specific gravity (Gmb), voids in total mix (AV), laboratory permeability, indirect tensile test and loss abrasion test. Since all Marshall parameters are designed for continuous grading asphalt mixture, it is necessary to determine a specification for asphalt mixture, Table (3.9) the proposed specification is prepared by (Nashir et al., 2014).

3.6.1. Marshall Test for Modified Asphalt Concrete Mixtures

The first test method for characterizing performance is Marshall test,

the properties of asphalt concrete mixtures for base layer, such as (stability, stiffness, flow, bulk density, VMA, VFA and air void) have been investigated to evaluate their effect on the performance of mixtures as well as to get the best ratio of each additive for asphalt concrete mixtures. The results of HDPE, and CR modified mixtures indicated that the optimum ratio of additive content is (4%, 6%, 8%, 10%) and (5%, 10%, 15%, 20%), respectively for base layer.

3.6.2. Air Void Analysis

This experiment's purpose is to find air voids within a sample of compressed bitumen pavement as a percentage as one of the paving design criteria. After the sample is prepared according to the optimum percentage adopted for the sample, the max theoretical density (Gmm) and the bulk-relative density (Gmb) is evaluated by utilizing the rice method depending on the procedure of (ASTM D2041-2041M) with the relative density.

Equation (3.2) is utilized for calculating the sample maximum theoretical relative density, as demonstrated in Plate (3.11), which shows the device for its calculation.

Equation (3.3) is utilized to measure the specific gravity that takes into account the air spaces and is called the actual gravity of the mixture. It is obtained by evaluating the mixture whole weight as well as its volume which is obtained based on equation (3.4).

The calculated air voids in a compressed sample (AV) relates to the Gmm and Gmb as demonstrated in Eq. (3.5). The standard procedure for testing the air void percentage in compressed paving mixtures of open graded bituminous is utilized to obtain them (ASTM D3203-94).

$$Gmm = \frac{A}{A-(C-B)} \qquad (3.2)$$

Whereas:

Gmm: theoretical max. Relative density, (gm/cm3).

A: air dry sample mass, (gm).

B: wet container mass, (gm).

C: specimen and container mass below water, (gm).

$$Gmb = \frac{Wmix}{Bulk\ volume\ of\ the\ mix} \qquad (3.3)$$

Whereas:

Wmix: Marshall's specimen weight, (gm).

Gmb: bulk-relative-density, (g/cm3).

$$Bulk\ volume\ of\ the\ mix = \frac{\pi d^2}{4} h \qquad (3.4)$$

d: the diameter of Marshall's sample, (mm).

h: Marshall's specimen height, (mm).

$$AV = \frac{Gmm - Gmb}{Gmm} * 100\% \quad (3.5)$$

Whereas:

AV: percentages of air voids inside the compacted specimen, (%).

Plate 3.12: Apparatus to Determine Max Theoretical Relative Density.

3.7. Indirect Tensile Test

The evaluation of the tensile strength for asphaltic concrete mixture used in construction of the pavement becomes increasingly more important. This is partially due to the fact that pavements during the service are exposed to various traffic loading and climatic conditions. These conditions may cause tensile stresses to be developed within the pavement and as a result, two types of cracks may be exhibited which are results from traffic loading called fatigue cracking and the other type of crack results from climatic conditions called thermal or shrinkage cracking.

Plate 3.10: The Indirect Tensile Test by Marshall Device.

The indirect tensile test (ITS) has been used to evaluate the mixture resistance to low temperature cracking. The tensile strength ratio method used to evaluate moisture susceptibility of asphalt mixture. The specimens which is subjected to indirect tensile strength tests in dry condition is ITS_d, the other which is subjected to indirect tensile strength in wet conditioning is ITS_w. The wet conditioning of the compacted asphalt specimens is performed by **(AASHTO T283)** with the use of the minor modifications.

The unconditioned (ITS_d) specimens are kept at a temperature of 25°C for a period of two hours without soaking before test. The specimens of ITS_w are first saturated by submerging into water bath for thawing to a temperature of 60 °C for 24 hours. After two cycles of moisture conditioning, the specimens are removed from the water bath to be ready for testing. The following equation (3.6) are used to compute ITS.

$$I.T.S = \frac{2Pult}{\pi\ t\ D} \tag{3.6}$$

Where:

I.T.S = Indirect tensile strength (Mpa).

Pult = Ultimate applied load at failure (N).

t = Thickness of specimen (mm).

D = Diameter of specimen (mm).

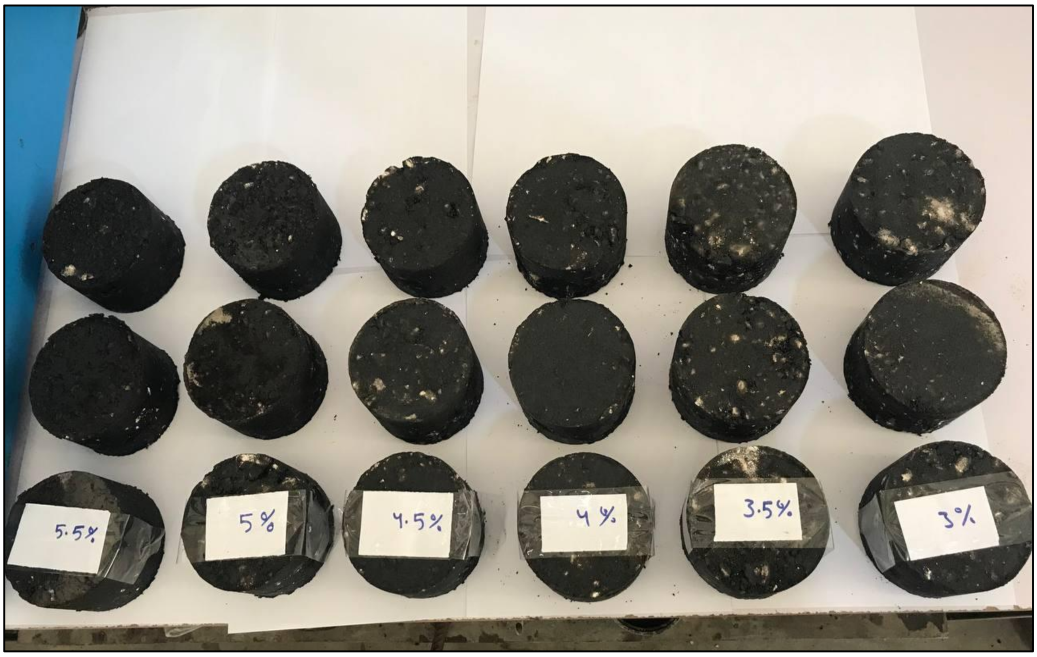
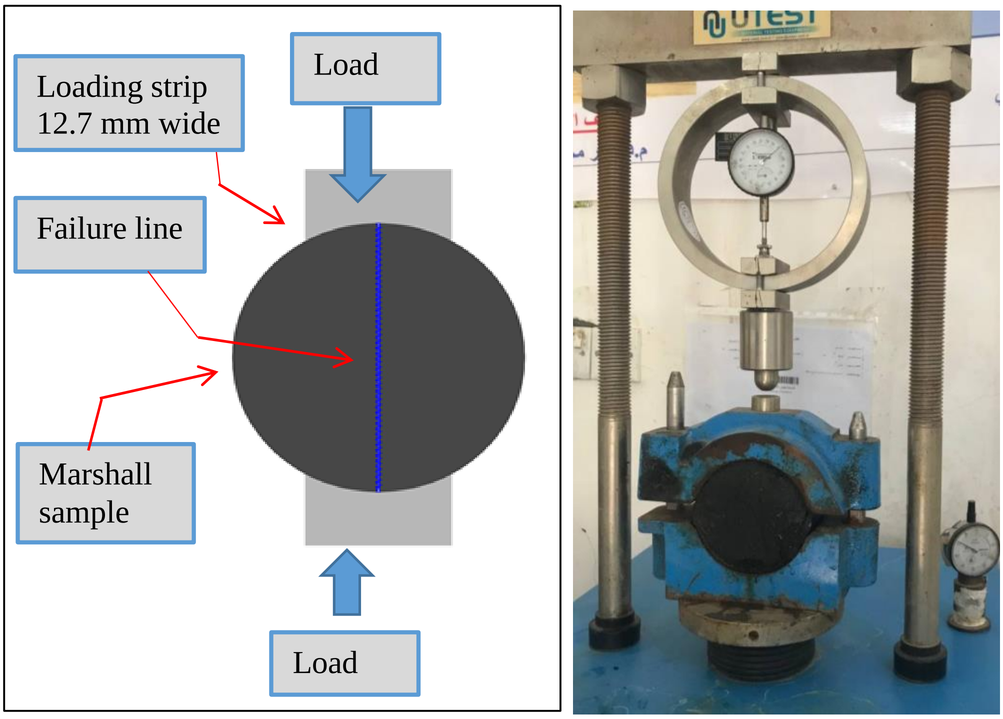


Plate 3.11: Specimens for Indirect Tensile Test.

The indirect tensile strength test has been widely used in HMA mixture design. The splitting strength is determined in this test as an indicator of the tensile strength of the compacted Marshall specimen. The results of ITS_d strength are employed to obtain the comparative relative strength of asphalt mixtures and predict the potential for pavement distress. Since the performance of mixtures depends on tensile strength of bitumen film, the ITS_d strength is also an important characterized test for asphalt mixture. The test is performed by using Marshall stability test equipment at 50 mm/min deformation rate, (25 and 40) °C temperature control system, an air or water bath capable of maintaining the specimens at the specified test temperature within ±1.0 °C in accordance with **(ASTM D6931)** procedure. A cylindrical specimen is exposed to a compressive load in Marshall stability test. It acts along the vertical diameter plane by a curved loading strip. The developed tensile stress, perpendicular to the direction of the applied load, ultimately causes the specimen to fail by splitting along the vertical diameter. The ultimate load at failure is recorded and used to calculate the ITS strength ratio of the specimen.



A-Load configuration and failure for specimen B- ITS tested by Marshall device

Figure 3.3. Details of Indirect Tensile Test.

3.8. Wheel Track Test

These methods of testing are utilized to determine the bituminous materials susceptibility to deform under load in accordance with British specifications **(BS EN 12697-22: 2003).** The wheel track is inspected at Baghdad's National Center for Construction Laboratories and Research. The applicability of tests is either for laboratory manufactured specimens or others that are cut from a pavement; a mold is utilized to keep test specimens whose surface flush with the mold upper edge. By applying a repeated loaded wheel passes at temperature of 50ºC&60ºC the bituminous materials susceptibility to deformation is evaluated by wheel track device. The load applied by the wheel is 700 N with a total travel distance of 23 cm and a 26.5 cycle's Per min. constant loading frequency. The details of wheel track device are demonstrated in Plate (3.13).

The composition of mixture is coarse aggregate, fine aggregates and mineral filler, all of these are combined at mixer machine to ensure the required gradations in accordance with SCRB specifications **(SCRB, R/9 2003);** the combined aggregate heated to a 160 ºC prior blending with asphalt cement.

Then, the mixture is placed in the mixer machine and mixed at speed of 20 rpm for 3 minute for control mixture and 5 minute for modified asphalt mixture, coating of all particles of aggregates with cement asphalt. The machine's mixer characteristics meet the specifications of **(EN 12697-35)**, with the max. 30 litter volume of container, the container speed of (5-35) rpm and 220 ºC as a max temperature.

The mixture is placed in the mold after mixing and compacted utilizing roller compacter. Then, the slab sample is left for one day and removed from mold and placed in the apparatus. In this study, the dimensions of the sample utilized are of (40 cm length× 30 cm width×4 cm height) as demonstrated in Plate (3.13).

Four samples are prepared, one control mix and three mixtures containing (10%, 15%and 20%) of crumb rubber. All samples placed at a temperature of 50ºC in the chamber for 4 hours. The test is run until a deformation of 20 mm is reached where the deformation is measured for each cycle using linear variable displacement transducers (LVDT).

Plate 3.12: The Dimensions of The Sample.

Plate 3.13: The Details of Wheel Track Device.

3.9. SPSS Software

SPSS (Statistical Package for the Social Sciences), also known as IBM SPSS Statistics, is a software package used for the analysis of statistical data **(Muijs, 2022).**

Although the name of SPSS reflects its original use in the field of social sciences, its use has since expanded into other data markets. SPSS is commonly used in healthcare, marketing and educational research.

The types of data analyzed using SPSS is widely varied. Common sources include survey results, organization customer databases, Google Analytics, scientific research results and server log files. SPSS supports both analysis and modification of many kinds of data and almost all formats of structured data. The software supports spreadsheets, plain text files and relational databases such as SQL, SATA and SAS.

SPSS provides data analysis for descriptive and bivariate statistics, numeral outcome predictions and predictions for identifying groups. The software also provides data transformation, graphing and direct marketing features.

The software interface displays open data similarly to a spreadsheet in its main view. With its secondary variable view, the metadata that describes the variables and data entries present in the data file are displayed.

The software package was created in 1968 by SPSS Inc. and was acquired by IBM in 2009. While the software was renamed to IBM SPSS Statistics, it is still commonly referred to as just SPSS.

Chapter Four

Result, Discussion and Analysis

CHAPTER FOUR

RESULTS, DISCUSSION AND ANALYSIS

4.1. Introduction

This chapter shows the tests results and discusses the effect of the modifier on the mechanical properties of asphalt pavement mixtures. It also deals with the analysis and the discussion of the results of the experimental work to develop models for the permeability of the local asphalt pavement. Furthermore, the influence of different variables such as: asphalt content, testing, temperatures and the percentage of the additive in sample have been investigated throughout the experimental work.

4.1.1. Stability

Stability is an important property for the performance of asphalt mixture in the base course design. It shows the ability to resist shoving, rutting and give layer the adequate stiffness under traffic. The stability of modified asphalt mixtures regardless of modifier type and concentration is higher than the control asphalt mixtures. The stability is increased by increasing the density of polymers. The density of polymers has an effective impact on the stability, because the plastomers and elastomer polymers produce mixtures with higher stability and stiffness that dependent on the molecular weight of polymers, it is related to increasing of density. The stability of modified mixtures varies according to the type, physical properties and concentration of modifier, the stability of modified mixtures by the optimum ratio for each type of additive (HDPE, and CR) are increasing, as shown in Figure (4.1) and (4.2). Figure 4.1 shows an increase of the stability along with increasing HDPE content from (Control to 10) % and the best stability obtained when using 8% of HDPE. While using of CR shows an increase and decrease in the stability depending on the CR ratio (5, 10 and 15) % cause an increase in the stability due to reduce the interaction between mixture components when using CR and increasing interaction when applying HDPE. The best results obtained when using 15% is shown in Figure 4.2, while increasing the CR ratio to 20% leads to decrease the stability to be similar to the control mix.

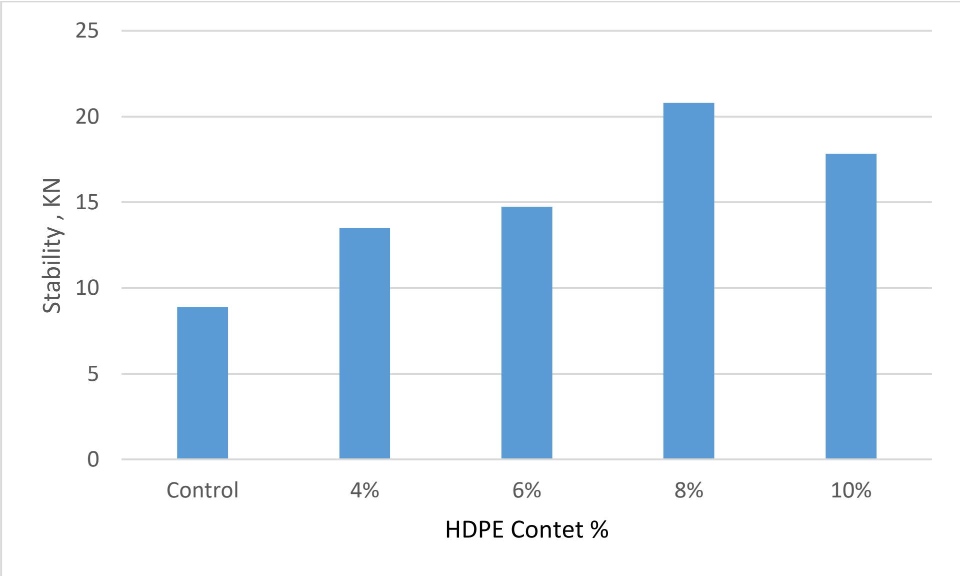


Figure 4.1. Effect of HDPE Content on Stability.

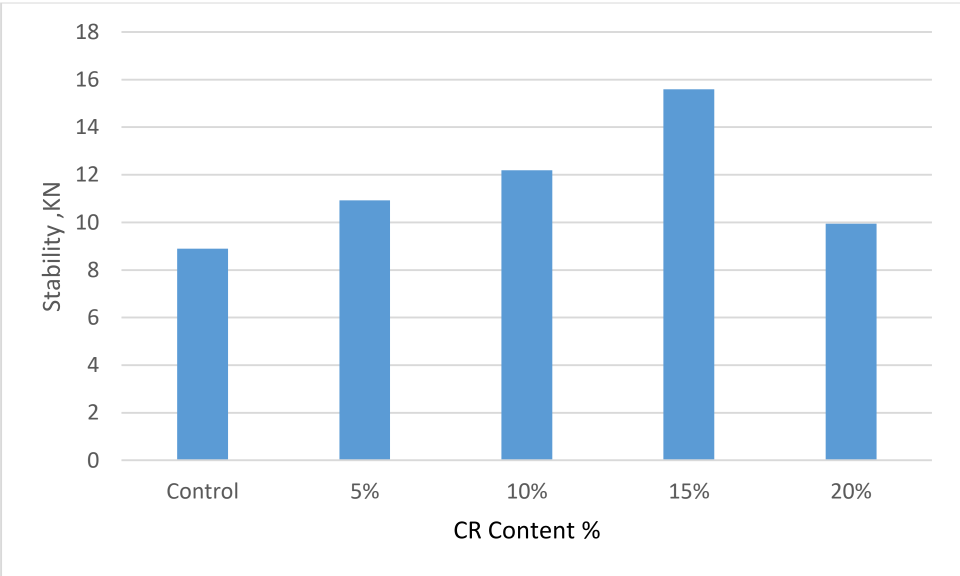


Figure 4.2. Effect of Crumb Rubber Content on Stability.

4.1.2. Stiffness

Marshall Stiffness is defined as the ratio between the Marshall stability and Marshall Flow (It is not required by S.C.R.B specification, 2003) and it has been adopted in this study because stiffness represents the combination of stability and flow in single value. The high Marshall Stiffness means that asphalt mixture has good resistance to plastic flow resulting from traffic loading when this mix is used in pavements. Also, the high value of stability of asphalt mixes does not mean that it has good resistance to plastic flow for high flow values, which have low Marshall stiffness. Marshall stiffness of the modified mixtures by the optimum ratio for each type of additive (HDPE, and CR) are increased as shown in Figures (4.3) and (4.4). The type of additives has a great effect on Marshall stiffness, and the test results are in agreement to use modifiers increasing Marshall stiffness and, hence reducing rutting potential.

Figure 4.3 shows an increase in the stiffness along with increasing HDPE content from (Control to 10) % and the best stiffness obtained when using 8% of HDPE. While using of CR shows an increase and a decrease in the stiffness depending on the CR ratio (5, 10 and 15) % to cause an increase in the stiffness The best results obtained when using 15% is shown in Figure 4.4, while increasing the CR ratio to 20% leads to decrease stiffness to be similar to the control mix. The comparison between Figures 4.3 and 4.4, can be detected where the use of HDPE gives better improvement in the stiffness comparison with the use of CR. due to reduce the interaction between mixture components when using CR and increasing interaction when applying HDPE

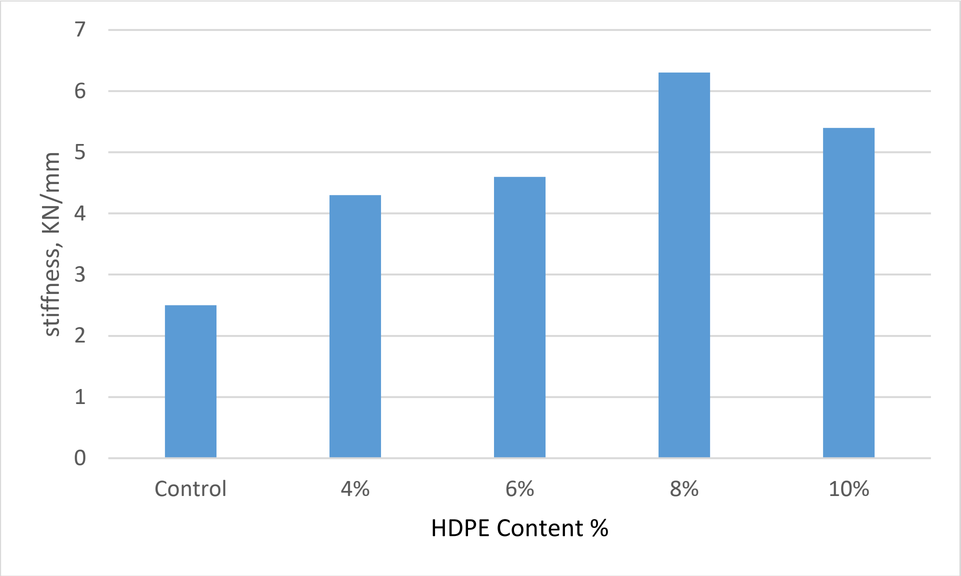


Figure 4.3. Effect of HDPE Content on stiffness Test.

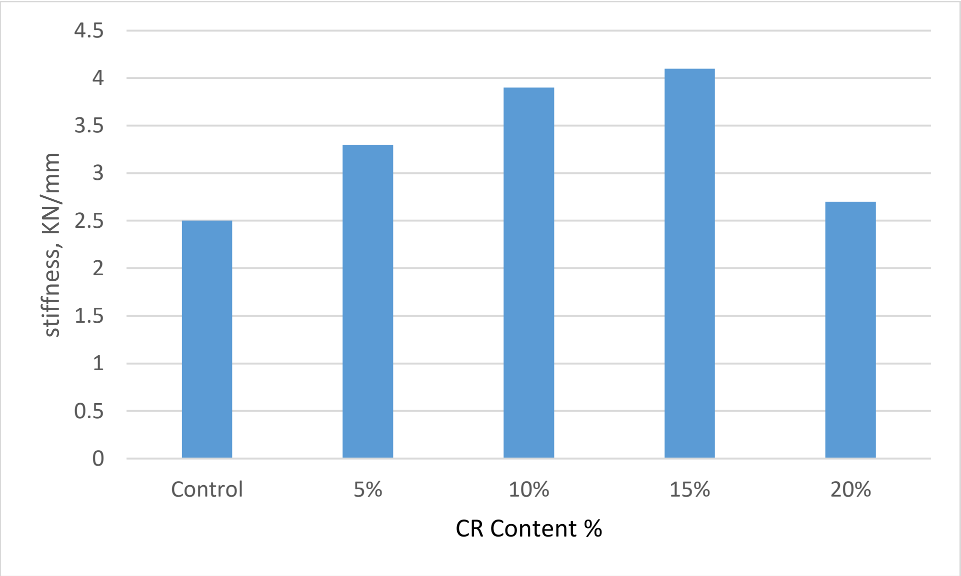


Figure 4.4. Effect of Crumb Rubber Content on stiffness Test.

4.1.3. Air Void

An air void in the mixture is an important parameter because it permits the properties and performance of the mixture to be predicted for the service life of the pavement. Air void proportion around 4% is enough to prevent bleeding or flushing that would reduce the skid resistance of the pavement and increase fatigue resistance susceptibility the air void content of the modified mixture does not differ much from that of the non-modified mixture as shown in Figure (4.5) and (4.6). Although the air void of modified mixtures increases with decreasing stability, the proportion remains within limits (3-5) % to meet the SCRB specifications. Air void in the mixture is an important parameter because it permits the properties and performance of the mixture to be predicted for the service life of the pavement.

Figure 4.5 shows increasing the air void along with the increase of HDPE content from (Control to 10) % where the best air void obtained when using 10% of HDPE. Also, using CR shows an increase in the air void depending on the CR ratio (5, 10 and 15) % causes an increase in the air void. The best results obtained when using 15% are shown in Figure 4.6. The comparison between Figures 4.5 and 4.6 shows that there is no significant difference on air void when using of HDPE or CR in the base layer. Due

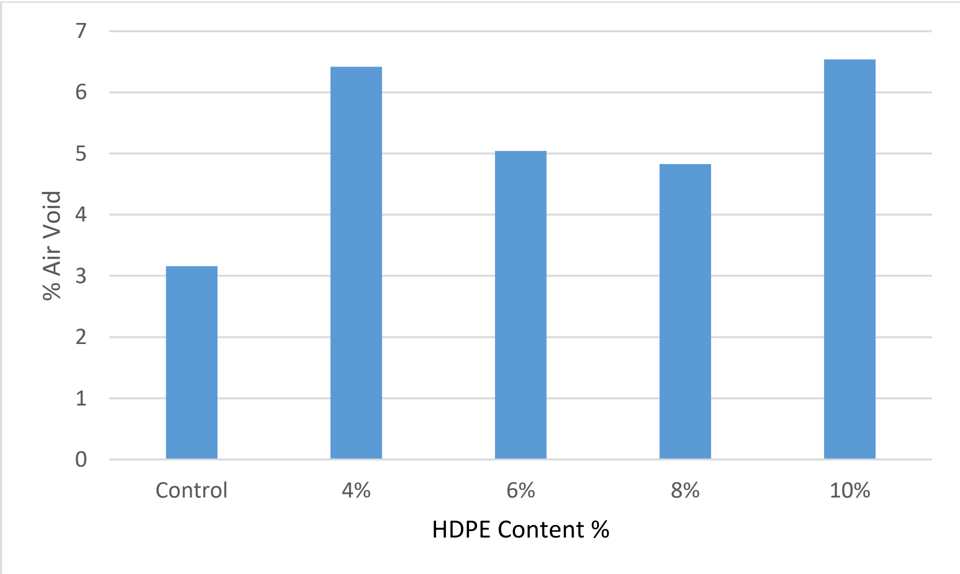


Figure 4.5. Effect of HDPE Content on Air Void Test.

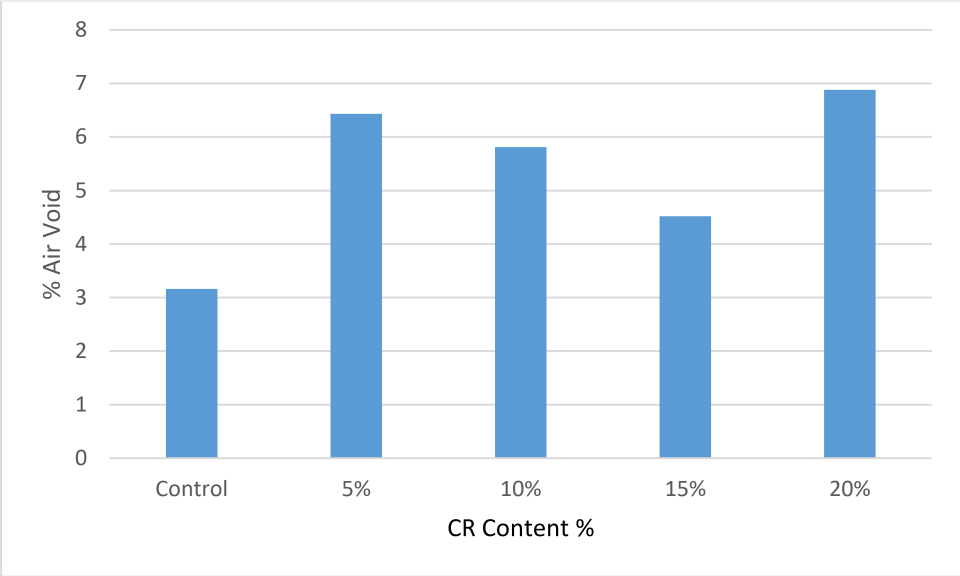


Figure 4.6. Effect of Crumb Rubber Content on Air Void Test.

Figure 4.7 shows an increase in the VFA along with the increase in HDPE content from (control to 10) % and the best VFA obtained when using 10% of HDPE. Also, using of CR shows an increase in the VFA with increasing CR ratio from (control to 20) % causing an increase in the VFA. The best results obtained when using 20% is shown in Figure 4.8. The comparison between Figures 4.7 and 4.8 reveals that using of HDPE gives better improvement in the VFA comparison with the use of CR.

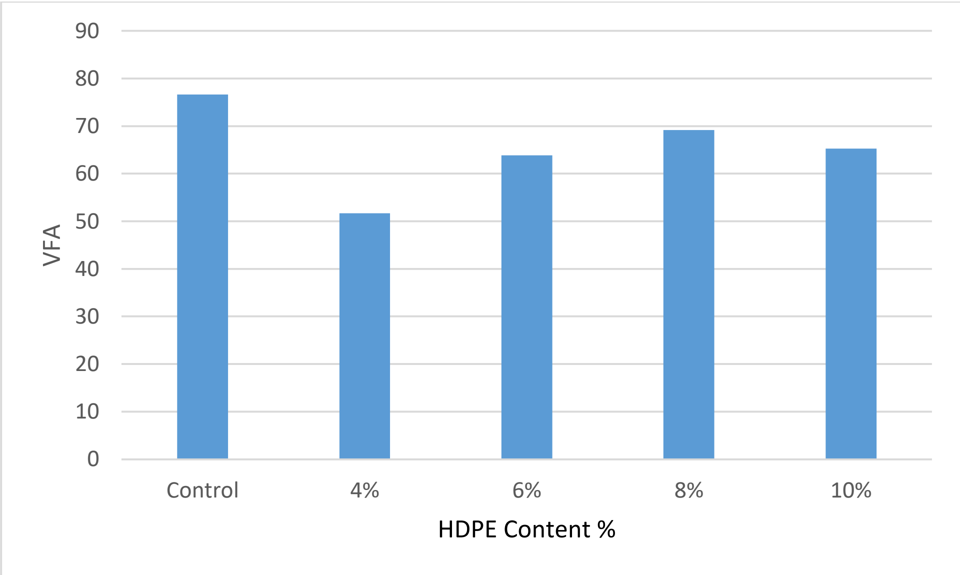


Figure 4.7. Effect of HDPE Content on VFA.

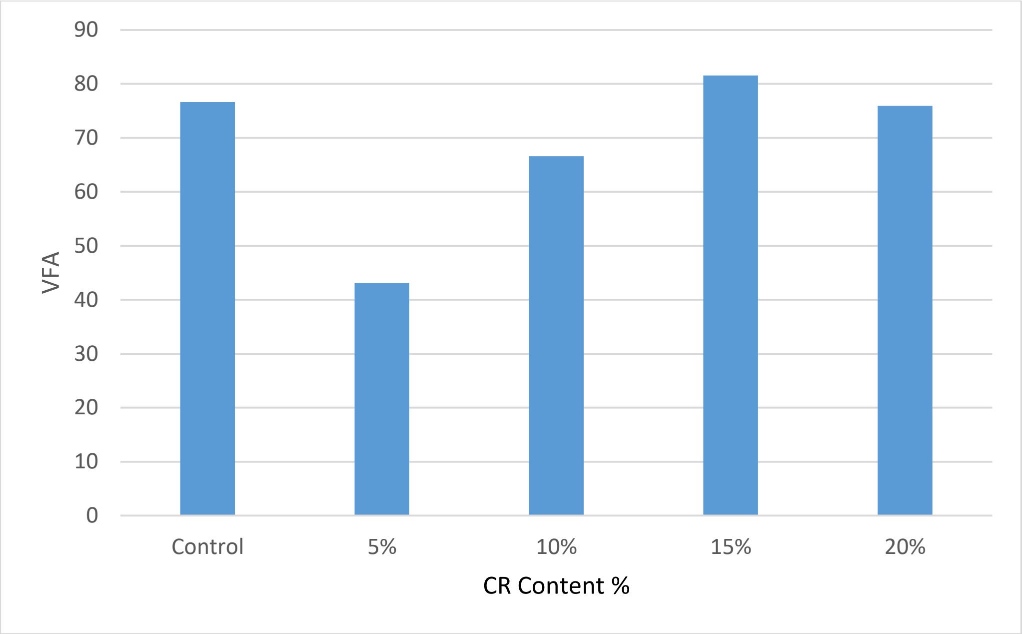


Figure 4.8. Effect of Crumb Rubber Content on VFA.

Figure 4.9 shows increasing the VMA along with increasing HDPE content from (Control to 10) % and the best VMA obtained when using 8% of HDPE. While the use of CR shows an increase of the CR ratio (5, 10 and 20) % causing an increase in the VMA The best results obtained when using 20% is shown in Figure 4.10, while increasing the HDPE ratio to 10% leads to decrease VMA to be similar to the control mix. The comparison between Figures 4.9 and 4.10, shows that using of CR, gives better improvement in the VMA comparison with using HDPE.

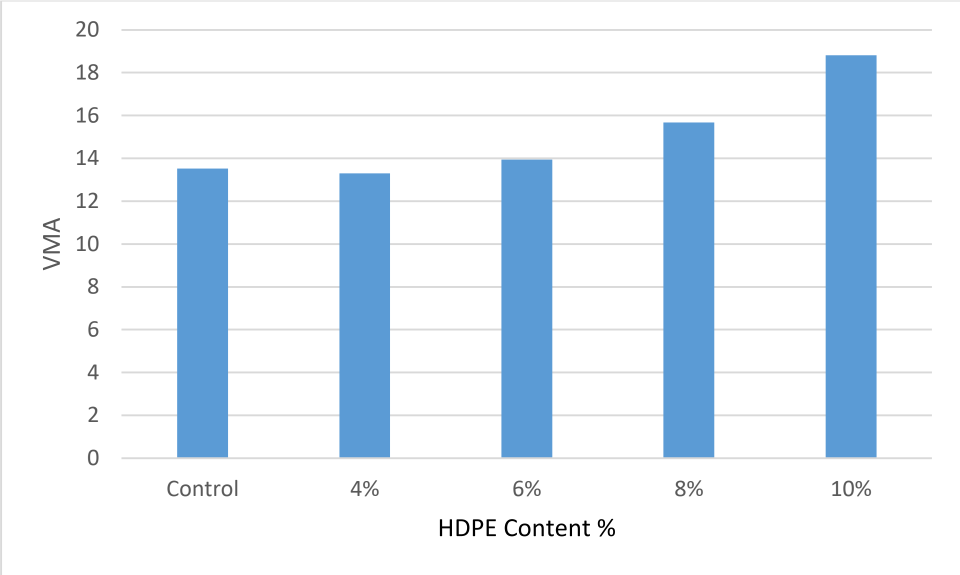


Figure 4.9. Effect of HDPE Content on Air Void VMA.

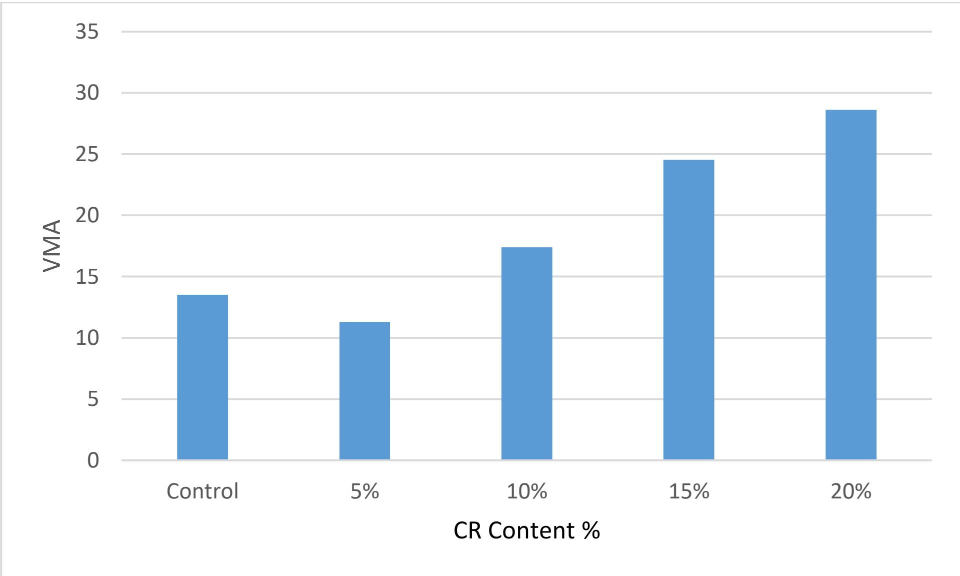


Figure 4.10. Effect of Crumb Rubber Content on VMA.

4.1.4. Marshall flow

The Marshall flow of the modified asphalt concrete mixtures is lower than the control mixture, also Marshall flow decreases with increasing stability for each type from additive as shown in figures (4.11) and (4.12).

Figure 4.11 shows an increase in the flow along with increasing HDPE content from (Control to 10) % and the best flow obtained when using 8 and 10%

of HDPE. While using of CR shows an increase and a decrease in the flow depending on the CR ratio (5, 15 and 20) % causing an increase in the flow The best results obtained when using 15% is shown in Figure 4.12, while using of 10% of the CR leads to a decrease in flow comparison with other ratios. The comparison between Figures 4.11 and 4.12 detects that using HDPE, gives better improvement in the flow comparison with using CR.

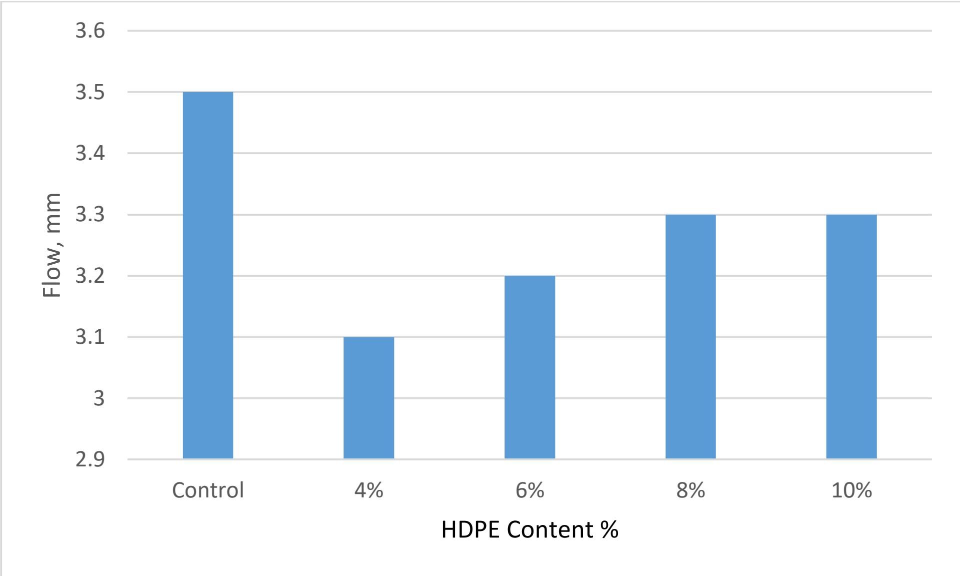


Figure 4.11. Effect of HDPE Content on Flow Test.

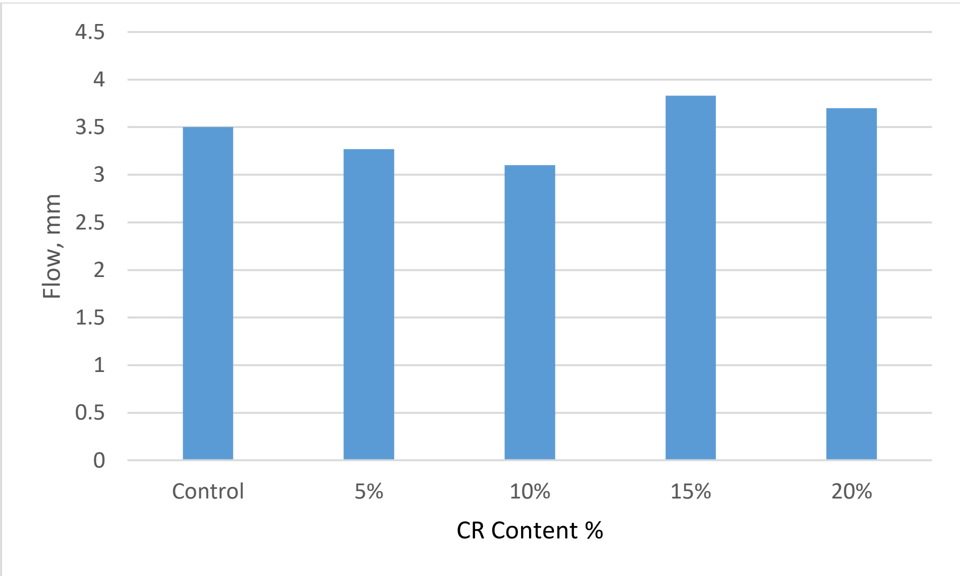


Figure 4.12. Effect of Crumb Rubber Content on Flow Test.

4.1.5. Bulk Density

The bulk density of the modified asphalt concrete mixtures is lower than the control mixture, although the difference in bulk density is due to type and concentration of the modifier. Also, the bulk density increases with increasing stability for each type from additive as shown in figures (4.13) and (4.14).

Figure 4.13 shows increasing the bulk density along with increasing HDPE content from (Control to 10) % and the best bulk density obtained when using 8 % of HDPE. While using of CR shows an increase and a decrease in bulk density depending on the CR ratio (5, 15 and 20) % causing an increase in the bulk density where the best results obtained when using 15% are shown in Figure 4.14. While using of 10% of the CR leads to a decrease of bulk density in comparison with other ratios. The comparison between Figures 4.13 and 4.14 shows that using of HDPE gives better improvement in the bulk density in comparison with use of CR.

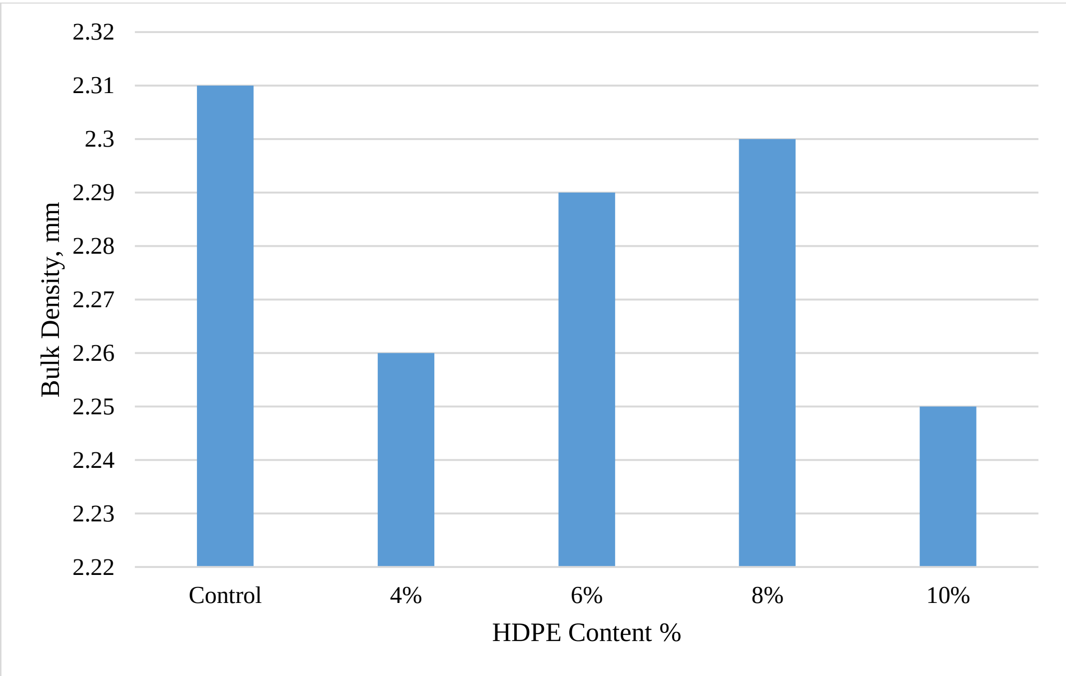


Figure 4.13. Effect of HDPE Content on Bulk Density.

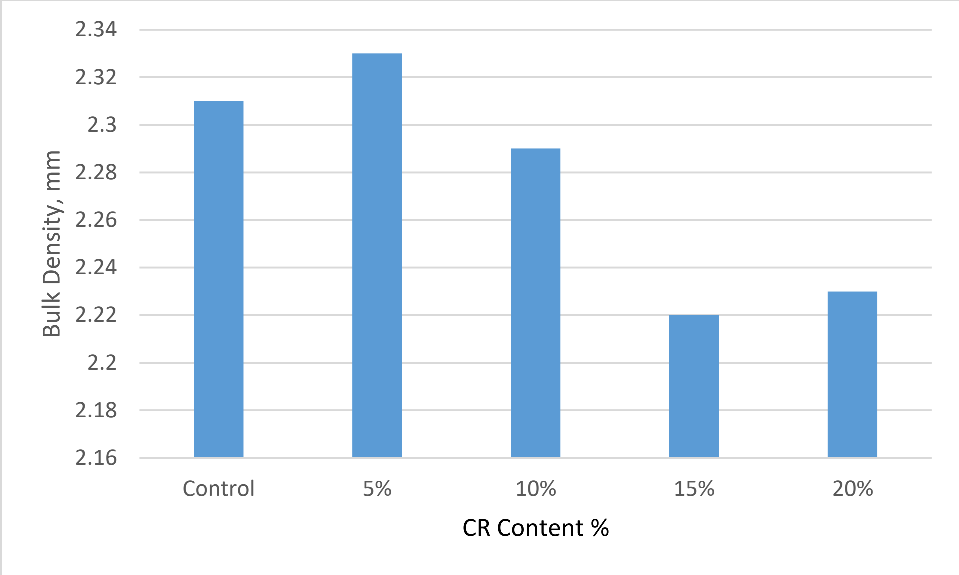


Figure 4.14. Effect of Crumb Rubber Content on Bulk Density.

4.2. Indirect Tensile Strength Test Results

Based on Table 4.1, indirect tensile strength test results has been improved after applying both materials (HDPE and CR) as well as, the load resistance for asphalt has been improved and best obtainable result was achieved when using CR due to high percent of CR comparison with HDPE.

Table 4.1: Indirect Tensile Strength Test Results for Control Mixture & Asphalt Mixtures Modified

Sample	Optimum Polymer Percent (%)	Temperate (c°)	Thickness (mm)	P (Max Load) (N)	ITS= $\frac{2p}{\pi t D}$ (Mpa)
Control (unmodified)	------	20	65	12095	1.17
Modified with HDPE	8	20	66.7	14543	1.37
Modified with CR	15	20	66	16017	1.52

4.3. Wheel track results

From Figures 4.15-4.17, the relationship between rutting depth and cycles number is positive one and increase one of them lead to increase the other one, as well as increase temperature led to increase rutting depth for all selected mixtures. However, control sample without any additive's polymer records highest rutting depth and using CR and HDPE reduced the rutting depth to approximately 30 to 50%, respectively. Due to increase both stability and stiffness of mixture after using polymer additives.

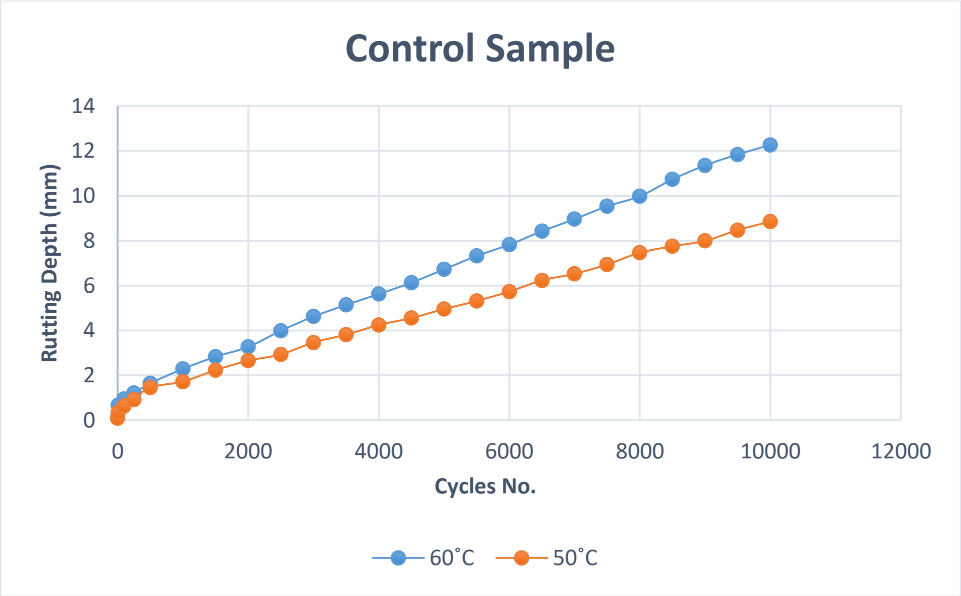


Figure 4.15: Wheel track results for control sample

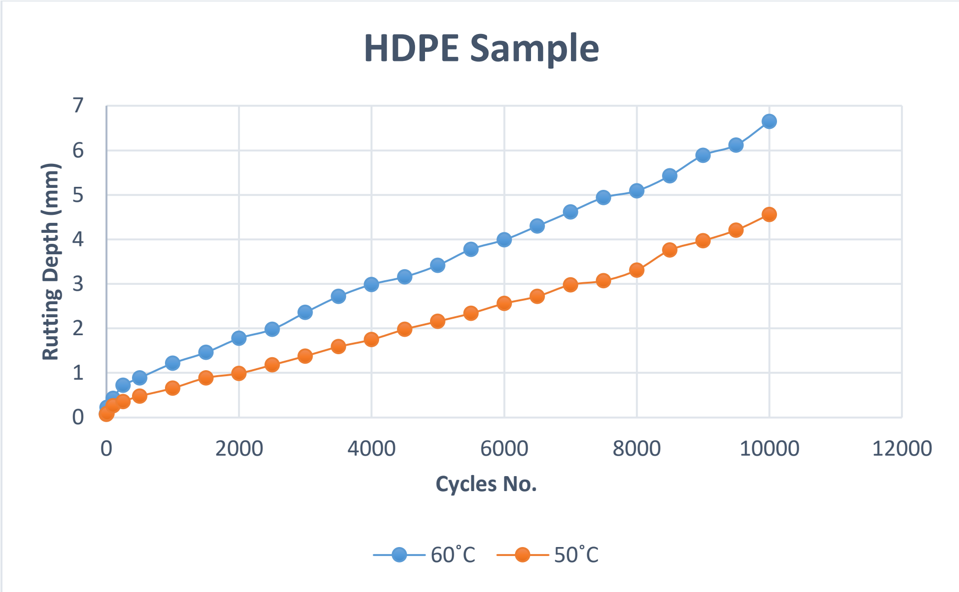


Figure 4.16: Wheel track results for HDPE sample

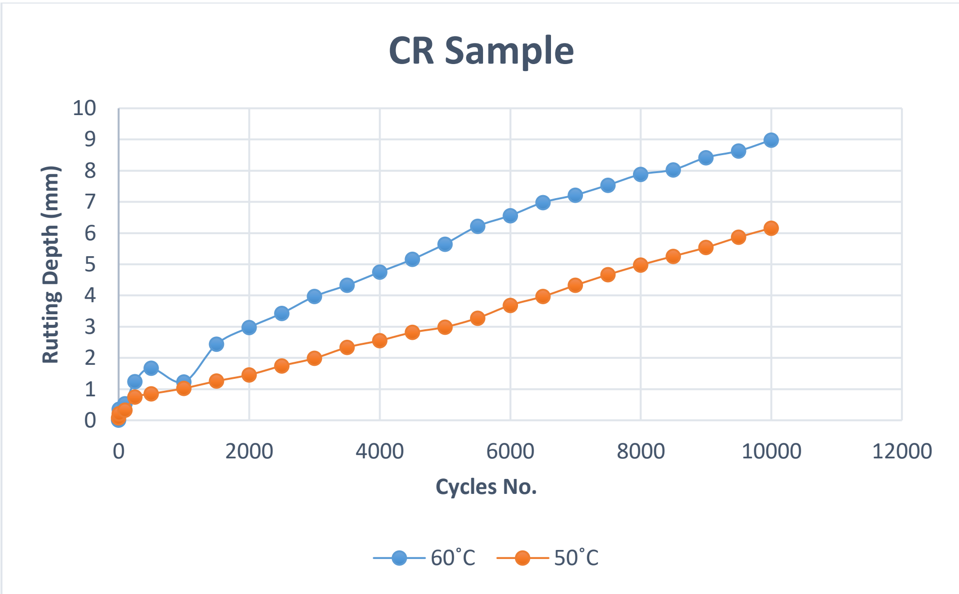


Figure 4.17 Wheel track results for CR sample

4.4. SPSS Results

Rut depth test results have been used as parameters' input in SPSS statistical analysis for both 50 and 60 degrees centigrade.

4.4.1. At temperature 50°C

4.4.1.1. Control

COMPUTE PRED= (b * AC) + (c * Cycles.No) + (d * Cyclesmin).

NLR RC50

Based on Table 4.2 correlation coefficient of control sample at 50 °C that obtained from SPSS is 0.994.

Table 4.2: SPSS results for control sample at 50 °C

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
A	0.000	2046442.358	-4317615.967	4317615.967
B	-0.875	0.000	-0.875	-0.875
C	0.001	347509.080	-733180.070	733180.071
D	0.177	0.000	0.177	0.177
E	0.000	0.000	0.000	0.000
F	0.000	0.000	0.000	0.000
G	0.000	0.000	0.000	0.000

Dependent variable: RC50

R squared = 1 - (Residual Sum of Squares)/ (Corrected Sum of Squares) =0.994.$_a$

4.4.1.2. Modified with HDPE

COMPUTE PRED= (0.007* AC) - (c* Cycles. No) + (0.008 * Cyclesmin).

NLR RC50

Based on Table 4.3 correlation coefficient of modified with HDPE sample at 50 °C that obtained from SPSS is 0.991.

Table 4.3: SPSS results for modified sample with HDPE at 50 ºC.

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
A	0.000	0.000	0.000	0.000
B	0.000	0.000	0.000	0.000
C	0.000	0.000	0.000	0.000
D	0.000	0.000	0.000	0.000
E	0.000	0.000	0.000	0.000
F	0.000	0.000	0.000	0.000
G	0.000	0.000	0.000	0.000

R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) =0.991.$_a$

4.4.1.3. Modified with CR

COMPUTE PRED= (b* AC) + (c* Cycles.No) + (d * Cyclesmin).

NLR RC50

Based on Table 4.4 correlation coefficient of modified with CR sample at 50 ºC that obtained from SPSS is 0.996.

Table 4.4: SPSS results for modified sample with CR at 50 ºC.

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
A	0.000	21514.208	-45391.010	45391.010
B	0.016	0.000	0.016	0.016
C	0.001	12177.852	-25693.022	25693.023
D	0.003	0.000	0.003	0.003
E	0.000	0.000	0.000	0.000

F	0.000	0.000	0.000	0.000
G	0.000	0.000	0.000	0.000

R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) =0.996.[a]

4.4.2. At temperature 60 °C

4.4.2.1. Control

COMPUTE PRED= (b* AC) + (c* Cycles.No) + (d * Cyclesmin) .

NLR RC60

Based on Table 4.5 correlation coefficient of control sample at 60 °C that obtained from SPSS is 0.997, comparison with the correlation coefficient of the control sample at 50 degrees centigrade, at 60 degrees centigrade is given better correlation coefficient.

Table 4.5: SPSS results for control sample at 60 °C.

Parameter	**Estimate**	**Std. Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
A	0.000	1113803541 31611.670	- 2349920062 11460.750	234992006211 460.750
B	1.500	0.000	1.500	1.500
C	0.001	1891364500 5050.414	- 3990430286 5263.820	399043028652 63.820
D	-0.221	0.000	-0.221	-0.220
E	0.000	0.000	0.000	0.000
F	0.000	0.000	0.000	0.000
G	0.000	0.000	0.000	0.000

R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) =0.997

4.4.2.2. Modified with HDPE

COMPUTE PRED= (b* AC) + (c* Cycles.No) + (d * Cyclesmin).

NLR RC60

Based on Table 4.6 correlation coefficient of modified sample with HDPE at 60 °C that obtained from SPSS is 0.995, comparison with the correlation coefficient of the control sample at 50 degrees centigrade, at 60 degrees centigrade is given better correlation coefficient.

Table 4.6: SPSS results for modified sample with HDPE at 60 °C.

Parameter Estimates				
Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
A	0.000	491928.319	-1037878.031	1037878.031
B	0.000	0.000	0.000	0.000
C	0.001	148506.664	-313321.672	313321.673
D	0.017	0.000	0.017	0.017
E	0.000	0.000	0.000	0.000
F	0.000	0.000	0.000	0.000
G	0.000	0.000	0.000	0.000

R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) =0.995.$_a$

4.4.2.3. Modified with CR

COMPUTE PRED= (b* AC) + (c* Cycles.No) + (d * Cyclesmin).

NLR RC60

Based on Table 4.7 correlation coefficient of modified sample with HDPE at 60 °C that obtained from SPSS is 0.978, comparison with the correlation coefficient of the control sample at 50 degrees centigrade, at 50 degrees centigrade is given better correlation coefficient.

Table 4.7: SPSS results for modified sample with CR at 60 ^oC.

Parameter Estimates				
Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
A	0.000	1538856.983	-3246704.434	3246704.434
B	-0.313	0.000	-0.313	-0.313
C	0.001	871051.121	-1837757.224	1837757.226
D	0.213	0.000	0.212	0.213
E	0.000	0.000	0.000	0.000
F	0.000	0.000	0.000	0.000
G	0.000	0.000	0.000	0.000

R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) =0.978.$_a$

Chapter Five

Conclusions and Suggestions for Future Works

Chapter Five

Conclusions and suggestions for Future Works

5.1. Conclusion

Three of Marshall Properties; 4.5% air voids (AV), bulk density, and stability are taken in consideration to choose the optimum asphalt amount, while other characteristics; Voids Filling with Bitumens (VFB), void in mineral-aggregates (VMA), and flow have been considered to approve the selected percentage. Depending on the study's results and within the constraints of the testing methodology and materials employed, the following main conclusions have been drawn:

1. When using additives material such as crumb rubber on asphalt mixture, many significant improvements has been indicated on mixtures properties compared with the control mixtures the stability and stiffness are increased.
2. Increasing the stability and stiffness along with increasing HDPE content from (control to 10) % the best stability obtained when using 8% of HDPE. While using CR shows an increase and a decrease in the stability depending on the CR ratio (5, 10 and 15) % causing an increase in the stability where the best results obtained when using 15%.
3. The stability increased by 113% with HDPE and by 75% with CR, while the indirect tensile strength increased by 17% with HDPE and by 30% with CR,and the rutting depth decreased by 46% with HDPE, 27% with CR, and stiffness increased by 148% with HDPE and 61% with CR.
4. It can be detected that using HDPE gives better improvement in the stiffness comparison with the use of CR.

5. The air void percentage was increased along with increasing HDPE content from (control to 10) % the best air void ratio obtained when using 10% of HDPE. Also using CR shows an increase in the air void and the increment ratio compatible with CR ratio (5, 10 and 15) % where the best results obtained when using 15%.
6. Increasing the VFA along with increasing HDPE content from (control to 10) % and the best VFA obtained when using 8% of HDPE. Also, use of CR shows an increase in the VFA and CR ratio from (control to 20) % causing an increase in the VFA where the best results obtained when using 15%.
7. Using HDPE gives better improvement in the flow comparison with using CR for marshal flow results.
8. The bulk density increases with increasing HDPE content from (control to 10) % where the best bulk density obtained when using 8 % of HDPE. While using CR shows an increase and a decrease in the bulk density depending on the CR ratio (5, 15 and 20) % causing an increase in the bulk density where the best results obtained when using 5%.
9. Indirect tensile strength test results have been improved after applying both materials (HDPE and CR) as well as, the load resistance for asphalt has been improved and best obtainable result was achieved when using CR.
10. Using additive's polymer such as CR and HDPE records reduction in the rutting depth to approximately 30 to 50%, respectively comparison with control sample.
11. Statistical analysis results have been conducted based on two kinds of formulas:

- Compute PRED=(b * AC)+ (c * Cycles.No)+ (d*Cyclesmin)
- Compute PRED=(0.007*AC)-(c*Cycles.No) + (0.008*Cyclesmin)

And the first one give better correlation coefficient (R^2) than the second one.

12. Statistical analysis results show that at 50-degree centigrade CR gives better correlation coefficient than HDPE, while at 60-degree centigrade HDPE gives better correlation coefficient than CR, therefore, CR suitable for cold and not extreme hot weather.

5.2. Recommendation for Future Investigation

1. The effect of polymers modified asphalt and reinforcing layers to enhance HMA overlay against appearance cracking utilizing a trial fields method.
2. Carrying out a finite element analysis approach to simulate test samples and main experimental finding of this research using available commercial software, such as Abaqus software.
3. Prediction of rutting in asphalt concrete by using finite element method.
4. Developing a comprehensive cost-effectiveness analysis framework study to evaluate the economic benefit of using reinforcement products in Local flexible pavement.
5. Simulated similar case of the selected study in SPSS software program in laboratory devices to calculate the effect of tire pressure and compare it with other statistical results that obtained from different research cases.
6. Studying the effect of temperature change on rutting failure before and after using asphalt modification.

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Appendix A

Appendix A:

Experimental Data

Appendix A: Experimental Data

Table (A.1) Marshal Properties of Mix

Asphalt Content%	Marshall Stability (KN)	Marshal Flow (mm)	Bulk Density (gm/cm)	AV (%)	VFA	VMA	Stiffness
3	7.33	3.3	2.251	8.70	41.02	14.75	2.22
3.5	9.27	3.4	2.276	6.47	54.47	14.22	2.75
4	10.37	3.4	2.304	4.58	66.33	13.61	3.02
4.5	8.90	3.5	2.318	3.16	76.64	13.53	2.54
5	8.13	3.7	2.279	2.87	81.37	15.43	2.22
5.5	7.27	3.9	2.264	2.44	85.18	16.44	1.88

Table (A.2) Marshall Test Results for Control Mixture and Asphalt Mixtures Modified

Sample	Polymer Percent by wt. of AC (%)	Marshall Stability (KN)	Marshal Flow (mm)	Bulk Density (gm/cm)	AV (%)	VFA	VMA	Stiffness
Control	4.5	8.90	3.5	2.318	3.16	76.64	13.53	2.54
Modified with HDPE	4	13.49	3.13	2.258	6.42	51.72	13.30	4.3
	6	14.75	3.2	2.289	5.04	63.83	13.94	4.6
	8	20.77	3.3	2.292	4.83	69.16	15.67	6.3
	10	17.83	3.3	2.255	6.54	65.25	18.82	5.4
Modified with CR	5	10.92	3.3	2.334	6.43	43.09	11.30	3.3
	10	12.19	3.1	2.294	5.81	66.57	17.39	3.9
	15	15.59	3.8	2.220	4.53	81.54	24.53	4.1
	20	9.95	3.7	2.232	6.88	75.93	28.59	2.7

Table (A.4) Rut Depth Test Results

Cycles No.	Variable	AC, %	Rutting Depth (mm)		Cycle/min
			50˚C	60˚C	
1	**Control**	4.5	0.084	0.12	26.5
10		4.5	0.34	0.67	26.5
100		4.5	0.63	0.95	26.5
250		4.5	0.92	1.21	26.5
500		4.5	1.46	1.65	26.5
1000		4.5	1.72	2.29	26.5
1500		4.5	2.23	2.83	26.5
2000		4.5	2.65	3.27	26.5
2500		4.5	2.93	3.99	26.5
3000		4.5	3.46	4.62	26.5
3500		4.5	3.81	5.14	26.5
4000		4.5	4.24	5.62	26.5
4500		4.5	4.55	6.13	26.5
5000		4.5	4.95	6.72	26.5
5500		4.5	5.31	7.32	26.5
6000		4.5	5.73	7.82	26.5
6500		4.5	6.23	8.42	26.5
7000		4.5	6.52	8.96	26.5
7500		4.5	6.94	9.53	26.5
8000		4.5	7.46	9.98	26.5
8500		4.5	7.75	10.73	26.5
9000		4.5	7.99	11.35	26.5
9500		4.5	8.47	11.84	26.5
10000		4.5	8.85	12.26	26.5

Cycles No.	Variable	AC, %	Rutting Depth (mm)		Cycle/min
			50˚C	60˚C	
1	HDPE	8	0.073	0.087	26.5
10		8	0.092	0.23	26.5
100		8	0.26	0.43	26.5
250		8	0.36	0.72	26.5
500		8	0.48	0.89	26.5
1000		8	0.66	1.22	26.5
1500		8	0.89	1.46	26.5
2000		8	0.99	1.78	26.5
2500		8	1.18	1.98	26.5
3000		8	1.38	2.36	26.5
3500		8	1.59	2.72	26.5
4000		8	1.75	2.99	26.5
4500		8	1.98	3.16	26.5
5000		8	2.16	3.42	26.5
5500		8	2.34	3.78	26.5
6000		8	2.56	3.99	26.5
6500		8	2.72	4.3	26.5
7000		8	2.98	4.62	26.5
7500		8	3.07	4.94	26.5
8000		8	3.31	5.09	26.5
8500		8	3.76	5.43	26.5
9000		8	3.97	5.89	26.5
9500		8	4.21	6.12	26.5
10000		8	4.56	6.65	26.5

Cycles No.	Variable	AC, %	Rutting Depth (mm)		Cycle/min
			50˚C	60˚C	
1	CR	15	0.087	0.012	26.5
10		15	0.22	0.36	26.5
100		15	0.33	0.54	26.5
250		15	0.75	1.24	26.5
500		15	0.85	1.67	26.5
1000		15	1.03	1.23	26.5
1500		15	1.26	2.44	26.5
2000		15	1.46	2.98	26.5
2500		15	1.75	3.43	26.5
3000		15	1.99	3.97	26.5
3500		15	2.34	4.33	26.5
4000		15	2.56	4.75	26.5
4500		15	2.82	5.16	26.5
5000		15	2.99	5.65	26.5
5500		15	3.28	6.22	26.5
6000		15	3.69	6.56	26.5
6500		15	3.97	6.98	26.5
7000		15	4.33	7.22	26.5
7500		15	4.67	7.54	26.5
8000		15	4.98	7.88	26.5
8500		15	5.26	8.03	26.5
9000		15	5.54	8.42	26.5
9500		15	5.87	8.63	26.5
10000		15	6.16	8.98	26.5

الخـــلاصـــــــة

يعد التشقق في الرصيف المرن أحد التشوهات الدائمة الرئيسية التي تظهر على معظم الطرق العراقية بسبب ارتفاع درجات الحرارة وزيادة الحمل المحوري المفرط للمركبات الثقيلة ، وهذه الظروف مجتمعة تسبب تأثيرًا كبيرًا على أداء الطريق السريع ، من خلال تقليل عمر خدمة الرصف وزيادة معدل الحوادث المرورية تم البدا في استخدام تقنيات الشبكات الجيولوجية لتقوية طبقات الرصف بالإضافة إلى استخدام البوليمرات كإضافات لتحسين خصائص الإسفلت مما يؤدي إلى تحقيق ارتفاع خليط الإسفلت عالي الجودة ، كل هذه التحسينات تهدف إلى منع حدوث تشوهات خشنة في طبقات رصف الأسفلت.

ان الهدف من هذه الدراسة هو تحسين الخلطات الاسفلتية باستخدام المضافات لكي تكون قادرة على مقاومة الاحمال المرورية العالية وإطالة عمر خدمة مقطع الرصيف وتجنب حصول فشل التخدد.

من خلال هذه الدراسة تم فحص نوعين من المواد المضافة: البولي ايثيلين عالي الكثافة (HDPE) بنسبة (4،6،8،10)٪ وفتات المطاط CR بنسبة (5،10،15،20)٪. . وجد أن أفضل نسبة تم استخدام 8 (HDPE)٪ وأفضل نسبة باستخدام 15 (CR)٪.

أظهرت الاختبارات المعملية أن الثبات زاد بنسبة 113٪ مع HDPE وبنسبة 75٪ مع CR ، بينما زادت مقاومة الشد غير المباشرة بنسبة 17٪ مع HDPE وبنسبة 30٪ مع CR ، وانخفض عمق الشق بنسبة 46٪ مع HDPE و 27٪ مع CR ، وزيادة الصلابة بنسبة 148٪ مع HDPE و 61٪ مع CR. بينما أظهر التحليل الإحصائي أن معامل الارتباط باستخدام CR عند 50 درجة مئوية يعطي نتائج أفضل من HDPE لدرجات حرارة مماثلة. ومع ذلك ، فإن زيادة درجة الحرارة إلى 60 درجة مئوية تعطي نتائج عكسية.

جمهوريـــــــــة العـراق
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جامــــعـة بابـــل كـــلية الهندســـــــــة
قسـم الهــندسـة المدنـيـــــة

تقييم وتحسين فشل التخدد لطبقه الأساس القيري المحلي

رسالة

مقدمة الى قسم الهندسة المدنية في كليه الهندسة / جامعة بابل

وهي جزء من متطلبات نيل درجة الماجستير في الهندسة/ الهندسة المدنية/ المواصلات

من قبل

فاطــــمة مســـلم هادي

(بكالوريوس في الهندسة المدنية - 2018)

بأشراف

أ.د. عبد الرضا ابراهيم احمد

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