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Evaluation of Using Different Types of Anti-Stripping Materials on Cold Cationic Emulsified asphalt Mixtures

A Thesis

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By

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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Dedication

I dedicate this work to...

My parents...

for their love and prayer

My brothers and sisters...

for their support

My wife...

for her love and support

My little princess Hamsa

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Abstract

Generally, stripping is the main form of moisture sensitivity in asphalt mixtures, it is a prime form of distress that occurs in asphalt pavement. It is described by two ways, the first way is the absence of the adhesive bond between the aggregate and the asphalt binder and the other is by degrading the cohesive bonds for the asphalt binder. The two types are due to the action of traffic loads in the presence of moisture.

In cold bitumen emulsion mixtures, the emulsion consists of bitumen, water, emulsifier, and other additives. The water should be evaporated during mixing, compaction, and curing process, this can lead to high air void contents in the pavement structure, hence the water may enter inside the pavement structure and makes it more susceptible to moisture damage.

The purpose of this study is to conduct a laboratory investigation to evaluate the effect of using three types of material named (hydrated lime, fly ash, and silica fume) as anti-stripping materials on cold mix asphalt, binder course layer with asphalt emulsion type cationic, slow setting, and a low viscosity (CSS-1). This is done by using the Superpave mix design system, the mixtures were prepared for three trails blend with five trails emulsion contents to find the design emulsion content. After the final mix design was selected, four types of test (indirect tensile strength, compressive strength, Marshall Stability test, and double punch test) were conducted on each type of mixture. Three percent of hydrated lime, fly ash, and silica fume were used as a replacement for limestone dust, which was (1, 1.5, 2) % for hydrated lime and (1, 2, 3) % for fly ash and silica fume.

Abstract

The results showed that using hydrated lime with 2% replacement of limestone dust can improve the volumetric and mechanical properties and the moisture resistance. It increased the indirect tensile strength, compressive strength and Marshall stability to about (28.2, 32.5 and 41.8) % at 2% of replacement. Also, increased the bulk specific gravity and reduced the air voids content and flow value, furthermore, it increased the tensile strength ratio, the index of retained strength, the retained Marshall stability, and punching strength by about (17, 19.4, 40, 95.2) %, respectively. Also the results indicated that the using of fly ash led to improve the moisture resistance, at 3% of replacement the tensile strength ratio, the index of retained strength, the retained Marshall stability, and punching strength was increased by (8, 12.7, 36.4, and 55.7) %, respectively. But at the same time it was led to decline in the indirect tensile strength, compressive strength, and Marshall stability by (13.4, 10.5 and 13.8) % at the same percent. Also declined the bulk specific gravity and increased the air voids content and flow values.

The results of using silica fume as a replacement to limestone dust showed that silica fume enhanced the indirect tensile strength, compressive strength, and Marshall stability significantly, also increased the bulk specific gravity and reduce the air voids and flow values. Furthermore, there was a slight increase in the tensile strength ratio, retained Marshall stability, and punching strength, this increase was up to (5.7, 22.2, 9.5) %, respectively at 3% of replacement. Whereas for the same percentage of replacement, there was a declined in the index of retained strength in comparison with control mix, this lowering was approximately (4.5) %.

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LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO: American Association of State Highway and Transportation Officials

AC: Asphalt Content

AEMA: Asphalt Emulsion Manufacturers Association

AI: Asphalt Institute

ASTM: American Society for Testing and Materials

CBEMs: Cold Bitumen Emulsion Mixtures

CIR: Cold In-place Recycled Mixtures

SCRB: State Corporation for Roads and Bridges (RBD at the Present)

DP: Dust Proportion

ESAL: Equivalent Single Axle Load

HMA: Hot Mix Asphalt

IEC: Initial Emulsion Content

IRS: Index of Retained Strength

ITS: Indirect Tensile Strength

NCCLR: National Center for Construction Laboratories and Researches (NCCL at the Present).

NCHRP: National Cooperative Highway Research Program

PCS: Primary Control Sieve

SGC: Superpave Gyratory Compactor

SSD: Saturated Surface Dry

Superpave: Superior Performing Asphalt Pavements

TSR: Tensile Strength Ratio

VFA: Voids filled with Asphalt

Va: Air Voids

VMA: Voids in Mineral Aggregate

SF: Silica Fume

HL: Hydrated Lime

FA: Fly Ash

RMS: Retained Marshall Stability

CMS-2: Cationic Medium Setting and High Viscosity Emulsified Asphalt

CRS-1: Cationic Rapid Setting and Low Viscosity Emulsified Asphalt

CRS-2: Cationic Rapid Setting and High Viscosity Emulsified Asphalt

CSS-1: Cationic Slow Setting and Low Viscosity Emulsified Asphalt

CSS-1h: Cationic Slow Setting, Low Viscosity and Hard Emulsified Asphalt

HFMS-1: Anionic Medium Setting, High Float and Low Viscosity Emulsified Asphalt

HFMS-2: Anionic Medium Setting, High Float and High Viscosity

HFRS-2: Anionic Rapid Setting, High Float and High Viscosity Emulsified Asphalt

MS-1: Anionic Medium Setting and Low Viscosity Emulsified Asphalt

MS-2: Anionic Medium Setting and High Viscosity Emulsified Asphalt Emulsified Asphalt

MS-2h: Anionic Medium Setting, High Viscosity and Hard Emulsified Asphalt

RS-1: Anionic Rapid Setting and Low Viscosity Emulsified Asphalt

RS-2: Anionic Rapid Setting and High Viscosity Emulsified Asphalt

SS-1: Anionic Slow Setting and Low Viscosity Emulsified Asphalt

SS-1h: Anionic Slow Setting, Low Viscosity and Hard Asphalt Emulsified Asphalt

CHAPTER ONE

INTRODUCTION

CHAPTER ONE**INTRODUCTION****1.1 Generals**

In general, most road construction plans and activities involve asphalt pavements with hot mix technology. Over many years hot mix technology has satisfied the performance requirements and supplies high quality and smooth ride to the public. However, the production of hot mix asphalt (HMA) requests a large amount of energy, because HMA requires high temperatures for mixing and compaction, it is conducted typically about 135°C to 180°C. Meantime leads to considerable air pollution by the contaminants and dust produced from high temperature heated aggregate and mixture (Ling, 2013).

Therefore, it is desirable to find more friendly environment production methods for asphalt materials and a suitable alternative for hot mix technology that provide a similar quality at reduced energy consumption and emissions.

In cold mix technology, the production of the mix, lying, and compaction is done at the room temperature (23°C to 25°C). Field trials have evidenced that cold mix asphalt (CMA) can be easily produced by utilizing hot mix plant and laid by using similar techniques for hot mix asphalt. And it is also friendly technology for work (Dash, 2013).

Although the (CMA) benefits, moisture damage in the form of stripping due to the loss of bonding between asphalt binder residue and aggregate is one of a number of performance-related concerns need to be studied. Moisture damage also leads to other types of pavement distresses such as rutting, fatigue cracking and raveling (Ahmed, 2011).

Normally, to study the moisture susceptibility of the CMA materials, selection of material quality is needed by using a simple and effective evaluation method. Also, to evaluate the moisture susceptibility of asphalt mixtures a number of methods have been successfully used for HMA, either for loose mixture or compact mixture. For loose mixture, the tests are economical and simple, however, they do not take into consideration the mechanical properties of the mixtures, whereas for compact mixtures the tests take into consideration the mechanical properties but they are costly, complicated, and time consuming (Ling, 2013).

1.2 Problem Statement

Pavement layers use an asphalt binder to bind aggregate together for a mixture that supports applied loads and ensures durability. Asphalt binder has the ability to bind the mineral aggregate and maintain this bond is a critical property. The bond may decline at the interface between asphalt and aggregate (loss of adhesion) or within the asphalt binder (loss of cohesion), due to loading and environmental condition (Copeland, 2007).

Moisture is the prime environmental condition that adversely influences on the asphalt concrete quality and firstly results in bond strength disintegration. Moisture-induced damage is a national matter that reduces the life-span of the nation's highways. A phenomenon referred to as stripping, which was the asphalt binder is "stripped" from the aggregate, is caused by distress mechanisms induced by the presence of moisture (Copeland, 2007).

Also, for cold mix asphalt, the reported higher air void content and the presence of water in the emulsified asphalt if not fully evaporating

during the curing process may be leading to higher moisture susceptibility of CMA (Ling, 2013).

1.3 Research Objective & Methodology

In this study three types of materials (hydrated lime, fly ash, and silica fume) are used as a replacement for limestone dust at (1, 1.5, 2) % for lime and (1, 2, 3) % for silica fume and fly ash. The main objective of this study is to evaluate the using of these materials as anti stripping materials on cold cationic emulsified asphalt.

In order to achieve the fundamental purpose of this study, The following procedures will be implemented on cold mix asphalt by laboratory investigation.

- 1) Design the mixtures by using the Superpave mix design method and explain the differences between many variables such as bulk density, aggregate gradation, filler content, dust proportion, asphalt emulsion content, air voids, voids in mineral aggregate (VMA), and voids filled with asphalt (VFA).
- 2) Study the bulk specific gravity and air voids for Marshall specimens.
- 3) Study the mechanical properties for mixtures by indirect tensile strength, compressive strength, Marshall stability and flow tests.
- 4) Study the moisture sensitivity by tensile strength ratio, the index of retained strength, and retained Marshall stability.
- 5) Use the double punch test to measure the stripping of the binder from the aggregate.

1.4 Structure of the Thesis

This thesis consists of five chapters as follows:-

- Chapter one introduces an overview of this research area and describes the problem statement and the objectives and scope of this study
- Chapter two presents a literature review of moisture damage definitions, mechanisms, factors influence moisture damage, theory of failure, source of moisture and moisture sensitivity tests. Also presents a literature review of bitumen emulsion definitions, component, manufacture, uses, Factors Affecting Quality and Performance, curing, breaking, and cold mix asphalt, cold bitumen emulsion mixtures and their advantage and disadvantage, and mix design of cold mix asphalt.
- Chapter three is allocated to the experimental work. It includes materials used and their properties, the mix design procedure, testing method and the experimental details.
- Chapter four deals with the results of the experimental work and explains their variations.
- Chapter five introduces the main conclusions derived from the analysis of the experimental results and the recommendations for the future work.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 Generals

This chapter is divided into three main parts. The first part provides a summary of asphalt mixture moisture damage, moisture sensitivity assessment and bitumen aggregate adhesion testing and discusses the concept of bitumen-aggregate adhesion, the second part provides an information about emulsified asphalt and cold mix asphalt. Whereas the third part illustrates the use of additives in the literature.

2.2 Moisture Damage

2.2.1 Definitions and Causes of the Moisture Damage

Normally, moisture damage is regarding to the loss of adhesion bond between bitumen and aggregate. Replacement of bitumen film from the aggregate surface with water is termed as (stripping) (Ahmad, 2011).

(Ahmad, 2011) mentioned that the chemical composition of bitumen and aggregates was largely affected the phenomenon of stripping, also their affinity towards each other. Hence, the structural performance of the road pavement largely affected by the particular properties of the material along with the properties of the resulting asphalt mixture. Impacts of traffic loading, aggregate type, bitumen characteristics and properties of the additives in mixtures can modify the resistance of mixes against moisture damage.

Generally, one of the major reasons of distress in an asphalt pavement is the moisture damage (Wang, 2012).

Although, the distresses in asphalt pavement not resulted directly from the moisture, but the existence of moisture increases the size and instances of already existing damages like cracking, potholes and patches, and others (Cho and Kim, 2010).

The mechanical properties of the asphalt mixtures will be degraded with the existence of moisture, this loss in mechanical strength and stiffness could result ultimately in the failure of the road structure (Ahmad, 2011).

For a long it has been known that the mechanical and physical properties of bituminous mixtures can be affected by the moisture. (Liu et al., 2014).

Generally, stripping, rutting, raveling and fatigue cracking which result partly from moisture contributes significantly to the failure in bituminous pavements. There are actually no solutions satisfactory for such problem, theories were existing only, this mainly because of a lack understanding of the problem of the moisture damage. However, two of these theories are, commonly accepted. There are two main factors that cause moisture-related problems comprise of adhesive failure (i.e. bitumen stripping off the aggregate surface) and cohesive failure (i.e. the loss of mixture stiffness, especially in the mastic). Furthermore, there are important factors affecting the durability of bituminous paving mixtures such as the volumetric properties of the binder, air voids, affinity of the bitumen and the aggregate, and the permeability of the mixtures.

The phenomenon of stripping normally begins at the bottom of the compacted bituminous layer, because the tensile stresses on the bottom are the greatest due to cyclic traffic loading. Then the stripping forward to the surface. Typically, the top layer can be replaced, but the stripping in

the load bearing layer does not provide support so the thickness of the effective compacted bituminous layer is decreased, and this may result in surface rutting, pavement cracking and loss of serviceability. There are four factors that promote stripping: presence of water, high temperature, high air void content, and high stress (Copeland, 2007).

2.2.2 Moisture Damage Mechanisms

According to the studies done by (Kiggundu and Roberts, 1988; Taylor and Khosla, 1983; Terrel and Al-Swailmi, 1994), there are several mechanisms for the bitumen (bitumen-filler mastic) films to be stripped from the aggregate surface, including detachment, displacement, spontaneous emulsification, pore pressure and hydraulic scouring.

1) Detachment

Detachment can be define as the microscopic separation of the bitumen films from the aggregate. This attributed to the existence of thin films of water without an evident break in the bitumen films. The thin films of water probably resulted from either aggregates that were not completely dry or interstitial pore water or moisture, which vapor raised and condensed on the aggregate surface (Johnson and Freeman, 2002).

2) Displacement

It occurs when the bitumen films are separated from the aggregate surface due to the presence of water or moisture. As compared to the detachment, displacement occurs due to the intrusion of water or moisture in the aggregate surface through breaks of the bitumen films. The breaks of the bitumen films may arise from incomplete coatings of the bitumen films on the aggregate surface or rupture of the bitumen films at the sharp corners or edges of the aggregates (Mohd Jakarni, 2012).

3) Spontaneous emulsification

It is defined as the bitumen phase that can be emulsified by the water or moisture, the bitumen phase that emulsified by water or moisture will result the separation of bituminous particles from each other (cohesive failure) and ultimately will cause the adhesive failure when the emulsion boundary transmission to the aggregate surface (Mohd Jakami, 2012).

4) Pore Water Pressure

Due to the repeated traffic loads, the water or moisture entrapped in the asphalt mixtures can cause an increase in the pore water pressure, and freeze and thaw cycles. At the end, the continuance of the increase in the pore water pressure will lead to the regression of the adhesive bond strength between bitumen (bitumen-filler mastic) and aggregates, then the micro-cracks growth in the asphalt mixtures (Mohd Jakami, 2012).

5) Hydraulic scouring

When the capillary tension and the pressure around a moving traffic presence on the saturated pavement surface, this occurred the hydraulic scouring. Bitumen are stripped from the aggregate surface, hence, distresses such as raveling will be produced. Furthermore, dust exist on the aggregate surface can enhance the abrasion of bitumen films from the aggregates, because the dust will mix with water or moisture, in the presence of traffic (Mohd Jakami, 2012).

2.2.3 Factors Influencing Moisture Damage

Many factors affect the moisture damage, to evaluate moisture damage, some of these factors should be considered such as characteristics of asphalt, characteristics of aggregate, the type and use of

the mix, environmental effects during and after construction, and the use of anti-stripping additives. (Kandhal et al., 1998).

Figure (2-1) shows the environment factor influencing moisture damage and Table (2-1) shows the factors influencing moisture damage.

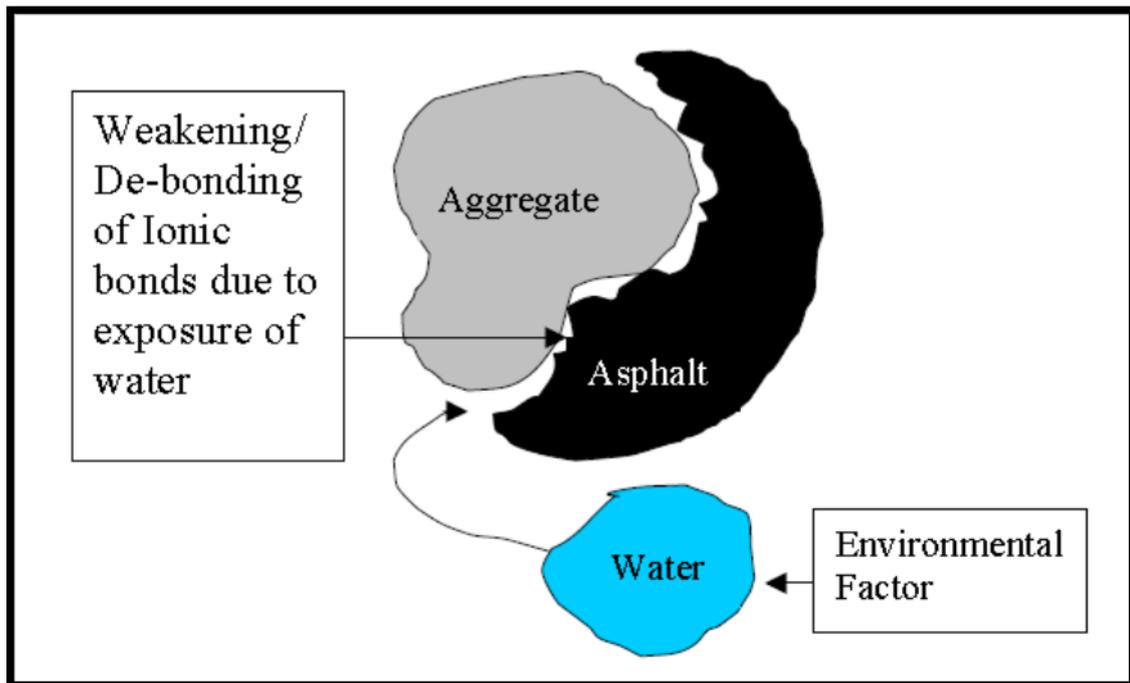


Figure (2-1) Moisture within an asphalt concrete mix due to environmental factors (Shah, 2004)

2.2.4 Theory of Adhesion & Cohesion of Asphalt Mixtures

Generally, two theories have been specified: a failure of bonding between the binder and the aggregate (i.e., a failure of adhesion) and a failure within the binder itself (i.e., a failure of cohesion) (Copeland, 2007).

Figure (2-2) illustrates the adhesion and cohesion in mixtures and Figure (2-3) provides types of failure that might occur in asphalt mixtures.

Table (2-1) Factors Affecting Moisture Damage (Kim and Coree, 2005)

Factor	Desirable Characteristics	Supporting Researchers
1) Aggregate		
a) Surface Texture	Rough	Hicks, 1991, Majidzadeh and Brovold 1968
b) Porosity	Depends on pore size	Hicks, 1991 and Thelen, 1958
c) Mineralogy	Basic (PH=7) aggregate is more resistant	Rice, Majidzadeh and Brovold, 1968
d) Dust Coatings	Clean	Majidzadeh and Brovold, 1968 Tunnicliff and Root, 1982. Majidzadeh and Brovold, 1968, Kim, Bell and Hicks, 1985
e) Surface Moisture	Dry	Hicks, 1991
f) Surface Chemical Composition	Able to share electrons or form hydrogen bonds	Hicks, 1991
g) Mineral Filler	Increase viscosity of Asphalt	Hicks, 1991
2) Asphalt Cement		
a) Viscosity	High	Thelen, 1958, Schmit and Graf, 1958.
b) Chemistry	Nitrogen and Phenols	Curtis, 1991
c) Film Thickness	Thick	Hicks, 1991
3) Type of Mixture		
a) Voids	Very low or Very high	Terrel and Shute, 1989
b) Gradation	Very dense or Very open	Brown, 1985, Takallou, 1985
c) Asphalt Content	High	Hicks, 1991
4) Environmental Effect During Construction		
Temperature	Warm	Hicks, 1991, Majidzadeh and Brovold, 1968.
Rainfall	None	Hicks, 1991
Compaction	Sufficient	Hicks, 1991, Tunnicliff and Root, 1982
5) Environmental Effect after Construction		
a) Rainfall	None	Hicks, 1991
b) Freeze-Thaw	None	Lottman, 1982, Taylor and Khosla, 1983
c) Traffic Loading	Low Traffic	Fromm, 1974, Gzemski, 1968
6) Modifiers or Additives	Use	Tunnicliff and Root, 1982

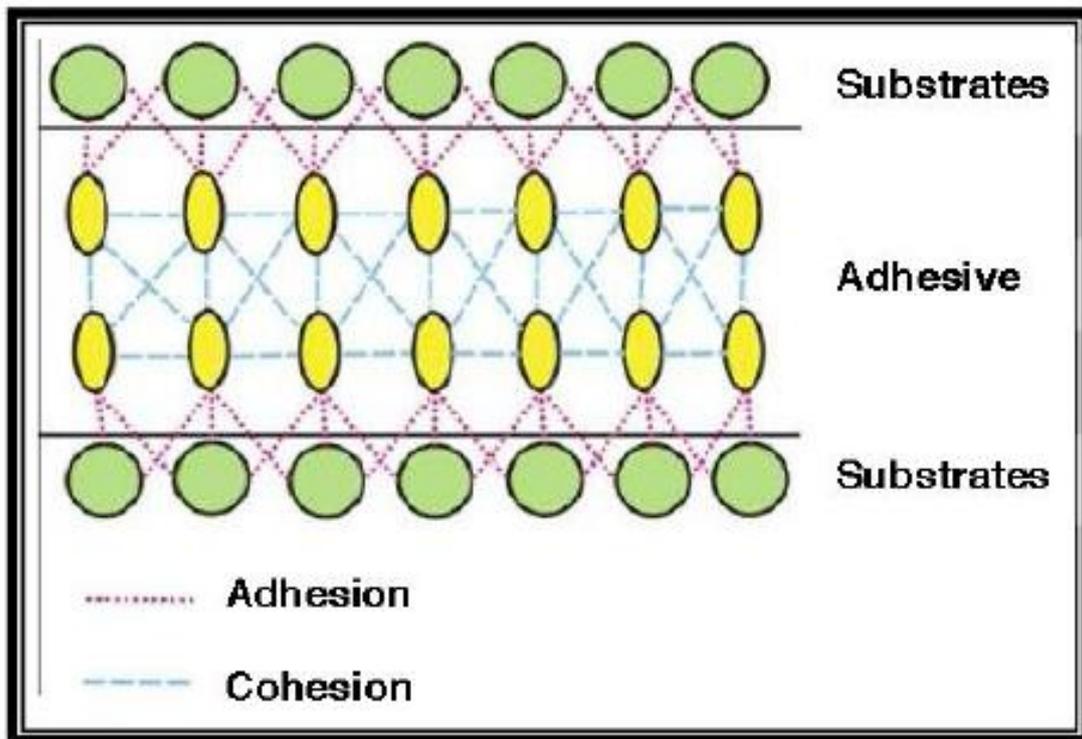


Figure (2-2) Adhesion and Cohesion Present Between Adhesive and Substrates and Within Adhesive (Mohd Jakami, 2012).

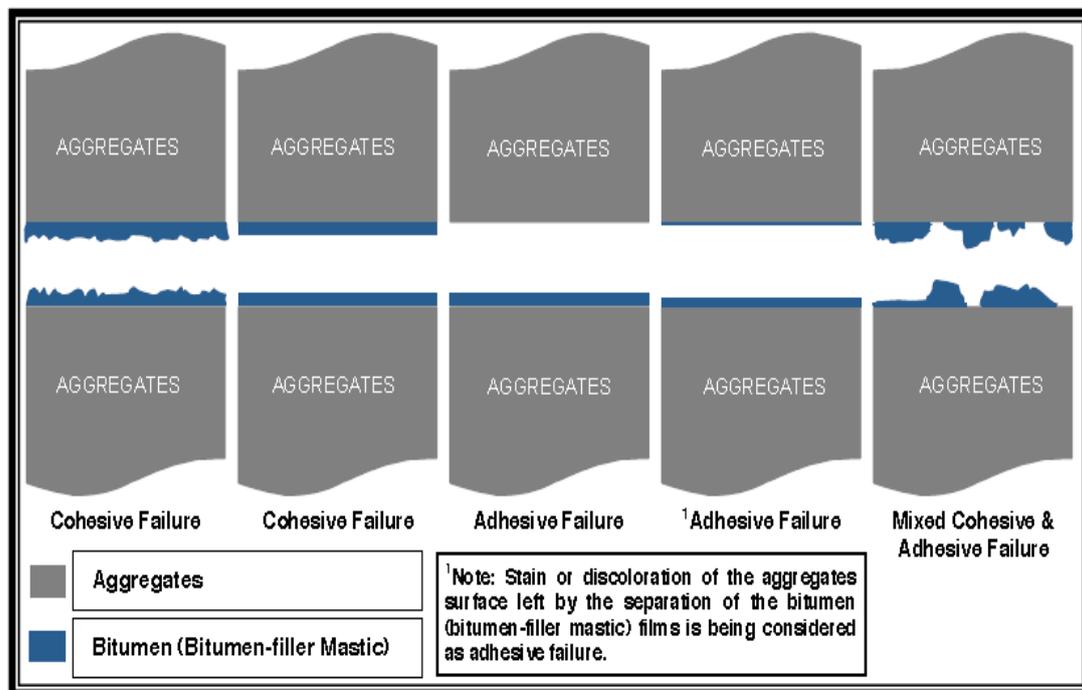


Figure (2-3) Possible Types of Failure that Might Occur in Asphalt Mixtures (Mohd Jakami, 2012).

2.2.4.1 Adhesive Failure

Most researchers reported that the moisture damage in asphalt mixtures is attributed to the adhesive failure more than to the cohesive failure. Adhesive failure, which is considered as an engineering failure in the design of a proper mixture and an economic loss produced from the separation of the binder from the aggregate surfaces in the presence of water (i.e., moisture damage). (Kim and Coree, 2005).

(Kennedy et al., 1982) stated that stripping was the degradation of adhesion between the asphalt binder and the aggregate due to the presence of water. Stripping was the separation of the asphalt binder film from the aggregate surface, which expounded using the chemical reaction theory of adhesion. In order for superior understanding to the phenomenon of stripping, a number of hypotheses were developed proportional to the adhesive bond between asphalt and aggregate.

There are four mainly theories that have been expanded to demonstrate the adhesion between bitumen and aggregates, namely as mechanical adhesion theory, chemical reaction theory, surface energy theory and molecular orientation theory. These theories, each individually explain some aspects of the adhesion but do not completely capture the mechanisms (Copeland, 2007; Dickinson et al., 1990; Kim, 2008).

1. Mechanical Adhesion Theory

(Terrel and Al-Swailmi, 1994) stated mechanical adhesion theory has suggested that adhesion between bitumen and aggregates is affected by the physical properties of the aggregates such as particle size, surface texture, angularity, porosity or absorption and surface areas. Bitumen gets into the surface irregularities and pores of the aggregates, and hardens,

causing a mechanical interlock. In general, stronger adhesive bond strength of bitumen and aggregates is created with rough, porous aggregates of large surface areas. However, aggregates having a relatively smooth surface texture are easier to coat as compared to the rough surface texture. The presence of water or moisture on the aggregate surface may decrease the mechanical interlock, thus increasing the susceptibility of the asphalt mixtures to stripping. The properties of the bitumen are less important than the physic-chemical properties of the aggregate surfaces for moisture induced stripping. (Tarrar and Wagh, 1991).

2. Chemical Reaction Theory

The chemical reaction theory has been generally accepted to explain the differences in the degree of adhesion between different types of bitumen and aggregates, in the presence of water or moisture. Aggregates may be classified as either hydrophilic (attract water) or hydrophobic (repulse water) as shown in Figure (2-4). The main properties of the aggregates that determine the characteristics of either hydrophilic or hydrophobic are surface chemistry, porosity and pore size. Hydrophilic aggregates such as siliceous aggregates (e.g. Granite) tend to strip easier than hydrophobic aggregates (e.g. limestone) (Kim, 2008).

Generally, a more acidic aggregate surface is less likely to form bonds as strongly with the bitumen and thus increase the susceptibility of the asphalt mixtures to stripping. In other words, the pH values of the aggregate surface and the bitumen affect the adhesive bond strength of the asphalt mixtures. The reason for this has been attributed to different polarities of the surface minerals in the aggregates and the bitumen (Mohd Jakarni, 2012).

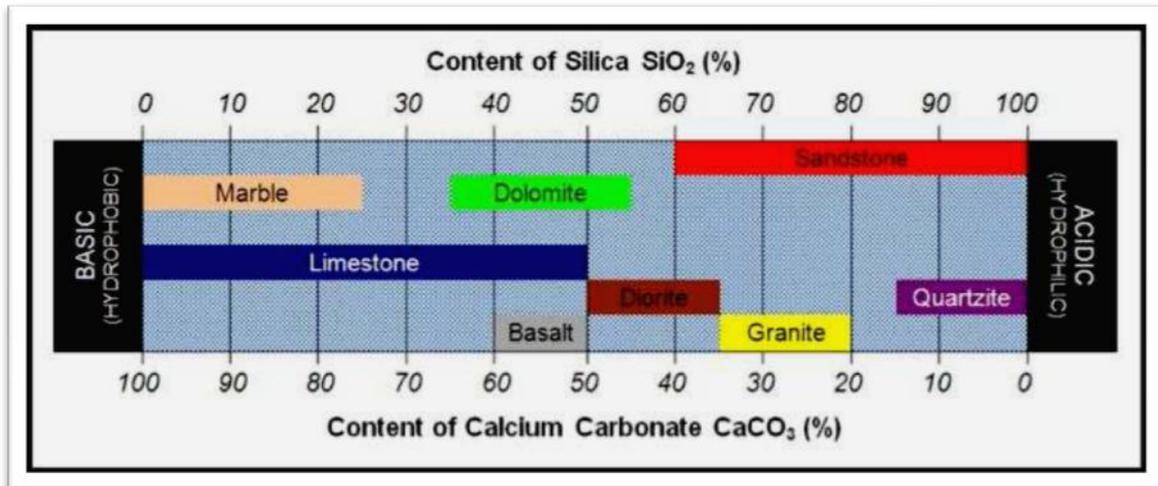


Figure (2-4) Classification of aggregates as hydrophilic and hydrophobic (Mohd Jakami, 2012)

3. Surface Energy Theory

For an effective bond, bitumen (bitumen-filler mastic) should completely coat or wet the aggregate surface. The wetting ability of the bitumen (bitumen-filler mastic) can be explained by using the surface energy theory. Surface energy is defined as the energy needed to create a unit area of new surface between bitumen (bitumen-filler mastic) and aggregates in vacuum condition. The adhesion tension is occurring when the bitumen (bitumen-filler mastic) was put in contact with aggregates. However, the adhesion tension between water or moisture and aggregates generally more than the adhesion tension between bitumen (bitumen-filler mastic) and aggregates.. Therefore, bitumen (bitumen-filler mastic) will tend to be separated from the aggregate surface in the exist of water or moisture. This can result in poor wetting of the aggregate surface by the bitumen films and lead to stripping (Mohd Jakami, 2012).

The adhesion tension between bitumen and aggregates varies with the types of aggregates, roughness of the aggregates surface and types of bitumen. Researchers at Texas A & M University and Western Research

Institute in Wyoming have conducted research in measuring the adhesive bond strength of bitumen and aggregates based on the thermodynamic surface free energy characteristics of aggregates, bitumen and water (moisture) (Bhasin et al., 2006).

4. Molecular Orientation Theory

Molecular orientation theory affirms that when bitumen (bitumen-filler mastic) is in contact with an aggregate surface, as shown in Figure (2-5), molecules of bitumen tend to orient themselves to satisfy the energy requirement of the aggregate surface. Bitumen consists of a combination of non-polar (Lifshitz-van der Waals) and polar (Lewis acid and Lewis base) molecules (Mohd Jakarni, 2012).

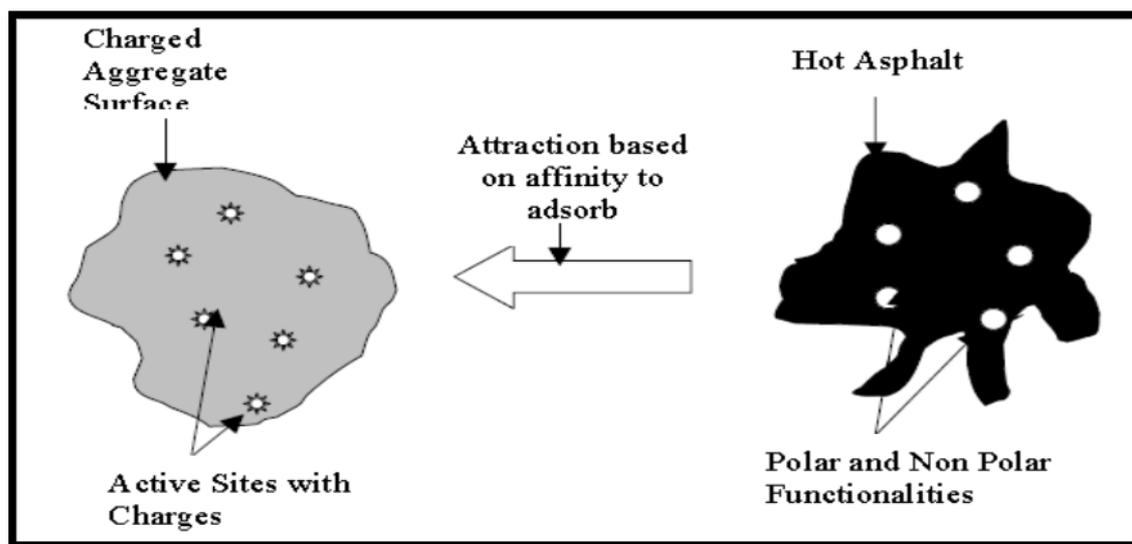


Figure (2-5) Asphalt-aggregate chemistry (Shah, 2004)

2.2.4.2 Cohesive Failure

Cohesive failure is occurring within the asphalt mastic, it was regarded as a less significant factor in the moisture damage of asphalt mixture, when the water was emulsified the asphalt phase, the cohesive failure can be illustrated. And this is various to conventional emulsified

asphalts, in which the asphalt is emulsified in a water phase. A water-in-asphalt emulsion can be formed when the water enters into the asphalt film. This emulsification of water in the asphalt film results in separation of asphalt particles from the asphalt film (cohesive failure) and finally this leads to an adhesive failure at a critical time when this emulsification boundary reached to the aggregate surface (Kim & Coree, 2005).

However, since the final mechanism was the adhesive failure, which may be produced from the mechanism of cohesive failure, most cases of cohesive failure may be concluded more than observed. Thus, it has complex to recognize between the two types of failure in predicting the failure mode, except the failure surface of asphalt mixture is visually inspected, though the definition of moisture damage in asphalt mixture has been regarded as the failure of adhesive and cohesive bonds between the asphalt and the aggregates in the presence of water. (Terrel, and Al-Swailmi, 1994).

2-2-5 Sources of Moisture

An asphalt pavement is exposed to several cycles of precipitation during its service life. Sources of moisture in an asphalt pavement can be either internal or external, (Ahmed, 2011).

2.2.5.1 Internal

Moisture is left in the pavement before construction in the form of inadequately dried aggregate (Santucci, 2002).

2.2.5.2 External

The following three sources can be considered as the external sources of moisture, (Ahmed, 2011).

- Moisture entering the pavement from the surface because of poor drainage, poor construction (compaction) or mixture design having high air voids and thus more permeability.
- Moisture entering from the sides because of poorly constructed shoulders and poor side drainage.
- Moisture from beneath the sub-grade because of high water table and poor drainage characteristics of base and sub-base material.

Figure (2-6) below illustrates different sources of moisture in a pavement structure.

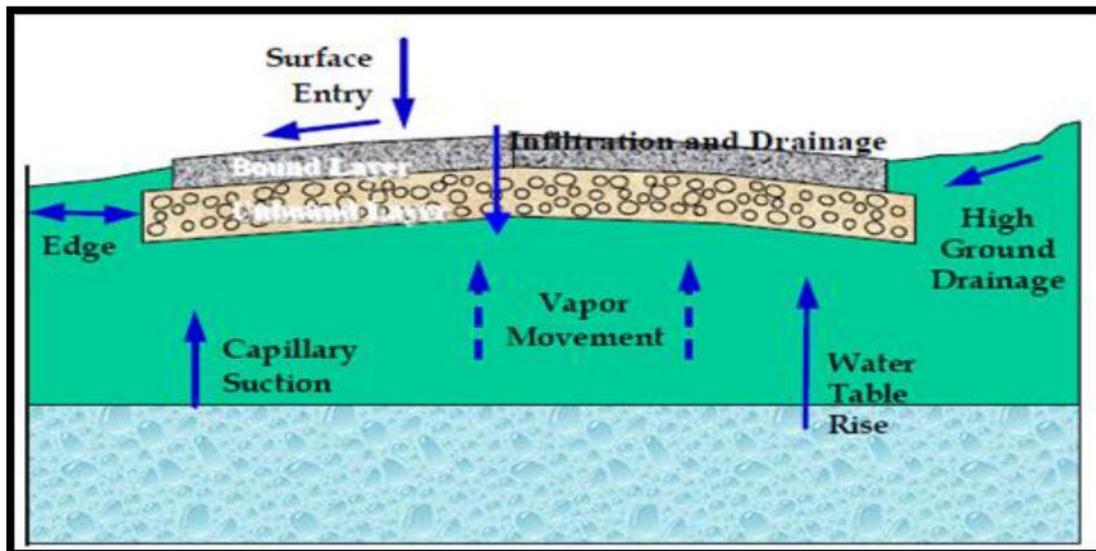


Figure (2-6) Sources of Water in an Asphalt Pavement (Yilmaz & Sargin, 2012)

2.2.6 Types of Moisture Sensitivity Tests

Overall, to evaluate the moisture sensitivity of asphalt mixture, there was a numerous test used. However, to this time, no test has achieved any wide acceptance. In fact, by comparing wet and dry sample test results, any performance test can be carried on a wet or submerged sample can be

applied to evaluate the influence of moisture on asphalt mixture. (Yilmaz and Sargin, 2012).

There are two major categories of tests that were developed, namely qualitative and quantitative, depending on the type of result. (Yilmaz and Sargin, 2012; Solaimanian, 2003).

The qualitative tests supply an internal evaluation of the stripping chance, these tests include:

- Boiling water test,
- Freeze–thaw pedestal test,
- Quick bottle test,
- Rolling bottle method, and

The quantitative tests supply an amount for a particular parameter such as strength before and after conditioning, these tests include:

- Immersion–compression test,
- Indirect tensile test,
- Marshall immersion test,
- Double punch method,
- Resilient modulus tests, and

On the other hand, the tests were divided into two groups, the first applied to the loose mixtures, this type was used to select whether an asphalt–aggregate system is appropriate and whether it has enough resistant versus separation in the exist of water without any trials to evaluate the mechanical properties of the mixture under applied loads and water. The other group was used to find the moisture sensitivity on compacted mixture. In this group of tests, trials are made to take in consideration the impact of the compacted mixture in addition to traffic

and the environment condition, when the mix behavior is evaluated in the presence of water. Normally, this type of tests divides to two sets, the first one used in water conditioning and second used take into account the interaction between traffic and the water. (Solaimanian et al., 2003).

To evaluate the moisture sensitivity, Tables (2-2) and (2-3) show the tests that conduct on loose and compacted mixtures, respectively.

**Table (2-2) Moisture Sensitivity Tests on Loose Samples
(Solaimanian, 2003)**

Test	ASTM	AASHTO	Other
Methylene blue			Technical Bulletin 145, International Slurry Seal Association
Film stripping			(California Test 302)
Static immersion	D 1664*	T182	
Dynamic immersion			
Chemical immersion			Standard Method TMH1 (Road Research Laboratory 1986, England)
Surface reaction			Isacson and Jorgensen, Sweden, 1987
Quick bottle			Virginia Highway and Transportation Research Council (Maupin 1980)
Boiling water	D3625		Tex 530-C Kennedy et al. 1984
Rolling bottle Net adsorption			Isacson and Jorgensen, Sweden, 1987 SHRP A- 341 (Curtis et al. 1993)
Surface energy			Thelen 1958, HRB Bulletin 192 Cheng et al., AAPT 2002
Pneumatic pull-off			Youtcheff and Aurilio (1997)

* No longer available as ASTM standard.

**Table (2-3) Moisture Sensitivity Tests on compacted Samples
(Solaimanian, 2003)**

Test	ASTM	AASHTO	Other
Moisture vapor susceptibility			California Test 307 Developed in the late 1940s
Immersion-compression	D1075	T165	ASTM STP 252 (Goode 1959)
Marshal immersion			Stuart 1986
Freeze-thaw pedestal test			Kennedy, 1982
Original Lottman indirect tension			NCHRP Report 246 (Lottman 1982); Transportation Research Record 515 (1974)
Modified Lottman indirect tension		T 283	NCHRP Report 274 (Tunnicliff and Root 1984), Tex 531-C Isacson and Jorgensen, Sweden, 1987
Tunnicliff- Root	D 4867		NCHRP Report 274 (Tunnicliff and Root 1984)
ECS with resilient modulus			SHRP - A-403 (Al-Swailmi and Terrel 1994)
Hamburg wheel tracking			1993 Tex-242-F
Asphalt pavement analyzer			
ECS/SPT			NCHRP 9-34 2002-03

2.3 Bitumen Emulsion

Bitumen emulsion is a dispersion of fine minute droplets of bitumen into water manufactured by using emulsifying agents to emulsify bitumen in water. These liquids are coexistent instead of mutually mixed, in contrast from solutions. The main purpose of using bitumen emulsions is to produce asphalt mixtures without any heating (Ojum, 2015).

(James, 2006) and (Akzo Nobel, 2008) define the bitumen emulsion as the dispersion of fine droplets of one liquid in another, in most emulsions water is one of these liquids. Hence, in the status of emulsified asphalt, although emulsifying agents are normally added to ease the stability, these are asphalt, which is a liquid with a high viscosity, and water.

Normally, the droplets are in the order of 1 to 20 μm in diameter with the majority less than one micron and the largest volume or mass between 5 and 10 gm, in good quality bitumen emulsions. The bitumen content is normally in the region of 60 to 70 %, but can be as low as 40 % or as high as 80 %. The globules of bitumen are termed the disperse phase, as they are discrete droplets, and the water is the continuous phase in which the droplets are suspended. At ambient temperatures bitumen emulsions are in a very fluid condition (Salomon, 2006, James, 2006).

When bitumen is grind into very fine particles and scattered in the water with a chemical emulsifier, it becomes a bitumen emulsion. (Asphalt Institute and Asphalt Emulsion Manufacturers Association, 1997), as shown in Figure (2-7).

(Akzo Nobel, 2008) and (James, 2006) showed that, there are three main groups of emulsion namely oil-in-water (O/W), water-in-oil and double phase emulsions. In oil-in-water emulsion type, the continuous phase is water when the dispersed phase is an oily water-insoluble liquid. Otherwise, water-in-oil (W/O) emulsions type the continuous phase is oil when the dispersed phase is water, and this type of emulsions sometimes called inverted emulsions.

Furthermore the multiple phase emulsions can be created, in this type the scattered droplets themselves include smaller droplets of a third phase, commonly, the same liquid as the continuous phase. The three main groups of emulsions are shown in Figure (2-8). Bitumen emulsions are normally of the first type (oil-in-water) (Oke, 2011).

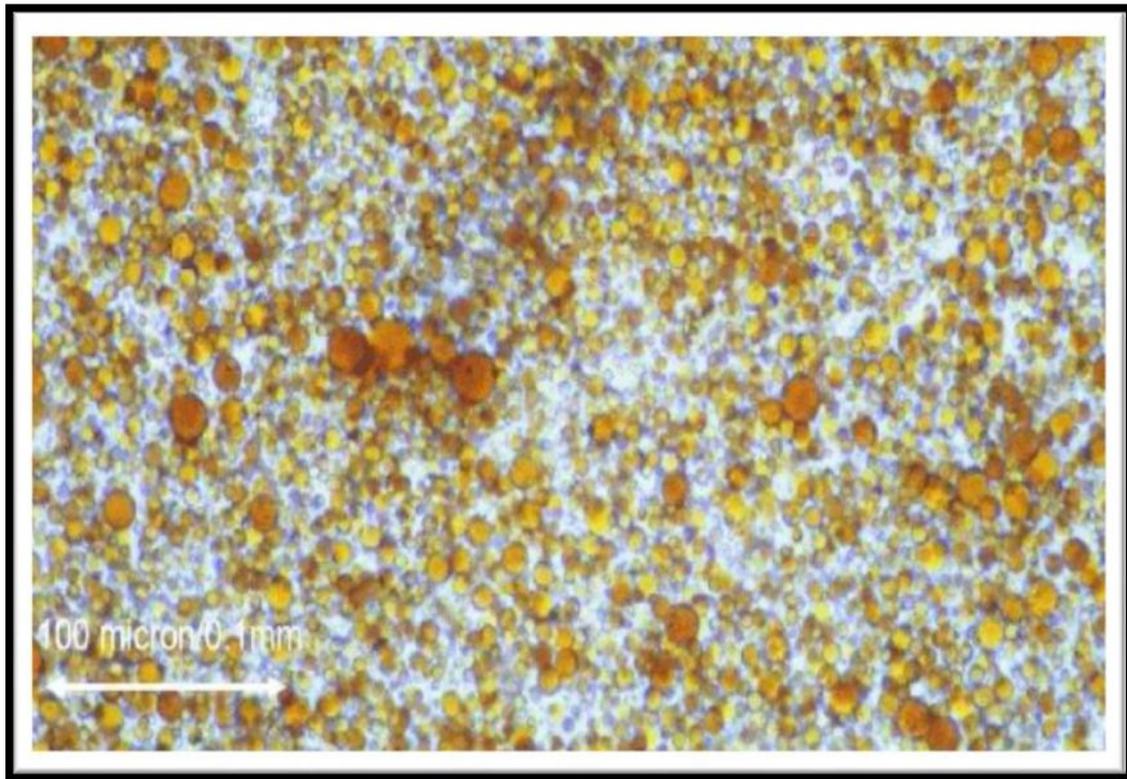


Figure (2-7) Photomicrograph of a Bitumen Emulsion (James, 2006, Oke, 2011)

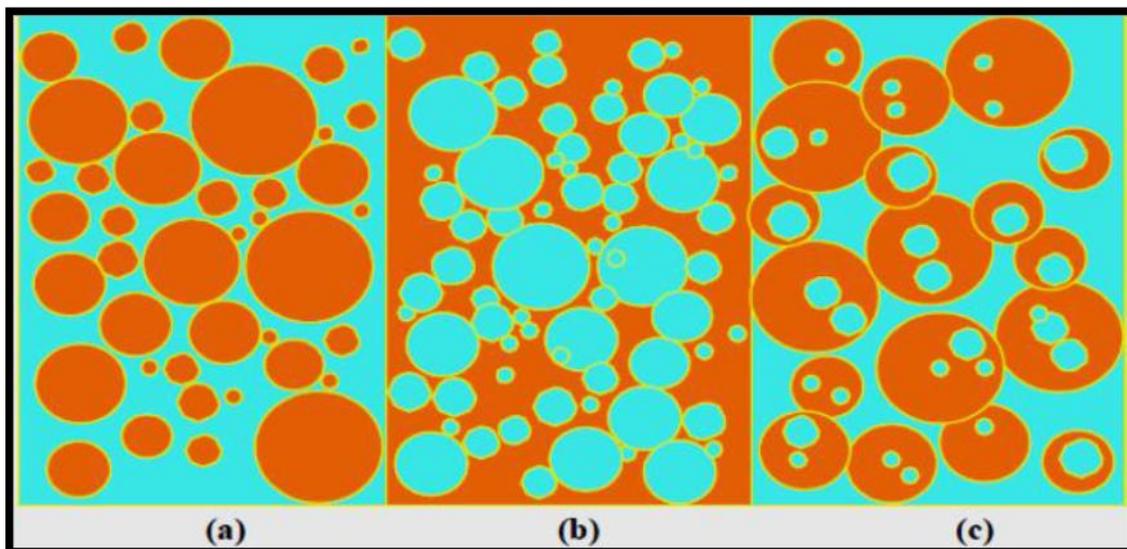


Figure (2-8) Emulsions cases (a) O/W (b) W/O (c) W/O/W (Salomon, 2006)

2.3.1 Bitumen Emulsion Components and Manufacturing

For the manufacture of emulsified asphalt three main elements are used, namely bitumen, water and emulsifier (AI & AEMA, 1997).

- **Bitumen**

Depending on the climate, the grade of base bitumen normally used for manufacturing emulsions can be ranged from 40 to 200 penetration. Harder binders are more suitable in hotter climates. The quality of the bitumen can affect the properties of the emulsion.

- **Emulsifiers**

There is more than one role for the emulsifier, it is very important to enhance emulsification, saves the emulsion stable, and the physical and chemical characteristics of the emulsion are fundamentally dependent on the chemical type and molecular weight of this component. The emulsifiers consist of two molecular groups: the first group is hydrophobic (non-polar part), which is dissolved in the bitumen, and the other group is hydrophilic, (polar part) which is dissolved in water. This unique arrangement enables the emulsifier to orientate itself amongst the bitumen soluble group which is hydrophobic and the water soluble group which is hydrophilic, as can be seen in Figure (2-9). The emulsifiers added separately to either binder or water, as a base or acid, or together as salts (Zgair, 2012).

(Read and Whiteoak, 2003) stated four main functions of emulsifiers, these are:

- Facilitates the emulsification process by decreasing the tension between bitumen and water.

- Specified if the emulsion is a water-in-oil or oil-in-water type.
- Prohibition coalescence of droplets that made the emulsion stabilizer.
- Affect the performance characteristics of the emulsion such as setting rate and adhesion.

There are four groups of emulsifiers, namely Anionic Emulsifiers, Cationic Emulsifiers, Nonionic Emulsifiers, and Colloidal Emulsifiers (Salomon, 2006).

The first two of these emulsifiers are most widely used. Anionic emulsions are usually alkaline, with a pH value higher than 7, with a negative electrical charge. Meanwhile Cationic Emulsions are acid emulsions with $\text{PH} < 7$, with a positive electrical charge. Worldwide, cationic emulsifiers are produced in greater quantities than anionic emulsifiers (Button et al., 2007).

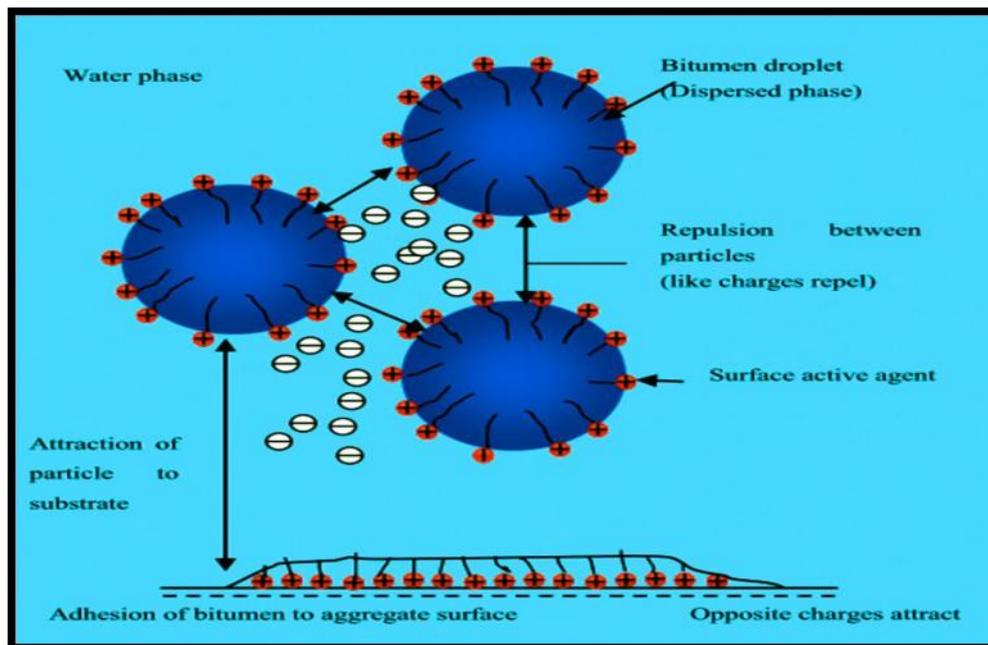


Figure (2-9) Schematic diagrams of charges on bitumen droplets (Read and Whiteoak, 2003).

Bitumen emulsion can be manufactured either by batch plant or by in-line or continuous plant as shown in Figure (2-10) and (2-11) respectively.

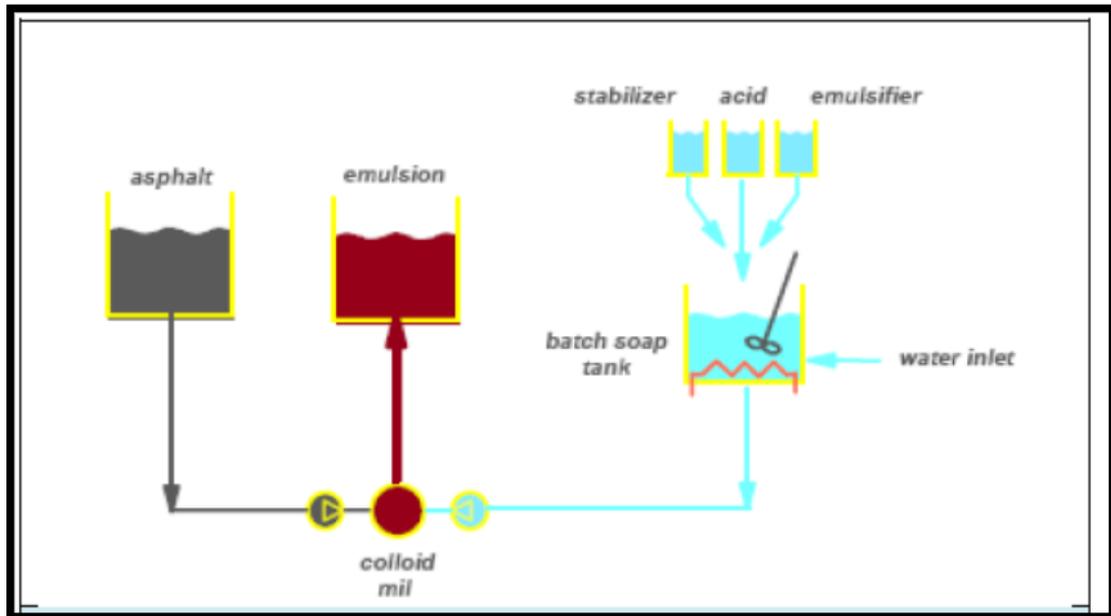


Figure (2-10) Schematic Diagrams of Batch Emulsion Plant (Ojum, 2015)

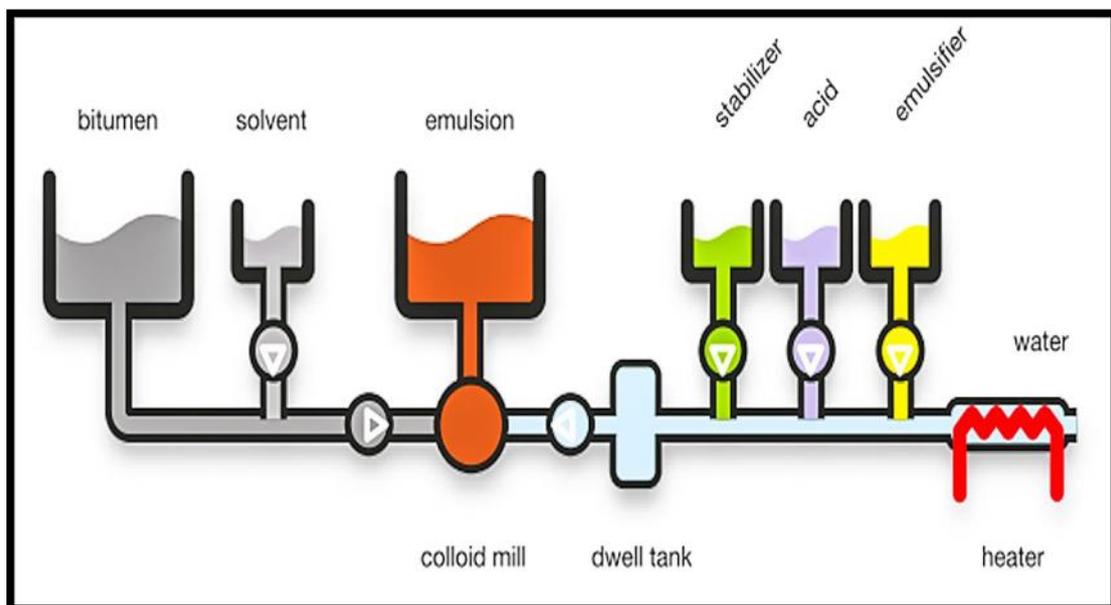


Figure (2-11) Schematic Diagrams of Continuous Emulsion Plant (Ahmed, 2016)

Other Bitumen Emulsion Components

Normally, some components are added to the bitumen emulsion to improve or control some of characteristics during manufacturing it. The most important of these components and their role are summarized below (Al-Busaltan, 2012).

- **Stabilizers:**

Stabilizers are used to control swelling of bitumen droplets that results from salt found with base bitumen. The insufficient desalting of the crude oil leads to leftover salt, and osmosis action leads to swelling. In a cationic system, about 0.05-0.2% calcium chloride (CaCl_2) or other soluble salts added into the water phase of the emulsion (as a stabilizer) to help in reducing osmosis of water into the bitumen. CaCl_2 can also increase the density of water this lead to reduce the settlement of emulsions, and in many cases CaCl_2 enhance the performance of emulsifiers (Akzo Nobel, 2008). In an anionic system, 'trisodium polyphosphate' can be used (Al-Busaltan, 2012)

- **Solvent:**

High bitumen density may cause settlement of base bitumen, followed by coagulation during the emulsion's static storage. Adding up to 15% of a high boiling point solvent such as kerosene to bitumen can control this problem (Salomon, 2006).

- **Acids:**

Acid is used to form salts from the emulsifier and for adjusting the pH to a predetermined level. Hydrochloric acid is used for cationic systems, and sodium hydroxides for anionic systems.

- **Latex:**

Polymer in bitumen can improve and increase the cohesion of bitumen, resistance to flow at high temperatures, and resistance to cracking at low temperatures. Latex principally improves emulsions as it is water based for dispersion. It can be included either in the water or bitumen phases, as well as being added to final emulsions. Although latex is used successfully with cationic, anionic and non-ionic emulsions, it should be compatible with the emulsion type (Al-Busaltan, 2012).

- **Adhesion Promoters:**

The final emulsion in mixtures and seals should be water resistant, so adhesion promoters are added to improve the adhesion of the cured emulsion film between aggregates. Generally, surface active amine compounds are added to the bitumen phase or to the finished emulsion as adhesion promoters (Al-Busaltan, 2012).

- **Thickeners:**

Thickeners are generally used to increase the viscosity of the emulsion, which leads to reduced runoff of emulsion, especially when used in open graded mixtures. The addition of the thickeners can be to the finished emulsion or to the water phase, usually with a dosage between (0.02–0.20) %. Practically, thickeners are found to affect the breaking and adhesion of emulsions, so they must be chosen with some care (Al-Busaltan, 2012).

2.3.2 Types of Emulsions

The three major groups of emulsion are anionic, cationic, or non-ionic, (AI & AEMA, 1997). Anionic emulsions in which the bitumen

droplets have a negative charge, whereas for cationic emulsions, the particles have positively charged, non-ionic emulsions have no charge on the bitumen droplets.

A fourth category referred to as clay-stabilized emulsions can be added to the types of emulsion. Normally, the anionic and the cationic emulsions are the most commonly used in the road construction (Needham, 1996; Thanaya, 2003; Read and Whiteoak, 2003; James, 2006).

According to ASTM (D2397) and (D977), the codes CRS, CMS, CQS, and CSS indicate for Cationic emulsions, whereas the codes RS, MS, QS, and SS indicate for anionic emulsions. The emulsion viscosity and residue properties are denoted by numbers and text attached to the codes as shown in Figure (2-12) and Table (2-4). This is to further simplify and standardize its use

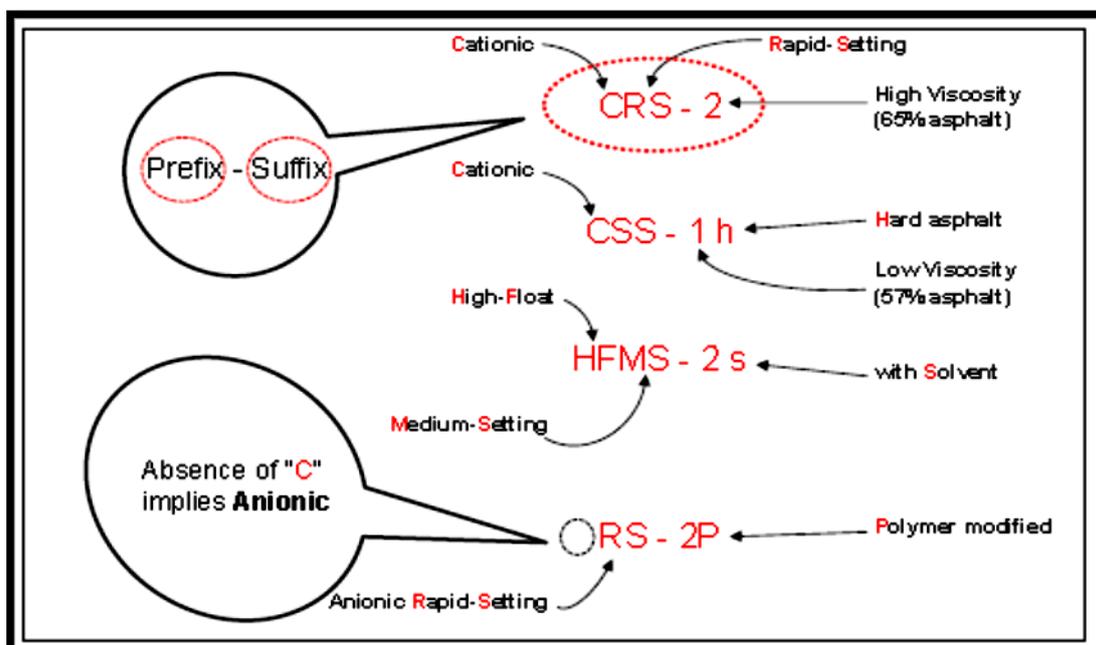


Figure (2-12) Classifications of Emulsions (AI & AEMA, 1997).

Table (2-4) Emulsion Types (Ebels, 2008)

Head Group Charge	Grade ASTM D977, Anionic ASTM D2397, Cationic	Type	Denotation
Anionic	Rapid Setting	Spray	RS
	Medium Setting	Pre-mix	MS
	Quick Setting	Stable-mix	QS
	Slow Setting	Stable-mix	SS
Cationic	Rapid Setting	Spray	CRS
	Medium Setting	Pre-mix	CMS
	Quick Setting	Stable-mix	CQS
	Slow Setting	Stable-mix	CSS

2.3.3 Uses of Bitumen Emulsion

Worldwide bitumen emulsions have been used successfully in different applications such as cold mix asphalt, fog seal, Soil stabilization, Slip coats, Protective coats, and others (Asphalt Institute MS-14).

Table (2-5) illustrates the typical uses of bitumen emulsion (AI & AEMA, 1997).

2.3.4 Factors Affecting Quality and Performance of Bitumen Emulsions

There are many factors that can affect the production, storage, handling, use and performance of bitumen emulsions.

(AI&AEMA, 1997) stated that these factors could significantly affect the performance and quality of the bitumen emulsions either in a positive or negative manner and they include:

- Chemical characteristics of the base bitumen
- Hardness and quantity of the base bitumen
- Particle size of bitumen in the emulsion
- Type and concentration of the emulsifying agent
- Manufacturing conditions such as temperature, pressure and shear
- Ionic charge on the emulsion particles
- Order of addition of the ingredients
- Type of equipment used in manufacturing the emulsion
- characteristics of the emulsifying agent
- Addition of chemical modifiers or polymers
- Water quality (hardness).

They, however, opined there is no good substitute for a laboratory evaluation of the emulsion and the aggregate to be used.

2.3.5 Curing and Breaking of Bitumen Emulsion

2.3.5.1 Breaking of Bitumen Emulsion

Based on the basic law of electricity that states that like charges repel each other while opposite charges attract, if the electrostatic charges on the bitumen particles are opposite to that of the aggregate surface, electrical attraction will take place. The bitumen particles then start to migrate to the aggregate surface. This migration will cause the emulsion to ‘break’ and start to separate into its original components: water and bitumen. The breaking of emulsion depends highly on the type and concentration of the emulsifying agent as stated by (Das, 2008).

The ability of the bitumen emulsion to break facilitates effective coating of the aggregate particles or pavement surfaces. The rate at which emulsions break depends on its use and mode of application. The

breaking of bitumen emulsions is usually characterized by a change in color from brown to black as announced by (Oke, 2011).

Table (2-5) Typical Uses of Bitumen Emulsion (AI&AEMA, 1997)

Type of Construction	ASTM D 977 AASHTO M 208									ASTM D 2997 AASHTO M 140					
	RS-1	RS-2	HFRS-2	MS-1, HFMS-1	MS-2, HFMS-2	MS-2h, HFMS-2h	HFMS-2s	SS-1	SS-1h	CRS-1	CRS-2	CMS-2	CMS-2h	CSS-1	CSS-1h
Asphalt-Aggregate Mixtures:															
Plant Mix (Hot or Warm)						X ¹									
Plant Mix (Cold)															
Open-Graded Aggregate					X	X									
Dense-Graded Aggregate							X	X	X					X	X
Sand							X	X	X					X	X
Mixed-in-Place															
Open-Graded Aggregate					X	X						X	X		
Well-Graded Aggregate							X	X	X					X	X
Sand							X	X	X					X	X
Sandy Soil							X	X	X					X	X
Asphalt-Aggregate Applications:															
Single and Multiple Surface Treatments	X	X	X							X	X				
Sand Seal	X	X	X	X						X	X				
Slurry Seal							X	X	X					X	X
Micro-surfacing															X ²
Sandwich Seal		X	X								X				
Cape Seal		X									X				
Asphalt Applications:															
Fog Seal				X ³				X ⁴	X ⁴					X ⁴	X ⁴
Prime Coat					X ⁵			X ⁵	X ⁵					X ⁵	X ⁵
Tack Coat				X ³				X ⁴	X ⁴					X ⁴	X ⁴
Dust Palliative								X ⁴	X ⁴					X ⁴	X ⁴
Mulch Treatment								X ⁴	X ⁴					X ⁴	X ⁴
Crack Filler								X	X					X	X
Maintenance Mix:															
Immediate Use								X					X	X	
Stockpile								X							
NOTES:															
1. Grades other than HFMS-2h may be used where experience has shown that they give satisfactory performance.															
2. Mixed-in prime only.															
3. Diluted with water by the manufacturer															
4. Diluted with water															
5. Mixed-in prime only.															

Fundamentally, the accurate chosen of emulsifier type and its concentration, bitumen droplet size, and emulsion pH, lead to get the optimum balance between breaking rate and stability. The charge on the emulsion is another factor as anionic emulsions work most effectively with positively charged aggregates that include limestone and marble. Though the evaporation of water can be obviously quick under proper conditions, the breaking and curing processes strongly tend to relate to the evaporation of the water occurrence, which has a direct implication on the breaking and curing rates. The breaking of cationic bitumen emulsions occurs through the electrochemical process, therefore the breaking rate of these emulsion types less dependent on weather conditions (Al-Busaltan, 2012; Ojum, 2015).

The breaking occurs when the emulsion touches the aggregate's surface, and the breaking rate depends on the next factors (Needham, 1996)

- The amount and type of emulsifier
- Nature of the aggregate and their specific area
- Nature of fine aggregate
- The quantity of water that added to the aggregate
- Ambient temperature (evaporation rate)
- Size of bitumen droplets and percentage of binder.

2.3.5.2 Curing of Bitumen Emulsion

Curing involves the development of cohesion (Congress, 2014).

Bitumen emulsion is completely cured when the water and/or any volatile oils have driven out and cohesive bond strength is established between the binder and aggregate. The water can be removed through evaporation,

pressure (rolling) and by absorption into the aggregate. Evaporation of the water is extremely dependent on weather conditions and it is difficult for bitumen emulsions to properly cure when submitted to low temperatures, high humidity, and rainfall quickly after construction. Curing facilitates the development of mechanical and performance properties of the mixture (Ojum, 2015).

The major factors that influence on the breaking and curing process of bitumen emulsions include the type and amount of emulsifier, weather conditions as warmer temperatures are favorable to the breaking of bitumen emulsions which facilitates curing (Ojum, 2015). Figure (2-13) illustrates the breaking, setting and curing stages of bitumen emulsions.

Asphalt Institute (MS-14) Select the curing protocol for CMA in an oven at 38 C for 24 hours.

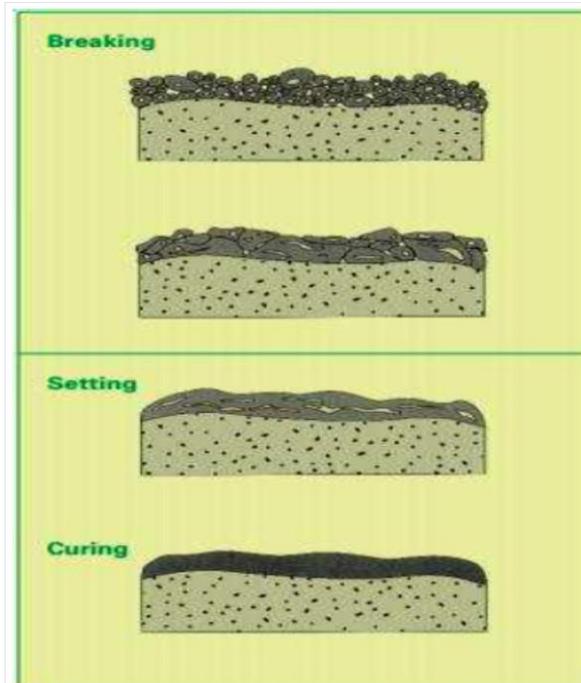


Figure (2-13) Major Stages for Bitumen Emulsions Curing (Al-Busaltan, 2012)

2.3.6 Adhesive of bitumen emulsion

The adhesion between bitumen emulsion and aggregate is highly dependent upon the maximum contact area achieved by the bitumen emulsion. In most applications, the aggregate surface needs to be slightly wet to ensure easy spreading of emulsion on the aggregate surface and better overall coating. The adhesion or bonding between aggregate and emulsion are influenced by a number of factors such as: (Al-Busaltan, 2012)

- The types and content of emulsifiers
- The bitumen grade and chemical composition of the emulsion
- The pH of the emulsifier solution
- The particle size distribution of the bitumen particles through the emulsion
- The aggregate type

Theoretically, adhesion between aggregate and emulsion should be better when they have reverse charges. Accordingly, anionic emulsions are more suitable for limestone or basalt aggregates which have positive charges, whereas cationic emulsions should be used with granite or quartzite aggregates which have negative charges. Practically, cationic emulsions were shown to have a good affinity with all types of aggregates. Furthermore, cationic emulsifier was shown to have an anti-stripping action; in other words, the mixtures that used cationic emulsion were more durable than the ones that used anionic emulsion (Al-Busaltan, 2012).

2.4 Cold Mix Asphalt CMA.

Generally, the graded mineral aggregates and the liquid bitumen are the main components of cold bituminous mixtures, it can be mixed and compacted at ambient temperature, without needed for heating. At room temperature, straight run penetration grade bitumen suitable for pavement applications generally have high viscosity, (i.e. are relatively hard semisolid) (Thanaya, 2003).

There are several ways of reducing bitumen viscosity, namely: by mixing with flux oil (cut back bitumen), by foaming (foamed bitumen), and by emulsification (bitumen emulsion). There are many advantages recognized for using cold bituminous mixtures such as, energy provision, environmental friendship, and simplicity in production, because the production of such mixtures lead to reduction or non emission of gases to the atmosphere (Thanaya, 2003).

The cold mix can be used to serve a range of different applications regimes, at most, for base course, binder course, or wearing course (Needham, 1996).

There are many types of cold bituminous mixtures, the commonly used are Grave Emulsion, Cold Lay Macadam, Foamed Bituminous Mixtures, and Cold Bituminous Emulsion Mixtures (Thanaya, 2003).

While other types of cold bituminous mixtures are detailed in literature, this research work will focus on Cold Bituminous Emulsion Mixtures (CBEMs).

2.5 Cold Bituminous Emulsion Mixtures (CBEMs).

Bitumen emulsions are mixed with mineral aggregates producing the Cold Bituminous Emulsion Mixtures (CBEMs). The CBEM industry is interested in preparation, e.g. A simple, less energy consumption and fewer emissions. But, the resultant CBEM has low early strength, thus it has been used in limited applications such as low/medium low trafficked roads, footways and reinstatements (Read and Whiteoak, 2003).

CBEMs can be used for heavily trafficked roads when overlaid by at least 40 mm of hot bituminous mixture layer (Al-Busaltan, 2012).

Previously, open or semi-dense aggregate gradation was used in the preparation of CBEMs, to allow suitable aeration within the higher air void mixture, facilitate evaporation of the trapped water and reduce curing time (Nikolaides, 1983).

Recently, even dense gradation has been used due to the modification and improvement in emulsion production technology and mixing techniques (Thanaya, 2003).

Cold Bituminous Emulsion Mixtures may consist of continuously graded or gap graded aggregate gradations and bituminous emulsions. These mixtures can be mixed at 'ambient' temperatures. The characteristics of the final CBEMs are significantly dependent on bitumen emulsion, aggregate gradation characteristics, and added water. The breaking mechanism of the emulsion and the compact-ability of the mixture determine the behavior of the mixture in service. The breaking of the emulsion during curing covers the total evaporation of water, followed by an effective distribution of the mixture's components and coating of the aggregate by the bitumen emulsions (Al-Busltan, 2012).

The CBEMs production process has three steps, as follows (Al-Busltan, 2012):

- i. The first step is the preparation and mixing of the emulsion with the aggregates. The emulsion should be stayed quietly stable and it should cover or coat the aggregates.
- ii. The second step is the store or laying of the mixed materials. The emulsion should remain workable and be slightly set at this stage. Also the emulsion should be having an adequate viscosity, to un-drained after blending with the aggregates.
- iii. The last step of (CBEMs) production is compacted the mixture, in this stage the emulsion should break quickly, to be able to back to its original base bitumen.

Generally, to obtain the ultimate strength of the mixture, the evaporation of the volatiles in emulsions requires long time for curing, (Nikolaides, 1983). This is according to lower early life strength desired to attain the maximum performance (at most, because of the trapped water) and due to high air voids (Thanaya et al., 2009).

2.6 Advantage and Disadvantage of CMA

2.6.1 Advantage of CMA

The use of CMA has many advantages, such as: (Ahmed, 2016)

- CMA is relatively consumed less energy than HMA, where the use of HMA demand to dry the materials before the binder added, that require more power and electric.
- Because of the less fuel consumption the production and laying of CMA relatively less emissions than other technologies.

- Health, the construction pavement of CMA is less fuel, less emission, less machinery required, and less noise.
- Safety, there was no required heating of materials before and during the preparation process, so CMA technology more safety.
- From the what mentioned above CMA is representing an environmentally friendly product. Also, can use the reclaimed aggregate in CMA mixture.
- Transportation, CMA can prepare in site, so less transportation is required. Additionally, before using and compaction of CMA, can be stored or stockpile.

2.6.2 Disadvantage of CMA

Unluckily, The use of CMA has some disadvantages, such as: (Ahmed, 2016)

- Weak early life strength of paving because of trapped water between binder film and aggregate.
- Long curing time is required to achieve ultimate strength.
- The air void content is high.
- For some mixture, before mixing of the emulsion, the materials should be wetted for coating purpose.

2.7 Mix Design of CMA

The main objective of a mix design is to produce mixtures that achieve their structural and functional requirements.

(Thanaya, 2007) stated the basic underlying principle design procedure for cold mix such as:

- Determine suitable aggregate gradations.
- Evaluate properties of the aggregate materials.
- Select type and amount of stabilizing agents.
- Aggregate - binder affinity/suitability (binder coating tests).
- Determine the design water content at compaction.
- Determine the design bitumen content.
- Mixture, compaction and testing of trial mixture.
- Establish a job mix formula.
- Testing of mechanical and performance properties.
- Field trials.

Table (2-6) illustrated the mix design approaches adopted in various specifications and organizations.

Table (2-6) Mix Design Approach Adopted in Various Specifications/Organizations (Ojum, 2015)

Specification/Organisation	Country	Category
NARC 96-I-III	Australia	Recipe/Volumetric/Performance related
ASTO/PANKTM95	Finland	Recipe/Volumetric/Performance related
AFNOR	France	Recipe/Volumetric/Performance related
DIN	Germany	Recipe/Empirical
CROW	The Netherlands	Volumetric/Performance related
BS 594/598	UK	Recipe/Empirical
Asphalt Institute	USA	Empirical/Volumetric
SHRP Superpave	USA	Volumetric/Performance related/Performance Based

2.8 Effect of Additives on Cold Mix Asphalt

Generally, fillers play a prime role predominating the properties of asphalt mixtures. It can significantly impact the resistance of permanent deformation, the stiffness, the fracture resistance, and the moisture susceptibility of asphalt mixtures (Kim et al., 2003; Kim et al., 2008).

Many attempts have been investigated to improve cold mixes, some of these attempts were discussed in the literature.

(Du, 2015) was studying the effect of chemical additives on recycled mixture performance, including the composite Portland cement (CPC), the hydrated lime (HL), and the incorporation of (HL) and ground granulated blast furnace slag (GGBS). The effect of additives was investigated by volumetric and strength tests, rutting resistance test, moisture susceptibility test, and low temperature bending test. His results showed that the hydration products from CPC or the incorporation of HL and (GGBS) behave as additional binder materials, and the (CPC), (HL), and the incorporation of (HL) and (GGBS) can improve the moisture resistance and rutting resistance.

(Dulaimi et al., 2016) studied the cold asphalt binder course mixtures that containing binary blended cementitious filler (BBCF). They used filler materials (high calcium fly ash (HCFA) and a fluid catalytic cracking catalyst (FC3R)) to produce the binary blended. The result indicated that a very high early strength can be observed with binary blended filler, also the permanent deformation, the fatigue resistance, and the water sensitivity can be improved significantly due to the progressive hydration with the new binary filler.

(Nassar et al., 2016) studied the properties such as mechanical, durability and microstructure of cold asphalt emulsion mixtures with many types of filler, they were using the binary blended fillers (BBF) and the ternary blended fillers (TBF), the (BBF) produced from using ordinary Portland cement (OPC), ground granulated blast furnace slag (GGBS), and fly ash (FA), whereas (TBF) produced by adding silica fume to (BBF). The durability and the mechanical results stated that the TBF was more appropriately microstructural assessed. Also, illustrated that was slightly negative influence of (BBF) of the internal microstructure and more noticeable in CAEMs containing FA.

(Niazi and Jalili, 2009) investigated the properties of cold in-place recycled (CIR) mixtures by using Portland cement and lime additives, they illustrated that the Marshall stability, resilient modulus, bulk specific gravity, and tensile strength were increased with addition of Portland cement and lime. Whereas, the void content and flow of the recycled mixtures reduced when Portland cement and lime was added. Also, stated that Marshall stability ratio (MSR) and a tensile strength ratio (TSR) results show that the using of Portland cement and lime can increase the resistance to moisture damage of (CIR) mixtures, moreover, the permanent deformation of recycled mixtures can be reduced and the rut depth decreased by using of Portland cement and lime.

(Al-Busaltan et al., 2012) utilized a waste domestic fly ash namely (LJMU-FA1) in the CBEM's to improve the Indirect Tensile Stiffness Modulus and the Creep Stiffness. The results stated a relative enhancement for these properties of the new cold mixtures. Also, they stated the using of (LJMU-FA1) in the CBEMs significantly enhanced water sensitivity. Moreover, with high content of (LJMU-FA1) can see having higher than 100% stiffness modulus ratio.

(Al-Hdabi et al., 2013) conducted a study on the evolution of cold rolled asphalt (CRA) mixtures by using waste fly ash (WFA) and by-product silica fume (SF). They used (WFA) as an alteration for traditional filler and (SF) used as the additive materials to improve the mechanical and the durability properties of (CRA) containing (WFA). The results showed that (WFA) enhance the mechanical and the durability properties of (CRA) significantly, and the increment of SF improves the primary strength, the long-term strength, and the durability of (CRA).

(Dash, 2013) examined the effect of cement, fly ash, and hydrated lime on the performance and the design of cold mix asphalt and stated that though the used of fly ash, lime and cement improved the stability value, but the performance of mix modified with cement is observed to be the superior in every aspect.. Comparing lime and fly ash as substituted for filler, greater stability, but the higher air void content is noticed in case of cold mixes modified with lime.

(Kim et al., 2012) studied the evaluation of anti-stripping additives in bituminous mixtures through multiple scale laboratory test results. Two additives (hydrated lime and fly ash) were used by adding them into two types of mixes, the results indicated that both hydrated lime and fly ash reducing moisture damage.

(Al-Busaltan, 2012) used by-product and waste materials as filler and/or activator in CBEMs, he used Paper Sludge Ash (PSA), silica fume (SF), and other materials to improve the mechanical properties and the durability of CBEMs. The results showed that the silica fume added further improvement to CBEM comprising (Ordinary Portland Cement)OPC or PSA, it played a main role in activating the PSA within the mix and accelerating the hydration process, also, a significant

improvement in mechanical and durability properties of CBEMs was shown when used a low percentage of silica fume.

2.9 Summary

Many factors influence the moisture susceptibility in asphalt mixture, these can be concluded from the research presented in the literature. These factors are such as characteristics of asphalt binder, characteristics of aggregate, type and the use of the mix, the environmental condition throughout and after construction, and the utilized of anti-stripping additives. Furthermore, the cold mix asphalt may be containing trapped water between binder and aggregate and high air voids content which makes it more susceptible to stripping.

Most studies mentioned that there were different factors including porosity of the mix, base bitumen grade, curing time and additives influence the mechanical properties of (CBEMs) so many researches were designed to use the additives materials as filler and/or activator materials such as Ordinary Portland cement (OPC), Paper Sludge Ash (PSA), Pulverized Fuel Ash (PFA), Granulated Ground Blast Furnace Slag (GGBS), Biomass Fly Ash (BFA), Silica Fume (SF), hydrated lime (HL), and others that were used at different percentages to improve the mechanical properties and durability of (CBEMs).

The current study was designed to use three types of additives principally to improve the moisture sensitivity of cold bitumen emulsion mixtures (CBEMs), these additives are namely hydrated lime at (1, 1.5, 2) %, fly ash at (1, 2, 3) %, and silica fume at (1, 2, 3) % of the weight of the mixture as a replacement of the main filler which was limestone dust.

CHAPTER THREE

METHODOLOGY

AND EXPERIMENTAL WORK

CHAPTER THREE

METHODOLOGY AND EXPERIMENTAL WORK

3.1 Generals

The methodology and experimental work that consists of preparing and testing materials, preparing samples according to the Superpave mix design system (Mohsin, 2016), and testing them for durability and moisture damage evaluation were illustrated in this chapter. Figure (3-1) presents a flow chart of this research

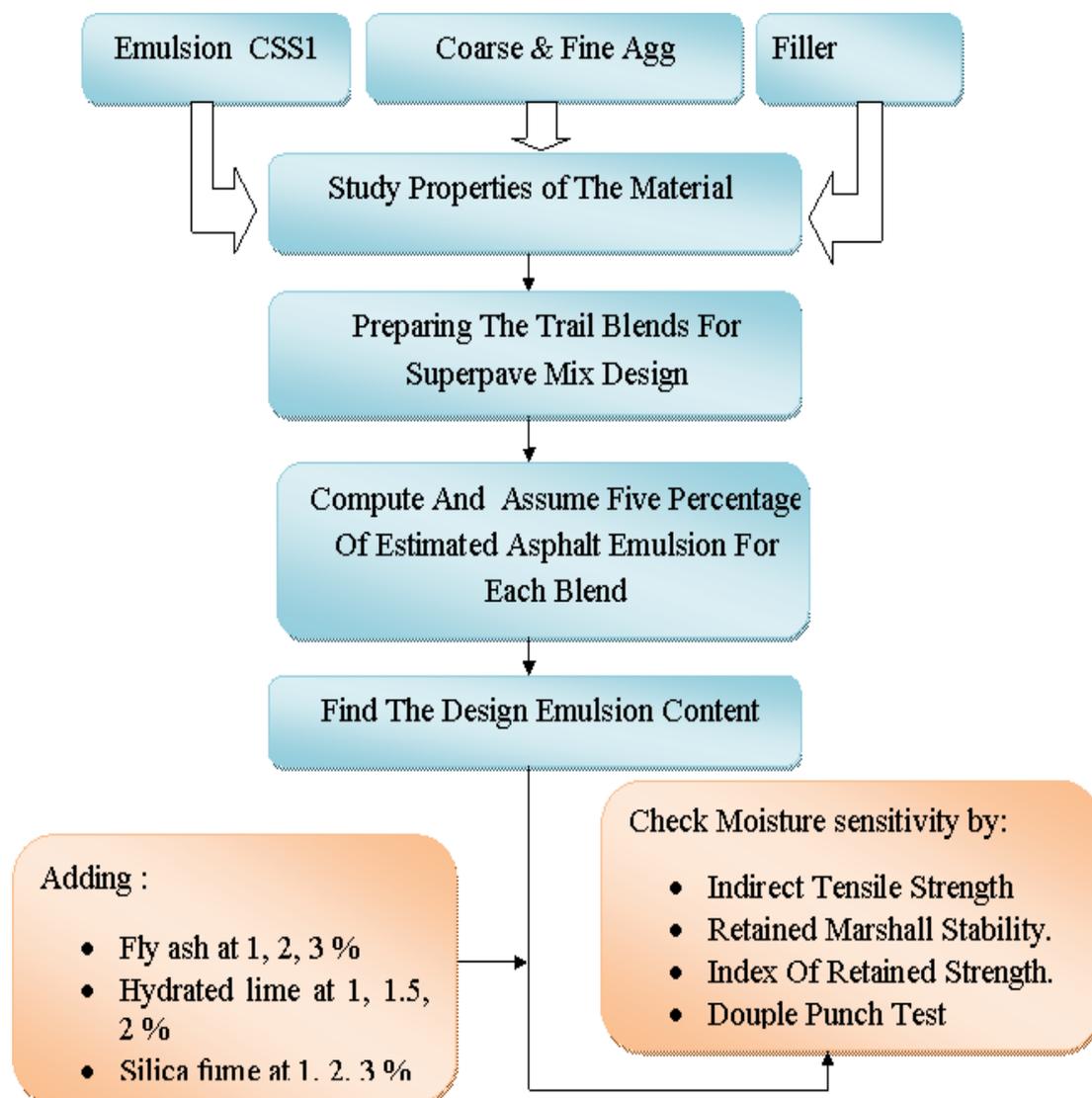


Figure (3-1) Methodology of Experimental Works

3.2 Materials

3.2.1 Coarse and Fine Aggregate:

The coarse and fine aggregate used in this work was crushed gravel brought from locally asphalt mix plant existing in Jurf Al Naddaf, where its source was Al-Nibaai quarry. This type of aggregate is largely used by the Baghdad City for asphalt mixtures. The aggregate size ranged from 25.0mm (1 in) to 4.75mm (No.4 sieve) for coarse aggregate and 4.75mm (No.4) to sieve 0.075mm (No.200) for fine aggregate. The chemical composition of crushed aggregate used is summarized in Table (3-1). While Table (3-2) presents the physical properties of the coarse and fine aggregate.

Table (3-1) Results of Chemical Properties of coarse Aggregate

Chemical Composition	Content %
Silica, SiO ₂	80.73
Lime, CaO	6.77
Magnesia, MgO	0.63
Sulfuric Anhydride, SO ₃	2.3
Alumina, Al ₂ O ₃	0.66
Ferric Oxide, Fe ₂ O ₃	0.98
K ₂ O	0.53
Loss on Ignition	6.3
Total	98.9

* Test was conducted by Directorate of Materials Research.

3.2.2 Filler

Fillers are added within construction materials to improve the properties of the mix. Four types of fillers were used in this study, namely, limestone dust from the local market for control mixture, hydrated lime (HL), fly ash (FA), and silica fume (SF) from the local market as an anti-stripping materials. The physical properties of all types

of fillers are shown in Table (3-3) whereas Table (3-4) presents the chemical compositions of them.

Table (3-2) Results of Physical Properties of Selected Aggregate

Laboratory Test		ASTM Specification	Results			
Specific gravity	Coarse aggregate	ASTM C127	Retained on sieve	Bulk Gs	App. Gs	Absorbtion %
			3/4"	2.621	2.657	0.5%
			1/2"	2.635	2.664	0.4%
			3/8"	2.645	2.649	0.6%
	Fine agg.	ASTM C128	Crashed sand (<#4)	2.663	2.691	0.4%
Angularity for Coarse aggregate*		ASTMD 5821 Min 90%	93 %			
Soundness for Coarse aggregate*		ASTM C88 10-20% Max	4.3 %			
Flat & Elongation for coarse aggregate*	Flat	ASTM D4791 Max 10%	0 %			
	Elongation		0 %			
Toughness By (Los Angeles Abrasion)	Aggregate Size < 25 mm	ASTM C131 35% Max	21.1 %			
Equivalent sand for fine aggregate (clay content) *		ASTM D2419 Min 45%	96 %			

* Tests were conducted by the National Center for Construction Laboratories and Researches (NCCLR).

Table (3-3) Physical Tests of Fillers

Physical Tests	Limestone dust	HL	FA	SF
Specific Gravity	2.72	2.63	2.27	2.42
% Passing Sieve No.200 (0.075mm)	92%	90%	95.5%	96%

Table (3-4) Results of Chemical Composition of Fillers

Chemical Composition	Limestone dust	HL	FA	SF
Silica, SiO ₂	4.06	1.88	57.76	90.04
Lime, CaO	47.48	67.9	1.35	1.9
Magnesia, MgO	0.91	0.45	0.5	0.01
Sulfuric Anhydride, SO ₃	5.4	0.56	0.5	0.24
Alumina, Al ₂ O ₃	1.02	0.38	19.45	1.03
Ferric Oxide, Fe ₂ O ₃	3.02	0.23	6.42	0.01

* Tests were conducted by the Iraq Geological Survey.

3.2.3 Emulsified Asphalt

The Cationic emulsified asphalt, Slow-Setting with low viscosity (CSS-1) was used in this study, this type was brought from MEGA INSAAT (Turkish company), its common utilization as a liquid binder everywhere in the world due to its compatibility with a wider zone of aggregate. Slow setting emulsions enable the production of mixtures with enough degree of coating and sufficient workability, due to its slow setting, remain workable for a certain time during mixing.

Some tests are carried out on emulsified asphalt to determine both their consistency and quality to ascertain whether it meets the specifications or not. These tests are designed to measure performance qualities, composition, consistency, and stability of the material. The results of these tests were compared with ASTM specifications (D2397).

The various physical tests for asphalt emulsion were conducted in the University of Technology, Building and Construction Department, asphalt laboratory and others conducted in Laboratories of the National Center for Construction Laboratories and researches (NCCLR), Highway Department and the manufacturer Laboratory as described in Table (3-5).

Table (3-5) Physical Properties of Cationic Slow Setting Low Viscosity Emulsified Asphalt (CSS-1)

Test	ASTM Designation (D244)	Test Result	Specification Limits (D2397) for CSS-1	
			Min.	Max.
Particle Charge Test *	D244	Positive	Positive	
Viscosity, Saybolt Furol at 25°C (77°F)	D244	24	20	100
Residue by Distillation, %.	D6997	53.1	57
Residue By Evaporation	D6934	52.7	50	70
Sieve Test, %	D6933	0.06	0.10
Cement mixing test, %	D6935	0.732	2.0
Settlement Test, 5day, %	D6930	0.4	0	1
1 Day Storage stability test, %	D6930	0.2	0	1
Tests on Residue				
Penetration, 25°C (77°F), 100 g, 5 s	D5	140	100	250
Ductility, 25°C (77°F), 5 cm/min,	D113	105	40
Solubility in trichloroethylene, % **	D2042	99	97.5
Specific Gravity at 25°C **	D70	1

* Test was conducted by the Manufactures Laboratory (MEGA INSAAT Company) of Asphalt Emulsion.

** Test was conducted by the National Center for Construction Laboratories and Researches (NCCLR).

Tests conducted in asphalt laboratory were done according to ASTM specifications (ASTM D244, 2000), It is important to point out that the cationic emulsion, as obtained from the factory, contained some large lumps. Therefore, this emulsion was sieved by using sieve NO.50 to

separate the lumps. Laboratory evaluation of selected emulsion was done and the results were compared with ASTM specifications (ASTM D2397), as shown in Table (3-5).

1. Emulsion Viscosity

The Saybolt Furol viscosity test is used as a measure of viscosity. Viscosity has significance in the use of emulsified asphalt because it is a property which affects their utility. The Viscosity of an emulsion should be low enough to enable easy handling, pumping, spraying, and mixing. The result obtained from the Saybolt Furol viscosity (24) seconds at 25°C where these values are within the ASTM limits (ASTM D2397) as shown in Table (3-5).

2. Distillation Test for Emulsions

Distillation is used to separate the water from the asphalt. The relative proportions of asphalt cement, water, and oil in the emulsion can be measured after the distillation has finished. The distillation test for asphalt emulsion was done by using an aluminum alloy still and ring burners. Firstly, weigh the glass-alloy still, then a 200 ± 0.1 g of a representative sample of the emulsion added to the glass. the distillation is done at 260°C for fifteen minutes. When the heating period ending, re-weigh the still and all accessories. Then, the percentage residue by distillation Calculated and report. The Distillation test result is (53.1%) as shown in Table (3-5), where this value is within the range adopted by the manufacture Company as listed in Table in (appendix A). However, this value is deviated from the limits of ASTM specification (ASTM D2397), and it is used in this study as available material.

3. Residue By Evaporation

This test method covers procedures for a relatively rapid determination of the percentage of emulsion residue. The test may be used to indicate compositional characteristics of emulsified asphalt. The percentage of residue can be calculated on each beaker as follows:

$$\text{Residue, \%} = 2(A-B) \quad (3-1)$$

Where:

A = weight of beaker, rod, and residue, gm, and

B = tare weight of beaker and rod, gm.

The test is conducted by evaporating the water. An average asphalt residue of (52.7%) was obtained. This value is within the specification limits (ASTM D2397), as shown in Table (3-5).

4. Sieve Test

This test method measures the degree to which emulsified asphalt may contain particles of asphalt or other discrete solids retained on 850 μm mesh sieve. The retention of an excessive amount of particles on the sieve indicates that problems may occur in handling and application of the material. In the sieve test, a representative sample of asphalt emulsion is poured through an 850- μm (No. 20) sieve. For cationic emulsions, the sieve and retained asphalt are rinsed with distilled water only. Record the weight of the sieve and pan. Weigh 1000 g of the emulsified asphalt into a suitable container and pour it through the sieve. Wash the container and the residue on the sieve with the distilled water until the washings run clear. Place the pan under the sieve and heat for 2 h in a 105°C drying

oven. Cool, and weigh the sieve, pan and residue. The percentage of samples retained on the sieve can be calculated as follows:

$$\text{Sample retained, \%} = (B - A)/10 \quad (3-2)$$

Where:

A= weight of sieve and pan, g, and

B= weight of sieve, pan, and residue, g.

The test is conducted by Sieve Test. An average asphalt residue of (0.06%) was obtained. This value is within the specification limits (ASTM D2397), as shown in Table (3-5).

5. Cement Mixing

This test method is a mixing test used to identify or classify a slow setting, SS or CSS, type of emulsion. The result of this test indicates the ability of a slow setting emulsified asphalt to mix with a finely divided, high surface area material (Type III Portland cement) without breaking the emulsion. In the field, the SS grades are often mixed with fine materials and dusty aggregates. Sieve a portion of the cement through the 180- μm sieve, weigh 50 ± 0.1 g of this cement in iron dish, then add 100 ml of the emulsion to the cement and motion the mixture with circular motion at a rate of 60 revolutions per minute with the steel rod immediately. When the 1-min mixing period ending, a 150 ml of distilled water add, and resume the stirring for next 3 min. At the end of the period, the mixture was poured through a weighed 1.4-mm sieve. Remove the material from the mixing bowl by using repeated washings and pour these materials through the sieve, then the sieve was rinsed with distilled water at a height till the water is poured. The sieve was put in a weighed shallow pan, and put in an oven at 163°C for 1 hr, and weigh.

The heating and weighing Repeat till sequent weights, no differ more than 0.1 gm. The result of this test was (0.732%), which indicates the ability of slow setting emulsified asphalt to mix with a high surface area material without breaking. This value is within the specification limits (ASTM D244 and ASTM D2397), as shown in Table (3-5).

6. Settlement Test

This test method measures the settlement of emulsified asphalt, so it a measure of the uniformity of emulsified asphalt dispersion in storage over a period of time. Place a 500-mL representative sample in each of the two glass cylinders. Stop the cylinders and allow them to stand undisturbed at laboratory temperature for 5 days. At the end of this period, by means of a pipette, or siphon approximately the top 55 ml of emulsion was removed without disturbing the balance. In a separate weighed 1000 ml glass beaker, Weigh 50 g of each sample, then the asphalt residue by evaporation was determined. After removing the top sample, approximately the next 390 ml of the cylinders siphons off, and mix the emulsion remaining in the cylinders Thoroughly. Weigh 50 g in a separate weighed 1000-mL from the remaining into beakers. Also, determine the asphalt residue by evaporation for these samples. Calculate the settlement for each cylinder as follows:

$$\text{Settlement, \% (5 days)} = (B - A) \quad (3-3)$$

Where:

A = the percentage of residue from the top samples, and

B = the percentage of residue from the bottom samples.

The result of this test was (0.4%) by weight, this value is within the specification limits (ASTM D2397), as shown in Table (3-5).

7. Storage Stability Test

This test method was used to find if the asphalt emulsion able to remain as a uniform dispersion during storage. It is applicable to asphalt emulsions composed principally of a semisolid or liquid asphaltic base, water, and an emulsifying agent. This test method done like the settlement test. Calculate the Storage Stability for each cylinder as follows:

$$\text{Storage Stability, \% (1 Day)} = (B - A) \quad (3-4)$$

Where:

A = the percentage of residue from the top samples, and

B = the percentage of residue from the bottom samples.

The results of this test (0.2%) by weight were this value is within the specification limits (ASTM D2397), as shown in Table (3-5).

8. Penetration Test

The penetration test gives an empirical measurement of the consistency of a material in terms of the distance a standard needle sink into that material under a prescribed loading and time. A sample of the asphalt residue to be tested is placed in a container which in turn is placed in a temperature-controlled water bath. Then the sample is brought to the prescribed temperature of 25°C (77°F) and the standard needle (loaded to a total weight of 100 g) is left to penetrate the sample of asphalt for the prescribed time of exactly 5 seconds. The penetration is given as the distance in units of 0.1 mm that the needle penetrates the sample.

Three determinations at points at least are made on the surface of the sample not less than 10 mm from the side of the container and not less than 10 mm apart. Details of the penetration test are given in the

AASHTO Designation T49 and the ASTM test D5. The results of this test was (140mm), where this value is within the specification limits (ASTM D2397), as shown in Table (3-5).

9. Ductility Test

This test method provides one measure of tensile properties of bituminous materials and may be used to measure ductility for specification requirements. Ductility is the distance in centimeters a standard sample of asphalt material will stretch before breaking when tested on standard ductility test equipment at 25°C (77°F). The result of this test indicates the extent to which the material can be deformed without breaking. The material is allowed to cool to 25°C (77°F) in a water bath for a period of 30 min. The prepared sample of residue asphalt of asphalt emulsion is placed in the ductility machine and extended at a specified rate of speed until the thread of material joining the two end breaks. The distance (in centimeters) moved by the machine is the ductility of the material. While the test is being made, the water in the tank of the testing machine shall cover the specimen both above and below it, by at least 2.5 cm and shall be kept continuously at the temperature specified within 0.5°C. The test is described fully in the ASTM D113. The result of this test was (105cm) where this value is within the specification limits (ASTM D2397), as shown in Table (3-5). Figure (3-2) illustrates some of test that conducted in Highway Department Laboratories.

3.3 Cold Mixture Design

Mixture design and testing procedures vary amongst the various road authorities, research institutions and asphalt researchers (Needam, 1996, Thanaya, 2003).



A



B



C



D



E



F



G



H

Figure (3-2) Tests Conducted on Asphalt Emulsion (A, B: Ductility Test; C: Settlement Test; D: Residue By Evaporation; E: Viscosity Test; F: Cement Mixing Test; G: Distillation Test; H: Sieve Test)

In general the design procedures cover many aspects such as: determination of suitable aggregate gradations, determination of optimum residual bitumen content, and testing for mechanical and performance properties. In this work Superpave Mix design system was applied to:

3.3.1 Determination of Aggregate Gradation

The features of the aggregate in any asphalt mix are very important in acquisition good mixture properties and performance. Aggregate makes up 90 to 95 percent by weight of an emulsion mixture. A wide variety of aggregate types and gradations may be used successfully in emulsion mixes. Materials for use as coarse aggregate, fine aggregate, and filler were graded into the following fractions: (19 - 4.75mm), (4.75 - 0.075mm), and passing (0.075mm) respectively, in order to obtain consistent gradation control. To maintain a degree of uniformity and to allow for direct comparison of mechanical properties, the aggregate gradations for all the bituminous mixtures studied in this investigation were restricted to binder course (BC) gradations with nominal maximum size (19mm).

In this study, three trial blends were selected and being compared with the gradation that was recommended in accordance to the specification limits of (SCRB/R9, 2003), (AASHTO M323, 2012), and (AI and AEMA, MS-19) to be used in cold mix asphalt concrete binder course as illustrated in Table (3-6). Figure (3-3) presents the size distributions of the trials blend.

Table (3-6) Trial Blends for CMA with the Limitations

Sieve size mm	AI & AEMA MS-19		Superpave Specification, 2007		Iraqi Specification (SCR P R9, 2003) Binder		Trial combined blends %Passing		
	Min	Max	Min	Max	Min	Max	Blend (1)	Blend (2)	Blend (3)
25	--	100	--	100	--	100	100	100	100
19	90	100	90	100	90	100	95	93	97
12.5	--	--	--	90	70	90	80	75	85
9.5	60	80	---	--	56	80	70	65	75
4.75	35	65	---	---	35	65	50	55	45
2.36	20	50	34.6	34.6	23	49	29	33	25
1.18	--	--	22.3	28.3	---	---	20	21	21
0.6	--	--	16.7	20.7	---	---	15	16	14
0.3	3	20	13.7	13.7	5	19	11	12	10
0.15	--	--	---	---	---	---	8	9	7
0.075	2	8	2	8	3	9	4.5	5	4

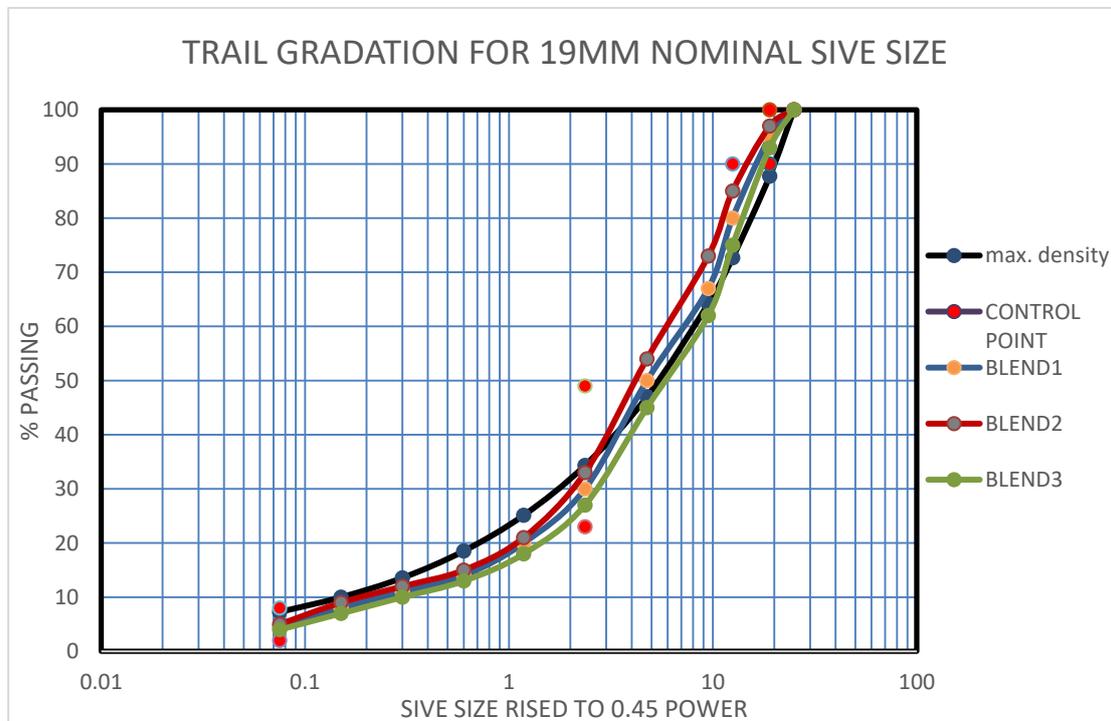


Figure (3-3) Trail Gradations for 19 mm Nominal Maximum Size

3.3.2 Estimation of Initial Residual Asphalt Content (IRAC) and Initial Emulsion Content (IEC)

The residual asphalt content was initially estimated for the three trial blends by utilizing the Asphalt Institute empirical formula as shown below.

$$P = (0.05 A + 0.1 B + 0.5 C) * (0.7) \dots \dots \dots (3-5)$$

Where:

P = % the residual asphalt Content by weight of dry Aggregate,

A = % of aggregate retained on sieve 2.36 mm,

B = % of aggregate passing sieve 2.36mm and retained in 0.075mm, and

C = % of aggregate passing 0.075mm.

The values A, B and C were determined based on the selected aggregate gradations.

For the three gradations selected by Superpave procedure, the residual asphalt content was (5.77, 6.05, and 5.49) for blend (1), blend (2), and blend (3) respectively.

To compute the initial asphalt content that was used to produce mixtures, the Asphalt Institute empirical formula was used as shown below.

$$IEC = \left(\frac{P}{X}\right) * 100\% \dots \dots \dots (3-6)$$

Where:

P = % Initial Residual Bitumen Content by total mass of aggregate,

X = Percentage of asphalt content of the emulsion (53.1%).

The initial emulsion content (IEC) for emulsion type used was calculated from the above equation for the three blends and the results were found at (10.87%, 11.4%, and 10.34%) for blend (1), blend (2), and blend (3) respectively, by the mass of total mixture.

(Mohsin, 2016) stated that when residual asphalt content less than (2.0%) was used, the adhesion and coating were decreased and led to the degradation of the samples after ejecting them from the compaction mold, whereas when using residual content more than (4.0%), samples will suffer from bleeding, and more susceptible to permanent deformation.

According to the previous studies (Zghair, 2012 and Mohsin, 2016), trail mixes derivative of (IEC) were selected to be used in this study that was (5%, 5.5%, 6%, 6.5%, and 7%) for all blends.

Normally, by using Superpave mix design procedure, An aggregate weight of 4700gm was utilized for Gyratory specimens, also, for the determination of the maximum theoretical specific gravity, a sample size of about 2500gm was used. The mixture was prepared by blending the initial asphalt emulsion content with aggregate and filler at ambient temperature for (2-5) minutes manually until an even coating obtained (Zghair, 2012) as illustrated in Figure (3-4). The degree of coating should not be less than 50% by visual observation (Thanaya, 2003)

To find the theoretical maximum specific gravity, Samples were prepared and kept at room temperature for 24 hours (Mohsin, 2016), then it is tested in accordance with (ASTM D2041). On the other hand, for gyratory, samples were prepared and compacted after mixing immediately, by using the Superpave Gyratory Compactor (SGC) as shown in Figure (3-4). The SGC mold has normally dimensions of 250 mm in height and 150 mm in diameter. It has an external angle of 1.25°

with velocity rotation of 30 RPM and loading equals to 600 Kpa is applied as shown in Figure (3-5).

Basically, the cycle numbers for compaction were selected according to the number of Equivalent Single Axle Loads (ESALs). The number of ESALs was approximately (3-30) millions for Baghdad city (Al-Moula, 2012), due to to the application of a roadway in Table (3-7) below the number of cycles for compaction were (8, 100, and 160) gyrations for $N_{initial}$, N_{design} , and $N_{maximum}$, respectively.

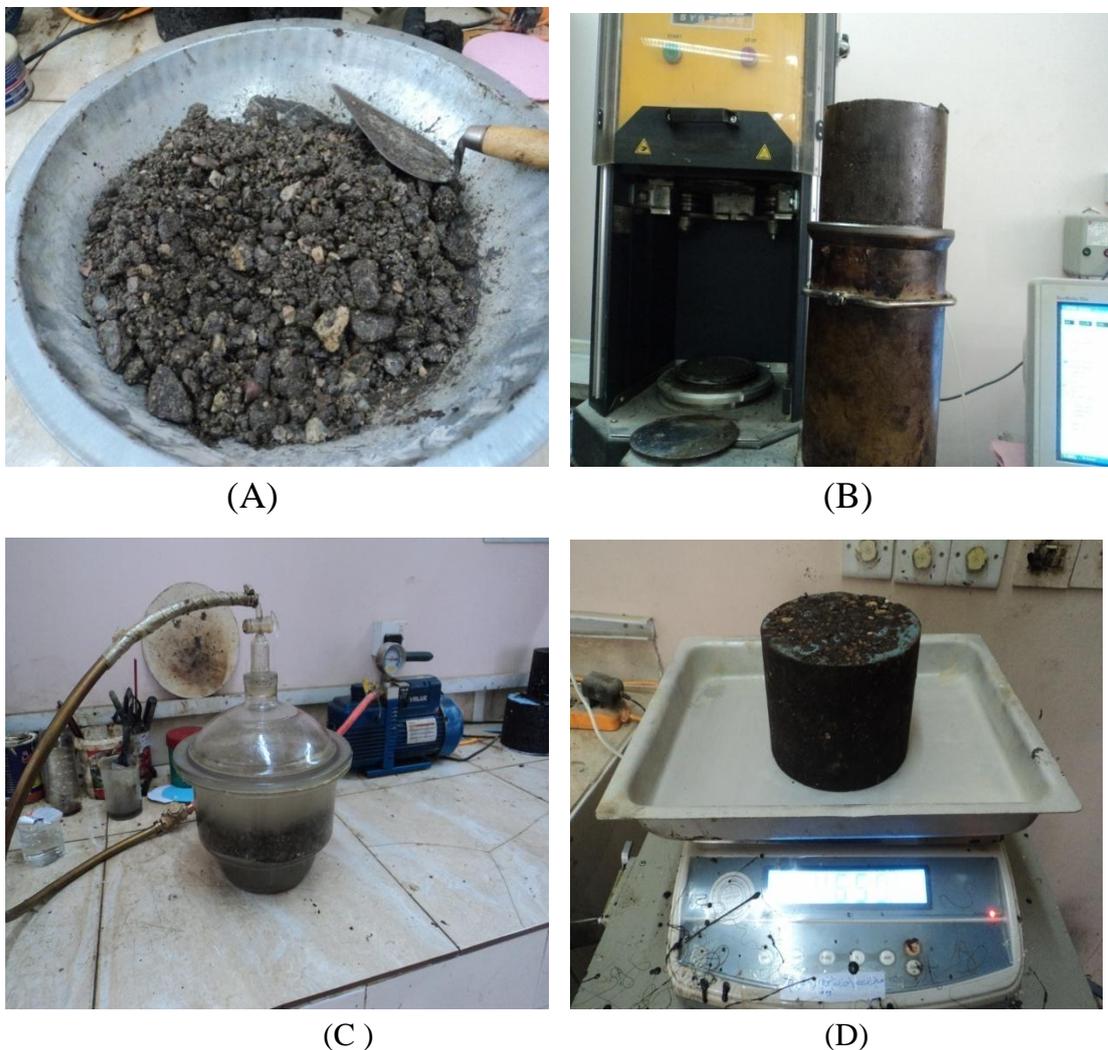


Figure (3-4) Superpave Mix Design Procedure (A: Sample After Mixing; B: Sample After Compacted By SGC; C: Sample to Calculate Gmm; D: Sample For Calculate Gmb)

Table (3-7) Superpave Gyrotory Compaction Effort According to AASHTO-R 35 (2010)

Compaction Parameters				Typical Roadway Application
Design ESALs (million)	Compaction Parameters			
	$N_{initial}$	$N_{des.}$	N_{max}	
<0.3	6	50	75	Applications include roadways with very light traffic volumes such as local roads, country roads, and city streets where truck traffic is prohibited or at a very minimal level. Traffic on these roadways would be considered local in nature, not regional, intrastate or interstate. Special purpose roadways serving recreation sites or areas may also be applicable to this level.
0.3 to <3	7	75	115	Applications include many collector roads or access streets. Medium trafficked city streets and the majority of country roadways may be applicable to this level.
3 to <30	8	100	160	Applications may include many 2-lane, multilane, divided, and partially or completely controlled access roadways. Among these are medium to highly trafficked city street, many state routes U.S. highways, and some rural interstates.
>30	9	125	205	Applications include the vast majority of the US I interstate System, both rural and urban in nature. Special applications such as truck-climbing lanes on 2-lane roadways may also be applicable to this level.

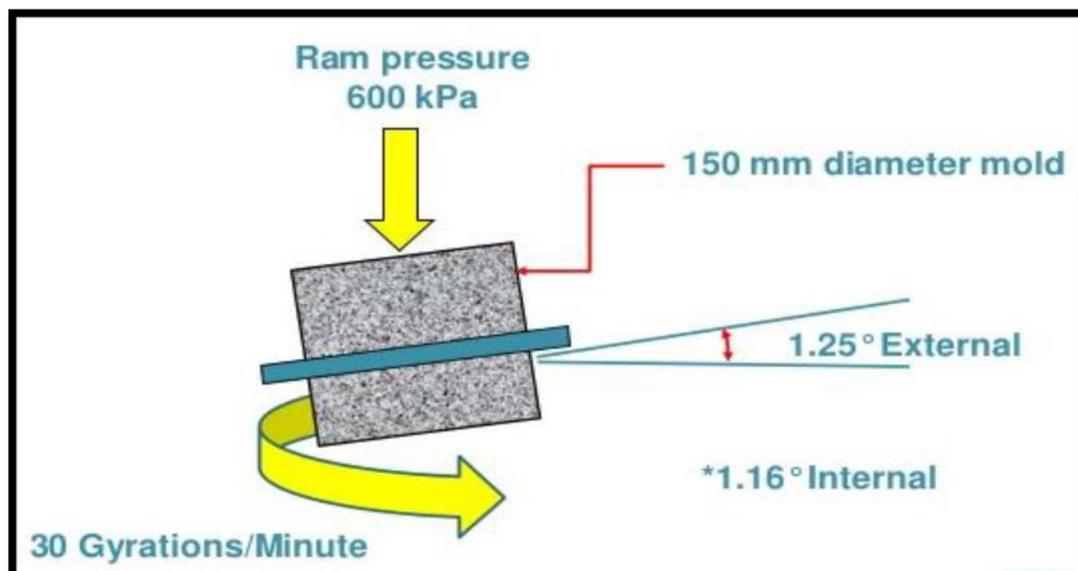


Figure (3-5) Details of The Superpave Gyrotory Compactor (SGC) Mold

Generally, after compacting each sample by using SGC for 160 cycles, it was extruded from the mold and permitted for 10 min and then transferred it and allowed to cure for 24 hours at ambient temperature, then the specimen transferred and placed in an oven at 40 °C for 24 hours (AI, MS14). After curing, samples were cooled to room temperature for (2-4) hours before testing them for the bulk specific gravity in accordance to (ASTM D 2726) which was calculated according to (Asphalt Institute, 2007). To check the volumetric properties, from the SGC software archive, the data were taken and the percent air voids (Va%), voids in mineral aggregate (VMA%), voids filled with asphalt (VFA%) and percent G_{mm} are calculated as illustrated in Table (3-8).

Table (3-8) Results of Volumetric Properties

Blend No	EC %	Gsb	Gsa	Gse	Gmb	Gmm	Va %	VMA %	VFA %	Gmm @ Nini %	Gmm @ Nmax %	DP
1	5	2.641	2.676	2.669	2.339	2.446	5.73	15.09	72.87	87.80	97.30	1.47
	5.5				2.339	2.428	5.05	15.35	73.58	89.28	97.37	1.46
	6				2.338	2.408	4.02	15.38	73.98	87.17	97.15	1.53
	6.5				2.331	2.392	3.89	16.06	75.11	87.2	97.35	1.42
	7				2.335	2.387	3.43	16.08	75.21	86.49	97.26	1.38
2	5	2.64	2.677	2.67	2.303	2.401	5.39	16.38	75.16	87.36	97.29	1.54
	5.5				2.329	2.399	4.34	15.77	74.52	87.26	96.54	1.62
	6				2.324	2.395	4.32	16.12	75.1	87.15	97.37	1.48
	6.5				2.331	2.387	3.64	16.05	75.14	87.04	97.32	1.47
	7				2.341	2.384	3.24	16.05	75.20	87.55	96.95	1.42
3	5	2.639	2.674	2.667	2.340	2.421	5.07	15.30	73.50	87.78	97.70	1.43
	5.5				2.327	2.413	4.96	15.73	74.26	86.85	97.42	1.32
	6				2.336	2.41	4.42	15.6	74.21	86.57	97.37	1.29
	6.5				2.334	2.40	4.24	16.03	75.01	87.06	97.48	1.21
	7				2.355	2.386	3.32	15.95	75.04	87.28	97.90	1.25

The results obtained were compared with the requirement of Superpave volumetric mix design criteria as shown in Table (3-9). Excepting the dust to binder ratio, many trials satisfy these criteria. According to (AASHTO M 323-15) that illustrated (If the aggregate gradation passes beneath the PCS Control Point specified, the dust-to-binder ratio range may be increased from 0.6–1.2 to 0.8–1.6 at the agency’s discretion), also due to the same Specification, the primary control sieve for nominal maximum size (19 mm) was (4.75 mm) as illustrated in Table (3-10). Blend three with (5%, 5.5%, and 6%) initial emulsion content covered these specification, and then blend three at 5.5% initial emulsion content (IEC) with 3.41% estimated residual asphalt content was selected to be the design blend where it covers the others percent when calculating the optimum emulsion content.

Table (3-9) Superpave Volumetric Mix Design Criteria (AASHTO M323-12)

Design ESALs, Million	Required Relative Density (Percent of Theoretical Maximum Specific Gravity)			Voids in the Mineral Aggregate (VMA), Minimum						(VFA) Range, %	Dust-to-Binder Ratio Range
				Nominal Maximum Aggregate Size, mm							
	Ninitial	Ndesign	Nmax	37.5	25	19	12.5	9.5	4.75		
<0.3	≤91.5	96.0	≤98.0	11	12	13	14	15	16	70–80	0.6–1.2
0.3 to <3	≤90.5	96.0	≤98.0	11	12	13	14	15	16	65–78	0.6–1.2
3 to <10	≤89.0	96.0	≤98.0	11	12	13	14	15	16	65–75	0.6–1.2
10 to <30	≤89.0	96.0	≤98.0	11	12	13	14	15	16	65–75	0.6–1.2
≥30	≤89.0	96.0	≤98.0	11	12	13	14	15	16	65–75	0.6–1.2

Table (3-10) PCS for All Aggregate Size (AASHTO M323-15)

Nominal maximum aggregate size	37.5mm	25mm	19 mm	12.5mm	9.5mm
Primary control sieve	9.5mm	4.75mm	4.75mm	2.36mm	2.36mm
PCS control points, % passing	47	40	47	39	47

3.3.3 Select the Design Asphalt Emulsion Content

After the aggregate structure with the initial emulsion content that was selected, then, begin to choose the design asphalt emulsion content, at varying emulsion content (estimated residual asphalt content %, estimated residual asphalt content $\pm 0.5\%$, and estimated residual asphalt content $+1\%$), the specimens were prepared and compacted.

Finally, The prior steps were conducted for mixing, compaction and curing for specimens at the design emulsion content. Then, evaluating and drawing figures for the volumetric properties with different asphalt emulsion contents to the mixture to find the design emulsion content, as shown in Figure (3-6). So, at 4% air voids, the design emulsion content was (6.37%); the $\%G_{mm}$ @ N initial, voids in mineral aggregate, voids filled with asphalt, dust to binder ratio, and $\%G_{mm}$ @ N maximum corresponding to 6.37 % were (87.77, 15.67, 74.4, 1.28, and 97.2 %), respectively.

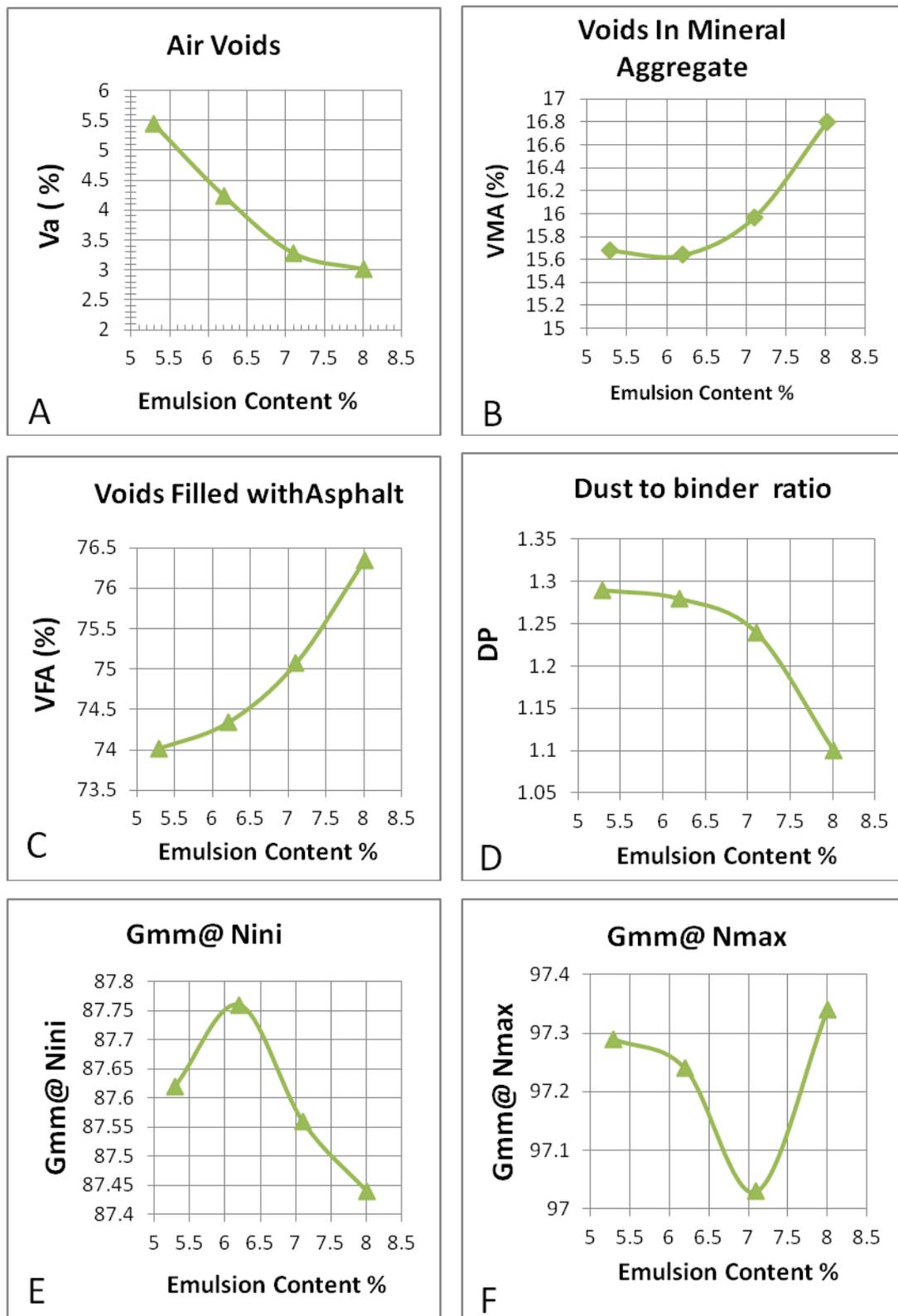


Figure (3-6) The Relationship between the Volumetric Properties of CMA with Different Emulsion Contents

3.4 CMA Evaluations for Moisture Damage

Many types of mixture were prepared with different types and percent of anti-stripping materials, the control mixture was designed by mixing aggregate with limestone dust at (4%) as the selected gradation above, then, hydrated lime was used as a replacement for limestone dust filler at (1, 1.5, 2) % of the total weight of aggregate, also, fly ash and silica fume were utilized as a replacement for limestone dust at (1, 2, 3) % of the total weight of aggregate.

All these mixtures were evaluated with some tests used to estimate moisture damage potential such as indirect tensile strength, index of retained strength, retained Marshall stability, and double punch test.

The tests were mentioned above conducted for all specimens after curing protocol that was let them (in the mold for Marshall specimens and in the room for Superpave specimens) for one day at ambient temperature, then 24 hours in an oven @ 40 °C.

3.4.1 Indirect Tensile Strength (ITS)

The ITS test provides two mixture properties that are useful in characterizing bituminous mixtures. The first property is tensile strength, which is often used in evaluating water susceptibility of mixtures. The tensile strength is also sometimes used to help evaluate the cracking potential of a bituminous mixture. However, the second property determined from the indirect tensile test, which is tensile strain at failure, is more useful for predicting cracking potential. Mixtures that can exhibit high strains prior to failure are more likely to resist cracking.

(Santucci, 2002) stated that the susceptibility to stripping or moisture can be evaluated by using this test for Superpave mixtures. This

test was conducted for all prepared mixtures according to standard specifications (ASTM D 4867 and AASHTO T 283). Six specimens were prepared for each type of mixtures, the specimens were compacted in the SGC for about 7 ± 0.5 . The (7 %) of air void was resulted approximately by calculating the (G_{mm}) in laboratory and estimated specific gravity from SGC. The (G_{mm}) was interring to the SGC and when air void arrived to the 7% compaction was stopped, then the bulk specific gravity and theoretical specific gravity were calculated for all specimens to sort them into two groups where the average air voids of both are approximately equal. The first group was kept at room temperature without any condition until testing for indirect tensile strength.

For the second group (condition group), to reach a degree of saturation in the range (55 to 80%) as recommended, samples were prepared by submerging them for a short time in a vacuum vessel filled with water. Then, the samples were subjected to freezing for a minimum of 16 hours at a temperature of $0\pm 5^{\circ}\text{F}$ ($-18\pm 3^{\circ}\text{C}$), then the specimens subjected to thaw cycle by transferring them to water bath for 24 ± 1 hours at $140\pm 2^{\circ}\text{F}$ ($60\pm 1^{\circ}\text{C}$). Lastly, the specimens transmitted to another water bath at $77\pm 1^{\circ}\text{F}$ ($25\pm 0.5^{\circ}\text{C}$) for (2-4) hours as shown in Figure (3-7).

By using indirect tensile strength apparatus at a loading rate of 2 inches per minute (51 mm per minute), all specimens were tested. Then, the corresponding maximum loads and displacements were recorded.

The indirect tensile strength was calculated for condition and uncondition specimen by using Equation (3-7) as follows:

$$ITS = \frac{2000P}{\pi * t * d} \dots\dots\dots (3-7)$$

Where

ITS = indirect tensile strength (kPa),

P = maximum load (kN),

T = thickness of the specimen (m),

D = diameter of specimen (m).

The evaluation of moisture induced damage can be made by determining the Tensile Strength Ratio (T.S.R). The Tensile Strength Ratio (T.S.R) was determined as the ratio of indirect tensile strength for condition group to an uncondition group, which should be a minimum of 80% in accordance to (Asphalt Institute, 2007).

The following equation was utilized to calculate the tensile strength ratio (TSR) in percent.

$$T.S.R = \frac{T2}{T1} * 100 \dots\dots\dots (3-8)$$

Where

TSR = tensile strength ratio in percent

T1 = average tensile strength of unconditioned group (kPa),

T2 = average strength of conditioned group (kPa).



A



B



C



D



E

Figure (3-7) Indirect Tensile Strength Test (A: Vacuum Saturation, B: Samples Freezing @ -18 ± 3 °C), C: Thawing @ 60 °C), D: Sample Before ITS Testing, E: Sample After ITS Testing).

3.4.2 Index of Retained Strength

This test method was used to measure the loss of compressive strength resulting from the action of water on compacted bituminous mixtures. A numerical index of reduced compressive strength is acquired by matching the compressive strength of new molded and cured specimens with the compressive strength of specimens that have been submerged in water under specified conditions.

Each specimen was prepared in accordance to standard specifications (ASTM D 1074) with dimensions of 101.6 by 101.6-mm (4 by 4-in.) by using the second type of SGC mold (this mold Borrowed it from the Holy Karbalaa Laboratory for Construction Tests). This mold has normally dimensions of about 300 mm in height and 100 mm in diameter

This test was conducted for all prepared mixtures according to standard specifications (ASTM D 1075). Six specimens were prepared for each type of mixtures with batch weight 1850 gm, the specimens were compacted in the SGC for the target of air voids which were approximately (6 ± 0.5) . The previous method was used for calculating the air voids for indirect tensile strength that was utilized in this test to obtain the desired air voids, also, the bulk specific gravity was calculated for all specimens to sort them into two subsets where the average bulk specific gravity of the specimens in subset 1 is essentially the same as for subset 2.

For subset 1, the specimens were stored in room temperature for more than 4 hours, then, their compressive strength was determined at $25.0\pm 1^\circ\text{C}$ by using equation (3-9) below.

The specimens for subset 2 were conditioned by submerging them for 24 hours in a water bath at $60.0 \pm 1^\circ\text{C}$. Then, the specimens were transported to different water bath for 2 hours at $25.0 \pm 1^\circ\text{C}$. Lastly the compressive strength was determined by using compressive strength apparatus at a loading rate of 2 inches per minute (51 mm per minute) and the peak load was recorded.

The following equation was used to calculate the compressive strength for condition and uncondition specimens.

$$S = \frac{P}{3.14(R)^2} \dots\dots\dots (3-9)$$

Where

S = compressive strength (kPa).

P = maximum load (kN)

R = radius of the specimen (m).

The index of retained strength of resistance of bituminous mixtures to the damaging impact of water can be determined as the ratio of average compressive strength for condition specimens to uncondition specimens, as shown in equation (3-10) below, which should be a minimum of (70%) as adopted by (SCRB/R9, 2003) for binder course.

$$\text{Index of Retained Strength (I.R.S)} = (S_2 \setminus S_1) * 100 \dots\dots\dots (3-10)$$

Where:

S1 = average compressive strength of unconditional specimens (kPa),

S2 = average compressive strength of condition specimens (kPa).

Figure (3-8) presents stages of gyratory compaction, conditioned, and specimens in compressive apparatus before and after the test.



A



B



C



D

Figure (3-8) Compressive Test Stages (A: After Compaction, B: Condition Stage, C: Before Test for Compressive Strength, and D: After Test)

3.4.3 Retained Marshall Stability

The Retained Marshall Stability is the ratio of soaked or wet stability to dry stability (Thanaya, 2003). Thanaya, 2003 was stated that a minimum of (50%) Retained Stability shall be achieved for cold bituminous emulsion mixtures, where as shell, 2003 regarded a value of more than (75%) retained Marshall stability is usually accepted.

This test was carried out according to (AASHTO T245-08). Six specimens were prepared for each type of mixtures with batch weight 1200 gm in the same method of mixing used for design, and compacted by means of Marshall compactor were compacted with 75 (SCRB/R9, 2003) blows on each face for heavy traffic utilized compaction hammer of 4.536kg weight and 457.2mm fall distance to produce specimens with 101.6mm in diameter and (63.5 to 70.5) mm in height. Three samples for determination of an average dry stability value, these samples are obtained after conducting design curing for one day in the mold and 24hrs in oven at 40 °C, then the samples were immersed in the water bath at 25°C for 30 minutes (Asphalt Institute MS-14), instead of at 60°C which was used in HMA.

The other three samples were used for the determination of an average soaked stability, After having been subjected to oven curing as explained earlier, the samples were water conditioned. In this procedure half thickness of each compacted specimen was soaked in water at room temperature for 24 hrs. the specimens, then were inverted and the other halves were soaked for a further 24 hrs (Thanaya, 2003). (Also referred to as capillary soaking). During soaking, the samples would rest on a bed of approximately 15 to 20mm coarse aggregate. The samples are

subsequently to well dried, and they are then tested for Marshall stability at room temperature Figure (3-9).

The dry and soaked stability of specimens can be calculated from the following equations:

$$\text{Corrected stability (KN)} = \text{Measured Stability} * \text{Correction Ratio.. (3-11)}$$

Where:

Correction rate = values from list, relying on volume of specimen and/or height.

Finally, the retained stability was determined by using the following equation.

$$\text{Retained Stability} = \text{soaked stability} / \text{dry stability}..... (3-12)$$

Flow of dry specimens were determined from the following equation:

$$\text{Measured flow (mm)} = \text{Flow Reading}..... (3-13)$$



A



B



C



D

Figure (3-9) Retained Stability Test (A: Curing In Mold For 1 Day, B: Curing In An Oven For 24hrs, C: Wet Condition For Specimens Partially Immersion, D: Sample during the Test).

3.4.4 Double Punch Test

This test was utilized to measure the stripping of the binder from the aggregates, this method was advanced by (Jimenez, 1974) at the University of Arizona. The test falls in the category of those that include measurement of mix mechanical properties, Jimenez was explained the severity of this test by comparing predictions on similar mixtures using the immersion–compression test. This test was reported by numerous studies (Solaimanian, 2003; Sarsam and Al–Azzawi, 2012; Turos, 2010; Sarsam and Alwan, 2014; Mashkoor, 2015; Mohsin, 2016).

The previous procedure of mixing, compaction, and curing for retained Marshall stability was used to prepared sample for this test, after curing the samples were conditioned in water bath at 25°C for 30 min, then they were tested, the compacted cylinder specimens were placed between two steel rods (2.54cm in diameter), at either end of the specimen in a punching configuration where the specimen is centered between the two steel rods, perfectly one over the other, then loaded at a rate of 2.54cm /minute until failure by using Marshall apparatus as shown in Figure (3-10). Figure (3-11) shows a double punch test. The maximum load resistance is recorded and the punching strength is calculated by using the following equation (Jimenez, 1974).

$$(S) = \left(\frac{P}{2(1.2bh - a^2)} \right) \dots\dots\dots (3-14)$$

Where:

S = Punching shear stress, Pa.

P = Maximum load, N.

a = Radius of rod, mm

b = Radius of specimen, mm.

h = Height of specimen, mm

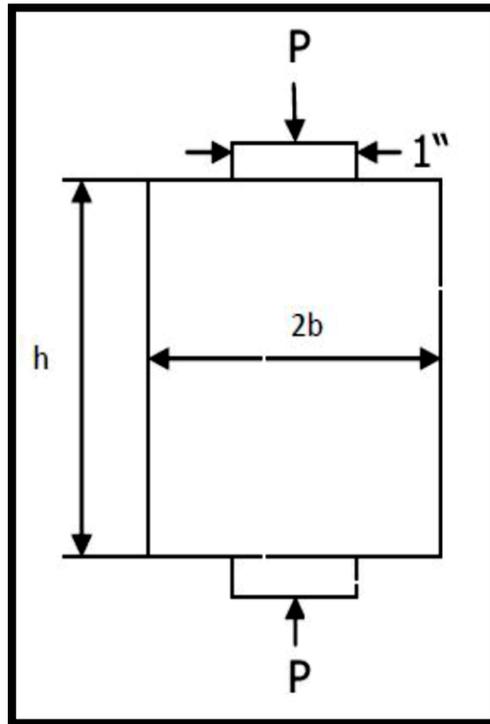


Figure (3-10) Geometry of the Sample for the Double Punch Test



A



B



C

Figure (3-11) Double Punch Test (A: Samples After Curing, B: Sample During The Test, C: Sample After Test)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

CHAPTER FOUR
RESULTS AND DISCUSSIONS**4.1 Generals**

In this chapter, the results are presented and discussed for all the experimental works described in chapter three. The results and discussion gained from the experimental work will be focused on two topics; properties of mixture design and moisture damage resistance evaluation.

4.2 Mixture Design Properties

Three trial blends were selected and compared with gradation that was recommended in accordance with specification limits of (SCRB/R9, 2003), (AASHTO M323, 2012), and (AI & AEMA MS-19) as illustrated in Table (3-6), previously.

According to the prior studies (Zghair, 2012 and Mohsin, 2016), the trial mixes derivative of (IEC) were selected to be used in this study, which were (5%, 5.5%, 6%, 6.5%, and 7%) for all blends with residue content (2.66, 2.92, 3.19, 3.45, and 7.72) %, respectively.

(Mohsin, 2016) stated that when residual asphalt content less than (2.0%) was used, the adhesion and coating were decreased and led to the degradation of the samples after ejecting them from the compaction mold, whereas when using residual content more than (4.0%), samples will suffer from bleeding, and more susceptible to permanent deformation.

4.2.1 Theoretical Maximum Specific Gravity (G_{mm})

The theoretical maximum specific gravity is the specific gravity excluding air voids. Thus, theoretically, if all the air voids were eliminated from the sample, the combined specific gravity of the

remaining aggregate and asphalt binder would be the theoretical maximum specific gravity. Theoretical maximum specific gravity is the sample weight divided by its volume. It is calculated for loose mixture at various emulsion content according to (ASTM D 2041) for all trial blends and the results were presented in Figure (4-1). It is obvious that the theoretical maximum specific gravity slightly declined as the emulsion percentage increased. This behavior is expected because the increase of emulsion content reduced the proportion of air voids, decreased the saturated surface dry weight (SSD), this increased the volume of sample thereby decreasing G_{mm} . Also, it can be noticed that blend (2) has the minimum theoretical specific gravity, this may be due to high percentage of fine materials.

4.2.2 Bulk Specific Gravity (G_{mb})

The bulk specific gravity of a compacted sample is the ratio of its weight to the weight of an equal volume of water. It is calculated for compact samples after curing protocol according to (ASTM D 2726), the results of bulk specific gravity of the various emulsion contents for all trial blend are shown in Figure (4-2). It can be noticed in opposite to the theoretical maximum specific gravity, the results showed that the bulk specific gravity was increased as the emulsion content increased. Normally, as the emulsion content increased the moisture was increased, that provides easy compaction and less air voids, hence increasing the bulk specific gravity. Also, it can be seen that blend (2) has the greatest G_{mb} due to having high percentage of fine aggregate.

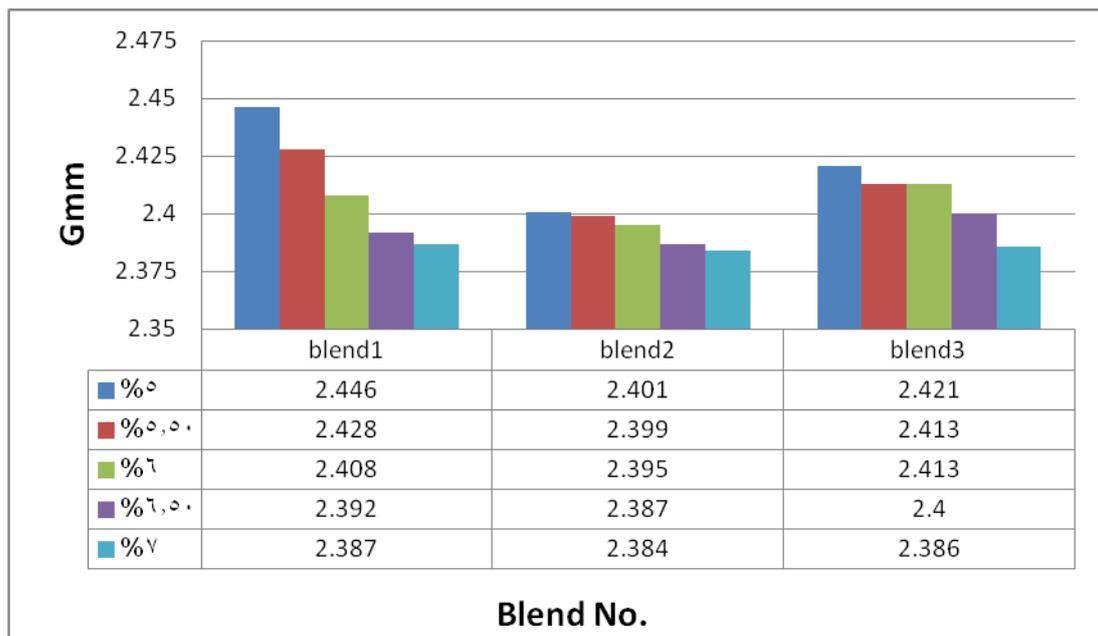


Figure (4-1) Theoretical Maximum Specific Gravity with Initial Emulsion Content For Trail Blends

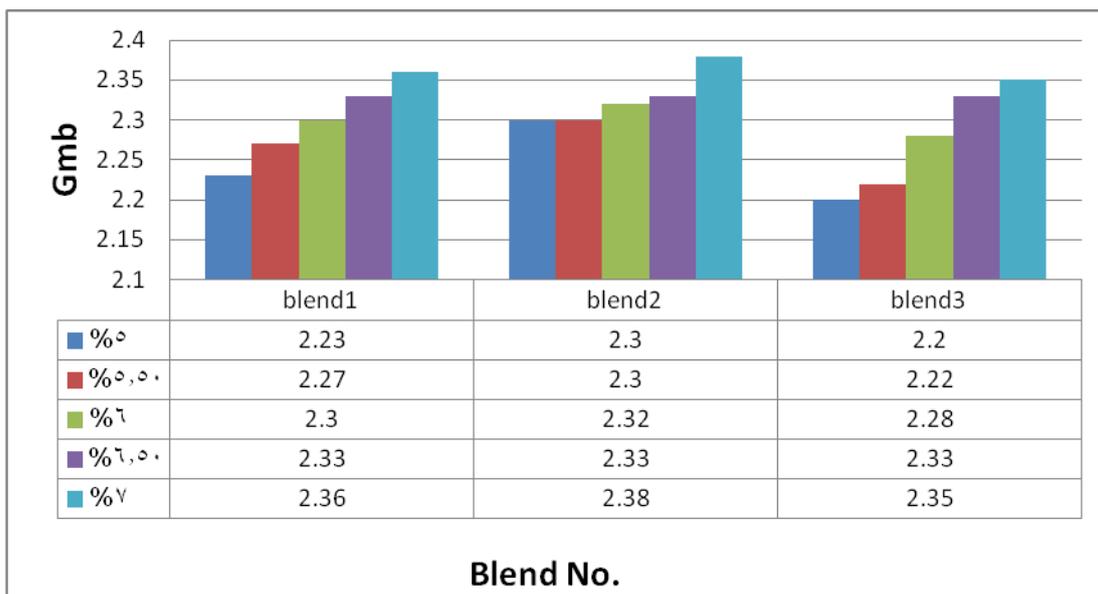


Figure (4-2) Bulk Specific Gravity with Initial Emulsion Content For Trail Blends

4.2.3 Air Voids (Va)

Air voids are the pockets of air trapped between the asphalt coated particles of aggregate in an asphaltic concrete pavement. A certain percentage of air voids are necessary in all dense-graded mixtures to allow for some additional pavement compaction under traffic and to provide a space into which small amounts of asphalt can flow during this subsequent compaction. It is expected that as the emulsion content increases, the air voids will decrease because the high percent of emulsion leads to fill voids with asphalt binder. The results of air voids with different percentages of emulsion content for the three blends were presented in Figure (4-3).

Generally, the higher degree of compaction and high percent of fine materials may give higher density, hence lower percentage of air voids was in asphalt mixtures.

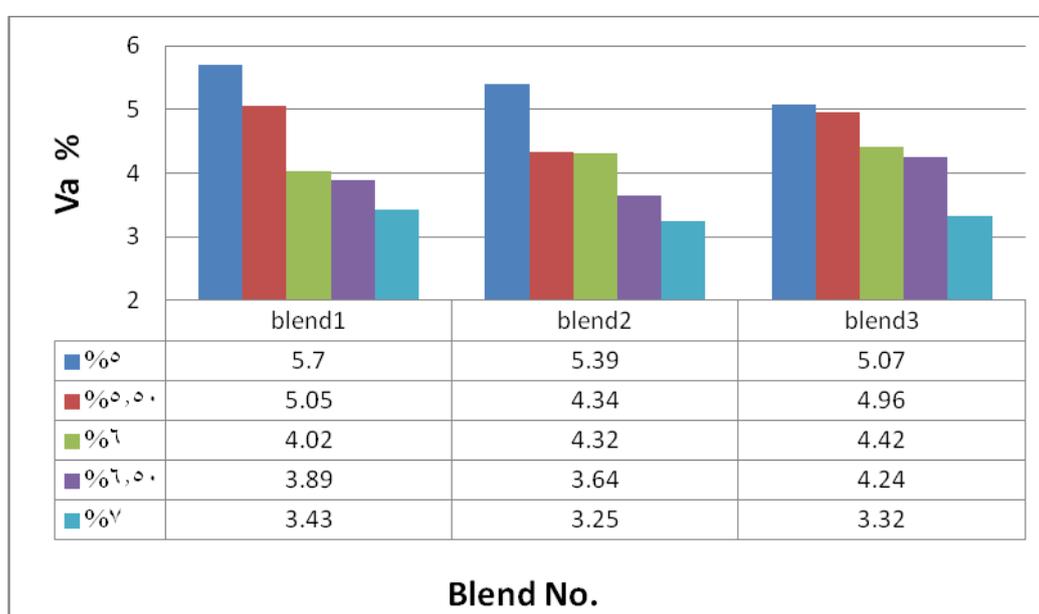


Figure (4-3) Air Voids with Initial Emulsion Content For Trail Blends

4.2.4 Voids in the Mineral Aggregate (VMA)

Voids in the mineral aggregate (VMA) are the air voids that exist between the aggregate particles in a compacted paving mixture including voids filled with asphalt. The results of VMA for the trails blend at different percentages of initial emulsion are shown in Figure (4-4). A gradual increase in the VMA with initial emulsion increase can be noticed for the first three percent of blend one, then there was a rapid increase in the other percent, in contrast, for blend two there was a slight decrease with initial emulsion percentage increase except at 5.5%, where there was sharp descent, this may be attributed to high percent of fine materials in the blend (2) that led to fill the voids between aggregate particles.

Overall, the three trail blends with different percentages of initial emulsion content satisfy requirement specifications for the Superpave mix design that illustrated in Table (3-12). This means more space is available for the film of asphalt, hence the mix will be more durable. Based on the fact that the thicker the asphalt film on the aggregate particles is the more durable the mix will be.

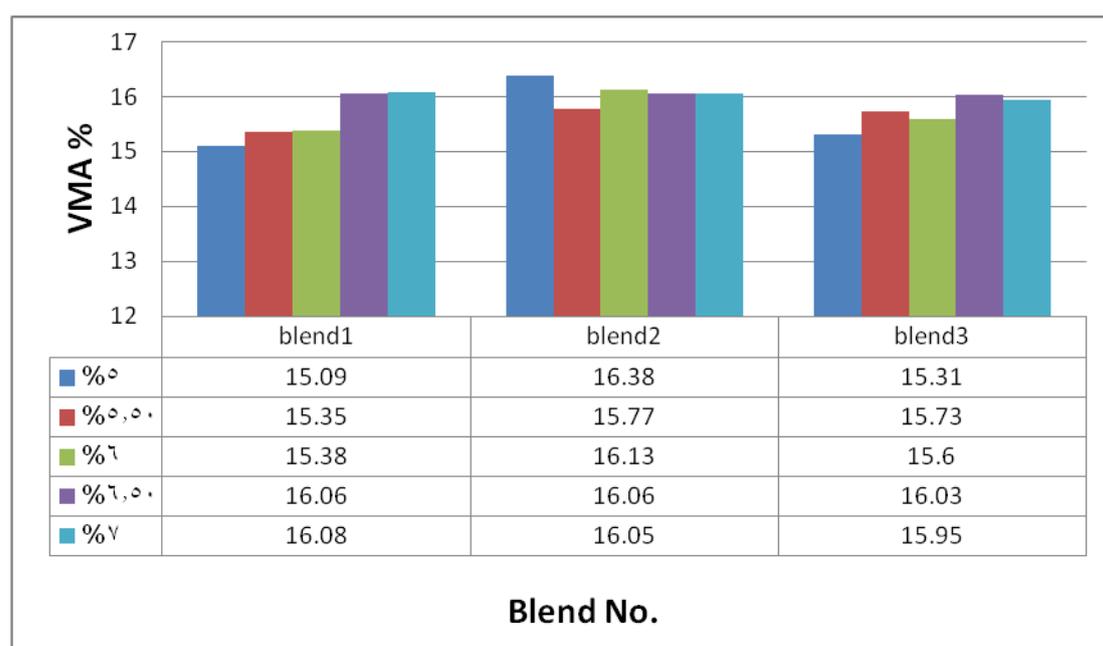


Figure (4-4) Voids in the Mineral Aggregate with Initial Emulsion Content For the Trail Blends

4.2.5 Voids Filled With Asphalt (VFA)

The VFA is the percentage of voids in the compacted aggregate mass that are filled with asphalt. The VFA property is important as a measure of relative durability, so if the VFA is too low, there is not enough asphalt to provide durability. Figure (4-5) presents the results of VFA for the trail blends with different percentages of initial emulsion content, it is clearly that the VFA increased as the emulsion content increased for blend one and three. In contrast, there was a decline in the values of VFA, then a gradual upward with increasing initial emulsion content for blend tow.

Overall, the three trail blends with different percentages of initial emulsion content satisfy minimum requirements for the Superpave mix design in Table (3-12) mentioned previously, whereas the three blends at (6.5 and 7) % also, at (5 and 6) % for blend two were out of the maximum limit.

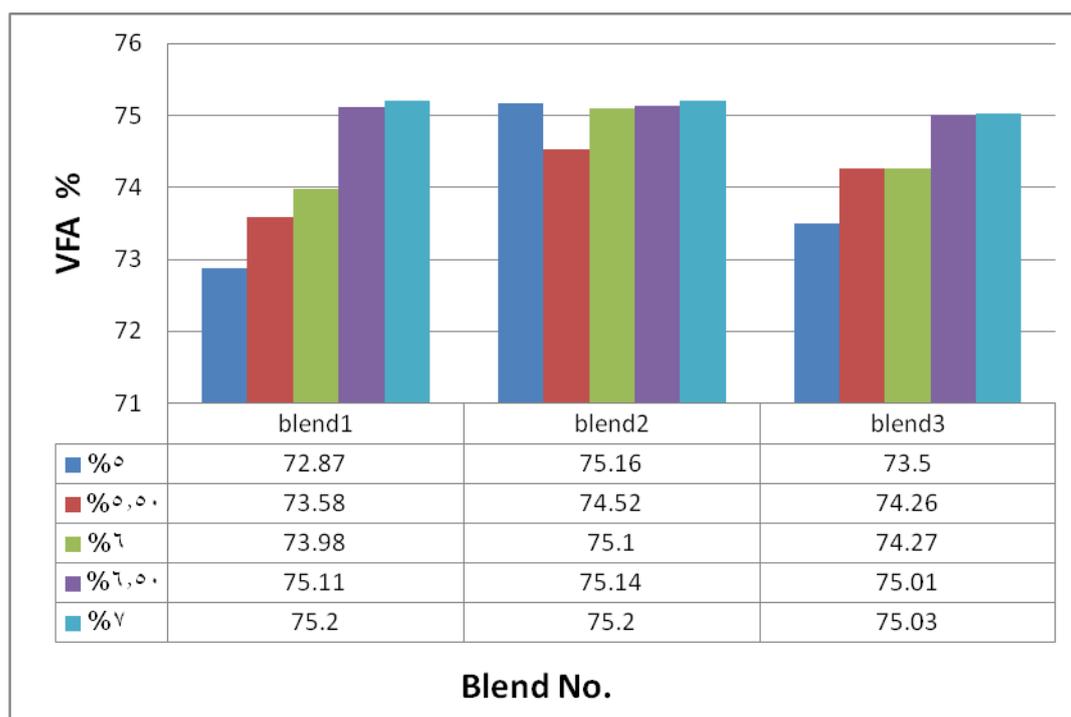


Figure (4-5) Voids Filled with Asphalt with Initial Emulsion Content for the Trail Blends

4.2.6 Theoretical Maximum Specific Gravity Percentages at Initial and Maximum Number of Gyration ($G_{mm}@N_{ini}$ and $G_{mm}@N_{max}$)

The results of $G_{mm}@N_{ini}$ and $G_{mm}@N_{max}$ for the trail blends with different percentages of initial emulsion content are shown in Figures (4-6) and (4-7) respectively. It can be noticed that the ($\%G_{mm}@N_{ini}$) results ranged from a low of 87.0 percent to a high of 89.2 percent, also, the three trail blends with different percentages of initial emulsion content, except blend (1) at 5.5 % were above the maximum requirements for the Superpave mix design which was 89%.

Specified a maximum value of percent specific gravity ($G_{mm}@N_{ini}$) prevented to design a mixture with weak aggregate structure and low internal friction (Asphalt Institute, 2007).

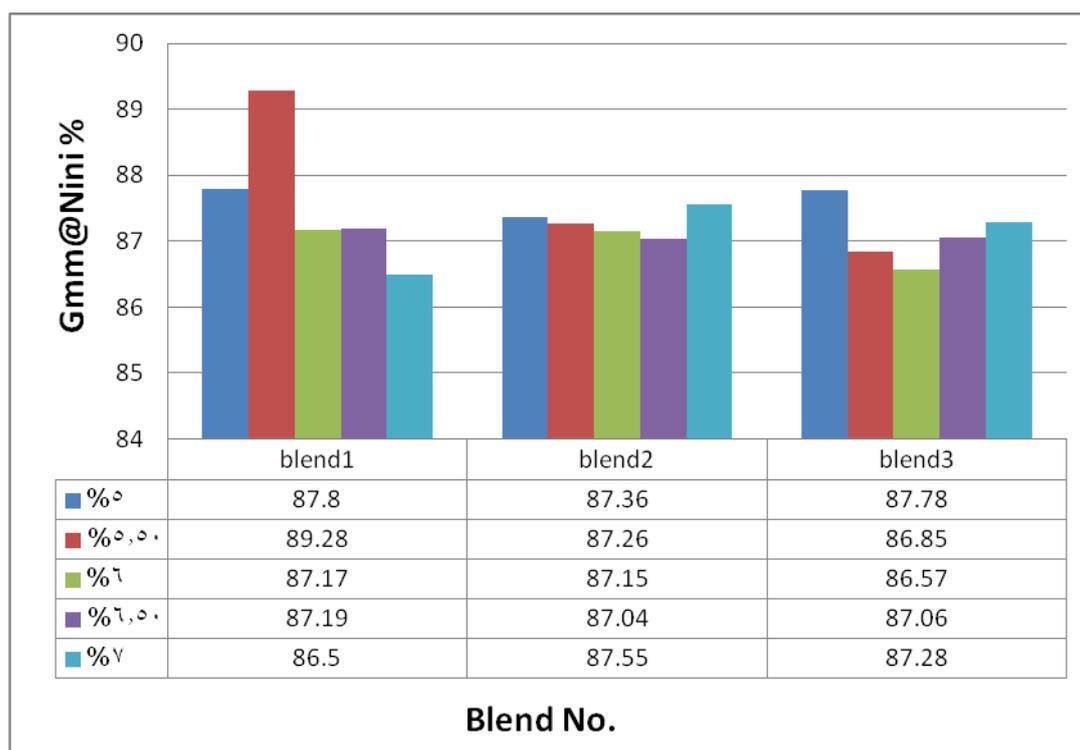


Figure (4-6) $G_{mm}@N_{ini}$ with Initial Emulsion Content for the Trail Blends

The results of ($G_{mm}@N_{max}$) ranged from a low of 96.6 percent to a high of 97.5 percent, the three trail blends with different percentages of initial emulsion content were below the maximum requirements for the Superpave mix design, which were 98 %.

Designating a maximum value of percent specific gravity ($G_{mm}@N_{max}$) prohibits designing of a mixture that will be compacted excessively beneath the design traffic, it becomes plastic and produces permanent deformation. Since N_{max} represents a compactive effort that would be equivalent to traffic much greater than the design traffic, excessive compaction under traffic will not occur (Asphalt Institute, 2007).

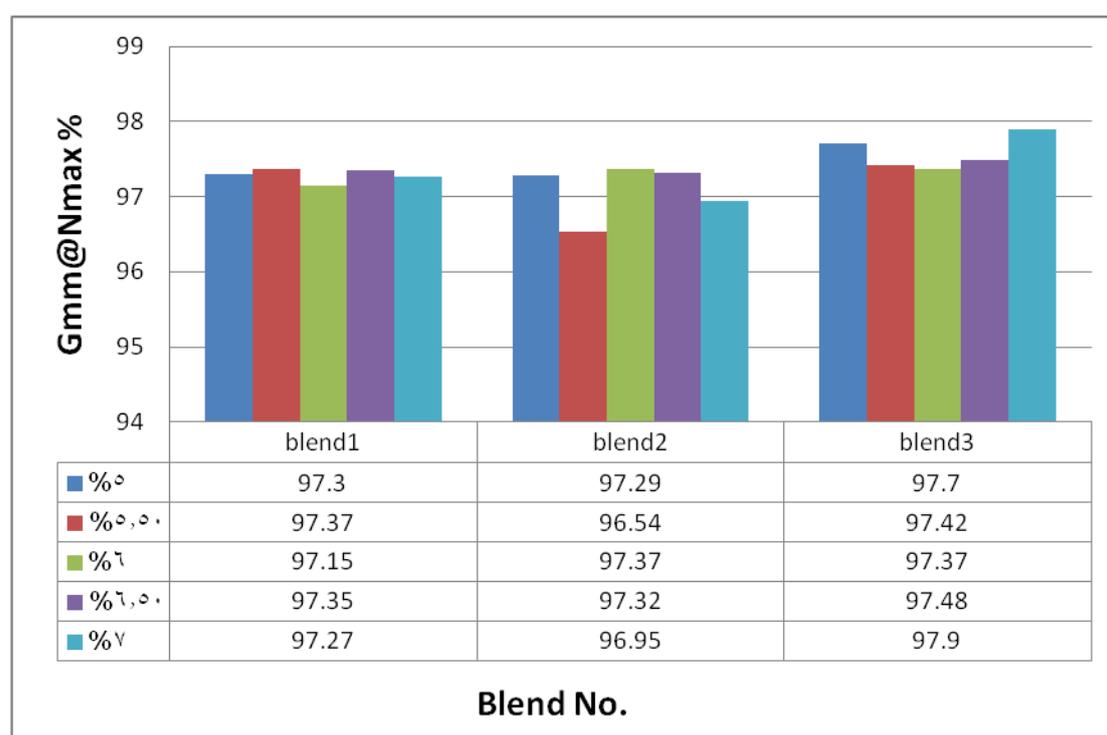


Figure (4-7) $G_{mm}@N_{max}$ with Initial Emulsion Content for the Trail Blends

4.2.7 Dust to Binder Ratio (Dp)

Figure (4-8) shows the dust to binder ratio (Dp) results for the three trail blends with different percentages of initial emulsion content. With the exception of some ratios for the three blends, there was a slight decrease with the increasing of initial emulsion content. It can be noted that blend two has the higher (Dp), this due to the percent of filler material passing sieve (No 200), in contrast, blend three has the lowest (Dp).

Overall, the three trail blends with different percentages of initial emulsion content exceeded the range required by Superpave mix design which was (0.6-1.2). On the other hand (AASHTO M 323-15) illustrated (If the aggregate gradation passes beneath the PCS Control Point specified, the dust-to-binder ratio range may be increased from (0.6–1.2)

to (0.8–1.6) at the agency’s discretion), also due to the same Specification, the primary control sieve for nominal maximum size (19 mm) was (4.75 mm) as illustrated in Table (3-10) previously, so blend three only satisfied this specification.

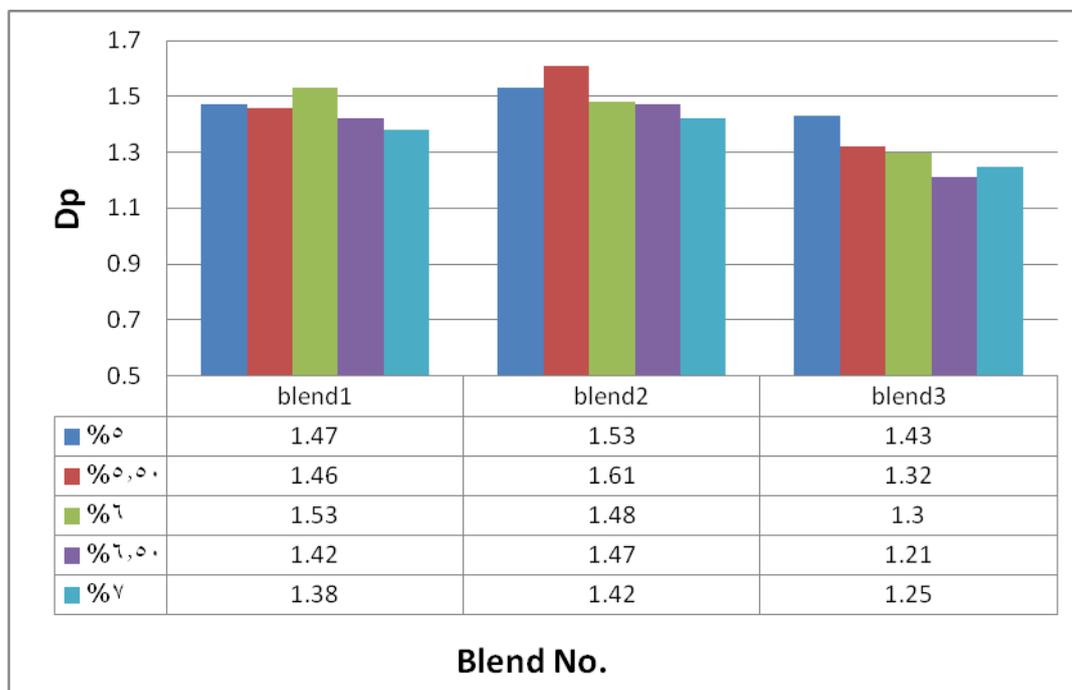


Figure (4-8) Dust to Binder Ratio with Initial Emulsion Content for the Trail Blends

4.2.8 Moisture Induced Damage

Generally, after comparing the results that were obtained from the above volumetric properties with the required specification for Superpave mix design, blend three with 5.5 % emulsion content (3.41 % estimated asphalt binder) was chosen to be the design blend. Then, the same procedure of mixing, compaction and curing was repeated with estimated binder content %, estimated binder content $\pm 0.5\%$, and estimated binder content +1%) and draw the relationship of binder content with the volumetric properties to choose the design emulsion content as described in chapter three (Figure (3-10)).

After selecting the design emulsion content, the final step of Superpave mix design procedure was the moisture susceptibility evaluation of the design emulsion content. It was conducted in accordance with standard specifications AASHTO T 283. Figure (4-9) shows the moisture susceptibility for control mixture, it can be noticed that the TSR is more than the minimum limit required which was 80 %.

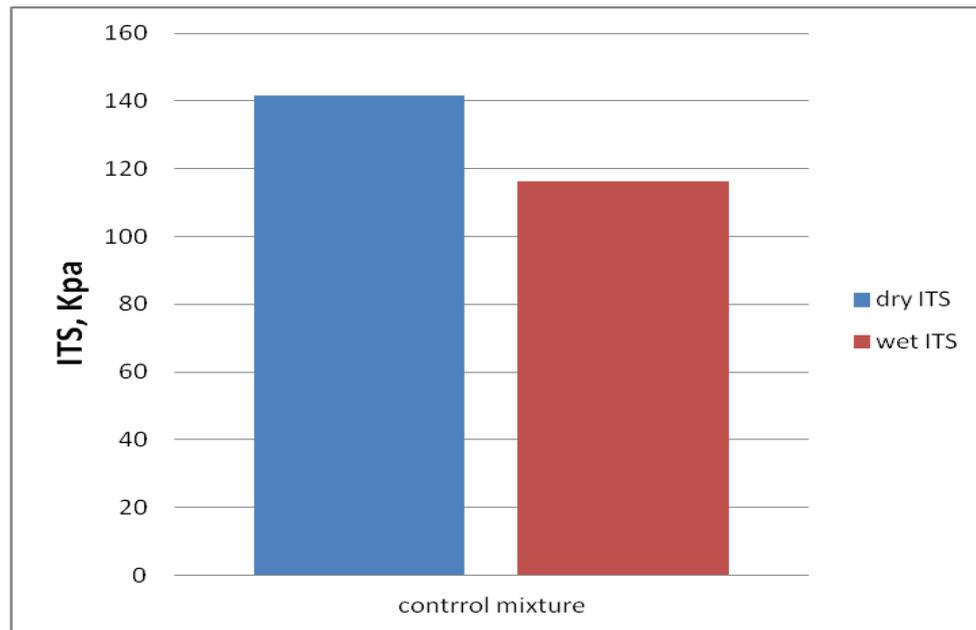


Figure (4-9) the Moisture Susceptibility for Control Mix with Design Emulsion Content

4.3 Effect of Anti-Stripping Materials

4.3.1 Effect of Adding Hydrated Lime

Hydrated lime is a type of dry powder made from limestone. It is created by adding water to quicklime in order to turn oxides into hydroxides. Its chemical name is calcium hydroxide, or $\text{Ca}(\text{OH})_2$. It is dissolved in pure water to produce an alkaline solution with a pH of about 12.4.

Asphalt emulsion manufacture association (AI&AEMA) specified the amount of hydrated lime to be used typically from (1- 2) % by weight of dry aggregate. Whereas, (SCRB, 2003) specified the typical percent for HMA as (1.5) % by weight of dry aggregate. So, in this study (1, 1.5, 2) % replacements have been used.

4.3.1.1 Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR)

The tensile strength was used in evaluating water susceptibility of mixtures. Also, it sometimes was used to help evaluate the cracking potential of a bituminous mixture. Figure (4-10) illustrates the results of ITS for both dry and wet specimens. It is clearly that the adding of hydrated lime improves dry and wet ITS significantly, but the increasing for wet specimens was more than that for dry specimens, where the ITS for wet specimens increased by (7.1, 28.1, 50) % at (1, 1.5, 2) % of hydrated lime respectively. On the other hand, the increasing of ITS for dry specimens at the same percent of replacement was (3.4, 17.9, 28.2) % respectively.

The results of TSR for hydrated lime replacement were presented in Figure (4-11). It can be noticed that there was a slight increase in TSR value as the percent of replacement was increased, where the TSR value was improved by (17 %) with 2% replacement. This reflects the capability of hydrated lime to work as an anti-stripping material. This behavior is very expected and many researchers agreed with this trend. When hydrated lime coats aggregate particles, it induces polar components in asphalt cement to bond to the aggregate surface. Also the hydrated lime structure consists of large and small particles, which makes

hydrated lime works as a filler and as anti-stripping additives and this conforms with (Mohan and Obaid, 2014).

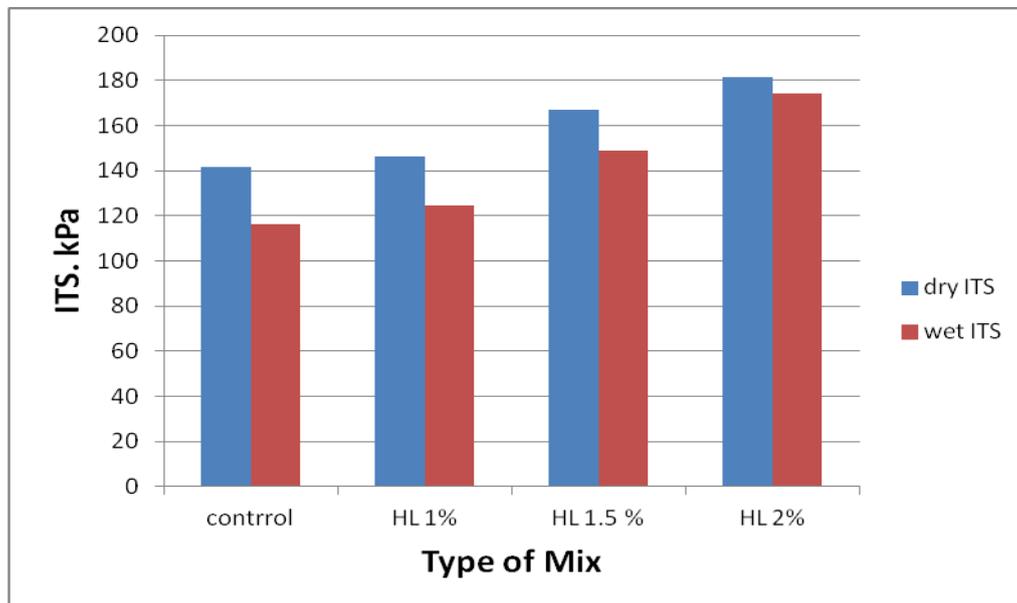


Figure (4-10) ITS Test for Mixture Containing Hydrated Lime

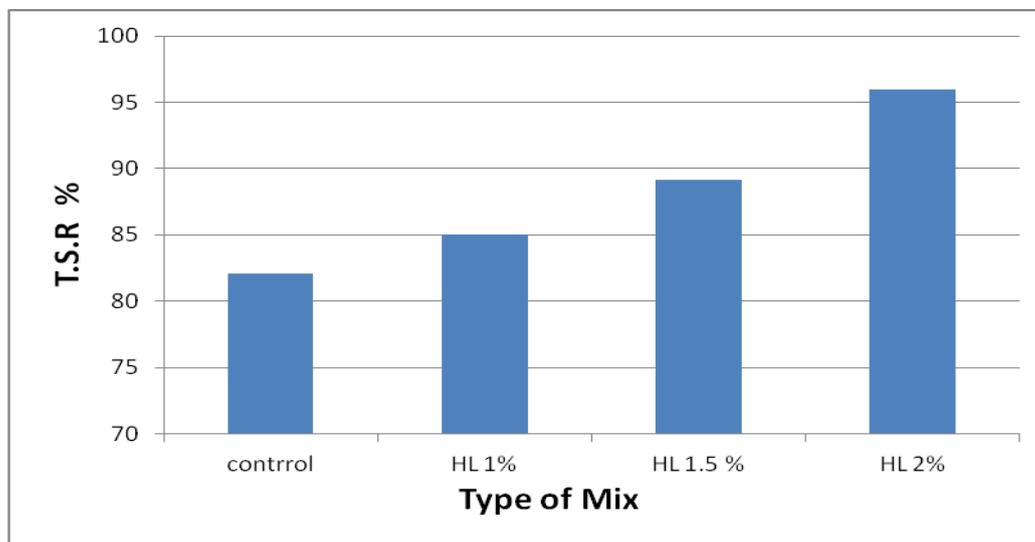


Figure (4-11) TSR for Mixture Containing Hydrated Lime

The aggregate used in this study was brought from Al-Nibaie quarry, which was Quartzite, these phenomena on local Iraqi paving materials can be discussed as: this aggregate is classified as acidic aggregate. So

the improvement is showed by changing the surface chemistry of acidic aggregate and causes a basic coating, this promotes a strong bond between acidic asphalt binder and aggregate. This bonding between asphalt binder and aggregate promotes moisture damage resistance in the asphalt mixtures, this agrees with (Khalil and Mohammed, 2016).

When hydrated lime is added to asphalt mixture, a part of the lime forms insoluble salts with the highly polar molecules of the asphalt, which could otherwise react in the mixtures to form water-soluble soaps that enhance stripping, also this conforms to (Khalil and Mohammed, 2016).

Hydrated lime is very effective in asphalt mixtures due to its interactions between the major components (aggregate and bitumen), effecting in four ways, two for aggregate and two for bitumen. Hydrated lime develops the surface composition (calcium ions) and roughness (precipitates) and this is more favorable to bitumen adhesion. Also, it has cured the clay particles adhering to the aggregate surface, prohibiting their effect on the mixture. For bitumen, hydrated lime reacts with the acids of the bitumen, enhancing the moisture resistance of the mixture. Finally, hydrated lime has a stiffening effect above room temperature due it is high porosity, so the replacement of hydrated lime with limestone dust has acquired a considerable admission due to its effect on both pavement and cost, it is decreasing maintenance and maintains current and newly constructed pavement, this conforms with (Mohammad et al., 2000).

The improvement in tensile strength ratio (TSR) values can be attributed to improve in the adhesion between asphalt cement and aggregate due to the presence of hydrated lime by reacting with

carboxylic acids in the asphalt and formation insoluble salts that are easily adsorbed at the aggregate surface, this is agreeing with (Khalil & Mohammed, 2016).

Among many benefits, hydrated lime reduces stripping, by acts as a mineral filler to stiffen the asphalt binder and It alters the plastic properties of clay fines to improve moisture stability and durability, this conforms with (Epps and Little, 2001).

4.3.1.2 Compressive Strength and Index of Retained Strength (IRS)

Figure (4-12) shows the results of compressive strength. There was an increasing in compressive strength for the dry and wet condition as the content of hydrated lime was increased up to (32.5 %) with 2 % replacement of hydrated lime for dry condition, whereas with the same percent of replacement, the increase was greater up to (58.3 %) for wet conditions.

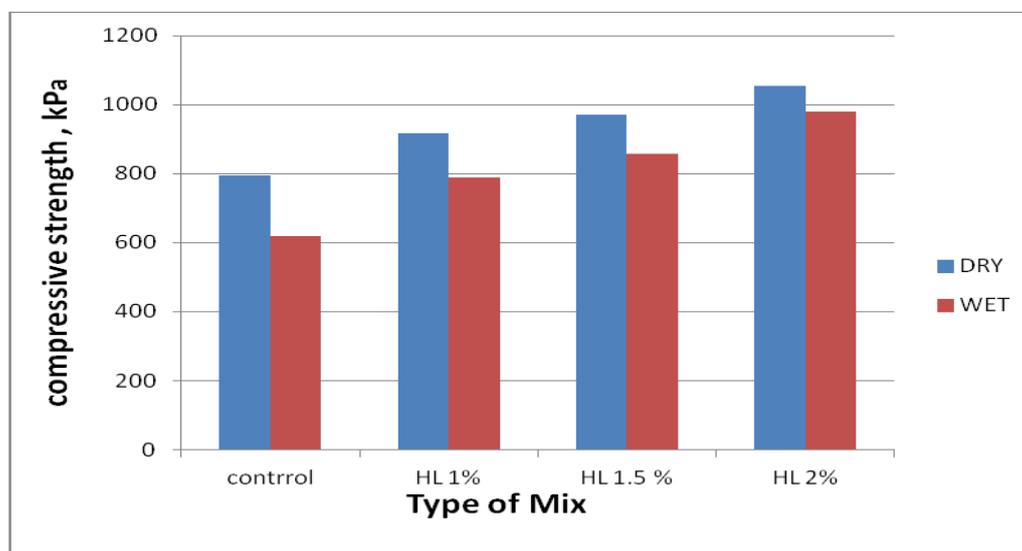


Figure (4-12) Compressive Strength Test for Mixture Containing Hydrated Lime

The results of the index of retained strength (IRS) were shown in Figure (4-13). It can be seen clearly that the IRS gradually increased with increasing the percent of hydrated lime. This increase is up to (19.4 %) at 2% replacement. Also, it can be noticed that all types of mixture were above the minimum limit recommended by (SCRB /R9, 2003) for binder course, which was 70%.

4.3.1.3 Marshall Stability and Retained Marshall Stability (RMS)

- **Bulk specific gravity (G_{mb})**

The results of G_{mb} for dry Marshall specimens are shown in Figure (4-14), it can be noticed that the G_{mb} increased as the lime content increased. This may be due to the high fineness of hydrated lime in comparison with limestone dust.

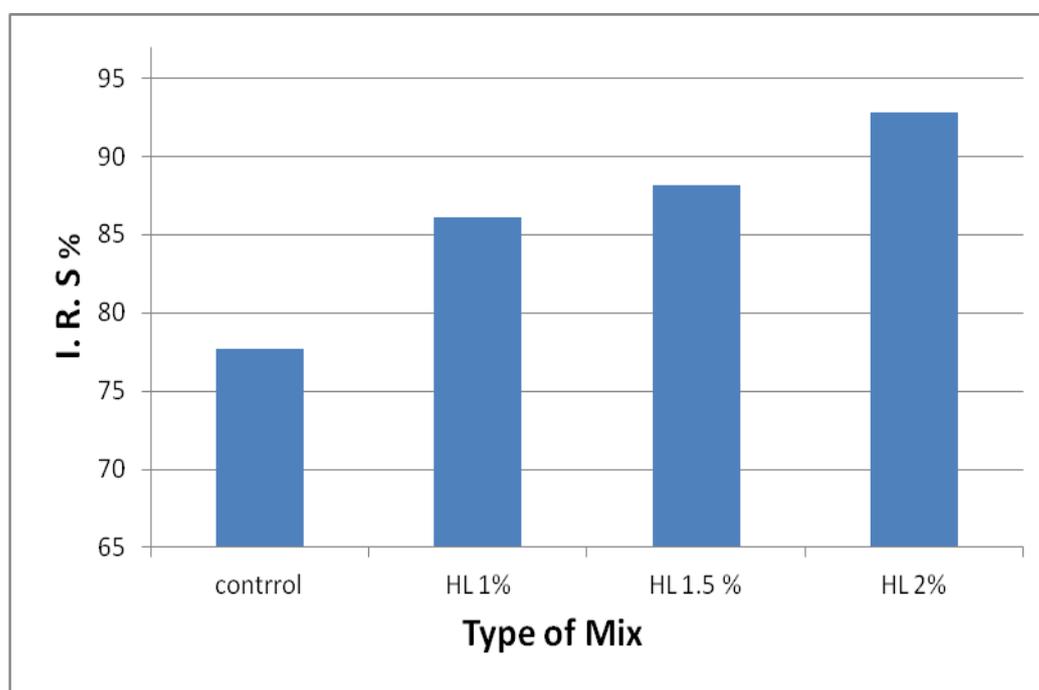


Figure (4-13) IRS for Mixture Containing Hydrated Lime

- Air voids (Va)

One of the most important factors that affects on moisture damage is air voids (VA), the air voids in (CBEMs) is very high due to the evaporate of water during the curing process. Figure (4-15) showed a decline in the void air results for dry Marshall specimens as the percent of hydrated lime increased, this is due to an increasing in G_{mb} value.

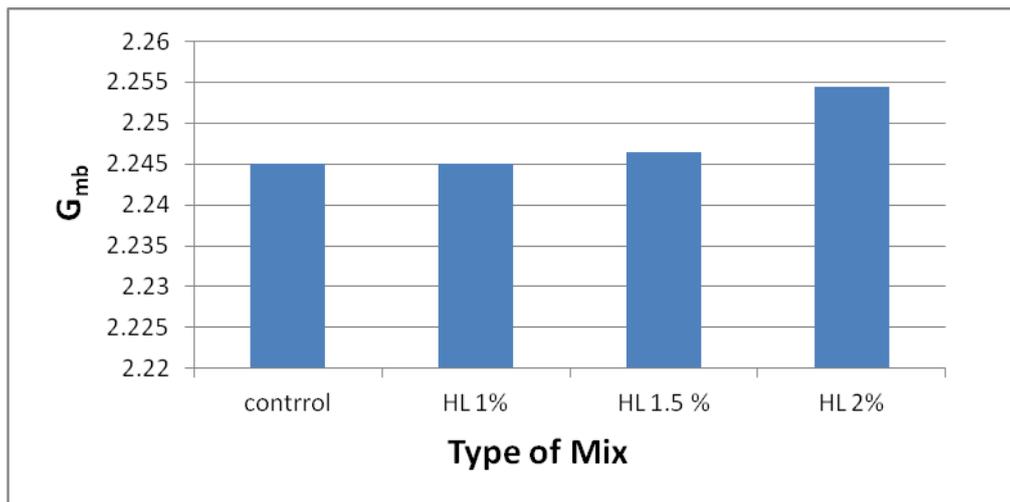


Figure (4-14) G_{mb} for Mixture Containing Hydrated Lime

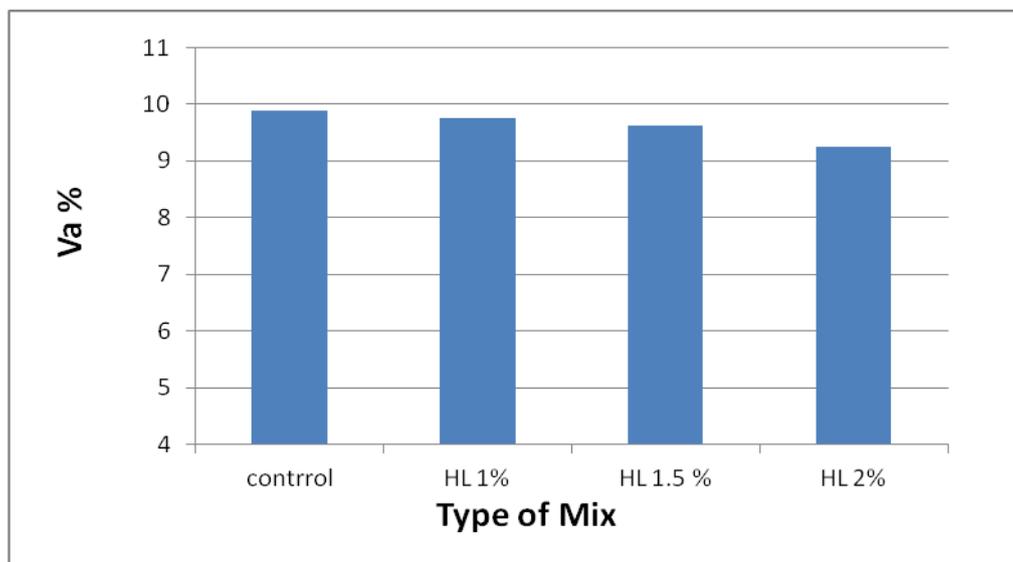


Figure (4-15) Air Voids for Mixture Containing Hydrated Lime

- **Marshall Stability**

Marshall stability is the resistance of asphalt mixture to plastic flow. The results showed increasing in Marshall stability with increasing the lime content, Figure (4-16), the increasing reached to (41.8 %) with 2% replacement. This increasing in Marshall stability is due to the increasing of G_{mb} and reducing of air voids, also due to the effect of hydrated lime to stiffen and reinforced the binder.

Generally, mixtures that containing hydrated lime exceed the minimum limit recommended by (SCRB \ R9, 2003) for binder course, which was (7 KN).

- **Flow Test**

Flow is defined as the measured of vertical deformation of the specimen at the moment of failure. Flow test was conducted for all dry mixture and the results are shown in Figure (4-17).

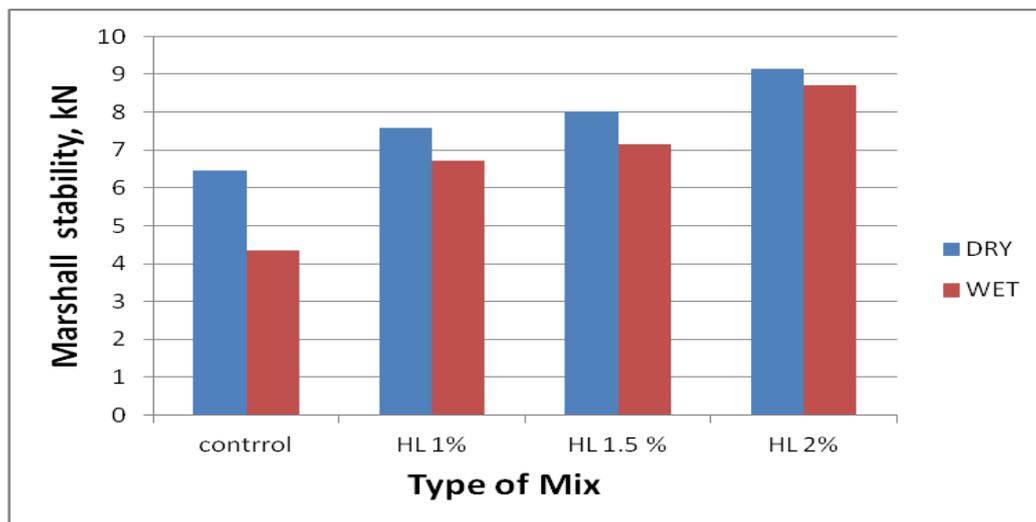


Figure (4-16) Marshall Stability for Mixture Containing Hydrated Lime

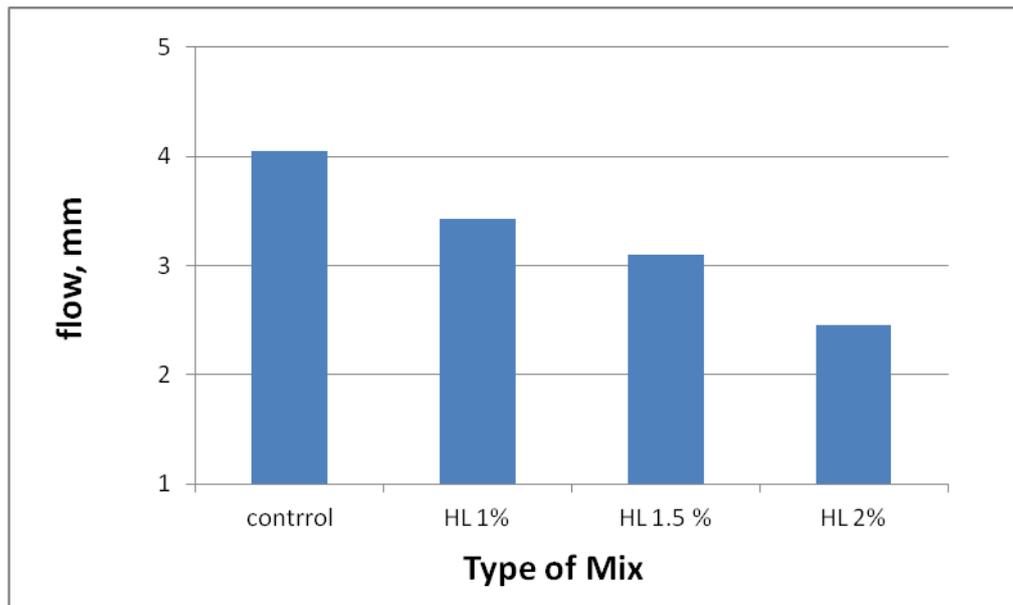


Figure (4-17) Flow Test for Mixture Containing Hydrated Lime

It can be seen that the flow results gradually declined with the increase in percent of replacement. Also, when G_{mb} increased, the air voids of specimens declined, hence the stability values raised and flow values decreased.

- **Retained Marshall Stability (RMS)**

Figure (4-18) illustrates the results of RMS. Although, the RMS for control mix was above the minimum limit recommended by (Thanaya, 2003) which was 50%, but it was a significantly improved when hydrated lime was added. This improvement reached up to about (40%) with 2% replacement of lime. This can be attributed to the effects of hydrated lime in increasing the bond between binder and aggregate. Also, it can be noticed there was no high difference between 1% and 1.5% of replacement.

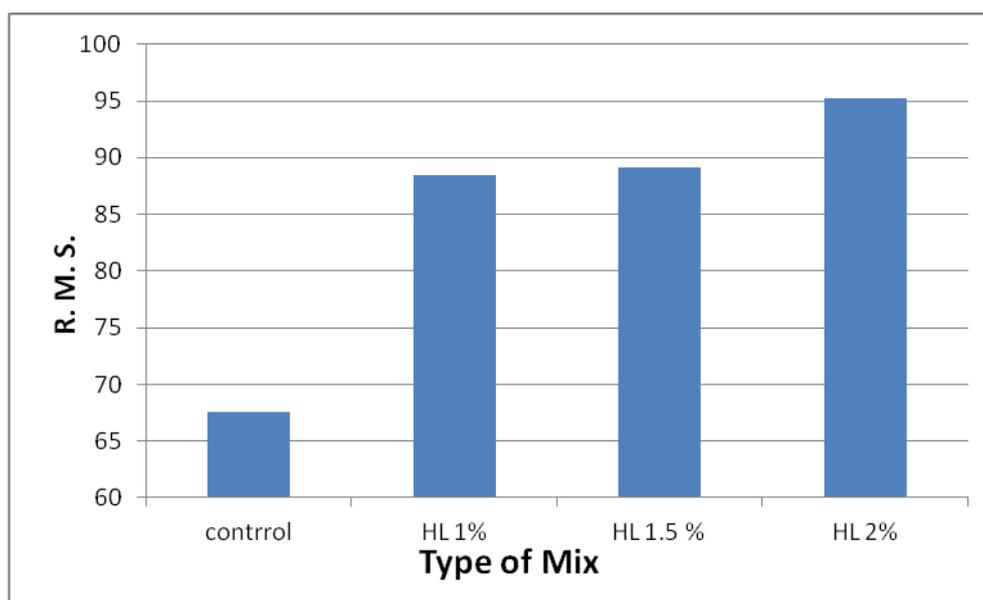


Figure (4-18) RMS for Mixture Containing Hydrated Lime

4.3.1.4 Double Punch Shear Test `

Double punch test indicates the shear resistance existing between binder and aggregate. The results of the double punch test are shown in Figure (4-19). There was a gradual increasing in punching strength with the increase of hydrated lime percent. Punching strength increased by (35.8, 55.7, 95.2) % at (1, 1.5, 2) %, respectively. This increase can be attributed to the capability of hydrated lime to improve the bond between binder and aggregate, this improvement occurred due to change the surface chemistry of acidic aggregate and causes a basic coating, this promotes a strong bond between acidic asphalt binder and aggregate, also by reacting with carboxylic acids in the asphalt and formation insoluble salts that are easily adsorbed at the aggregate surface.

In general, the using of hydrated Lime as a replacement to limestone dust can improve resistance to moisture damage of cold bitumen emulsion mixtures (CBEMs), and this is agreeing with (Niazi and Jalili, 2009).

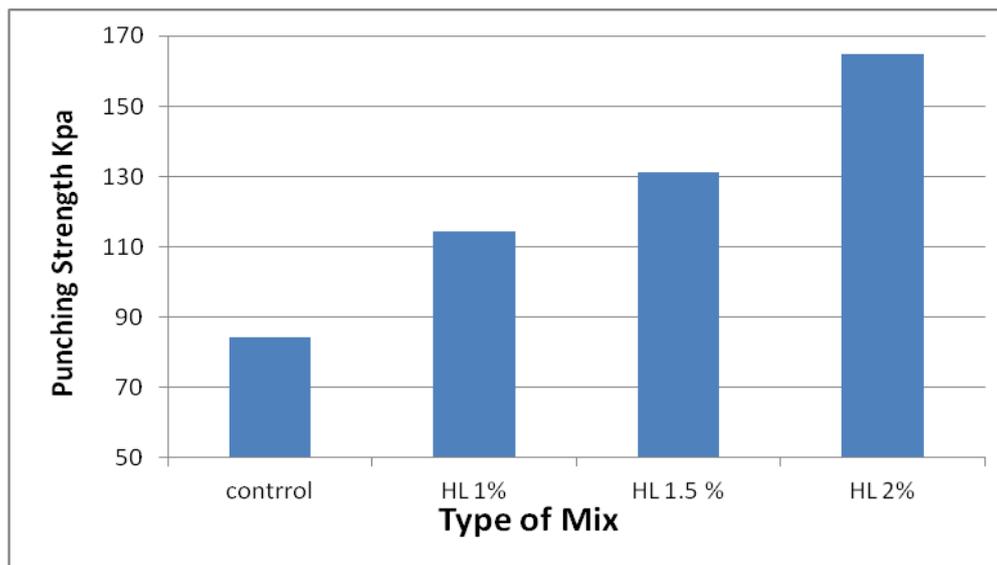


Figure (4-19) Double Punch Shear for Mixture Containing Hydrated Lime

4.3.2 Effect of Adding Fly Ash

Fly ash is a coal combustion product composed of fine particles that are driven out of the boiler with the flue gases.

There is no particular specification that specifies the ratio or quantity of fly ash in asphalt mixtures, so the percent of fly ash used in asphalt mixtures varies amongst researchers. In this study, three ratios of replacement were used for fly ash, which were (1, 2, 3) %.

4.3.2.1 Indirect tensile strength (ITS) and tensile strength ratio (TSR)

Figure (4-20) presents the results of ITS for mixture containing fly ash. There was a gradual reduction in dry ITS results as fly ash percent increased. Whereas this reduction in wet ITS results was less than the dry ITS results with the increasing of fly ash content. The failure in the tensile strength is attributed to the many voids that weaken the cross-section and this conforms to (Asmael, 2010).

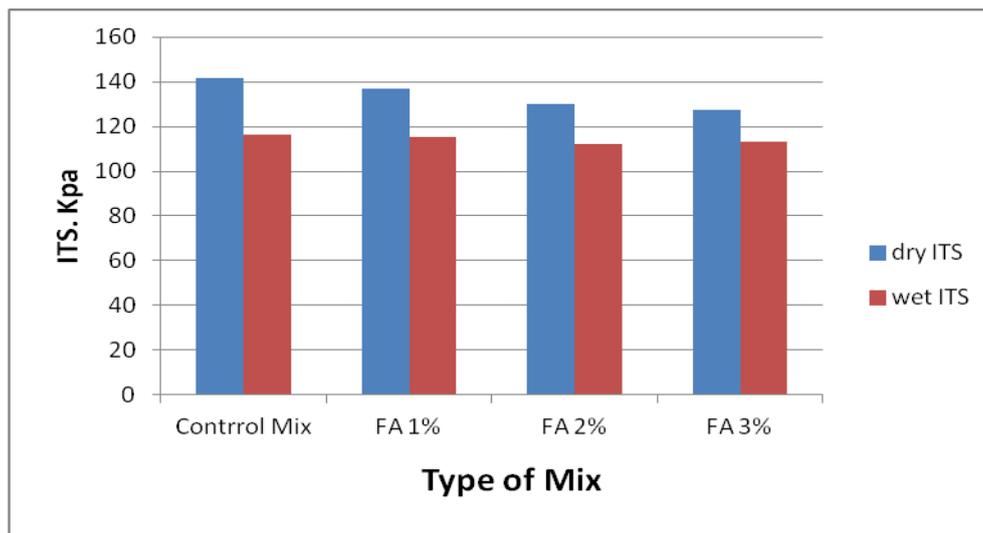


Figure (4-20) ITS Test Results for Mixture Containing Fly Ash

The results of tensile strength ratio (TSR) are shown in Figure (4-21). The results showed an increase in TSR value as the percent of replacement for (FA) was increased, this increased up to about (8%) for 3% replacement of (FA). Possolanic material reaction with calcium hydroxide to produce calcium silicate hydrate (C-S-H) is very similar to (C-S-H) produced by OPC; which means an increase in the binder products (Al-Busaltan, 2012).

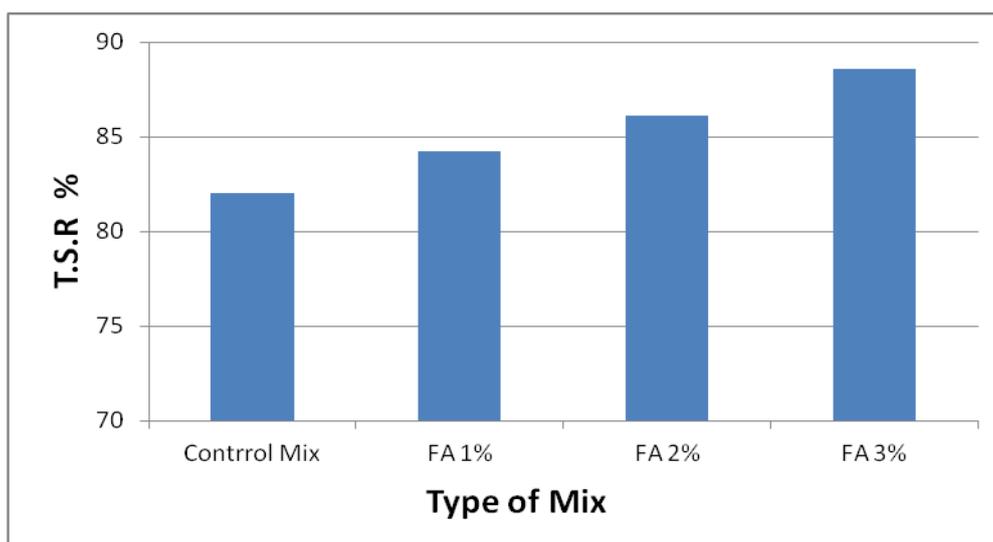


Figure (4-21) TSR Results for Mixture Containing Fly Ash

4.3.2.2 Compressive Strength and Index of Retained Strength (IRS)

Figure (4-22) displays the compressive strength for mixtures with fly ash. There was a gradual decline in compressive strength with the increase of fly ash content, this can be attributed to high workability due to particle shape, hence needs more curing periods.

The index of retained strength (IRS) results for mixture containing fly ash are shown in Figure (4-23). In contrast to dry compressive strength, the loss of compressive strength resulting from the action of water on each compacted bituminous mixture was declining as the percentage of fly ash increased, so the (IRS) value was increased. This increase reached up to (12.7) % at 3% fly ash content. Also, it can be noticed that the IRS for all types of mixture is more than the minimum limit recommended by (SCRB\9, 2003), which was 70 %.

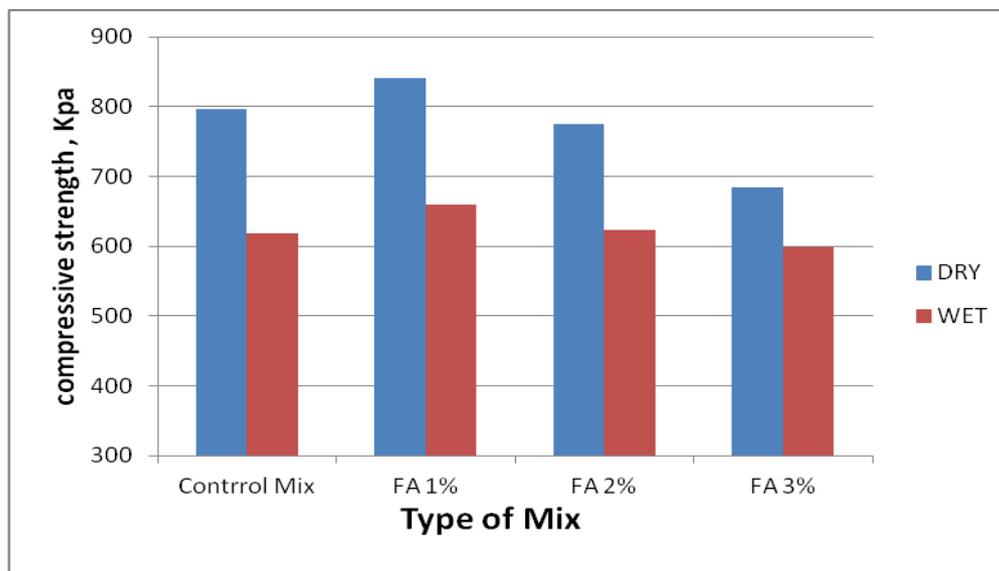


Figure (4-22) compressive strength Test Results for Mixture Containing Fly Ash

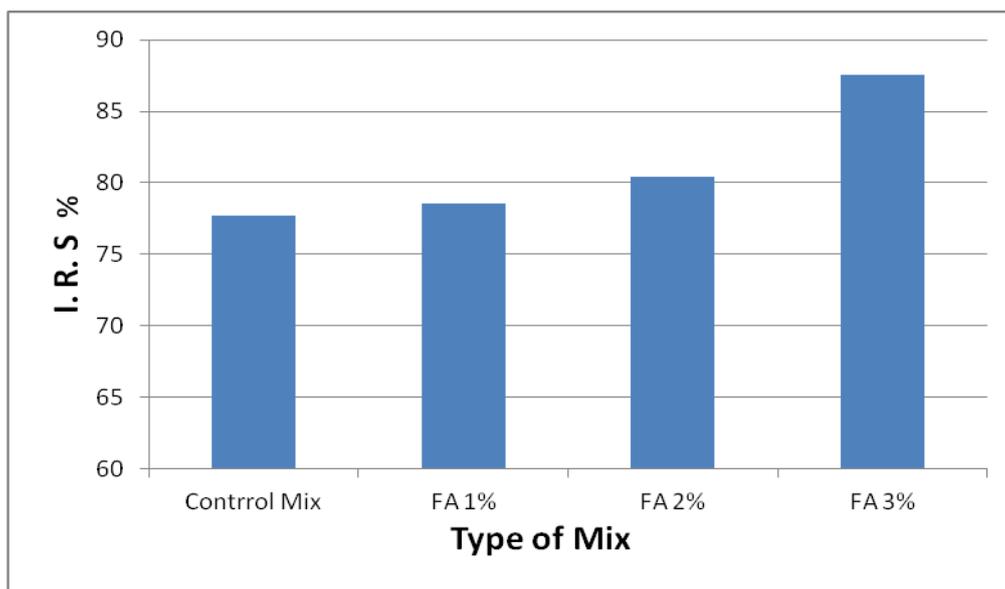


Figure (4-23) Index of Retained Strength Results for Mixture Containing Fly Ash

4.3.2.3 Marshall Stability and Retained Marshall Stability (RMS)

- **Bulk specific gravity (G_{mb})**

Figure (4-24) presents the results of G_{mb} for dry Marshall specimens for mixtures containing fly ash as a replacement, it can be seen that the G_{mb} decreased with increasing of fly ash content, this may be due to crystalline particle shape.

- **Air voids (V_a)**

Figure (4-25) showed a slight decline in the air void results for dry Marshall specimens as the percent of fly ash was increased. This can be attributed to the low specific gravity of fly ash, therefore, a given weight percentage of fly ash will usually occupy a greater volume than that of a conventional filler material, and this agrees with (Asmael, 2010).

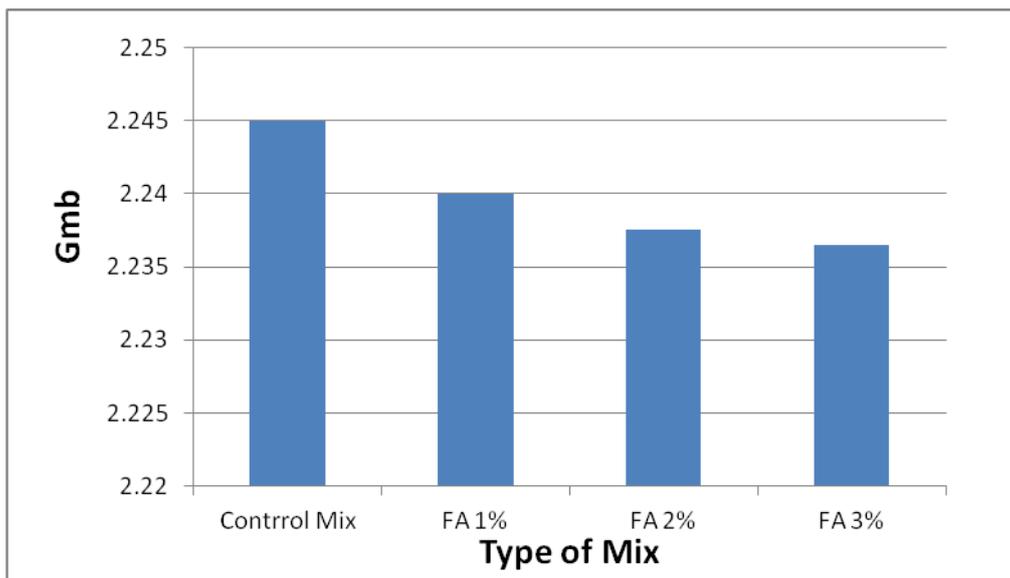


Figure (4-24) G_{mb} for Mixture Containing Fly Ash

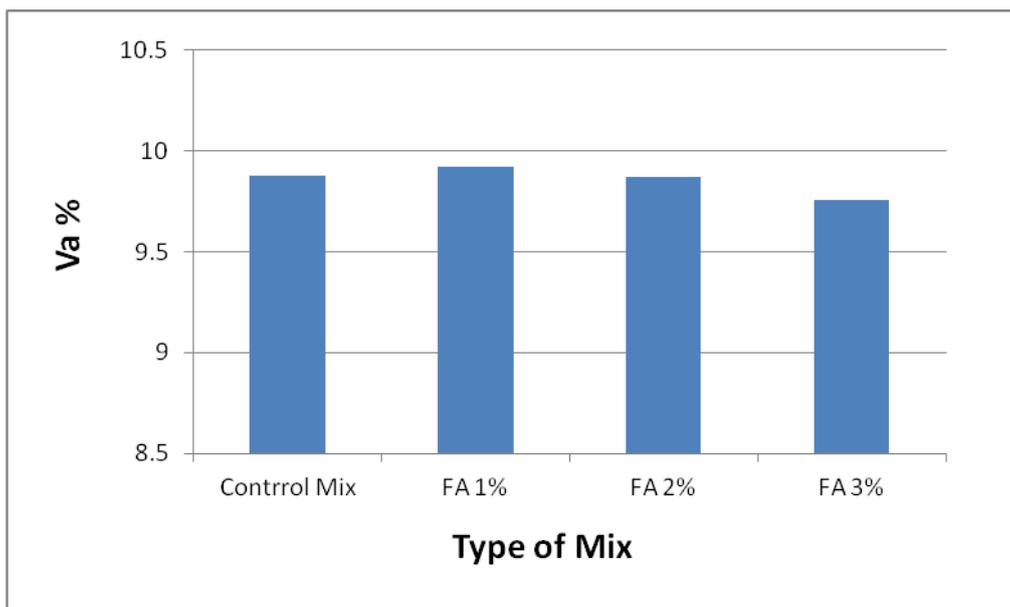


Figure (4-25) V_a Results for Mixture Containing Fly Ash

- **Marshall Stability**

The results of Marshall stability showed a decreasing in dry and wet results as the fly ash percentage was increased as shown in Figure (4-26), there was a (13.4 %) reduction in dry value at 3% replacement of fly ash when compared with control mix.

- **Flow Test**

Figure (4-27) illustrates the results of flow test for dry samples of mixture containing fly ash. The flow results showed that flow of mixtures containing fly ash increased as the content of fly ash was increased. This can be attributed to high workability.

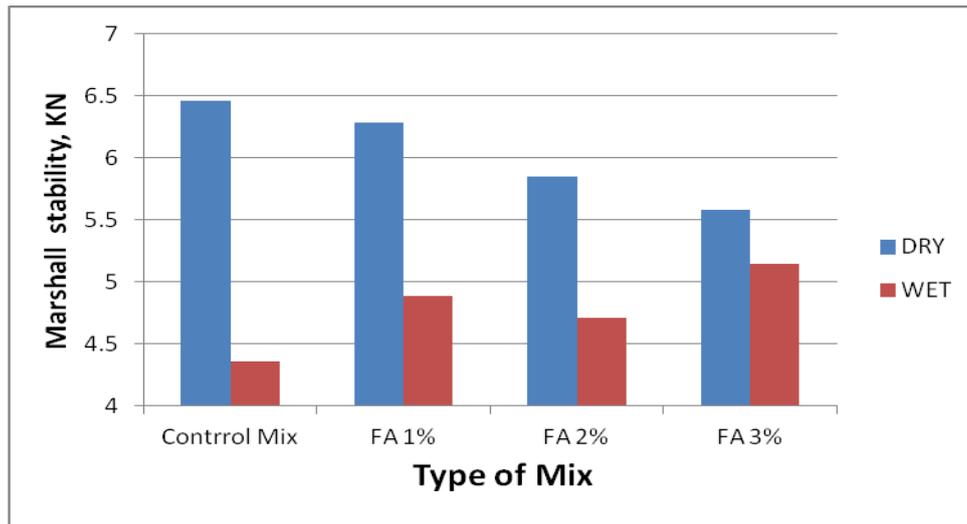


Figure (4-26) Marshall Stability Results for Mixture Containing Fly Ash

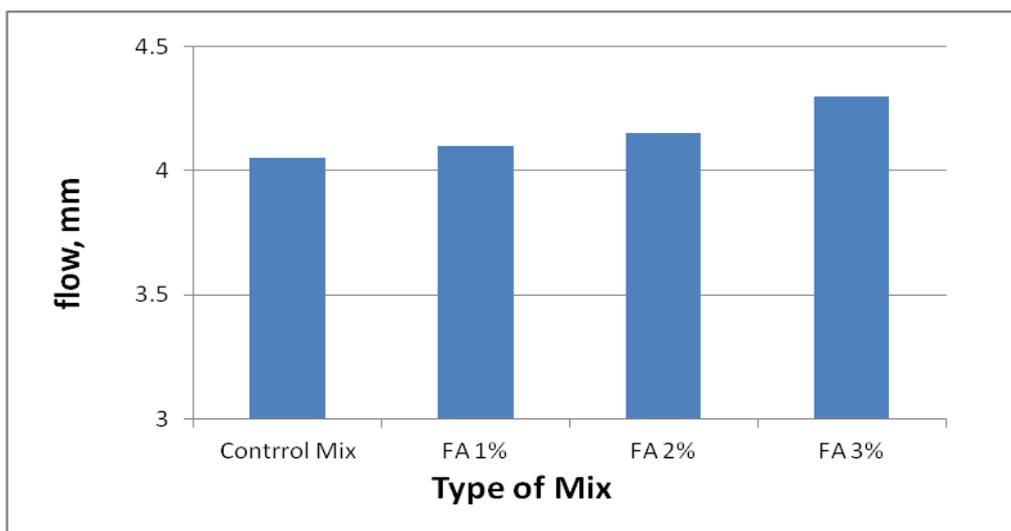


Figure (4-27) Marshall Flow Results for Mixture Containing Fly Ash

- **Retained Marshall Stability (RMS)**

Figure (4-28) demonstrates the results of RMS. It can be noticed that there was a significant improvement in RMS results when fly ash was added. This improvement reached up to about (36.3%) at 3% replacement of fly ash. This may be due to Pozzolanic effects of fly ash.

4.3.2.4 Double Punch Shear Test

The results of the double punch test are shown in Figure (4-29). There was a gradual increasing in punching strength with the increase of fly ash percent. Punching strength increased by (55.7) % at 3%. This may be due to the capability of fly ash to improve stripping resistance.

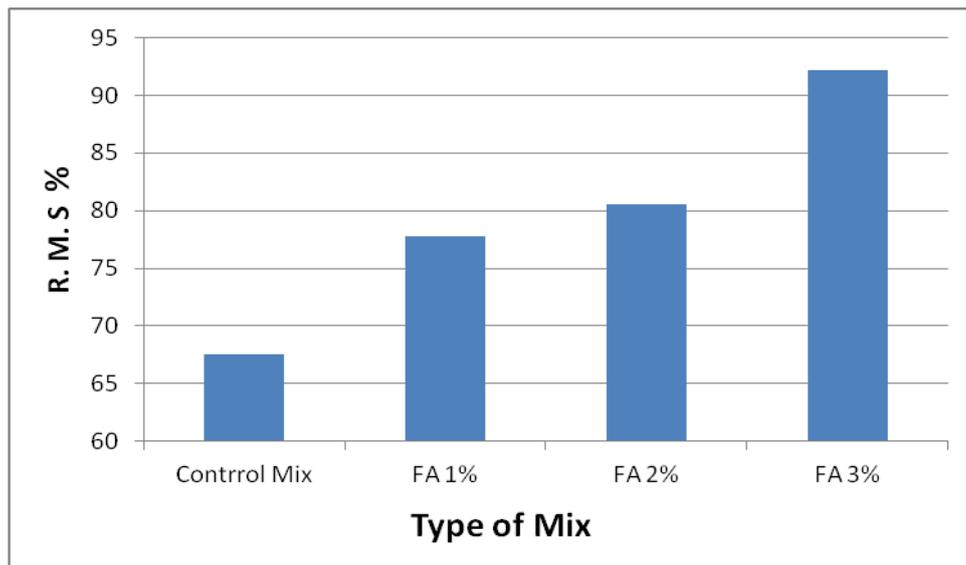


Figure (4-28) RMS Results for Mixture Containing Fly Ash

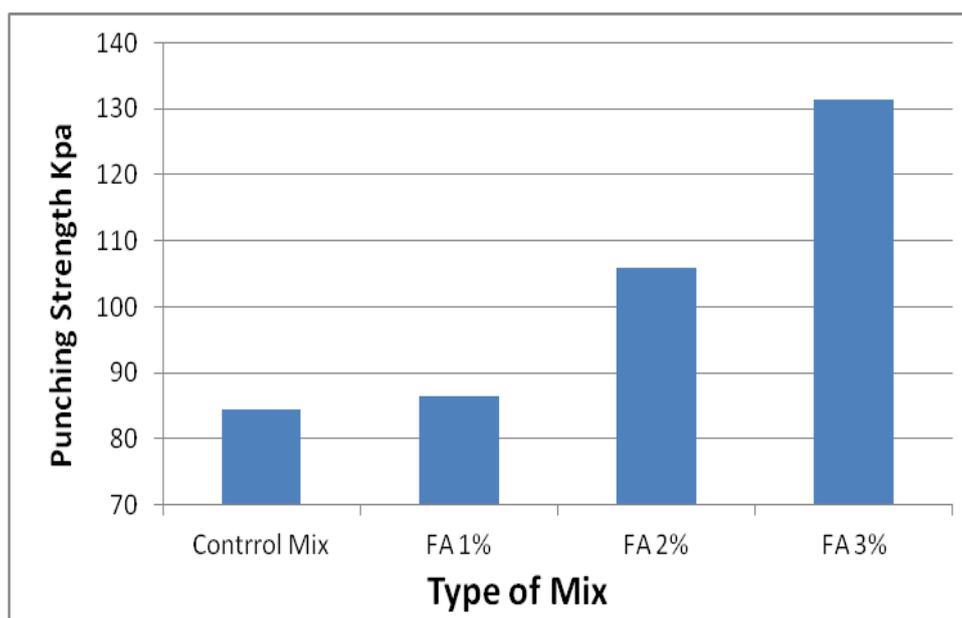


Figure (4-29) Punching Strength Results for Mixture Containing Fly Ash

4.3.3 Effect of Adding Silica Fume

Silica fume (SF) is defined as a very fine non-crystalline silica produced in electric arc furnaces as a by-product during production of elemental silicon or alloys containing silicon, Silica fume is an ultra-fine powder consisting of particles around 100 times smaller than a grain of cement powder (Asmael, 2010) with a very high specific surface area (15,000–25,000 m²/kg).

There is no particular specification that specifies the ratio or quantity of silica fume in asphalt mixtures, so the percent of silica fume used in asphalt mixtures varies amongst researchers.

4.3.3.1 Indirect tensile strength (ITS) and tensile strength ratio (TSR)

Figure (4-30) showed the dry and wet ITS results. There was an increasing in these results when the percent of replacement of silica fume

was increased, This due to effect of silica fume in increasing the viscosity of the binder and this conforms with (Abutalib et al., 2015).

The results of tensile strength ratio (TSR) are shown in Figure (4-31). The results demonstrated a slight increase in TSR value as the percent of replacement for silica fume was increased, this increased up to about (6%) for 3% replacement of silica fume. Possolanic material reaction with calcium hydroxide to produce calcium silicate hydrate (C-S-H) is very similar to (C-S-H) produced by OPC; which means an increase in the binder products (Al-Busltan, 2012).

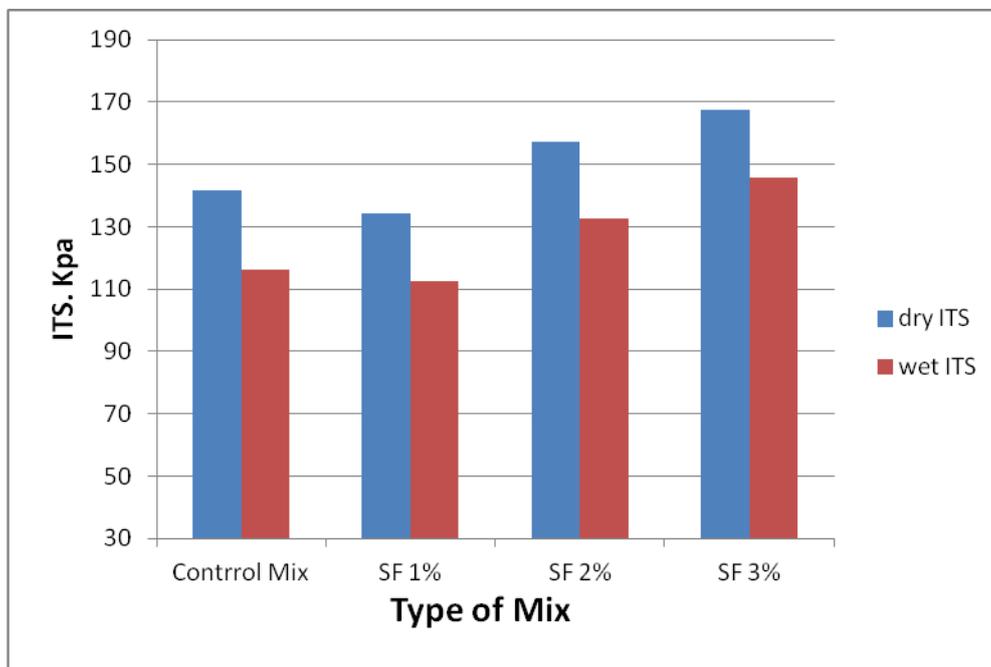


Figure (4-30) ITS Test Results for Mixture Containing Silica Fume

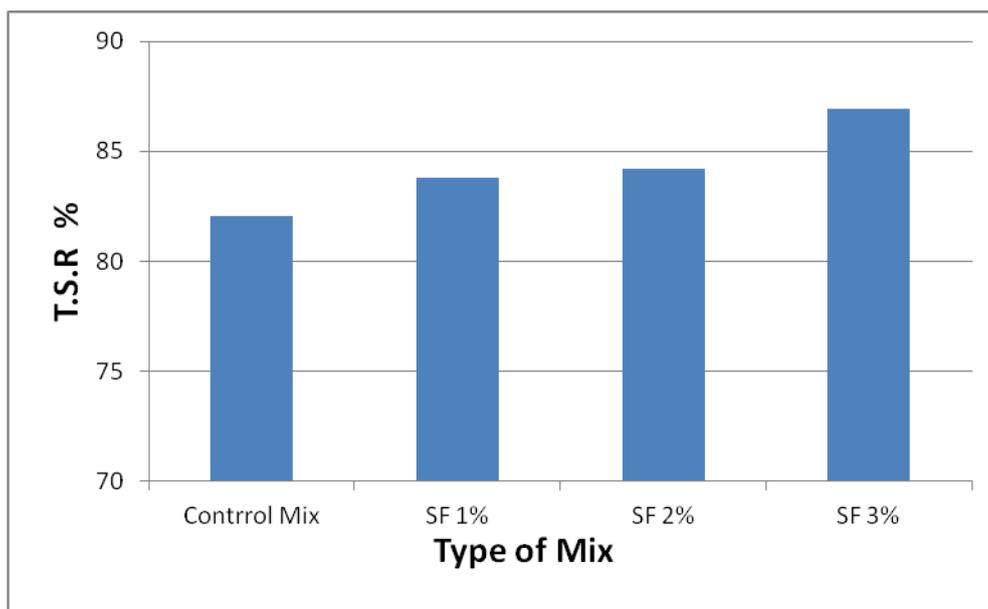


Figure (4-31) TSR Results for Mixture Containing Silica Fume

4.3.3.2 Compressive Strength and Index of Retained Strength (IRS)

Figure (4-32) displays the compressive strength for mixtures containing silica fume. There was an increasing in compressive strength for both dry and wet conditions as percentage of silica fume, this can be attributed to high fineness of silica fume that leads to fill the small pores between the aggregate and limestone dust, and this conforms with (Al-Busultan, 2012), but the increasing is very significant for dry condition.

The index of retained strength (IRS) results is shown in Figure (4-33). The (IRS) value was increased slightly as the percentage of silica fume was increased. Despite this increase, the value of IRS for all percentages of silica fume is lowering the control mixture.

Overall, the index of retained strength values for all types of mixture is more than the minimum limit recommended by (SCRB\R9, 2003) which was 70 %.

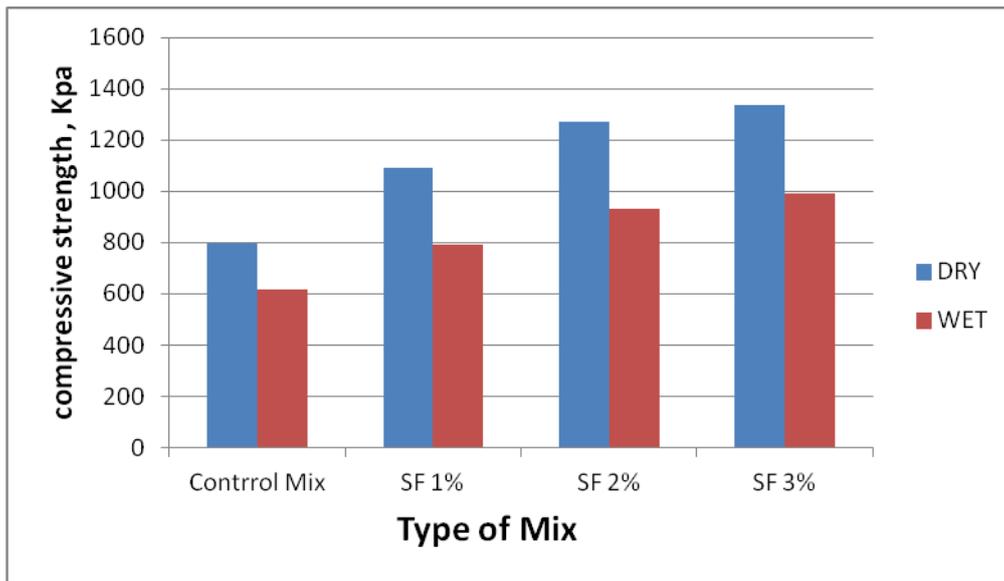


Figure (4-32) compressive strength Test Results for Mixture Containing Silica Fume

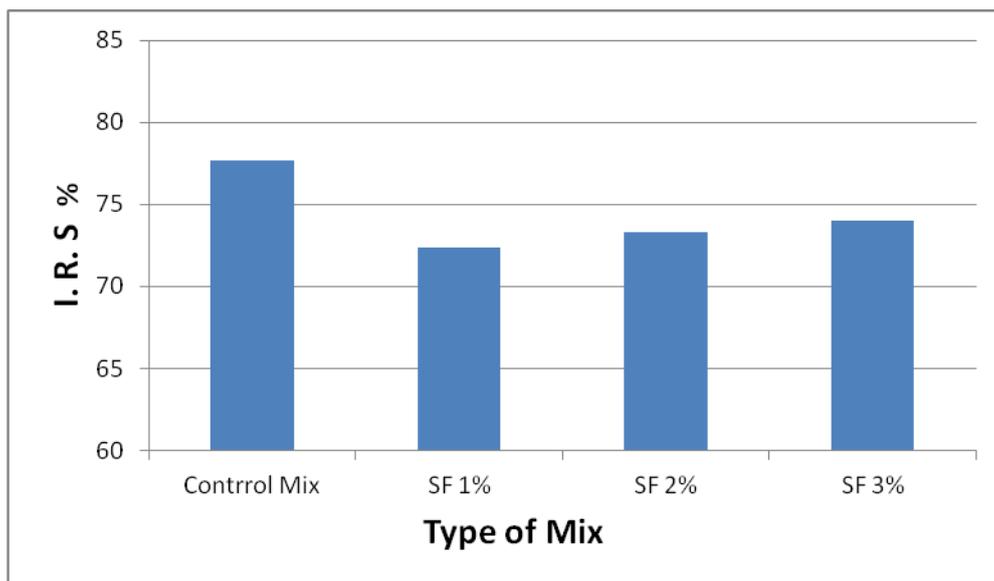


Figure (4-33) Index of Retained Strength Results for Mixture Containing Silica Fume

4.3.3.3 Marshall Stability and Retained Marshall Stability (RMS)

- **Bulk specific gravity (G_{mb})**

Figure (4-34) shows the results of G_{mb} for dry Marshall specimens for silica fume replacement. The G_{mb} value increased as the silica fume content increase, this behavior is expected because of high fineness of silica fume that leads to fill the voids between aggregate particle.

- **Air voids (V_a)**

Figure (4-35) showed a significant decline in the void air results for dry Marshall specimens as the percent of silica fume increased.

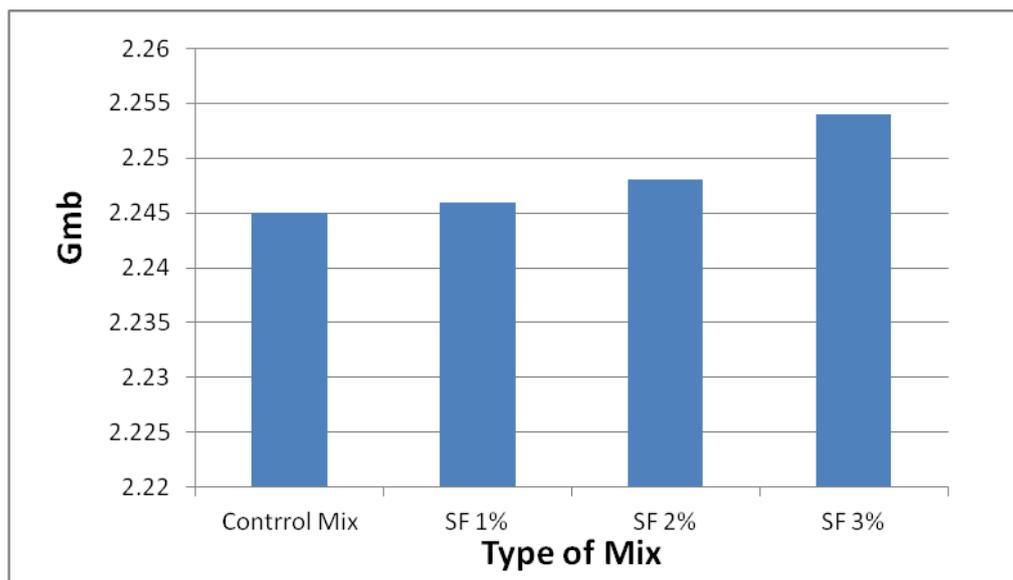


Figure (4-34) G_{mb} for Mixture Containing Silica Fume

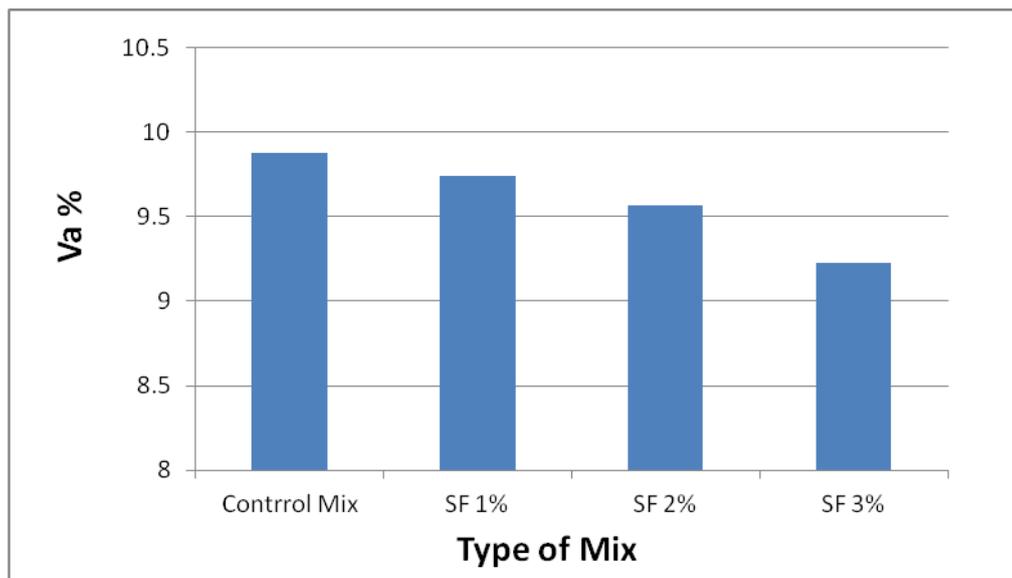


Figure (4-35) Va Results for Mixture Containing Silica Fume

- **Marshall Stability**

The results of Marshall stability showed an increasing with increase the silica fume content for dry and wet results, but this increasing is lowered for a wet condition as shown in Figure (4-36), the increasing reached up to (78.4 %) with 3% replacement of silica fume, as compared with control mix. This increasing in Marshall stability due to increasing of G_{mb} and reducing of air voids.

- **Flow Test**

Figure (4-27) illustrates the results of flow test for dry samples of a mixture containing silica fume. The flow results showed that a decrease in flow values as the percentage of silica fume increased and this trend may be due to lowering workability as the percentage of silica fume was increased.

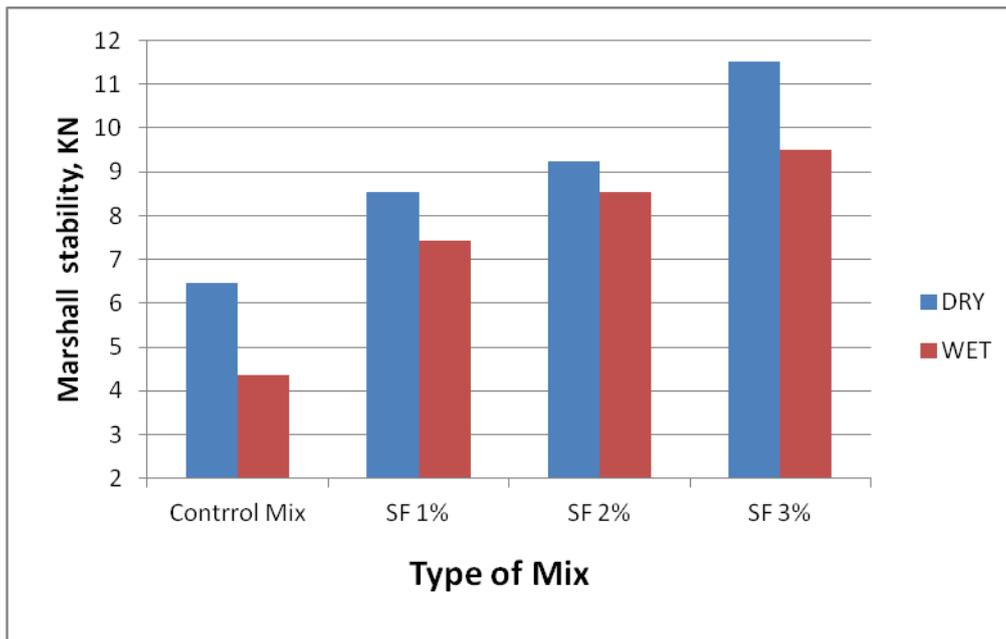


Figure (4-36) Marshall Stability Results for Mixture Containing Silica Fume

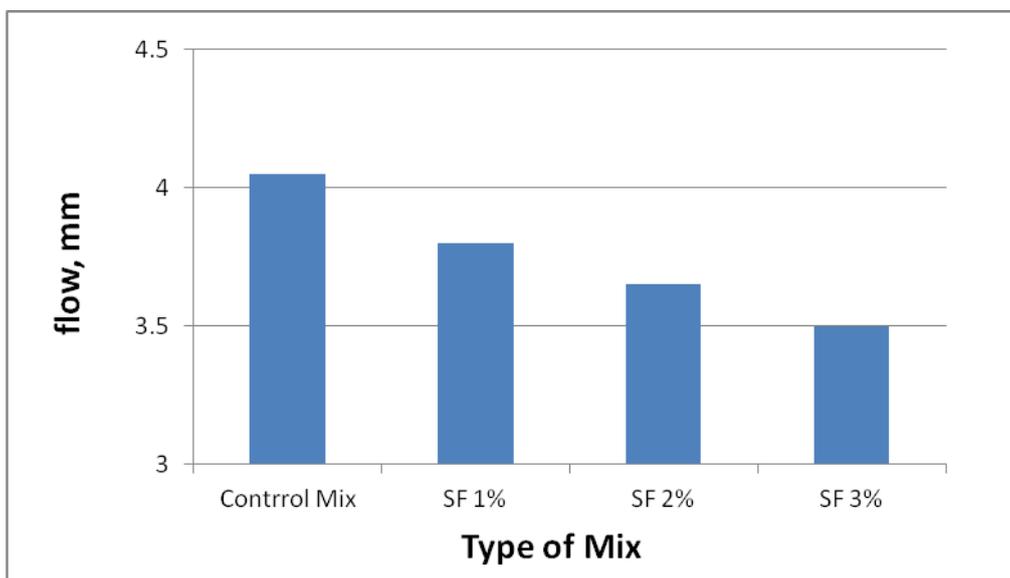


Figure (4-37) Marshall Flow Results for Mixture Containing Silica Fume

- **Retained Marshall Stability (RMS)**

Figure (4-38) demonstrates the results of retained Marshall stability. It can be clearly noticed that there was an increasing in RMS value, then decreasing in this value with increasing silica fume content, this may be due to the high increasing in value of dry Marshall stability in comparison with wet value, However, these values of RMS are above the control mix.

4.3.3.4 Double Punch Shear Test `

The results of the double punching shear test are shown in Figure (4-39). There was a slight decreasing in punching strength value with the increase of the silica fume content. Silica fume plays a role an activator and needs an hydraulic products to give good results, this conforms with (Al-Busaltan, 2012), so as the content of silica fume increased, this led to decrease in limestone dust content, hence, decreasing in hydraulic products, then, decreasing in punching strength.

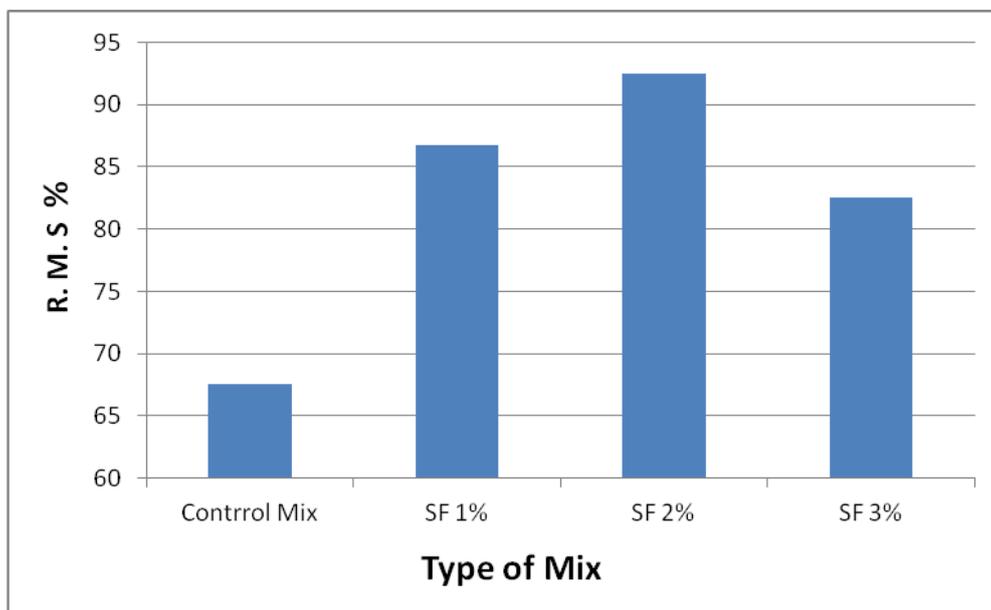


Figure (4-38) RMS Results for Mixture Containing Silica Fume

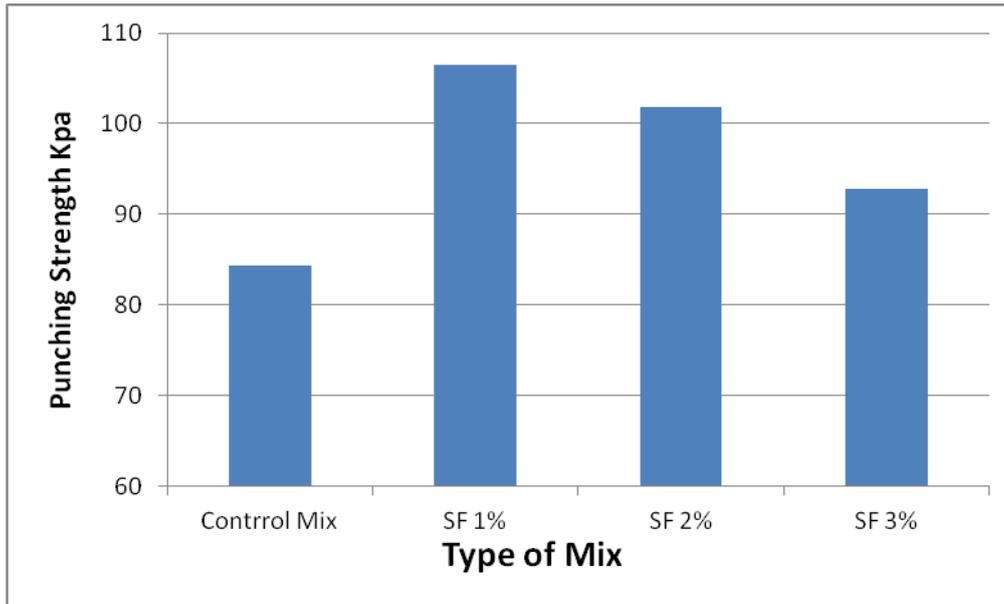


Figure (4-39) Punching Strength Results for Mixture Containing Silica Fume

CHAPTER FIVE

CONCLUSIONS

AND

RECOMMENDATIONS

CHAPTER FIVE**CONCLUSIONS AND RECOMMENDATIONS****5.1 Generals**

This chapter presents the conclusions which derived from this study, as well as the recommendations for future work based on the test results obtained from the limitation of materials and testing program along with the interpretation of the results.

5.2 Conclusions

- 1) It can be used Superpave mix design method to select the trial gradation of aggregate to meet the requirement of cold mix asphalt as for hot mix asphalt.
- 2) Emulsified asphalt type (CSS-1) mixed with the quartz aggregate at optimum emulsion content, the product mixture has a coating more than 80 % by visual inspection and gave a suitable mixing.
- 3) Sample product by using the Superpave gyratory compactor (SGC) has air voids (7.2) %. While the sample that produced by Marshall hammer has (9.7) % air voids content of control mixture.
- 4) Mechanical properties such as indirect tensile strength, compressive strength, Marshall stability, and punching strength were increased to about (28.2, 32.5, 41.8 and 95.2), respectively, when hydrated lime was used as a replacement for limestone dust at 2 %.
- 5) Hydrated lime is a good anti-stripping material. It improves moisture resistance by increasing the TSR, IRS, RMS, and

punching strength to approximately (17, 19.4, 40, and 95.2) %, respectively, at 2% percent of replacement.

- 6) Using fly ash as a replacement to limestone dust decreased the Marshall stability, indirect tensile strength, and compressive strength of dry specimens to about (13.4, 10.5 and 13.8) %, respectively at 3%, also it has increased the flow values to 6.17 % at the same percent of replacement. The reduction in the indirect tensile strength, Marshall stability, and compressive strength values for wet specimens is less than for dry specimens.
- 7) Fly ash was given good results to moisture resistance by increasing (TSR, IRS, RMS, and punching strength) up to about (8, 12.7, 36.3, and 55.7) %, respectively at 3% replacement.
- 8) Silica fume in cold mix asphalt improved the indirect tensile strength, compressive strength, and Marshall stability by increasing them to (18.3, 65, 78.4) % at 3 % of replacement. Also, it has reduced the flow values to 14.5 % at the same percent.
- 9) The results of moisture damage for mixtures containing silica fume as a replacement were less than those with fly ash and hydrated lime.
- 10) The punching strength declined as the silica fume content increased, but still more than control mix by (9.5) % at 3 % of replacement.
- 11) Use of hydrated lime and silica fume improves the volumetric properties (increase bulk specific gravity and reduce air voids).

While, fly ash leads to reduce the bulk specific gravity and increases air voids.

- 12) Mixture with fly ash have a higher workability than that with hydrated lime and silica fume so needs more curing time.

5.3 Recommendations

Depending on the results of this study. The following recommendations for future study can be given:-

- 1) An investigation is required to study the effect of other or full replacement of moisture damage, also on the optimum emulsion content for full replacement.
- 2) An investigation is required to survey the influence of asphalt emulsion modified with polymer on moisture damage, also make a comparison with the other anti-stripping materials in this study.
- 3) An investigation is required to make a comparison between SGC and Marshall compacter and their effect on volumetric and mechanical properties of cold asphalt mixtures.
- 4) A suggestion can be given to correlate the laboratory prepared sample characteristics with in-site samples by transforming of such mixtures from laboratory to site as field trial.

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APPENDIX A

APPENDIX A

ENEM 500 CSS-1 ASTAR TEST RAPORU

ALICI
ÜRÜN
KULLANIM
SİPARİŞ NO
ASFALT

:MEGA İNŞAAT
:ENEM 500 CSS-1 ASTAR
:ASTAR
:İÜ 1711567/17.11.2011
:AC-160/220 PEN ASF.

<u>DENEYLER</u>	<u>(TESTS)</u>	<u>LİMİTLER (TS1082)</u>
Çökme, 5 gün, % (Settlement Test, 5day,%)	-	0-5
Partikül yükü deneyi (Particle Charge Test)	Pozitif	Pozitif (positive)
Destilasyon kalıntısı, yağ destilatı (Distillation residue, oil Distillate)	0.5	0-3
Kalıntı (residual)	50	50-65
Saybolt furol viskozite, 25 °C, sn (Viscosity, Saybolt Furol at 25°C)	26	20-100
Elek deneyi, 850 mic. (Sieve test, 850 mic.)	0.0	0.0-0.10
Kesilme endeksi, gr (Ductility, 25°C, 5 cm/min)	210	40
Depolama stabilitesi, 1 gün, % (1 Day Storage stability test, %)	-	1

Özgür KAPLAN SEREN

Papers

- 1) Joni, H. H., & Hashim, M. S. (2017). **"Evaluation of the Effects of Anti-Stripping Materials on the Performance of Cold Bitumen Emulsion Mixtures (CBEMs)"** published in the International Journal of Current Engineering and Technology, Volume 7, No 5, pp 1770–1776, (Sept/Oct 2017).

- 2) Joni, H. H., & Hashim, M. S. **" Evaluation of Silica Fume Additional on Some Properties of Cold Bitumen Emulsion Mixtures (CBEMs)"**. Accepted to the 2nd International Conference on Engineering Sciences – University of Kerbala (ICES-UoK).

المستخلص

بشكل عام، تعتبر التعرية الشكل الاساسي لضرر الرطوبة في الخلطات الاسفلتية، وهو شكل رئيسي من الاضرار التي تحصل في الطرق الاسفلتية ويمكن تحديد اسباب الاضرار بسببين رئيسيين هما بسبب عدم وجود او نقصان قوة اللصق بين الركام والمادة الرابطة او بسبب تدهور قوة التماسك داخل المادة الاسفلتية الرابطة، هذان النوعان من الفشل يحدثان بسبب تأثير الاحمال المرورية بوجود الرطوبة.

في الخلطات الاسفلتية المستحلبة الباردة، يتألف المستحلب من المادة الرابطة، الماء والمذيب، وغيرها من المواد المضافة، لذلك يجب ان يتبخر الماء الموجود في المستحلب خلال عمليات الخلط والحدل والمعالجة وهذا ممكن ان يؤدي الى ارتفاع محتوى الفراغات الهوائية في الطريق الاسفلتي مما يجعل من الطريق الاسفلتي اكثر عرضة لضرر الرطوبة.

الغرض من هذه الدراسة هو إجراء تحقيق مختبري لتقييم تأثير استخدام ثلاثة أنواع من المواد المسماة (الجير المطفأ والرماد المتطاير ودخان السيليكا) كمواد مضادة للتعرية على الخلطة الاسفلتية الباردة لطبقة الاسفلت الرابطة بأستخدام مستحلب موجب الشحنة بطى التصلب ذو لزوجة منخفضة، ويتم ذلك عن طريق استخدام نظام تصميم الخلطات (Superpave) (التبليط الاسفلتي فائق الاداء)، تم إعداد الخلطات بأستخدام ثلاثة مزجات من الركام ، مع مزج خمسة نسب مختلفة من الاسفلت المستحلب لكل مزيج من الركام للحصول على محتوى المستحلب الامثل مع المزيج الامثل. بعد اختيار المزيج الامثل النهائي، تم إجراء أربعة أنواع من الفحوصات (مقاومة الشد غير المباشرة، مقاومة الانضغاط، فحص ثباتية مارشال، وفحص الاختراق المزدوج) على كل نوع من الخلطات ذات النسب المختلفة من المواد المضادة للتعرية. ثلاثة نسب من الجير المطفأ والرماد المتطاير ودخان السيليكا تم استخدامها كبديل للمادة المألثة (غبار الحجر الجيري) والتي كانت (1، 1.5، 2)٪ للجير المطفأ و (1، 2، 3)٪ للرماد المتطاير ودخان السيليكا.

أظهرت النتائج أن استخدام الجير المائي مع استبدال 2٪ من المادة المألثة يمكن أن تحسن من الخصائص الحجمية والميكانيكية وأيضاً مقاومة الرطوبة. تم زيادة مقاومة الشد غير المباشرة ومقاومة الانضغاط وثباتية مارشال بنحوالي (28.2، 23.5 و 41.8) % على التوالي، وكذلك أدى الى زيادة الوزن النوعي الكلي وتقليل محتوى الفراغات الهوائية والزحف فضلاً عن زيادة نسبة قوة الشد ومؤشر القوة المتبقية وثباتية مارشال المتبقية ومقاومة الاختراق بنحو (17،

19.4، 40، 95.2)٪، على التوالي. كما أشارت النتائج إلى أن استخدام الرماد المتطاير أدى إلى تحسين مقاومة الرطوبة عند استخدام 3٪ من استبدال المادة المألثة، حيث زادت نسبة مقاومة الشد ومقاومة الانضغاط المتبقية وثنائية مارشال المتبقية ومقاومة الاختراق بنسبة (8، 12.7، 36.4، و 55.7٪) على التوالي. ولكن في الوقت نفسه أدى إلى انخفاض قوة الشد الغير مباشرة ومقاومة الانضغاط وثنائية مارشال بمقدار (10.5، 13.4، و 13.8)٪ وكذلك نقصان الوزن النوعي الكلي وزيادة محتوى الفراغات الهوائية والزحف.

وكذلك أظهرت نتائج استخدام دخان السيليكا كبديل للمادة المألثة بأن دخان السيليكا هذا يعزز من مقاومة الشد غير المباشرة، مقاومة الانضغاط، وثنائية مارشال بشكل ملحوظ، كما يزيد من الوزن النوعي الكلي وتقليل الفراغات الهوائية وقيم الزحف. وعلاوة على ذلك هناك زيادة طفيفة في نسبة مقاومة الشد، وثنائية مارشال المتبقية، ومقاومة الاختراق، وهذه الزيادة تصل إلى (5.7، 22.2، 9.5)٪، على التوالي عند استخدام نسبة 3٪ من الاستبدال. في حين أن هذه النسبة للإستبدال ادت الى انخفاض في مقاومة الانضغاط المتبقية مقارنة مع الخلطة المرجعية، وهذا أقل بنحو (4.5)٪



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تخصص طرق ونقل

تقييم استخدام أنواع مختلفة من المواد المضادة للتعرية على الخلطة الاسفلتية الباردة ذات المستحلب الموجب

رسالة

مقدمة الى قسم هندسة البناء والانشاءات في الجامعة التكنولوجية
كجزء من متطلبات نيل درجة الماجستير
في علوم هندسة الطرق والنقل

مقدمة من قبل

محمود شاكر هاشم

(بكالوريوس في الهندسة المدنية 2010)

بإشراف

أ.م.د حسن حمودي جوني

