Modified Marshall Mix Design Method for Asphalt Roads in Hot and Arid Climate

by

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Méthode modifiée de conception d'un mélange Marshall pour les routes asphaltées en climat aride et chaud

Khlifa EL-ATRASH

RÉSUMÉ

Les propriétés rhéologiques des enrobés bitumineux, la température ambiante et le taux de chargement ont un effet déterminant sur la performance des chaussées en béton bitumineux. Ces paramètres doivent donc être pris en compte de manière appropriée lors de la conception des enrobés bitumineux.

La plupart des pays en développement s'appuient sur la méthode empirique des mélanges Marshall pour obtenir des mélanges homogènes. Cependant, la méthode Marshall ne répond pas aux conditions climatiques; et -ne simule pas les conditions de compactage des enrobés bitumineux d'autant plus importantes dans les climats chauds et arides.

La migration vers des méthodes de formulation plus appropriées et par ailleurs plus récentes pour les enrobés bitumineux, telles que la méthode Superpave nécessite l'acquisition de nouveaux équipements coûteux et la formation des opérateurs, et exclut presque tous les équipements qui sont actuellement utilisés, dans ces pays.

L'approche préconisée et justifiée dans cette thèse consiste à recourir à une approche hybride, dans le cadre de laquelle la méthode traditionnelle de la Marshall est améliorée pour tenir compte d'une part compte des conditions environnementales de ces régions et d'autre part d’un compactage plus représentatif des conditions réelles de chantier. Ce complément repose sur l'intégration des caractéristiques des nouveaux liants bitumineux (bitume de performance ou bitume modifié) et l'essai de compactage réalisé avec la presse à cisaillement giratoire propre à la méthode de formulation Superpave.

La méthode Marshall modifiée (3M) proposée est intéressante parce qu'elle ne nécessite pas d'équipement et d'outils coûteux, hormis le compacteur giratoire, lequel est-relativement facile à utiliser et ne nécessite pas de formation importante. Elle améliore les propriétés des enrobés et augmente la durée de vie de la chaussée dans les régions chaudes et arides. La méthode 3M pourrait être utilisée dans les pays en développement dans les années à venir.

Mots-clés : Presse à cisaillement giratoire (PCG), Superpave, Marshall, Laboratoire, Climat, Enrobé, Formulation

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Modified Marshall mix design method for asphalt roads in hot and arid climates

Khlifa EL-ATRASH

ABSTRACT

Rheological properties of asphalt mix materials, prevailing temperatures, level and rate of loading time have substantial effects on the performance of asphalt concrete pavements. Thus, they must be given appropriate consideration during asphalt mix design.

Most of all developing countries rely on the empirical Marshall mix design (MMD) method to obtain homogeneous mixtures for asphalt roads. However, the MMD method does not take into account the climatic conditions, the level of compaction, and the asphalt binder properties required for hot and arid climates.

The migration to more appropriate asphalt mix design methods such as the Superpave method, requires the purchase of expensive equipment, training of operators, and excludes all the laboratories, and the equipment currently used in these countries for asphalt mix design.

The solution proposed in this thesis is to resort to a hybrid approach whereby the traditional MMD method is enhanced to also consider the environmental conditions of these regions. This approach is based on the integration of the characteristics of new asphalt binders *(performance grade or modified asphalt)* and the compaction test performed with the gyratory compactor as associated to the Superpave mix design (SMD) method.

This proposed Modified Marshall Method (3M) is cost-effective because it does not require expensive equipment and tools (except the gyratory compactor), is relatively easy-to-use, and does not require substantial training for operators and engineers.

The results of the laboratory investigations conducted as part of this thesis show substantial improvement of the properties of asphalt mixtures and an equally substantial increase in performance, indicative of extended pavement life in hot and arid (HA) climates with minimal additional equipment as proposed in modified Marshall method.

Keywords: - Gyratory Compactor, Superpave, Marshall, Laboratory, Climate, Asphalt Concrete, Mix design.

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LIST OF SYMBOLS AND UNITS OF MEASUREMENTS

Symbols	Definition
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ASTM	American Society for Testing and Materials
Va	Air void
ACP	Asphalt Concrete Pavement
3M	Modified Marshall Mix Design Method
SMD	Superpave Mix Design
MMD	Marshall Mix Design
HA	Hot and Arid
MW	Mid-West
°C	Degree Celsius
VFA	Voids filled with asphalt
Vbe	Volume of effective asphalt binder
cm	Centimeter
D	Diameter
Gmm	Maximum theoretical specific gravity

Gsb	Bulk density of the mixture
G*	Shear modulus
E	Elastic modulus due to loading
E*	Complex Modulus
E0	Initial Modulus
CR	Crumb Rubber
SBR	Polymer
SIW	Solid Industrial Wastes
Fr	Frequency
g	Gram
H	Hight
OBC	Optimum Bitumen Content
Hz	Hertz
QI	Quality index
kg	Kilogram
km	Kilometer
kN	Kilo Newton
MPa	Mega Pascal
m	Meter
PG	Performance Grade Binder
m	Slope of the m for temperature curve
S	Slope of the stiffness-temperature curve

aT	Shift factor (Slope of the log modulus-log Temperature)
E00i	Initial modulus at the first cycle
Er	Relative error
EN	Norm of complex modulus at cycle N
mm	Millimeter
N	Number of cycles
No	Number of gyrations
Pa	Pascal
p.	Page
R	Universal gas constant
SN	Standard deviation
OBC	Optimum bitumen content
CM	Complex Modulus

INTRODUCTION

Road agencies in hot and arid (HA) climates overlook the challenge of keeping their asphalt concrete pavements in a satisfactory condition throughout their design life. Newly constructed asphalt concrete (AC) pavements in HA climates often develop premature cracking, rutting and shoving within the first few years of operation (Assaf, 2019).

The mid-west of Libya is a good example of a HA climate, consisting of large deserts. The Libyan road network is composed of 47,590 km of paved roads, as well as more than 100 airports in various cities. The government has invested billions of USD in road construction in HA climates (Al-Fenadi 2010).

Hot and arid climates are common in developing countries and have specific concerns whereas asphalt mix design methods and specifications are issued by road agencies in developed countries, most of which are in cold or temperate climates.

The Marshall mix design (MMD) method was developed in the US and is still used in most developing countries (Bressi et al., 2016). In Libya, the mix design of asphalt mixtures is based on the MMD method. However, this method has shown poor performance as it is not suitable for heavily trafficked roads in the climates prevailing in the region (Almadwi & Assaf, 2017).

The MMD method does not have a suitable penetration asphalt test appropriate for extreme HA climates resulting in-each road agency using different asphalt penetrations with some additives (Al-Mistarehi, 2014). Although, the MMD is easy to use and inexpensive, and the Marshall Stability and Flow Test is fast and effortless, it is not appropriate for the heavy traffic loads and temperature spectrum to which the asphalt mixture is subjected to in the field (Al-Mistarehi 2014; Pooley 1985).

In addition, this method has many other shortcomings and limitations, such as the absence of simulating field conditions in the laboratory. Therefore, it is important to improve this method to reflect actual operating conditions in the field. Since prevailing temperatures are not a part of the Marshall mix design (MMD) method, this thesis provides a hybrid approach, hereafter designated the Modified Marshall Method (3M), to integrate the effect of temperatures and the asphalt performance grading in the AC mix design, and the level of compaction.

The aim of this research is to minimally modify the traditional MMD method for HA climate as found in most developing countries to achieve cost-effective mixtures.

Based on the above, this research gradually investigates the addition of various equipment to the conventional MMD and demonstrates that the addition of only the Superpave gyratory compactor (SGC) provides a substantial improvement in mix design along with the introduction of performance grade asphalts.

This minimal addition to the MMD leads to substantial cost savings in laboratory equipment and associated training needs in developing countries, and an equally substantial increase of the performance of the AC as shown in the investigations conducted in this thesis. This in turn should increase pavement life. It is therefore hoped that the proliferation of this enhancement may lead to improved performance of asphalt pavements in HA climates with a minimum investment and minimum technology transfer requirements.

This is based on the experience with the SMD method whereby the incorporation of critical performance grade factor of the new binder and the recourse to the simulation of compaction in the laboratory have led to significant improvements in terms of pavement life and cost savings. Designing Asphalt Concrete mixtures for heavily trafficked roads in HA climates with the 3M method by using Performance Grade (PG) asphalt cement and verification of the improvement in asphalt performance with the SGC only has not yet been investigated.

CHAPTER 1

DISSERTATION LAYOUT AND PURPOSES

1.1 Introduction

Road agencies in hot and desert jurisdictions such as those found in HA climates face the daunting challenge of preserving their pavements in a fair to good condition throughout their design life. This has not been the case, since a number of newly constructed highway pavements in these areas have been reported in the literature as having exhibited poor to very poor performance over time, namely severe rutting, shoving, and depressions within the first few years of operation (Bressi, Dumont, & Partl, 2016).

Asphalt pavements are typically designed for a specified “design life” which is defined by AASHTO as the period of time from the pavement initial serviceability to the end of the pavement serviceability (Kucukvar et al., 2014). The majority of developing countries relies on the Marshall mix design method to obtain homogenous mixtures for their asphalt roads. This method is an empirical design method that does not replicate the field compaction, the asphalt binder characteristics, and the climate prevailing in the region (Ahmad et al., 2014). However, the migration to newer mix design methods such as the Superpave mix design method right away will be difficult and expensive.

There are several parameters that contribute to improving pavement performance as assessed by the manifestation of surface distresses over time such as increased rigidity, enhanced ability to deform without rupturing, reduced sensitivity to temperature, reduced sensitivity to the rate of load application, etc. All of these parameters may be improved with additives such as polymers, fibers, crumb rubber. Performance under heavy traffic and HA climates may also be improved with recourse to optimal mix designs or innovative compaction methods (Sol-Sánchez et al., 2015).

The aim of this research is to modify the traditional Marshall mix design method for heavily trafficked roads in HA climates with the inclusion of various factors such as the type of asphalt binders, the compaction level, and the prevailing environmental conditions based on Laboratory mix design trials of asphalt-aggregate blends performed at *École de technologie supérieure* (ETS) with representative aggregates obtained from Libya. The result of the investigation conducted at ETS has established that the optimal modification is obtained with the incorporation of the new asphalt binders (performance grade (PG) or modified asphalt) and a new compaction method (gyratory compactor) into the Marshall mix design method.

The analysis and discussion of the obtained results show a substantial improvement in performance over the stand-alone traditional Marshall mix design. The incorporation of critical factors of the new binder and compaction method was created a pavement well suited to the hot in-service temperatures and heavy loading, leading to significant expected improvements in terms of cost saving and pavement life.

This Ph.D. thesis is manuscript-based, consisting of eight (8) chapters. Of these chapters 3 to 8 are published or submitted journal articles and conference papers.

1.2 Problem Statement

The majority of HA countries relies on the MMD method. This method does not meet the requirements of climatic conditions (Bansal et al., 2018) exacerbated under very heavy loading. The newly constructed asphalt pavements in HA climates such as those found in Libya showed poor to very poor performance or substantial distresses over the first few years of operation; as well, these distresses rapidly reappear after maintenance is applied (Al-Neami, Al-Rubaee, & Kareem 2017). This demonstrates the need to address the root cause of the problem which is "by applying a properly designed asphalt" to resist hot temperatures and heavy loading.

As a result, all these rapidly manifesting distresses are reducing driving comfort and road safety (Adlinge & Gupta, 2013). The current MMD method is based on meeting certain requirements such as the aggregate selection with recourse to a semi-logarithmic graph, voids in mineral aggregate (VMA), voids filled with asphalt (VFA), stability and flow, optimum asphalt binder content, etc. (Harman et al., 2002; Lira, Jelagin, & Birgisson, 2013).

However, the Strategic Highway Research Program SHRP (1993) has shown that: 1) the compaction with a Superpave Gyratory Compactor (SGC) is more appropriate to simulate field density and, 2) the concept of asphalt performance grade (PG), based on the rheological behavior of asphalt binders, integrates the in-use temperature range (Jamshidi et al., 2016; Kennedy et al., 1994) . Hot weather environments such as in Libya have their own challenges and requirements in terms of climatic factors, materials, and method of mix design; all this has led to a discrepancy in the performance of asphalt roads throughout their design life (Crvenkovic et al., 2014).

The compaction method and the type of binder are the most essential elements of a final asphalt mix; they affect almost all the important properties of HMA (Iwański & Kowalska, 2015). The evolution to the new generation of mix design methods such as SMD in most developing countries will be difficult due to complexity of SMD and will also exclude all equipment and active material laboratories.

1.3 Objectives

The main objective of this thesis is to cost-effectively modify the traditional MMD method to integrate the specific conditions of HA climates with minimal and easy to implement changes. The sub-objectives are as follows:

- Show how the climate, binder type, and method of compaction influence the performance of asphalt mixtures based on the MMD method in HA climates such as those found in Libya.

- Amend the MMD method to develop an asphalt mix design formulation for HA climates by introducing the Gyratory Compactor and performance grade asphalt binders.

- Based on the amended MMD, demonstrate in the laboratory the improved performance of AC pavements in HA climates with a minimum investment and minimum technology transfer requirements.

1.4 Methodology

In this research, the methodology was divided into three phases. Figure 1.1 illustrates the research framework including the three different phases.

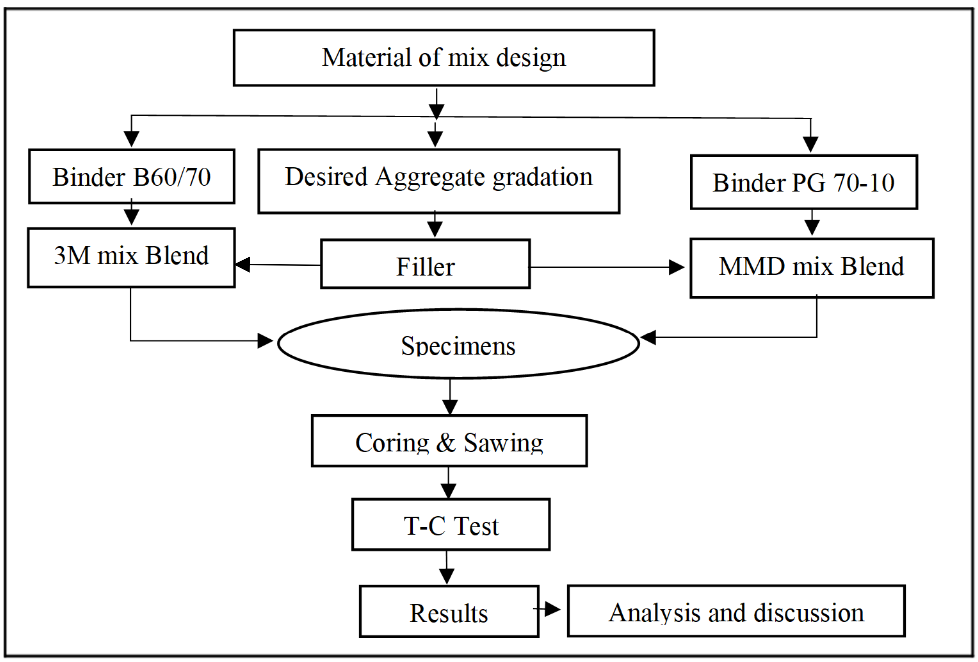


Figure1.1 Operational framework of the entire testing

Pavement temperature range assessment: The first phase consisted in measuring the temperature of the asphalt concrete at different depths. A pavement monitoring station was set up in a mid-west city in Libya, in the city of Ash Shwayrif. The purpose of this first phase was to determine the temperature range and assist in the selection of the proper PG as well as to measure the amount of solar radiation using the "Micro Hobo Station" (MHS). The MHS is equipped with a built--in USB port for fast and efficient weather data reading and transferring it to a computer with built-in mounting tabs. The study area is located in a hot and dry climate region, characterized by high temperatures during the summer and low temperatures during the winter. This large temperature range substantially influences pavement performance (Zhou et al., 2015).

Identification of factors that influenced pavement performance in the area: In the second phase, a total of fifty five (55) engineers working for engineering firms, contractors and road agencies participated in a questionnaire survey to identify the factors that influence asphalt pavement performance in HA climate. An example of the questionnaire is available in Annex III. The questionnaire consisted in queries regarding the asphalt mix design method used and the factors relevant to the methods used for HA climates. An oral interview, based on the aforementioned questionnaire, was also performed with 26 other engineers and the factors leading to unsatisfactory performance of the asphalt pavement were recorded. 72 % of all the written and 80 % of the orally questioned participants attributed the premature distresses in asphalt pavements to the mix design method, type of asphalt binders, method of compaction, and climatic conditions.

Laboratory Experiments: Several trials of aggregate-asphalt binder blends were conducted in this experimental research. Five (5) blends of asphalt cement using asphalt binders B60/70 and another (5) blends using asphalt binder PG70-10, were used for a total of ten (10) reference specimens. These specimens were replicated for a total of twenty (20). Two (2) additional specimens were used for the appreciation of theoretical specific gravity. These tests were repeated to have forty-four (44) reference specimens. These specimens have been tested by MMD, 3M, SGC, Rutting, and Complex Modulus tests with both pen binder system and Performance Grad. These specimens have been utilized for comparison under different HA environments, for a total of twenty-two (22) specimens. Asphalt mixtures contained different bitumen contents, below and above the optimal bitumen content. The procedures performed in this research, including sample preparation and the method used for conducting laboratory experiments, are discussed in chapters 3, 4, 5, 6 and 7.

- **Measurement of asphalt temperature range and solar radiation**

The functional behaviour of asphalt concrete pavements during their service life depends on many factors, the most important being the temperature range during the service life of the pavement. The Libyan climate can be split into two main zones: the Mediterranean Sea and the desert. From the weather map below, we see that the city of Ash Shwayrif is located in the Mid-West of Libya; the area in yellow on the map below shows the location of the city. The map in Figure 1.2 shows all Libyan regions. The numbers 12, 14, 15, 16, 18, 19, 20, and 21 are eight different regions that have the same weather and cover approximately 0.668 million km², i.e. 40% of Libya. The next step was to choose the city of Ash-Shwayrif as a representative of the HA climate.

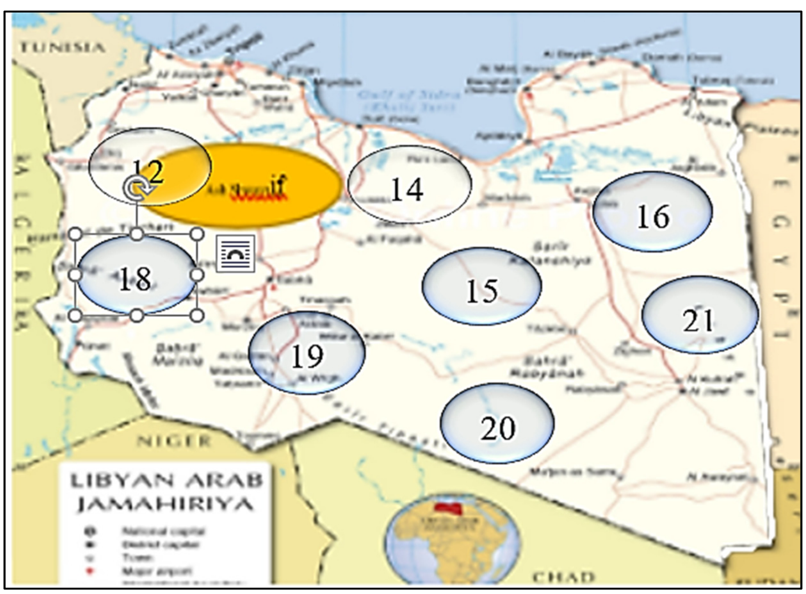


Figure 1.2 Eight regions representative of the HA climates in Libyan (Source Ezilion maps)

The temperature was measured over different seasons of the year using special measuring tools (Thermocouples) at different depths up to 300 mm from the pavement surface. This technique provides the temperature changes in the top and base course layers, as well as an estimate of the solar radiation by using Micro Hobo Station (MHS) during an entire day. Those results were compared with the results of similar studies performed in other areas of Libya to select the adequate PG. The monitoring station was installed at Ash-Shwayrif city. The temperatures of the road, wind speed, and solar radiation were measured. This method allows observing the changes of temperature in the pavement layers, as well as measuring solar radiation in the region. Weather data in this area were obtained from the Libyan National Climate Data Centre for the last 10 years.

Table 1.1 shows the depth and location of each cable in the pavement layers, at the surface (C1) and at depths of 20 mm (C2), 40 mm (C3), 80 mm (C4), 100 mm (C5), 140 mm (C6), 220 mm (C7), and 290 mm (C8).

Table 1.1 Average highest and lowest annual pavement temperatures over one year at different pavement depths

Points	Depth (mm)	Average highest pavement temperature over one year	Average lowest pavement temperature over one year
Air temp.	No depth	45.5	-3.0
Point No. 1	0	69.5	7.8
Point No. 2	20	64.1	12.9
Point No. 3	40	60.1	25.6
Point No. 4	80	55.1	31.8
Point No. 5	100	51.7	33.2
Point No. 6	140	48.5	34.8
Point No. 7	220	43.3	36.0
Point No. 8	290	40.8	37.7

The pavement temperature was measured in different seasons of the year using special measuring instruments at different depths from the surface layer up to subgrade. The results obtained were compared with the results of similar studies in other parts of Libya. Among data collected for the whole year, only the lowest and the highest daily temperatures were recorded. The proper PG should be selected based on the lowest annual pavement temperature (one day) and the highest annual pavement temperature (seven days).

From these data, maximal and minimal daily temperatures were extracted for air, pavement surface and at different pavement depths (2, 4, 8, 10, 14, 22, and 29 cm). Then, the average highest temperatures were calculated based on the hottest seven days; the average lowest temperatures were calculated based on the coldest day. Data were registered during 2016–2017, for reference.

1.5 Dissertation Layout

This dissertation summarizes the study into the MMD method using the Superpave gyratory compactor and performance grade binder. This Ph.D. thesis is manuscript based, which means that the chapters from 3 to 8 are published or submitted papers. The layout of this thesis is as follow:

Chapter 1 – This chapter presents the dissertation layout and summarises the purpose of the thesis.

Chapter 2 – This chapter summarises the relevant literature review with reference to the MMD and the SMD method and equipment.

Chapter 3 – This chapter presents the first published conference paper of this Ph.D. thesis, titled: "**The effect of several parameters on the behaviour of asphalt mixture in Libya**". This paper summarizes some of the tests performed at ETS to assess the critical factors affecting the performance of asphalts.

Chapter 4 - This chapter presents the second published conference paper, titled: "**Improving mechanical properties of hot mix asphalt using crumb rubber in Libya**". This paper describes an effort conducted to address the problem of premature deterioration of asphalt roads in Libya, that are subjected to heavy loading and very hot temperatures, with crumb rubber used as aggregates in asphalts.

Chapter 5 - This chapter presents the third published conference paper, titled: "**Measurement of asphalt pavement temperature to find out the proper asphalt binder performance grade (PG) to the asphalt mixtures in southern desert of Libya**". This paper describes the process by which the temperature range was assessed in order to identify the adequate performance grade asphalt for the conduct of the tests performed in the laboratory.

Chapter 6 - This chapter presents the first published journal paper, titled: "**Evaluating factors influencing asphalt road construction quality in high temperature condition (case study in Libya**)". This paper describes the effect of some factors on the asphalt mix design in Libya and introduces the problem statement of the thesis.

Chapter 7 - This chapter presents the second published journal paper, titled: "**Comparison of two asphalt mixtures using complex modulus tests in Libyan weather**". This paper summarizes the complex modulus tests performed on penetration grade asphalt versus performance grade asphalts.

Chapter 8 - This chapter presents the third submit journal paper, titled: "An assessment of the suitability of Marshall and Superpave asphalt mix designs in relation to the weather conditions in Libya". This paper summarizes the laboratory tests performed on different asphalt mixtures.

- Conclusion and Recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Asphalt mixtures for AC pavements are manufactured from aggregates, sand, filler, bitumen and voids; the formulating or proportioning of all these components is particularly important to obtain optimal performance of the AC. The concept of asphalt mix design is to obtain homogenous asphalt mixtures of bitumen, aggregates, and suitable air voids after compaction. The asphalt mix design should be an advanced method involving several factors that have an effect on the performance of the AC pavement (Bressi et al., 2016).

The Hubbard-Field Method is considered to be the first mix design method; it was originally established to design sand-asphalt mixtures and later modified for aggregates (Kucukvar et al., 2014; Rtolani, & Sanberh, 1952). The Marshall mix design (MMD) method was initially developed by Bruce G. Marshall and later amended by the US Waterways (Klomp & Niesman 1967; Ogundipe, 2016). The Marshall Mix Design method continues to be commonly used for preparing asphalt mixtures within developing countries, such as Libya. This method depends on a single piece of equipment to design and control the asphalt-aggregate formulation (Al-Mistarehi 2014; Pooley, 1985).

In 1980, the Superpave mix design (SMD) method was developed as a part of the Strategic Highway Research Program (SHRP) for Superior Performing Asphalt Mix Design. The Superpave mix design method was designed to replace the Hveem and Marshall methods. Volumetric analysis, common to the Hveem and Marshall methods, provides the basis for the Superpave mix design method (Lv et al. 2018). The SMD method proposes new criteria for the selection of the asphalt binder, resulting in a Performance Grade system (PG). Its objectives are to overcome some limitations of the asphalt binder, and to develop a new compaction method to be compatible with the future traffic loads and environmental conditions (Mallick, & El-Korchi, 2017).

The compaction tools from the Hveem and Marshall methods have been replaced by the Superpave gyratory compactor (SGC) and the compaction effort in mix design is based on the expected traffic (Olard & Pouget 2015). In recent years, studies have been conducted outside the US to evaluate the feasibility and performance of Superpave-designed mixtures. Many studies were conducted worldwide to compare the volumetric and mechanical performance properties of Superpave mixtures and Marshall mixtures under different conditions (Jitsangiam, Chindaprasirt, & Nikraz 2013).

These aforementioned studies conclude that the binder contents of the Superpave-designed mixtures are lower than those of Marshall-designed mixtures together with low densification values and overall superiority in performance. The gyratory compactor (SGC) can achieve a lower air void content than that achieved by the Marshall Hammer compactor with better creep resistance and it is more economical than Marshall traditional mixes because of the reduced asphalt content (Ahmad et al., 2014).

It is also reported that the key factors contributing to the improvement of AC performance, are (1) the type of asphalt binder related to climate and (2) the method of compaction linked to the field conditions.

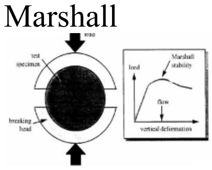
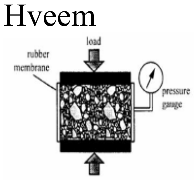
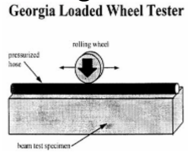
Therefore, this thesis focuses on the effects of the climate, binder type, and method of compaction on the performance of the HMA based on a modified MMD method for HA climates.

This research proposes an innovative approach to improve the formulation of asphalt mixtures within road agencies operating in HA climates.

2.2 Critical Review of Asphalt Mix Design and Testing

Various methods are used to prepare an asphalt mixture for asphalt roads in different climates. Table 2.1 below shows some of the current ways to formulate asphalt mixtures.

Table 2.1 Critical Review of Asphalt Mix Design Reports

HMA Mix design method	Features	Advantage	Disadvantage
Marshall 	Impact compaction. -Density/void analysis. -Stability/flow test.	- Attention to volumetric properties for durability. -Equipment not portable and inexpensive.	-Impact compaction unrealistic. -Marshall Stability not related to performance.
Hveem 	. Kneading compaction. . Density/void analysis. . Stability analysis. . Swell analysis.	-Kneading compaction simulated compaction at the field. -Hveem stability to measures the aggregate components to shear strength	. Equipment, expensive and not portable. . Some of volumetric properties not proven. . The asphalt content selection was very subjective.
Empirical Testing Georgia Loaded Wheel Tester 	. Primarily rolling wheel tests. . Addendum to Traditional Mix Design. . Accept/Reject Criteria.	. Criteria calibrated to experience with real pavements	. Expensive equipment. . Expensive to run. . Time consuming to calibrate criteria. . Only applicable to local conditions. . Affected by boundary conditions.

2.3 Climate

Libya and North Africa are typical examples of regions experiencing hot and arid (HA) climates. Materials properties, traffic characteristics, and weather conditions can affect long-term pavement performance (Pan et al., 2014).

2.3.1 Fluctuations of Pavement Temperature

The variation of temperature in asphalt pavement can lead to the fact that significant daily fluctuations in temperature from 0 C° to over 60 C° increase the rigidity of the bituminous mixture, which makes the pavement surface vulnerable to thermal cracking. In such a situation, only lowering the viscosity of the asphalt binder or reducing the hardening rate of the bitumen binder will be beneficial in reducing the thermal cracking potential (Mashaan et al., 2014).

It is generally accepted that bituminous hardening is a good relative measure of the durability of asphalt. Many researchers reported that a low quality of bitumen binder is due to premature aging problems in hot and dry regions in different parts of the world (Lei, 2011).

Temperature is an important factor affecting the performance of asphalt pavement, the change in the quarterly and daily temperature can lead to certain types of asphalt pavement distresses, such as permanent deformation and bleeding are usually associated with high temperature; thermal cracking is associated with low temperature environments (Dawson 2014; Dawson et al., 2012).

In 1987, SHRP Launched a long-term road traffic monitoring program (LTPP) to facilitate the pavement performance analysis, leading to enhanced engineering criteria for the mix design, execution of the asphalt pavement, and management of road networks. In 1991, the LTPP established the Seasonal Monitoring Program (SMP) to evaluate and assess the effects of solar radiation, humidity, and temperature changes on the asphalt mixture properties. The pavement temperature prediction and measurement were developed using SHRP test and SMP data to help in the selection of the proper PG asphalt performance grade related to the climate condition (Sreedhar, & Biligiri, 2016).

2.3.2 Energy Equilibrium in Asphalt Pavement

The main types of heat transfer are the thermal and longwave radiation between the road surface and the sky, phenomenon of solar radiation, and convection consequent to heat exchange between the fluid and road surface that is in contact with the surface and conductivity inside the road pavement layers, as shown in Figure 2. Solar radiation leads to heat gain on the road surface due to the absorption of solar energy. Convection heat flow concerns the fluid velocity and direction of the fluid, it relies on the speed and direction of air moving on the surface of the pavement (Dawson et al., 2012).

The coefficient of heat transfer increases due to high air speed and compatible wind directions; the convective heat flow also increases (Athienitis, 2013). Thus, at relatively high air speeds, convective surface cooling occurs when the temperature of the wind is lower than the temperature of the road surface.

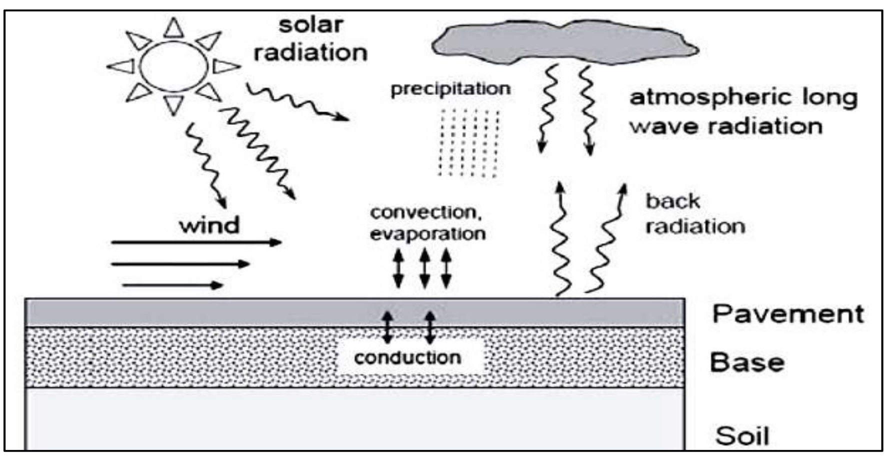


Figure 2.1 Energy equilibrium of the pavement
Adapted from William et. al., (2006)

Actually, the temperatures in the under layers are usually much colder than the surface temperatures of the asphalt pavement. In fact, the heat transfer and longwave radiation are in direct contact with the pavement surface (Hall et al., 2011).

2.3.3 Variation of Solar Radiation

Libya for example is located in a harsh HA climate, where about 88% of the cities are considered desert. The desert climate in Libya is almost clear and sunny; So, there is a high chance of solar radiation in the region (Mahgoub, & Mohamed, 2016). Some of the solar radiation is absorbed by various compounds in the atmosphere, some is scattered, some is reflected in space, and the rest arrives to the Earth as direct solar radiation (Lee et al., 2014).

The intensity of incoming solar energy varies widely during the day, and also during the year. For example, at the location of the city of Gate, the radiation ranges from zero tonight to a maximum of about 1300 watts per square metre of W / m2 in the mid-day (Uzelac et al., 2014).

Normally, the solar radiation transfers through empty space. The variations of solar energy between day and night and throughout the year, causes the rise and fall of daytime temperature; moreover the huge absorption coefficient of the black body (Asphalt pavement) to solar radiation, leads to the upper layers of the asphalt pavement being rapidly affected, in contrast to the lower layers (Qin, & Hiller, 2014).

Therefore, before introducing the influence of solar radiation on the layers, this work introduces the prediction model of the asphalt pavement temperature in different depths as a part of this thesis.

2.3.4 Changing the Properties of Bitumen Due to Hardening

The aging of the asphalt binder is an operation of the changing in properties of bitumen due to hardening and oxidation, which change the structure and composition of the asphalt bitumen (Xu, & Wang, 2017). The temperature, presence of oxygen, and arid climate lead to a quick reduction of the volatile compounds in the bitumen.

The change of the bitumen properties leads to a decrease in penetration and increases hardening of the bitumen (Soenen, Lu, & Laukkanen, 2016). Short-term aging is affected by the source of bitumen, time of the mixing, temperature, and chemical composition. Long-term aging is mainly due to hardening of bitumen and climate conditions (Abdelaziz, 2018).

Long-term aging occurs commonly in the bitumen layer for the presence of oxygen, and the pavement temperature changes (Kumbargeri, & Biligiri, 2016). Aging in operation, which occurs when the oxygen and moisture react with the asphalt binder (bitumen) in the presence of air (Wang et al., 2019). Aging of bitumen is one of the main elements affecting the pavement performance when the bitumen is exposed to a various range of temperatures during mixing, lying, and storage.

2.4 Comparison of different aspects of mix design methods and materials

2.4.1 Superpave versus Marshall mix design method

The Marshall mix design method continues to be commonly used in developing countries, such as Libya. This method is easy to use and low-priced and it depends on a single piece of equipment to design and control the asphalt-aggregate formulation. However, many engineers believe that the impact compaction obtained with the Marshall method does not thoroughly simulate the compaction at the field.

Actually, the Marshall mix design method principles allow the designer to choose an OBC in a specific asphalt-aggregate mix design formulation where the desired properties of stability and flow are met. The construction of asphalt pavement using the Marshall method requires in most cases, a compaction of 95% or greater of the maximum lab value. It is possible to achieve a maximum density greater than 100% due to the limitations on the control sample in the lab and the unlimited compactive effort available in the field. If a pavement material is compacted over 100%, this means that the percentage of air voids is null and air is completely removed from the asphalt mixture.

Consequently, there has been a growing feeling among asphalt experts that the Marshall method is no longer valid for modern asphalt mix design.

The objective of the Superpave mix design method is optimize asphalt mixture resistance to pavement distresses. The Superpave mix design method introduces new equipment and notions, such as the Superpave Gyratory Compactor (SGC) and asphalt binder (PG) to take into account projected traffic and climate conditions, as well as mix design changes.

The SGC can provide information about the compatibility of the particular mixture by capturing data during compaction, and the PG must meet performance criteria respectively at the hottest and the coldest annual pavement temperatures.

The differences between the Superpave and the Marshall mix design methods are mainly in the material selection procedure, the compaction method, specimen dimensions, void analysis approach and specifications. Besides, adoption of the Superpave mix design method provides advantages of extended paving temperature, reduction in fumes, and improved environmental compatibility.

2.4.2 Gyratory Compactor versus Marshall Hammer

Harman et al. (2002) investigated the applicability of the Superpave gyratory compactor (SGC) for different compaction levels. The results show tolerance limits for SGC acceptance parameters. Hafez and Witzack (1994) compared the asphalt content in the design obtained with the Marshall method to the level 1 procedure of Superpave. Note that the SGC was used to simulate a compaction comparable with 75 blows in the Marshall procedure.

Five groups of mixings and three climatic regions were evaluated from cool to warm climates with both methods. They concluded that the difference in asphalt content in any mixture is not sensitive to the air void that was chosen when developing the design value. The design range of air voids was between 3% to 5%. In samples, the average difference in air voids was 0.1% for the three SGC specimens and 0.6% for the three Marshall specimens.

In conclusion, the SGC procedure produces specimens with a smaller dispersion within the group. This may be due to the compaction process or to the large specimen size in the Superpave procedure. The authors concluded that the SGC procedure is a tool for field control as good as the Marshall procedure. The smaller variability resulting from the SGC will be even more clear in the test results.

Similarly, Von Quintus (1991) described the effect of five different laboratory compactors *(Texas gyratory compactor, Rolling wheel compactor, Kneading compactor, Arizona vibratory/kneading compactor, and standard Marshall hammer)* on the selected properties of the compacted mixtures. Field cores and specimens compacted in the laboratory were tested for indirect tensile strength (ITS), strain at failure, resilient modulus and creep, and their aggregate particle orientations were evaluated. The authors compared the similarity between laboratory compaction and field compaction techniques. The authors concluded that the Marshall hammer is the least able to simulate any of the construction and laboratory compaction methods. Table 2.2 shows the results of different compaction devices.

0.1 Summary of different compaction devices,
adopted from (Von Quintus, 1991)

S.No	Compaction devices	Properties of laboratory-compacted specimens and field cores by (%)
1	Texas Gyratory	63
2	Rolling Wheel	49
3	Kneading Compactor	52
4	Arizona Vibratory/ Kneading	41
5	Standard Marshall hammer	35

2.4.3 Performance Grade PG binder versus Penetration Grade system

On the other hand, in recent years, new asphalt-binder selection criteria known as the Performance Grading (PG) system, has been developed by the Strategic Highway Research Program (SHRP) to overcome some of limitations of the Pen Grade system. The PG concept is based on the rheological theory that asphalt binder properties should be related to the climatic conditions under which it is to be used.

Properties related to the expected performance (maximum 7-day pavement temperature, minimum pavement temperature, loading duration based on truck speed, and traffic volume) are featured in the PG binder specifications to allow proper selection for a highway application. Strain levels are typically maximized by traffic loading at the bottom of a hot mix asphalt (HMA) layer of 2-inch to 3-inch in thickness.

The use of a stiff PG binder in these structures will severely limit the life of a stiff mix. The PG System measures the fundamental properties (stress and strain) of the binder at the various stages of binder conditions (service temperatures and binder aging) throughout the expected life of the pavement. Unlike the Pen Grade System, the PG System also takes into consideration long term aging of the asphalt-binder, traffic levels, and reliability characteristics.

2.5 Summary

This literature review allows to draw the following conclusions:

1. Aggregate gradation is important for improving the strength of the asphalt mixture:
2. The compaction method affects the stability, air void content, voids in mineral aggregates, optimum bitumen content, and deformation of the specimens; and,
3. The specimens that are compacted with a gyratory compactor have the same properties as the field samples.

CHAPTER 3

THE EFFECT OF SEVERAL PARAMETERS ON THE BEHAVIOUR OF ASPHALT MIXTURE IN LIBYA

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3.1 Abstract:

In Libya, many steps have been taken to extend the life of the pavement and improve the design of asphalt mixture to have a better connection to Libyan climate. This study is to evaluate the effect of some parameters on the performance of the asphalt mixture in hot arid weather as Libya. Two asphalt concrete mixtures were designed using two different binders, Performance Grade binder (PG70-10) and Pen Grade System (B60/70).

In addition, the results obtained from Superpave mix design test have shown a better performance indicator than those obtained with the Marshall Stability tests and they were superior at all stages of tests. These results provide a guideline to improving the production of the hot mix asphalt (HMA) and a foundation for different paving mixes, by adopting PG binder and Superpave Gyratory compactor (SGC) instead of Marshall's hammer and binder B60/70.

These mixtures were formulated in accordance with the Marshall mix design method and the Superpave mix design method. Rutting test also tested these mixtures to evaluate the performance of the bituminous mixtures under certain conditional parameters. The study

clearly showed that the asphalt mixtures with binder PG70-10 are slightly performed better than the mixtures with binder (B60/70).

In addition, the results obtained from Superpave mix design test have shown a better performance indicator than those obtained with the Marshall Stability tests and they were superior at all stages of tests. These results provide a guideline to improving the production of the hot mix asphalt (HMA) and a foundation for different paving mixes, by adopting PG binder and Superpave Gyratory compactor (SGC) instead of Marshall hammer and binder B60/70.

Keywords: Pavement Performance, Climatic, Asphalt mix design, Local materials

3.2 Introduction

Asphalt mixture properties such as density and air voids are largely dependent on the type of the compaction method, selection of materials and method of mix design. These properties, in turn, have an influence over the pavement performance indicators such as rutting, fatigue, potholes and alligator cracks (Malunga et al., 2014). Therefore, this research aims to improve the local mix design formulation of a pavement asphalt mixture to obtain an economical mixture that would meet the requirements for the characteristics of the pavement in hot weather.

The Marshall Mix Design Method selected the asphalt binder based on the empirical Penetration Grading Pen Grade System. It does not mandate for viscosity measurements and hence, it is difficult to establish the correct HMA. Moreover, temperature can be a major contributor to several types of distress (Salem et al., 2014). Binder and compaction method are perhaps the most important elements for an asphalt mixture design. They influence almost all the important properties of HMA mixtures such as stiffness, stability, durability, etc.

Therefore, the following research will adopt a new asphalt binder PG which should be related to the climatic conditions of Libya and a new method of compaction which is SGC. Marshall

Hammer Compactor is very old method of compaction in the laboratory. Nevertheless, the variation in the methods of laboratory compaction is not only the result of the methods of assessment, but is due to the technology used (Foster, 1982; Chang et al., 2014).

3.3 Objectives

This research aims to show the effect of some factors on the asphalt mix design such as the type of bitumen binder, skeleton of aggregate and the method of compaction. These mixtures were formulated in accordance with the Marshall mix design method and the Superpave mix design method. Rutting tests also tested these mixtures to evaluate the performance of the bituminous mixtures under certain conditional parameters. Additionally, the purpose of this paper is to show the limitation of Marshall Mix Design Method, which is still used today and to increase the implementation of earlier research.

3.4 Background and Literature Review

Hubbard-Field Method might be considered as the first formal design method for asphalt mixtures. It was originally developed to design sand-asphalt mixtures and later modified for aggregates (Roberte et al., 2002).

The Marshall mix design method, initially developed by Bruce G. Marshall from the Mississippi Highway Department in 1939, and later amended by the US Waterways Experiment Station of the US Army to include deformation measurements. This is based on two criteria, a minimum stability and a minimum range of flow values. However, it was based on a single piece of equipment to design and control the asphalt paving mixtures which referee to as the Marshall Test.

The Superpave mix design method, for Superior Performing Asphalt Pavement System, was developed in the 1980s as a part of the Strategic Highway Research Program (SHRP). Superpave addresses aggregate selection and asphalt binder selection in the perspective of future traffic and climatic requirements. It selects aggregates based on gradation distribution, angularity, clay content, water absorption, abrasion, soundness etc. (AASHTO, 1993). In Libya, mix design of asphalt mixture is based on the Marshall method which is an empirical design method that does not replicate the compaction, materials, and climate prevailing in Libya.

Previous studies have shown that the compaction by impact in the Marshall method is unrealistic compared to the SGC, which simulates the field density. And the Pen Grade system is typically conducted at a single test temperature of 25 °C, which does not account for the entire temperature spectrum to which the asphalt-binders are subjected to in the field (Almadwi, & Assaf, 2017). However, the term “Superpave” refers to more than just the computer program.

The system includes test equipment, test methods, and criteria. Most important, it represents an improved system for specifying component materials, asphalt mixture design and analysis, and pavement performance prediction (Asi, & Khalayleh, 2011).

3.5 Methodology

Two asphalt concrete mixtures of aggregate-asphalt binder were designed using two different binders, PG70-10 and B60/70. These mixtures were formulated in accordance with the Marshall mix design method and the Superpave mix design method. Rutting tests also tested these mixtures to obtain an economical mixture that would meet the requirements for the characteristics of the pavement in hot weather. These specimens were used for a comparison under different Libyan weather conditions. Evidently, the test mixtures contained several asphalt bitumen contents both above and below the optimum content of asphalt.

3.5.1 Mix Design Experiments

The purpose of this research is to determine the proper proportions of aggregates and asphalt to obtain an economical mixture that would meet the requirements for the characteristics of the pavement in hot weather. Over the years, several design and development methods have been taking place and have been implemented by various agencies. This review focuses on the producing and design of HMA in Libya.

3.5.2 Aspects Influencing the Design of Asphalt Mixtures

The physical properties of the materials that are used in this mix design are shown in Table 3.2.

3.5.2.1 Aggregate Gradation

In general, stone skeleton in HMA, such as porous asphalt and SMA (Stone Matrix Asphalt), are quite resistant to rutting due to their high stone concentration. To obtain a good overall asphalt mixture performance, there must be an aggregate structure that favours resistance to rutting. The gradations of aggregates are expected to pass within specified bands presented on a semi-logarithmic (semi log) graph. Specifications, however, do not address the more recent findings regarding the physical characteristics of aggregates.

These specifications include findings from studies conducted by Kandhal et al., (1998), who found that Aggregate shape properties, such as form, angularity, and surface texture, highly influence the performance of HMA. These findings have led to the introduction of the Superpave consensus aggregate properties. They are aimed at improving performances of HMA mixes.

3.5.2.2 Type of Bituminous Binder

Asphalt binder changes its properties with time under traffic loads and environmental affects. Asphalt-binder B60/70 is used in the traditional Marshall Mix Design Method and is selected based on the empirical Pen Grade System. It does not mandate for viscosity measurements and hence, it is difficult to establish the correct HMA. Lastly, the original Pen Grade System was developed for low traffic loading conditions, which regrettably do not tally with the current high traffic on the roads in the hot climate of Libya.

Due to these limitations, asphalt-binder selection using this method to ensure satisfactory pavement performance is highly questionable. In recent years, a new asphalt-binder selection criterion known as the Performance Grading system has been developed by the Strategic Highway Research Program (SHRP) to overcome of some the asphalt pavement distresses such as rutting, fatigue cracking, and thermal cracking.

The PG concept is based on the rheological theory that an asphalt-binder's property should be related to the climatic conditions under which it is to be used. Engineering properties believed to be related to the expected performance (maximum 7-day pavement temperature, 1-day minimum pavement temperature, loading duration based on truck speed, and traffic volume) are featured in the PG binder specifications to allow for a proper selection of asphalt roads (Wahhab et al., 1997).

3.5.2.3 Compaction Method

Compaction of asphalt mixes in flexible road surfaces play an important role in the behavior of the pavement under the traffic load. The properties of the mixture, such as density and air voids, strongly depend on the degree and the method of compaction. Marshall Hammer Compactor is the oldest method of compaction in the laboratory.
The number of impacts applied to each face of the specimen was set at 35, 50 or 75, depending on the anticipated volume of traffic. The higher the amount of traffic, the greater the number

of blows. In fact, a proper method of compaction is also necessary to take measures to extend the life of the pavement using various compaction methods.

One of the compaction methods is the SGC. Although the equipment used in the Marshall method is inexpensive, studies have shown that the impact compaction is unrealistic compared to a SGC that simulates a field density of about 50% of the time (Button et al., 1994).

3.5.3 Materials Used in Hot Mix Design

3.5.3.1 Aggregate

In this research, the mix, of course, and fine aggregate with sizes between 0.08 to 28 mm were used in the design of asphalt mixture according to the requirements. The characterizes and gradation for both coarse and fine aggregate were shown in Tables 3.1, 3.2.

Table 3.1 Sieve analysis Result and aggregate gradation for laboratory mix design

Sieve size mm	% Lower Limit	% Upper Limit	% Passing
28	100	100	100
20	95	100	98
14	67	90	85
10	52	75	68
5	34	55	45
2.5	24	45	27
1.25	16	39	18
0.63	9	31	12
0.31	6	23	9.6
0.16	4	15	7.5
0.08	3	8	6.3

Table 3.2 Specific Gravity for the Compound Aggregates and Asphalt Binders

Agg. Size and asphalt binder	% of Agg. in mixture	Gsb	Compound mix Specific Gravity	% Water Absorption
20-14 mm	15	2.739	2.716	0.005
14-10 mm	15	2.736		0.006
10-5 mm	26	2.733		0.007
Crushed 0-5 mm	36	2.698		0.630
Sand 0-5 mm	3	2.595		0.670
Filler mm	5	2.700		0.700
Bitumen (B60/70)	4.50	1.025	1.020	-
Bitumen PG 70-10	4.25	1.029	1.029	-

3.5.3.2 Bituminous Binder

In this research, the bituminous binder for asphaltic concrete mix was the bitumen of PG70-10 or B60/70.

3.5.3.3 Mineral Filler

The mineral filler used for this study was the dust of limestone. It should be dry enough and should be essentially free of agglomerations.

3.6 Laboratory Experiments Results

3.6.1 Marshall Mix Design Result

In this experiment, specimens were conducted by using bitumen binder B60/70 and the other specimens by using bitumen binder PG70-10. The specimens were then tested, and the results obtained are presented in Table 3.3, and illustrated in Figure 3.2.

Table 3.3 Calculation of Marshall Stability based on LC 26 Q.C. Standard

Calculation of Marshall Stability					
Sample No	VMA%	VFA%	Va%	Flow (mm)	Stability (KN)
PG70-10 S1	14.1	78.2	3.0	5.3	15.8
PG70-10 S2	14.8	73.9	3.8	6.4	14.3
PG70-10 S3	14.8	74.1	3.8	5.4	13.9
PG70-10 S4	14.2	77.4	3.2	4.6	12.7
Average	14.5	75.9	3.5	5.4	14.2
B 60/70 S1	15.5	67.7	5.0	4.0	5.2
B 60/70 S2	16.5	63.1	6.0	3.9	10.7
B 60/70 S3	16.6	62.6	6.2	3.7	10.7
B 60/70 S4	15.5	67.7	5.0	3.5	5.8
Average	16.0	65.3	5.5	3.7	8.1

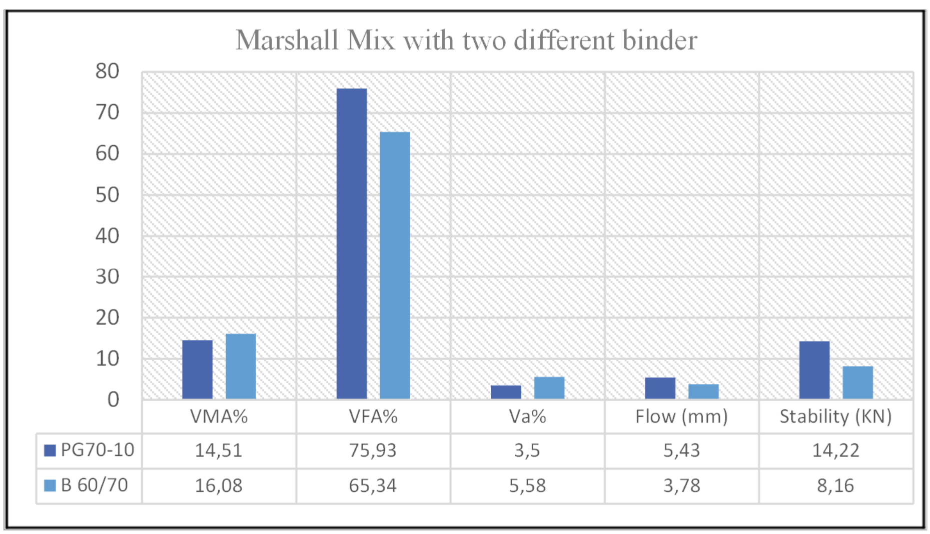

Figure 3.1 Values of Marshall's asphalt Mix with two different binders

3.6.2 Superpave Mix Design Test Result

In this experiment, specimens were tested by using bitumen binder B60/70 (mix A) and the other specimens by bitumen binder PG70-10 (mix B). The obtained results are shown in Table 3.4 and illustrated in Figure 3.3.

Table 3.4 Mixtures properties from the (SGC), based on LC 26 Q.C. Standard

Result of SGC specimens with two different binders and Vbe = 12.28						
Numbers of Gyrations	Mix B			Mix A		
	VMA %	VFA%	Va%	VMA%	VFA%	Va%
10	22.0	49.6	11.1	24.3	43.5	13.7
80	18.1	63.1	6.6	17.6	65.5	6.1
200	15.0	79.0	3.1	15.0	79.5	3.0

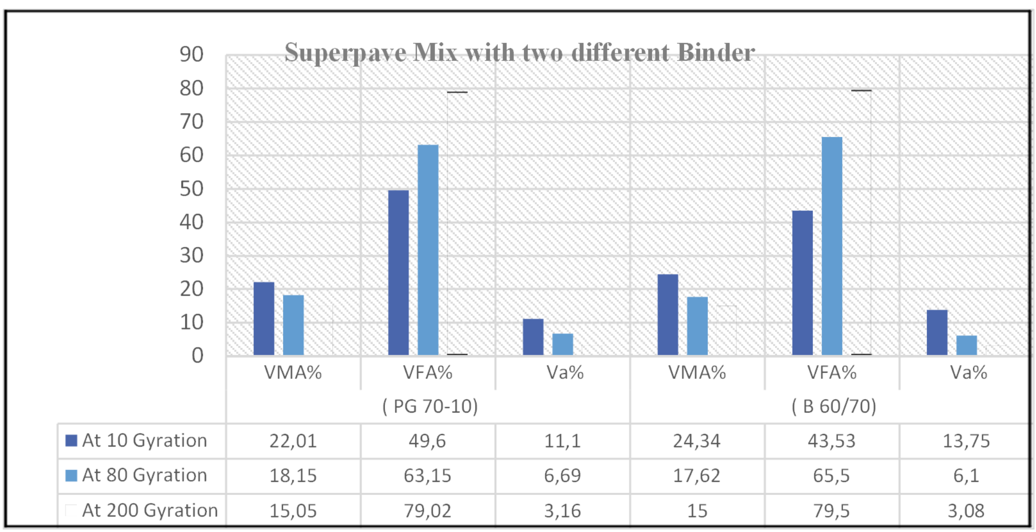

Figure 3.2 Values of Superpave Asphalt Mixes with two Different Binders.

3.6.3 Rutting Test Result

In this experiment, specimens had been tested by using bitumen binder B60/70 and the other specimens by bitumen binder PG70-10. The obtained results are presented in Table 3.5 and illustrated in Figure 3.4 and Figure 3.5.

Table 3.5 Results of rutting analyzer test

Number of Cycles (Cumulative) at 65 °C	Rutting (mm)			
	Specimens with PG70 − 10		Specimens with B(60/70)	
	S_I	S_{II}	S_I	S_{II}
1000	3.5	2.1	4.6	4.0
3000	3.9	2.6	5.2	5.0
10000	3.8	2.7	5.9	5.8
30000	4.2	3.2	7.4	7.0
Average after 30000 cycles	3.85		7.27	
Criteria	LC Method of Mix Design ≤ 10 for slab 100 mm thickness			

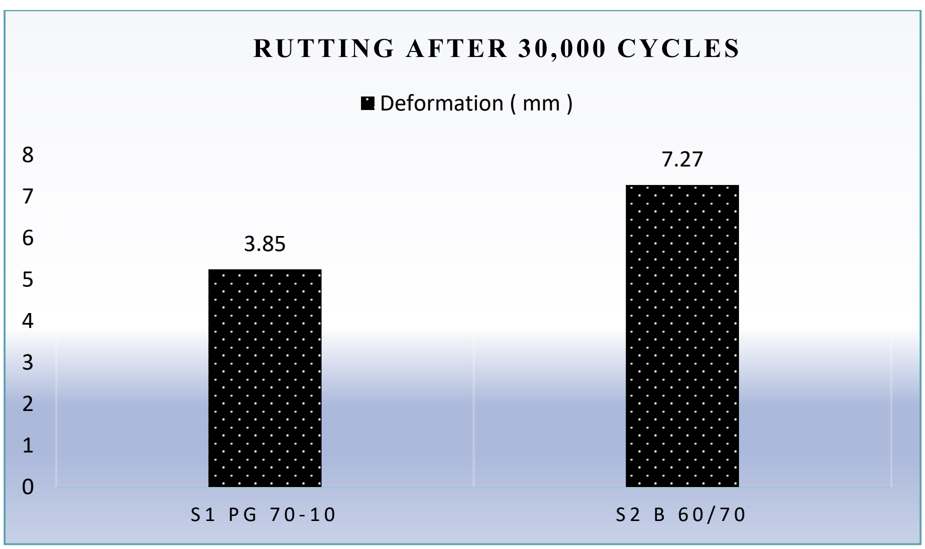

Figure 3.3 Rutting values after 30000 cycles with two different binders

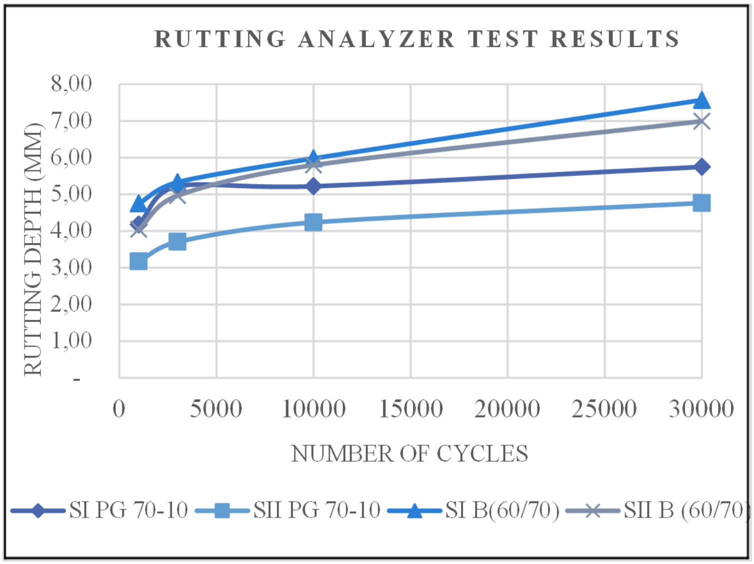

Figure 3.4 Rutting depth of different specimens
with two different binders

3.7 Synthesis and Discussion of the Findings

The asphalt binder that was used in the Marshall method may not be sufficient to ensure that selected asphalt binders can satisfactorily meet the paving service temperatures experienced in Libya. The method of selecting the binder and the bituminous content in the mixture is still questionable.

However, in this study, the conventional local specifications of selecting and blending the aggregate and binder that were used in the Marshall mix design did not perform well and thus yielded inadequate results. On the other hand, the Marshall mixes were designed using the SGC, PG asphalt binders and a proper aggregate gradation indicated that the Marshall method performed like the Superpave method.

Asphalt-binder type, asphalt-binder content, aggregate properties, and gradations showed a significant effect on the performance of the mixes as expected. Table 3.3, Table 3.4 and Table 3.5 illustrated all the laboratory experiment results. Figure 3.2, Figure 3.3, Figure 3.4, and Figure 3.5 show the behaviour of asphalt mixtures with new binder PG70-10 and a new compaction method under the hot weather conditions such as in Libya.

It can be seen from Figure 3.2, Table 3.3 and Figure 3.3, Table 3.4 that the volumetric property values of the Superpave mixes are properly better than that of Marshall's mixtures. The flow values of Marshall's mixtures with PG70-10 are slightly less than that of Marshall mixes with B60/70. This could be due to the differences in the binder properties, OBC%, or due to the compaction techniques used.

The SGC rotates at a constant rate during the compaction, and this characteristic provides around a better orientation of aggregate particles and aggregate interlock. This process simulates closely to the field compaction. In Figure 3.4, Figure 3.5 and Table 3.5, asphalt blends using the asphalt binder PG70-10 showed better resistance to rutting than the mixes using the asphalt binder B60/70.

The study clearly showed that the amount of air voids in the mixture was one of the most important properties. Although the number of air voids had a significant effect on the pavement deformation, this parameter could not be used to predict the deformation. When air voids were low, as a rule, there was considerable deformation, and when air voids were high, it was much less likely of deformation.

It is therefore important that air voids be carefully controlled during construction. In the future, the air voids will be determined from samples compacted with the SGC. Regardless of the type of compaction used, it is important that the sample is compacted to about the same density as in the field after several years of traffic.

3.8 Conclusion and recommendation

The proper selection of the aggregates, method of compaction and the asphalt binder can improve the pavement performance. However, the most important factors which affect the pavement performance are the compaction technique, type of asphalt binder and selection of aggregate. In this research, two asphalt concrete mixes were designed using two different binders. These mixtures were formulated in accordance with the Marshall mix design method and the Superpave mix design method and these mixtures also tested with rutting test. The analysis was conducted to evaluate HMA properties such as durability, air voids, voids in mineral aggregate, voids filled with asphalt, etc.

The study in which the Marshall mixes were designed using the SGC, PG asphalt binders and a proper aggregate gradation (source and consensus requirements), indicated that the Marshall method performed like the Superpave method. The type of asphalt binder, the asphalt-binder content, and the aggregate properties showed a significant effect on the performance of the mixes, as theoretically expected. A virtual need to evaluate the mix-design methods on the hot weather locale is still mandatory. It, therefore, can be concluded that the Marshall method can perform equally well if the method of compaction and asphalt-binder selection criteria are updated in Libya.

CHAPTER 4

IMPROVING MECHANICAL PROPERTIES OF HOT MIX ASPHALT USING CRUMB RUBBER IN LIBYA

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4.1 Abstract

This paper deals with the possible reuse of rubber waste such as car tires and plastic bottles in the design of asphalt mixtures in Libya. This work is a continuation to the laboratory research that began in the last year. In the earlier study, the volumetric properties of the traditional asphalt mixture using penetration grade binder (B60/70) were compared with the Superpave mixture using performance grade binder (PG70-10). However, this study is to evaluate the effect of the crumb rubber (CR) on the performance of the asphalt mixture in Libya. Four asphalt concrete mixtures were designed using asphalt-binder B60/70, aggregate and CR and then tested by both Marshall and Superpave mix design procedures. These results were compared with the results obtained from the previous traditional Marshall mix design test using asphalt binder B60/70 and Superpave mix design test using PG70-10. This study clearly showed that asphalt mixtures with CR performed slightly better than the traditional mixtures with binder B60/70. In addition, the results obtained from the Superpave mix design test with asphalt binder PG70-10 have shown a better performance indicator than those obtained with Marshall modifier mixture with CR. These results provide a guideline to improving the production and mechanical properties of the hot mix asphalt (HMA) in Libya by adopting new

mix design methods such as Superpave or adding additives such as CR to the traditional mix design method with binder B60/70.

Keywords: Asphalt-modifiers, performance, additives, Marshall mix design method, Asphalt binder.

4.2 Introduction

Improving the mechanical properties and long-term characteristics of hot mix asphalt (HMA) should be considered as an intention to achieve a truly sustainable method of infrastructure development. However, this issue becomes a challenge if you are using a conventional HMA. In fact, the performance of a conventional HMA typically represents a poor long-term performance and functional problems associated with the daily traffic intensity and extreme temperature changes, which in turn implies higher maintenance costs.

One of the methods that should be used in Libya to improve the behaviour of HMA is the use of an asphalt binder that is highly insensitive to the temperature changes such as modified bitumen, performance grade binder or use of additives to the asphalt mixture. On the other hand, the preparation of hot mix asphalt by adding CR can have very interesting advantages in terms of economy, production and sustainability (Zhu, Birgisson, and Kringos 2014). These advantages will be discussed in more detail in the next sections of this paper. Thus, laboratory tests including Marshall and Superpave mix design were performed to assess the effect of the inclusion of CR on the mechanical and volumetric properties of the asphalt mixtures.

The results showed that the CR can be used to improve the characteristics and long-term properties of HMA. Asphalt rubber is a noise-reducing material for paving and improves the flexibility of asphalt pavement which consists of conventional asphalt mixed with rubber chips from recycled tires (Park, Kim, and Schapery 1996). Asphalt mixture properties such as density and air voids are largely dependent on the type of the asphalt binder, compaction method, selection of aggregate and method of mix design. These properties, in turn, have an influence over the pavement performance indicators such as rutting, fatigue, potholes and alligator cracks (El Khatib 2016). The properties of the asphalt mixture depend very much on its temperature.

At high temperatures, asphalt mixtures become viscous and behave like a plastic body under load traffic that exceeds its viscosity at a certain temperature.

This behaviour at high temperature can be a contributing factor to one of the most common distresses of asphalt pavement, which is rutting. In extremely cold climates, asphalt mixtures become very rigid and behave like an elastic body in which induced elastic deformation is completely restored. It is characterized by several failures represented by the low temperature cracking, fatigue cracking, and shrinkage cracks (Haixu, Yongliang, and Haibo 2012).

Therefore, this research aims to improve the mechanical properties of the HMA mixture to obtain an economical mixture that would meet the requirements for the characteristics of the asphalt roads in Libya. The Marshall Mix Design Method used the asphalt binder B (60/70) based on the empirical Penetration Grade System. It is not capable of viscosity measurements and hence, it is difficult to establish the correct HMA.

Therefore, this paper presents results of laboratory tests for four specimens of asphalt mixtures. Two asphalt concrete mixtures which are designed using asphalt-binder B60/70, aggregate and CR and then tested by Marshall's mix design procedures, the results compared with results obtained from the previous traditional Marshall mix design test using asphalt binder B60/70. Another two asphalt concrete mixtures were designed using asphalt binder B60/70, aggregate and CR and then tested by Superpave mix design procedures, the results compared with the previous results obtained from the Superpave mix design using asphalt binder PG70-10.

4.3 Objectives

Asphalt pavement in Libya is significant and constantly increasing, and the use of additives such as solid industrial wastes (SIW), polymer (BSR), performance grade binder (PG) and CR as components in new mixtures is strongly supported by companies who produce the asphalt. Currently, the specification of the asphalt binder in Libya is based on the Penetration Grade, which is an empirical measure of consistency and is almost always used as a traditional indicator of the susceptibility to deformation (rutting) and fatigue; it is not related to the pavement performance. To overcome these weaknesses, the bitumen industry has been developing new modifiers and additives to improve HMA behaviour. Therefore, this research aims to improve the mechanical properties of hot mix asphalt using additives in Libya to obtain an economical mixture that would meet the requirements of the pavement in hot weather.

4.4 Background and Literature Review

There was fairly extensive experience of using CR in developed countries, some with a wet process, others with dry. More than 3,000 kilometres of streets in the USA were paved with asphalt rubber mixtures in the early 1970s. The use of chip seals was discontinued in the 1990s in favour of single-layer coatings based on 1-inch asphalt rubber.

A superposition of a hot mixture is used to pave about 600 roads in the USA. It is stated that both chip seals and hot mix linings can be used to slow the reflection of alligator cracks and shrinkage cracks with a width of less than 6.3 mm (1/4 inch). It is also concluded that, the asphalt rubber on the hot mix allows for a more improved riding surface and a significant reduction in traffic noise (Charania, Cano, and Schnormeier 1992).

The Washington State Department of Transportation (WSDOT) has used three types of paving from a wet process since 1977. Detergent technology products include SAM, SAMI courses and open asphalt-rubber friction courses (Charania et al. 1992). WSDOT reported that the performance of asphalt rubber SAM and SAMI was not sufficient enough to validate their construction's extra costs (Salini, 2000). All five units with an open friction course demonstrate good performance, except for one deck overlap, which displays some discomfort in the wheel path area (Heitzman 1992). Three demonstration projects with rubber modified asphalt has been evaluated in Ontario, Canada in terms of road surface performance. The success of projects with asphalt rubber (wet process) was encouraging, as the strength of these asphalt mixtures seems to have been improved by using a crumb rubber modifier.

Actions to modify asphalt concrete material began in the 1840s. Unfortunately, the goal was difficult to achieve, the formula of asphalt rubber was not successful, and the result was a modified asphalt that was more expensive to produce and difficult to maintain than the usual asphalt (Roy et al., 2013). The Marshall mix design method was initially developed by Bruce G. Marshall from the Mississippi Highway Department in 1939, and later amended by the US Waterways Experiment Station of the US Army to include deformation measurements. This is based on two criteria, a minimum stability and a minimum range of flow values. However, it was based on a single piece of equipment to design and control the asphalt paving mixtures which are referred to as the Marshall Test (Almadwi & Assaf 2017). By 1968, the Arizona Department of Transportation in the United States began a variety of research and development projects involving asphalt rubber. By 1975, crumb rubber (CR) was successfully incorporated into HMA (Amorim et al., 2015). In the mid-1980s, the Europeans began developing new polymers and additives for use in modifying the bituminous binder (Brule 1996).

4.5 Methodology

Asphalt concrete mixtures were designed during laboratory work using asphalt-binder B60/70, aggregate and CR and then tested by Marshall and Superpave mix design procedures. These mixtures were used to evaluate the performance of the bituminous mixtures in the region. Also, the specimens were used for a comparison of several asphalt mixture using Marshall and Superpave mixtures with the traditional mix design methods in Libya. Evidently, the test mixtures contained several asphalt bitumen contents both above and below the optimum content of asphalt.

4.6 Mix Design Experiments

The purpose of this research is to determine the proper modified proportions of aggregates and asphalt to obtain an economical asphalt mixture that would meet the requirements of pavement in hot weather. Over the years, several design and development methods have been taking place and have been implemented by various agencies.

Materials Used

Aggregate: In this research, the mix, of course, and fine aggregate with sizes between 0.08 to 14 mm was used in this mix design according to the requirements. Table 4.1, Table 4.2, and Figure 4.1 show the characterizes and gradation of the aggregate.

Bituminous Binder: In this research, the asphalt binder for asphaltic concrete mix was the binder grade PG70-10 or B60/70.

Mineral filler: The mineral filler used for this study was the dust of limestone. It should be dry and essentially free of agglomerations

Crumb Rubber: The rubber from scraps can be included in asphalt mixes using two methods, a wet process and a dry process. In the wet process, crumb rubber performs as an asphalt cement modifier, while in the dry process, granular rubber or crumb is used as part of the aggregate skeleton. In both cases, crumb rubber is sometimes referred to as a rubber modifier (RM) and in most cases the output is called the modified mixture, which is usually used in content between 7 % to 22 % of bitumen (Hicks, Tighe, and Cheng 2012). The manufacturers are giving the information and recommendation on the use of the modifier. Based on the manufacturer's instructions in this experiment, the CR was added to hot aggregates with a dose 0.5% by weight of the dry aggregate prior the addition of bitumen.

4.7 Laboratory Experiments Results

In this experiment, specimens were produced by using aggregate, mineral filler, asphalt binder B60/70 and CR. The specimens were then tested by both Marshall and Superpave mix design procedure, and the results obtained are presented in Table 4.3 and Table 4.4 illustrated all the laboratory experiment results. Figure 4.2 and Figure 4.3 show the behaviour of the modifier-asphalt mixtures compared to traditional mixtures. However, in this process before mixing, the aggregates were heated to 110 ºC to ensure that there was no water content.

Then aggregates were heated until they reached the mixing temperature (179 ºC) for asphalt modified mixtures (Zoorob and Suparma 2000). This temperature was chosen in accordance to the CR data sheet. The percentage of additives was chosen by trial and error method; 10%, 15%, 20% were tried and finally 18% was determined to be the best ratio, which gave the best homogeneous mixture. The modified additive compound CR was then poured into a mixer and mixed with the aggregate.

In this experiment, specimens were prepared using asphalt binder B60/70, CR with 18%, filler and aggregate, and the other specimens were tested in the pervious laboratory work with the same aggregate gradation, filler and asphalt binder PG70-10. The obtained results at gyrations numbers 10, 80, and 200 are shown in Table 4.4 and illustrated in Figure 4.3.

4.8 Modified Mixture Test Results Using Marshall Mix Design Procedures

In this section, all specimen experiments were conducted by using Marshall Mix design methods including modified additives CR. Samples with standard sizes were compacted with a Marshall hammer with 75 blows on each side and at (168 °C). Mechanical and volumetric properties of all samples were obtained after a curing period. The obtained results are shown in Table 4.3 and Table 4.4 and illustrated in Figure 4.2 and Figure 4.3.

4.9 Synthesis and Examination of the Findings

The asphalt binder that was used in the Marshall method may not be sufficient to ensure that the selection of asphalt binders can satisfactorily meet the paving service temperatures experienced in Libya. The method of selecting the binder and the bituminous content in the mixture is still questionable. However, in this study, the conventional local specifications of selecting and blending the aggregate and binder that were used in the Marshall mix design did not perform well and thus yielded inadequate results. On the other hand, the Marshall mixes were designed using the CR, B60/70 and a proper aggregate gradation indicated that the Marshall method performed adequately.

Asphalt-binder type, asphalt-binder content, aggregate properties, and gradations showed a significant effect on the performance of the mixes as expected. Table 4.3 and Table 4.4 illustrate all the laboratory experiment results. Figure 4.2 and Figure 4.3 show the behaviour of the modifier-asphalt mixtures compared to traditional mixtures.

Modifier-asphalt mixture and Superpave mixtures with new binder PG70-10 may be a proper choice for formulating the asphalt mixture under hot weather conditions such as in Libya. It can be seen from Figure 4.2, Table 4.3 and Figure 4.3, Table 4.4 that the volumetric property values of the Superpave mixes are properly better than that of Marshall's mixtures.

The flow values of modified mixes of the Marshall method are slightly less than that of unmodified mixes. The OBC, VMA, VFA, Va % and stability are more than that in unmodified mixes. This could be due to the differences in the mixture properties and may be related to the compaction effect. In Figure 4.3, and Table 4.4, asphalt blends using Superpave with asphalt binder PG70-10 showed better properties than the modified blends using B 60/70 and CR at all stages of tests. The Superpave gyratory compactor rotates at a constant rate during the compaction, and this characteristic provides a better homogenous mixture of aggregate/ PG 70-10 binder than the other mixture that contained a CR. This process simulates closely to the field compaction, reversing the compaction with Marshall's hammer, which is unrealistic. The study clearly showed that the amount of air voids in the modified mixture with Marshall's method is twice as much as that in the Superpave method.

Although the number of air voids had a significant effect on the pavement performance, this parameter could not be relied on to predict the pavement performance. It is therefore important that air voids be carefully balanced during designing an asphalt mixture. Regardless of the type of mix design method used, it is important that the introduction of new generations of mix design methods and new additives are used to improve the properties of asphalt mixtures in Libya.

4.10 Conclusion and Recommendation

The use of modified mixtures or new generation methods for asphalt mix design can have a significant impact on the improvement of asphalt paving properties in Libya. However, the most important factors which affect the pavement performance are the environment, type of materials and the update of mix design methods. In this research, three asphalt concrete mixes were designed using modified, Marshall and Superpave mixtures.

These mixtures were formulated and tested in accordance with the Marshall mix design method and the Superpave mix design method. The analysis was conducted to evaluate HMA volumetric properties such as air voids (Va), voids in mineral aggregate (VMA), voids filled with asphalt (FVA), optimum bitumen content, etc. The study has shown that in those in which the Marshall mixes were designed using CR and asphalt-binder B (60/70) and a proper aggregate gradation, the Marshall method performed better than the traditional Marshall mixes.

The type of asphalt binder, the asphalt-binder content, and the mixture properties, showed a significant effect on the performance of the mixes, as theoretically expected. On the other hand, the Superpave mixes were designed using PG 70-10, indicated that the Superpave mixture performed better than the modified mixture. Marshall modified mixtures and Superpave mixtures with new binder PG70-10 may be a proper choice for formulating the asphalt mixture under hot weather conditions such as in Libya. A virtual need to evaluate the mix-design methods on the hot weather is still mandatory.

TABLES

Table 4.1 Sieve analysis result and aggregate gradation for laboratory mix design

Sieve size mm	% Lower Limit	% Upper Limit	% Passing
20	95	100	98
14	67	90	85
10	52	75	68
5	34	55	44
2.5	24	45	27
1.25	16	39	17
0.63	9	31	12
0.31	6	23	9.6
0.16	4	15	7.5
0.08	3	8	6.3

Table 4.2 Specific gravity for the compound of aggregates and asphalt binders

Agg. Size and asphalt binder	% of Agg. in mixture	Bulk Specific Gravity	Compound mix Specific Gravity	% Water Absorption
20-14 mm	15	2.739	2.716	0.630
14-10 mm	15	2.736		0.670
10-5 mm	26	2.733		0.700
Crushed 0-5 mm	36	2.698		0.005
Sand 0-5 mm	3	2.595		0.007
Filler mm	5	2.700		0.006
Bitumen (B60/70)	4.50	1.020	1.020	-
Bitumen PG 70-10	4.25	1.029	1.029	-

Table 4.3 Result of Marshall specimens with two different mixtures

Mixture Properties	unmodified mixes with B (60/70)				B (60/70) modified mixes with 18% CR			
	SI	SII	SIII	Ave.	SI	SII	SIII	Ave.
OBC%	5.0	5.2	5.5	5.2	6.5	7.0	7.5	7.0
VMA%	14.5	15.5	16.6	15.6	15.9	18.7	19.0	17.8
VFA%	68.4	62.9	63.9	65.1	60.6	68.1	63.5	64.0
Va%	5.2	5.8	6.5	5.8	7.4	5.8	7.6	6.9
Flow (mm)	4.1	3.6	3.9	3.8	4.2	3.5	3.2	3.6
Stability (KN)	9.5	9.4	8.6	9.2	22.2	18.3	16.7	19.1

Table 4.4 Result of Superpave specimens with two different mixtures

Numbers of Gyrations	Superpave mixes with PG 70-10			B (60/70) modified mixes with 18% CR		
	VMA %	VFA%	Va%	VMA %	VFA%	Va%
10	23.2	52.6	12.2	24.4	51.5	11.7
80	20.4	62.4	6.5	18.3	60.5	5.9
200	21.6	70.0	4.1	18.6	70.5	3.2

FIGURES:

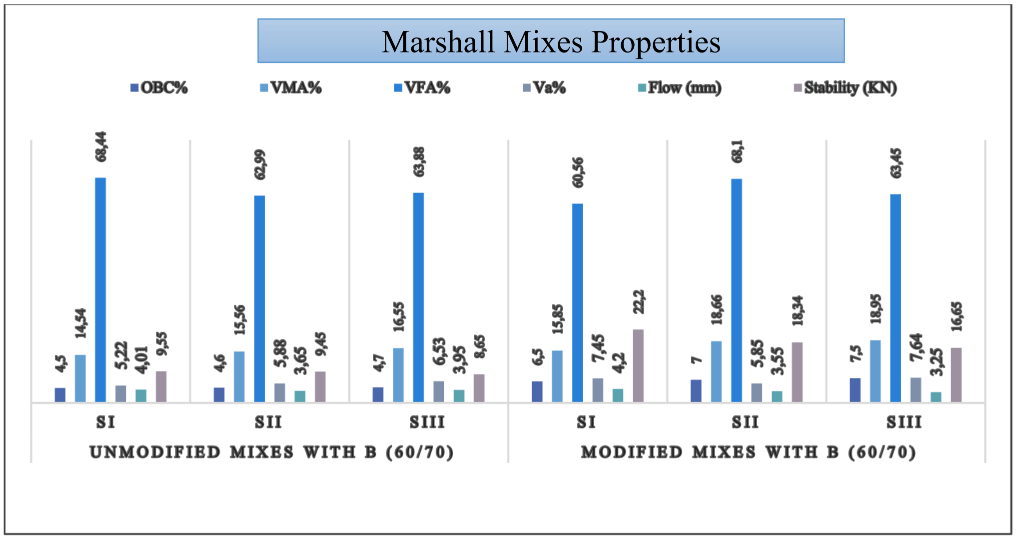

Figure 4.1 Comparison between modified with CR and unmodified mixture under Marshall mix design

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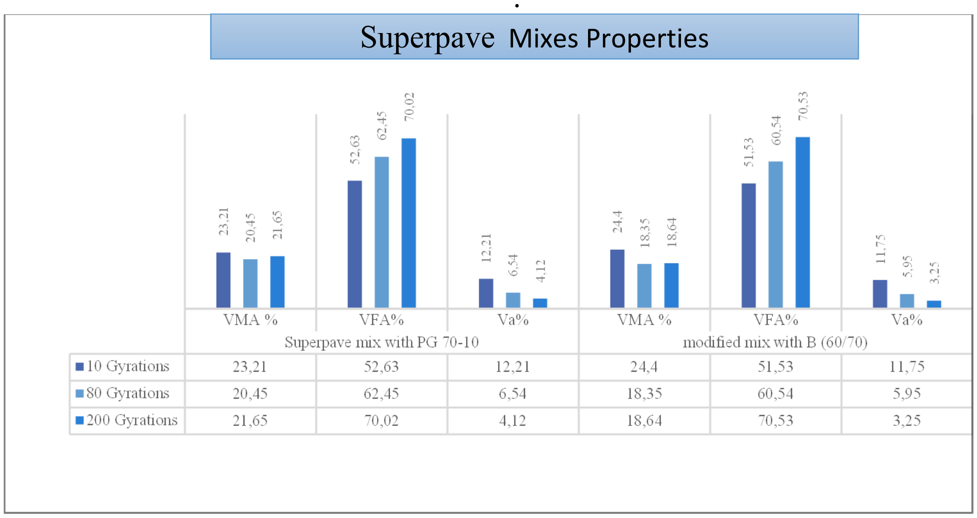

Figure 4.2 Comparison between Superpave mix with PG 70-10 and modified mixture with CR and B60/70 under Superpave mix design

CHAPTER 5

MEASUREMENT OF ASPHALT PAVEMENT TEMPERATURE TO FIND OUT THE PROPER ASPHALT BINDER PERFORMANCE GRADE (PG) TO THE ASPHALT MIXTURES IN SOUTHERN DESERT OF LIBYA.

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5.1 ABSTRACT

Structural capacity of the asphalt concrete pavement depends on many factors such as materials, environmental, equipment and technology used. Consequently, these factors have significantly affected the performance and life span of the pavement. This paper presents the investigations undertaken to develop models to predict high and low asphalt pavement temperatures in the city of Ash Shwayrif at the southern of Libya. The study area is found in a hot dry climate region which is characterized by high temperature during the summer and low during the winter. This large temperature variation between summer and winter and day and night influences the pavement performance. This paper conducted to measure the temperature of pavement in the area of Ash Shwayrif. The temperature had measured in different seasons of the year using special measuring tools (Thermocouples) at different depths up to 300 mm from the surface of the pavement to the subgrade. This technique assisted to observe the temperature changes in the pavement layers during the day, as well as the measurement of the solar radiation by using HMS in the region. Those obtained results were compared with the

results of similar studies in other parts of Libya. This model was developed to help in the proper selection of the asphalt binder performance grade (PG).

5.2 OBJECTIVES

The main aim of this research is to measure the temperature of the pavement directly at different depths and to assist in the selection of the proper PG as well as to measure the amount of solar radiation using Station Micro Hobo.

5.3 BACKGROUND AND LITERATURE REVIEW

An important factor that affects the performance and life span of a pavement is the effect of temperature. Temperature can affect some common types of asphalt pavement distresses, such as permanent deformation or rutting usually associated with high-temperature environments, bleeding and thermal cracking associated with low-temperature environments. In 1987, the Strategic Highways Research Program (SHRP) developed a long-term road traffic monitoring program (LTPP) to support a wide range of road performance analyzes, leading to improved engineering criteria for the design, construction and management of asphalt roads (Ortega 2017).

The Seasonal Monitoring Program (SMP) was established as an element of the LTPP in 1991 to measure and assess the effects of temperature and humidity changes on pavement characteristics and the testing of available models (Imbarek et al. 1996). Based on the initial SHRP test and SMP data, several pavement temperature models were developed to help in the proper selection of the asphalt binder performance grade (Arangi and Jain 2015).

Diefenderfer et al., 2006; Wahhab, & F. A. Balghunaim 1994 conducted a study in two regions in Saudi Arabia to manually measure pavement temperatures in different pavement sections. The study concluded that the extreme pavement temperatures in arid environment ranged between 3 and 72°C, while in coastal areas, the temperature ranged between 4 and 65°C. In another study, Wahhab, H., and F. A. Balghunaim, 1994 recommended five performances graded binder zones for the whole Gulf area (Al-Abdul Wahhab and Balghunaim 1994).

5.4 METHODOLOGY

A pavement monitoring station was set up at Ash Shwayrif to monitor air, pavement temperatures, wind speed and solar radiation. This technique enables to observe the temperature changes in the pavement layers during the day, as well as the measurement of the solar radiation in the region. The weather data for the area were obtained from the Libyan National Climatic Database Centre.

The weather data included 10 years of daily maximum and minimum temperatures, average daily percent sunshine, daily average rainfall, and daily average wind speed. The temperature of the pavement had measured in different seasons of the year using special measuring tools at different depths from the surface of the pavement up to the subgrade. Those obtained results will be compared with the results of similar studies in other parts of Libya. The data collected for the whole year, lower and higher level of daily temperatures were recorded.

Regression analysis using air temperature, wind speed and solar radiation were used to develop the lowest and highest models of pavement temperature. The corresponding PG should be selected depending on the lowest and highest pavement temperature in the region.

5.5 PAVEMENT TEMPERATURE PREDICTION

Flexible pavements comprise a majority of the primary highways in Libya. These primary roads are subjected to heavy loading that can cause significant damage to the hot-mix asphalt (HMA) pavements. As HMA is a viscoelastic material, the structural or load-carrying capacity of the pavement varies with temperature. Thus, to determine in-situ strength characteristics of flexible pavement, it is necessary to predict the temperature distribution within the HMA layers. Most of previously published research on pavement temperature prediction has consisted of predicting the annual maximum or minimum pavement temperature so as to recommend a suitable asphalt binder performance grade.

To determine the pavement temperature profile, the influence of the air temperature and seasonal changes must be understood so that the large temperature variation between summer and winter and day and night influences the pavement performance. Hence, this study has shown that the highest and lowest temperature of the pavement can be measured at any depth. Pavement temperature can be expected by knowing the maximum and minimum air temperatures, the depth at which the pavement temperature is desired, and the day of the year of appearance of extreme temperatures at a particular location (Lewis 2004).

5.5.1 Study Area

Ash Shwayrif is located between 29° 58′60″ N and 14°16′00″ E latitude, in a hot and arid climatic region characterized by high variation in daily temperatures, high solar radiation, low humidity, low precipitation, wind and dust storms. In the study area there is no railroad services nor airlines and the asphalt concrete roads are the main and only source of land transport system for most travellers and merchandise.

5.5.2 Work Procedure:

The purpose of the monitoring station is to obtain the maximum and minimum temperature of the asphalt pavement within one year. These measurements will help to obtain a mathematical model from which to predict the temperature of the pavement at any time of the year of Ash Shwayrif City. Eight thermal sensors were installed at various depths in the road pavement at different depths from 200 mm depth up to the subgrade using an electric punching machine (and installing the sensors using sand bitumen mix at the required depth).

Table 5.1 shows the depths of the installation. After completion of the necessary installation and modification of the length of the wires, the process of filling the previously excavated materials was completed using a mixture of cold asphalt concrete to lock the trench and return it to the original level of the pavement surface. Finally, a tower was built near the box to install the solar radiation measurement device, which installed in a hot mix asphalt.

5.5.3 Temperature Data Analysis

For Ash Shwayrif City, temperature data for one year were collected for air and pavement: at the surface (C1) and depths of 20 mm (C2), 40 mm (C3), 80 mm (C4), 100 mm (C5), 140 mm (C6), 220 mm (C7), and 290 mm (C8). From these data, maximal and minimal daily temperatures were extracted for air and pavements at the surface and depths of 2, 4, 8, 10, 14, 22, and 29 cm. Then, for maximal temperatures, the seven-day average of maximal daily temperature was calculated. Table 5.2 and Table 5.3 show the maximum of these seven-day averages and minimums of minimal daily air and pavement temperatures for data registered during the years 2016–2017 are given for the location.

5.5.4 Ash Shwayrif Pavement Temperature Models

Using regression analysis, models for predicting maximal and minimal daily pavement temperatures at different depths including the surface, from maximal and minimal daily air temperatures, days of the year, latitude, wind speed and cumulative solar radiation were made (Imbarek and Smith 1996). The model to predict maximal daily pavement temperature at any depth from maximal daily air temperature, the day of the year, and latitude is:

$$T_{\max pav} = 22.20576 + 0.197343 T_{\max air} + 0.71214 d - 0.00054 Day - 0.38103\, Day^2 lat \quad (5.1)$$

Where

$T_{\max pav}$ = Maximal daily pavement temperature at depth d. in (°C).

$T_{MAX\ air}$ = Maximal daily air temperature. (°C).

Lat = Latitude of the section. (degrees): and

d = Pavement depth (cm).

The model to predict minimal daily pavement temperature from minimal daily air temperature, the day of the year, and latitude is:

$$T_{\min pav} = 7.723302 + 0.781078\, T_{\min air} + 0{,}255764d - 0.06415Day - 0.000172Day^2 - 0.189455\, lat \quad (5.2)$$

Where

$T_{\min pav}$ = Maximal daily pavement temperature at depth d. in (°C).

$T_{\min air}$ = Maximal daily air temperature. (°C).

Lat = Latitude of the section. (degrees): and

D = Pavement depth (cm).

From these daily maximal (minimal) air temperatures, using regression models obtained, predicted values for maximal (minimal) pavement temperatures for eight depths were calculated. Based on data from the station for calculating PG, the model has been used as: Yearly maximum for the seven-day average of maximal daily air and pavement temperatures were determined for the location. Yearly minimum for minimal air and pavement temperatures was determined for the location.

5.6 RESULT AND DATA COLLECTION

5.6.1 Result from the Study Area

Temperature readings were started for recording about one day after the thermometers had been fixed in their depths at the pavement. The temperature measurements were taken at 6:00 am, 10:00 am, 2:00 pm, and 6:00 pm on a certain day of the year, which represent the range of the various weather conditions. In fact, to measure the surface temperature of the road, a mercury thermometer with an asphalt-coated bulb was used.

Table 5.2 presents a summary of the minimum, average and maximum temperatures measured for this investigation. The equipment of the station was set to start on the date of 2016.5.29 at 6 pm every 15 minutes and will continue for one full year. However, for this paper, readings of air temperature, pavement and solar radiation were monitored for one week from 2016.6.24. Figure 5.1 and Figure 5.2 show the highest and lowest pavement temperatures and solar radiation graphically.

5.6.2 Result from the Nearest Previous Study Area

Data were collected for 365 days, air and pavement temperature, wind speed and solar radiation was recorded every fifteen minutes. For all Brak location, temperature data for one year were collected for air and pavement at four layers: at the surface (C1) and depths of 3 cm (C2), 8 cm (C3), and 15 cm (C4). From these data, maximal and minimal daily temperatures were extracted for air and pavements at the surface and depths of 3, 8, and 15 cm. The results were illustrated at Table 5.5, and Table 5.6.

5.7 Data Analysis

5.7.1 Air temperature and Pavement Temperature at Ash Shwayrif Area

From Figures (5.1) and (5.2) we note the following:

This study showed that there is a direct correlation between the temperature of the air and the temperature of the pavement, especially at the surface of the pavement and at a depth of 20 mm. The higher the air temperature the higher the temperature of the pavement significantly and vice versa. In this study the temperature of the air considered as independent variable and the temperature of the pavement is a dependent variable.

Observed data are coming as repeated curves, where each day starts at the lowest temperature at sunrise approximately 6:00 a.m., and then begins to rise to the highest temperature (top of the curve) and then begins to fall at sunset until it reaches the lowest temperature (bottom of the curve) and so on in the next days.

The highest pavement temperature was seen during this period was 69.45 ° C at the surface when the air temperature was 45.7 ° C at midday and the lowest was 7.87 ° C. The maximum solar radiation was seen during this period was 1103.05 W / m2 and the lowest quantity was 0.65 W/m2. This minimum value of the solar radiation has been recorded during the night from sunset to sunrise every day.

Figure 2 shows the maximum seen solar radiation at 1103.05 W / m^2 at the corresponds to the maximum temperature of the pavement observed at 1:00 pm to 2:00 pm on June 2016 and the lowest quantity was .65 W / m^2. This shows the positive relationship between the amount of solar radiation and the temperature of pavement during the day.

Solar radiation is measured in days when there are no air currents because these currents reduce the pavement surface temperature relatively. Table 5.4 shows some data for solar radiation on 2016.6.20 from 6:00 am to 9:00 pm.

5.7.2 Air Temperature and Pavement Temperature at Bark Area

From the earlier study conducted by Salem, Hassan Awadat 2014 at Libya, Table 5.5 and Table 5.6 were shown the following. The highest pavement temperature observed during this period was 69.1 ° C at the surface when the air temperature was 50.1 ° C at midday and the lowest was 7.78 ° C. This indicates that the temperature goes to the highest at the surface at the midday then the temperature decreases gradually until it reaches the lowest temperature at the bottom layer of the pavement.

The maximum solar radiation observed during this period was 1033.5 W / $m^2$and the lowest quantity was 0.55 W / m^2. this minimum value of the solar radiation has been recorded during the night from sunset to sunrise every day. Figure 5.2 shows the maximum observed solar radiation at 1033.5 W / m².

5.8 CONCLUSION AND DISCUSSION

Through the analysis and discuss of the obtained results, the existing asphalt mix does not have enough strength to maintain equilibrium. It is required to improve the asphalt binder characteristics to enhance the physical and mechanical properties to the HMA. Anyhow, improve the flexibility of asphalt mix at the lowest temperatures to prevent the shrinkage cracks and increase the solidity of asphalt mix at the high temperatures to prevent Rutting.

The pavement temperature is directly related to major climate factors such as air temperature and solar radiation. For both locations, data on daily maximum and minimum air temperature spectrum °C were collected for a whole year. For the hot zones, asphalt should be selected based on the maximum and minimum temperature of the asphalt pavement; otherwise, problems of premature rutting and other pavement failures would continue by using conventional B (60/70) grade binder. The study was conducted at Ash Shwayrif city in Libya showed that the popper asphalt binder to produce HMA to this area is PG 70 – 10.

Yearly maximum for the seven-day average of maximal daily air and pavement temperatures was determined for the location. These maximums and minimum were used to determine PG grades with 98% reliability. The study was conducted at Bark City in Libya concluded that the popper asphalt binder to produce HMA to this area is PG 70 – 10. These results confirmed that the climatic zones use the same asphalt binder in the production of hot asphalt mixtures, according to the temperature and solar radiation.

TABLES:

Table 5.1 The depth of the thermal sensors from the pavement surface

Cupel Number	Depth from the surface (mm)	Description of location
1	0	Surface of pavement
2	20	within the surface layer
3	40	Between surface layer and primary coat
4	80	Within the primary coat
5	100	Under the primary coat
6	140	Within the base course
7	220	Under the base course
8	290	Within the subgrade

Table 5.2 Minimum, Average and Maximum Air Temperature by (◦C)

Months	Min. Air Temp.	Min. Pavement Temp.	Average Air Temp.	Average Pavement temp.	Max. Air Temp.	Max. Pavement temp.
Feb.	-3	15	23.2	33.5	28	50
March	1	17	30.3	41	30	60
April	3	19	36.4	51	38	63
May	5	23	42.4	61	42	68
Jun	14	29	45.3	65.5	45	70
July	15	27	40.4	58	48	69
Aug	15	25	42.6	62	47	67
Sep	14	23	39.6	54.5	45	65
Oct	5	18	30	39	39	59
Nov	4	16	24.3	34	25	48
Dec	3	13	19.8	29	23	43
Jan	-2	11	19.3	28	22	40

Table 5.3 Quantity of solar radiation

Time of measurement	Quantity of solar radiation w/m²	Time of measurement	Quantity of solar radiation w/m²
6:00 a.m.	0.65	2:00 p.m.	1035.5
7:00 a.m.	130.7	3:00 p.m.	974.4
8:00 a.m.	343.2	4:00 p.m.	784.3
9:00 a.m.	590.7	5:00 p.m.	601.1
10:00 a.m.	778.2	6:00 p.m.	400.5
11:00 a.m.	971.6	7:00 p.m.	173.3
12:00 a.m.	1103.05	8:00 p.m.	3.4
1:00 p.m.	1091.9	9:00 p.m.	0.65

Table 5.4 Maximum of seven-day average and of minimal daily temperatures for 2000 to 2009 and 2012–2013, for the Brak city, (Salem, Uzelac, and Matic 2014).

Brak	Mean	Min	Max	Std Dev	Mean ± SD		Mean ± 1.65 SD		Mean ± 2 SD		Mean ± 3 SD	
Air_max	.35	44	50.1	1.82	44	47	43	49	42	49	40	51
C1_max_P	63.5	62	69.1	1.96	62	65	60	67	60	67	58	69
C2_max_P	60.14	58.6	65.2	1.84	58	62	57	63	56	64	55	66
C3_max_P	57.67	56.1	62.7	1.81	56	59	55	61	54	61	52	63
C4_max_P	52.04	50.7	56.6	1.64	50	54	49	55	49	55	47	57
Air_max_ aver	43.55	41.8	47.2	1.53	42	45	41	46	40	47	39	48
C1_max_P_aver	62.08	60.7	66.1	1.56	61	64	60	65	59	65	57	67
C2_max_P_aver	58.63	57.2	62.8	1.64	57	60	56	61	55	62	54	64
C3_max_P_aver	56.23	54.8	60.6	1.68	55	58	53	59	53	60	51	61
C4_max_P_aver	50.79	49.5	55	1.59	49	52	48	53	48	54	46	56
Air_min	-0.04	-3	2.2	1.73	-2	2	-3	3	-4	3	-5	5
C1_min_P	9.79	7.78	12.1	1.25	9	11	7.7	12	7	12	6	14
C2_min_P	3.79	2.13	7.17	1.76	2	6	0.9	7	0	7	-1	9
C3_min_P	4.44	2.77	7.69	1.75	3	6	1.5	7	1	8	-1	10
C4_min_P	6.01	3.84	9.71	1.88	4	8	2.9	9	2	10	1	12

Table 5.5 Reliability data for PG at Brak location (Salem, Uzelac, and Matic 2014).

Brak	50% rel. Mean		85% rel. Mean±SD		95% rel. Mean±1.65 SD		98% rel. Mean ± 2 SD		99.9% rel. Mean ± 3 SD	
N = 11 years	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
C1	9.79	62.08	8.55	63.65	7.74	64.66	7.3	65.21	6.06	66.77
C2	3.79	58.63	2.04	60.27	0.89	61.34	0.28	61.91	1.48	63.55
C3	4.44	56.23	2.68	57.92	1.54	59.01	0.93	59.6	0.83	61.29
C4	6.01	50.79	4.13	52.38	2.91	53.41	2.25	53.97	0.38	55.56

Figures

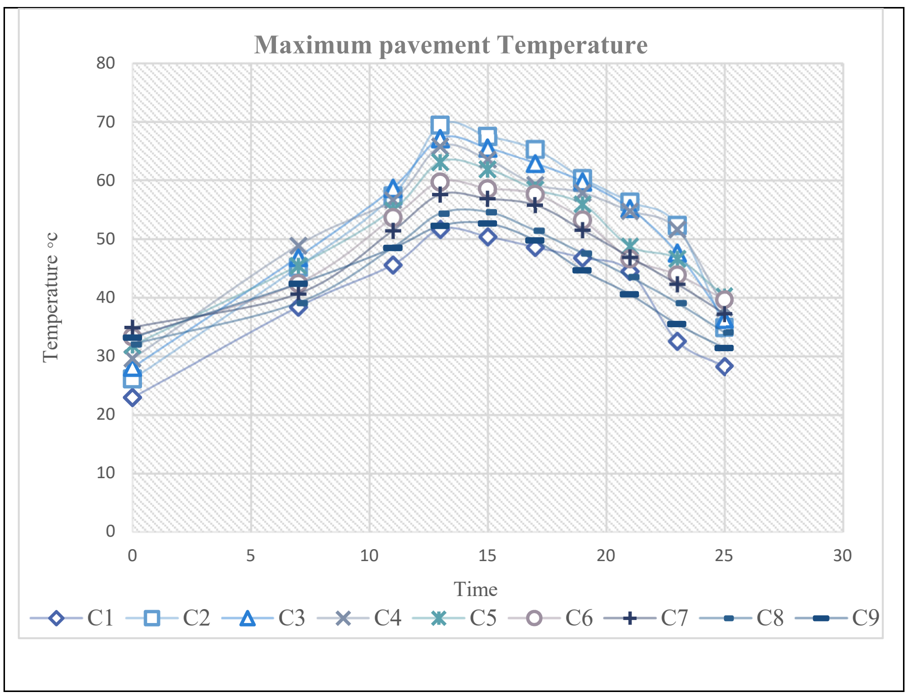

Figure 5.1 Maximum Pavement Temperature

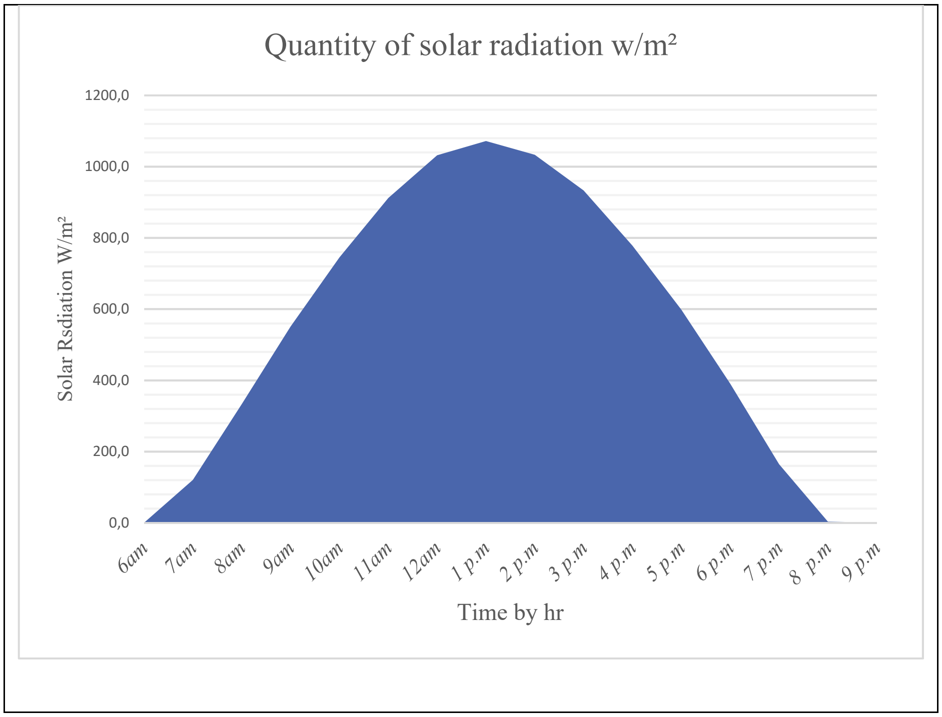

Figure 5.2 Quantity of solar radiation

CHAPTER 6

EVALUATING FACTORS INFLUENCING ASPHALT ROAD CONSTRUCTION QUALITY IN HIGH TEMPERATURE CONDITION (CASE STUDY IN LIBYA)

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6.1 Abstract:

The assumption of a linear viscoelastic behaviour of asphalt mixes suggested that the response of the material to the inquiry is the sum of the responses of that material to each elementary petition. However, the construction of asphalt concrete pavements (CAP) is a complicated procedure, including some of climate parameters and material availability. Hot weather environment such as Libya has its own challenges and requirements in terms of weather factors, materials, construction equipment and the availability of materials in each area.

However, the condition of some roads was further down than the required level. Rutting distress is one of the major defects that occur in asphalt pavements in the hot region weather of Libya and severely influence the driveability. Questionnaires and laboratory experiments were conducted for several mixtures at representative temperature and traffic load. In this study, rutting tests are conducted on two different mixtures.

The first blind used traditional asphalt bitumen type B (60/70), another blind carried out using the Superpave design procedure using asphalt bitumen type performance grade PG (70-10). The questionnaire was sent to tens of engineers and specialists. The interview was carried out

to a few others, the interview was among the factors that were leading to explain of an unsatisfactory performance of the asphalt roads in Libya.

Consideration and improvement of these factors will play an important role in improving the characteristics of the road surface, increasing service life and reducing maintenance costs. ACP should employ asphalt bitumen, which works perfectly in the Libyan environment. Materials properties in asphalt mixture have a high impact of the pavement performance.

Keywords - asphalt mixtures, consistency, performance (PG), construction.

6.2 INTRODUCTION

Libya has an area of 1,759,540 km². The country serves a highway network with a total length of 83,200 km, of which 47,590 km are paved, as well as more than 100 airports in various cities of Libya (Goldschmidt, 2018). The government has invested billions of USD in road construction. Throughout the world, there are many models of successful construction of asphalt pavements that have been designed to resist load traffic affection in a hot weather or on airport taxiways.

However, there are many elements that contribute to improving the goodness of the pavement production. Aggregate angularity for example in asphalt hot mixture has a significant impact on rutting resistance (Sun 2016; Souza et al., 2012) found that the form, angularity, and outer texture of the aggregate strongly influence the characteristics of asphalt roads. The lack of supervision and decontrol over the implementation of asphalt roads in the hot weather leads to inadequate performance of ACP.

Approximately most of the newly established asphalt roads in Libya are showing many of failures. As, there are many elements affecting the goodness of the asphalt roads during its design life. Also, there are many elements that may improve the effectiveness of the asphalt roads (El-Hamrawy, Abu El-Maaty, & Akal, 2017). These elements are the views of contractors and engineers, related to design and specifications, as well to construction. This can be achieved through a survey of engineers and contractors and a laboratory work. This study aims to a better understanding of ACP performance and, so, to improve the properties of asphalt pavement, increase the service life and reduce the cost of maintenance.

6.3 Background

Since about 70% of the total area of Libya located at the hot region, there are a few elements that affect the quality of pavement performance from the design up to the implementation stage. During many years of road construction, authorities have been committed to find out solutions for specific objects. In Libya, the widely used method of road construction is to build the road to backfill materials above the water table level at a height of not less than 1.2 metres (Al-Hassan, 1993). Regarding design specifications, the initial set of specification was inserted in 1964 by international experts and was usually based on the experimental of USA and European standers. In fact, these specifications are not always suitable for environment of Libya. Now all projects are made based on foreign standards.

Although there are many models of asphalt mixture failure. In Libya, rutting is the common failure modes, the United States and other countries adopted the rutting as one of the criteria for designing asphalt pavements (Rahman, Uddin, & Gassman, 2017). The increased appearance of ruts, especially on road surfaces, relates to an increase of traffic load and tire pressure. The producing of asphalt mixtures, materials selection and method of construction should be providing to upgrade the hot mix asphalt design in Libya to a level that exceeds traffic load and tire pressure.

6.4 OBJECTIVES

The main objective of this study is to explain of an unsatisfactory performance of the asphalt roads and to a better understanding of ACP performance and, so, to improve the properties of asphalt pavement in Libya. In the other hand, this research aims to develop a mix design method of the asphalt mixtures locally using a suitable material to Libyan environment such as the asphalt binder PG 70-10.

6.5 METHODOLOGY OF RESEARCH

Rutting is one of the major failures that occur in asphalt pavements in Libya and the most countries adopted the rutting as one of the criteria for designing asphalt pavements. In this paper, two different asphalt mixture was tested by rutting machine test. These mixtures have used same materials of aggregate and filler then used two different asphalt binders, one to each mixture. The first mixture prepared using traditional mix design method and asphalt binder B (60/70), the second one prepared using Superpave mix design method and asphalt binder PG (70-10). In the other hand, survey questioner was designed to show elements that affect the quality and performance of the asphalt roads in Libya. The form of the questionnaire was developed based on an analysis of relevant literature and several interviews with engineers and contractors. The questionnaire consists several questions that affect the performance of the road surface.

The questions are owner name and background, type of asphalt binder, upgrading of asphalt mix design methods, scarcity of data collection, contractor manpower and equipment capability and construction control. In hot weather such as Libya, there are many other factors that can influence the behaviour of the pavement; However, these factors were proposed by contractors and engineers during the interviews. These aspects were explained and evaluated by their impact. Respondents chose one of four possible responses, standing for different degrees of effect, on a scale of 1 to 4. The answer 4, EE: Major Effect; 3, E: Effect; 2, LE: Low Effect; 1, NE: No Effect means that the factor did not affect (NE); 1, low effect (LE); 2, effects (E);3 and 4, Major effect (EE). The questionnaires were analyzed, and the influence indicator was calculated for each factor and the following equation has been used:

$$\text{Influence Indicator} = \sum_{i=1}^{4} = \left(\frac{Xi \times Yi}{N}\right) \times \frac{100}{4} \qquad \mathbf{6.1}$$

Where Xi = weight for each participant; $i = 0, 1, 2, 3$

and 4; and Yi = frequency of the i th response.

These elements greatly improve pavement performance, durability, and lower maintenance costs.

6.6 Factors Influence Pavement Properties

Table 6.1. illustrates the result of the survey and presented the factors that are affecting the characteristics of the pavement. Six factors were listed with their level of influence is discussed in the following paragraphs.

Table 6.1 Factors Affecting Pavement Performance in Libya

Factor	Inf. Indicator
Owner Name and Background	87%
Type of Asphalt Binder	93%
Upgrading of Asphalt Mix Design Methods	84%
Scarcity of Data Collection	92%
Contractor manpower and equipment capability	80%
Construction Control.	78%

6.6.1 Owner Name and Background

Although the quality of road performance is direct functions of material selection and mixture design, the owner experience and technical staff have high impact on the final product. An important element of successful construction process is human resources, equipment, and owner experience. The first factor influences the qualification is the inspection team of the owner and the contractor. It has an impact of 87%. Qualifications and experience inspection groups are important for a perfect construction. The supervision team must ensure compliance with the drawings and specifications to ensure that the construction process meets the requirements of the project. The supervising team should be familiar with all the details of the project and its functions. Otherwise, the pavement it may not meet the minimum requirement as a result of in a reduced level of productivity (Woodall and Montgomery 1999); (Akal, El-Maaty, and El-Hamrawy 2017). Almost all labourers in Libya are unqualified or semi-qualified and they come from either Africa or the Third World. Since the quality and the performance of the road pavement is a function in the materials used and the construction process. Therefore, a shortage of experienced to the owner or contractor may lead to inadequate control of the process, which leads to poor quality work.

6.6.2 Type of Asphalt Binder

In Libya until to this date, the asphalt binder that is using into the preparation of asphalt mixture is selected based on a penetration system, which has several limitations. The viscosity grading system is based on binder viscosity at 60 degrees Celsius. Viscosity grading is related to the consistency of the binder at a specific temperature and not directly related to its performance throughout the anticipated life of the pavement.

As a result, it does not mandate for viscosity measurements and therefore it is difficult to set up the correct HAM (Abdullah et al. 2016). On the other hand, in recent years, the Strategic Research Programs in High Technology (SHRP) have developed new criteria for the selection of asphalt binder, known as a Performance Grade system (PG), to overcome certain limitations. The concept of PG is based on the rheological theory that the properties of asphalt binder should be related to the climatic conditions under which it should be used. The engineering properties that are believed to be associated with the expected performance (maximum pavement temperature of 7 days and one-day minimum pavement temperature) are featured in the specifications of the PG binder (Almadwi and Assaf 2017).

6.6.3 Upgrading of Asphalt Mix Design Methods

Most developing countries use volumetric analysis in designing asphalt mixtures, which can also be upgraded in arid hot weather. However, to be effective, it should include some proper aspects which are material, environment, and method of construction. Lack of database, not allocating a budget and encouraging scientific research in paving asphalt roads. Furthermore, the use of multiple specifications by foreign companies that don't take into consideration the climatic condition and the resources of local materials.

All this leads to premature permanent deformation, unsuitable asphalt mixtures and the inability to develop a mix design method locally. "Almadwi, F. and Assaf, G. (2017)"; found that ''The performance of PG70-10 mixes was found to be superior to than the mix-using B 60/70. Also, the results of the Super Gyratory Compactor tests were found to be a better indicator of performance than those given by Marshall Stability tests." The existence of a database, local specifications, and the encouragement of scientific research inevitably lead to the development of the design of the asphalt mixtures in the region.

6.6.4 Scarcity of Data Collection

Engineers and contractors in Libya are faced with the problems of building a pavement for a desert or sand dune (hot desert area), typically found in North Africa and the Arabian areas. In addition, the prediction of traffic growth in Libya is quite a difficult due to many reasons, such as the inaccessibility of annual road traffic counts by road agencies. The fluctuation in the economic situation is very high. In Libya, there is no development strategies, plans for roads, services, sources of fund and land use are not available. The construction of hot mix asphalt (HMA) is a complicated process, including many critical factors, which affect the quality of the asphalt pavement and are not considered at mix design (Xu and Chang 2016). Recently built pavements in Libya showed a poor quality of pavement distresses, namely rutting, shoving and depressions within the first few years of operation.

6.6.5 Contractor Manpower and Equipment Capability

Throughout the execution of asphalt roads, there are a few elements that affect the quality of pavement performance from the design up to the implementation stage. Placement, testing, monitoring the aggregate gradient, asphalt bitumen content, mixing temperature, compaction temperature, and compaction method are critical factors affecting the final product quality (Sun, 2016). Aggregate (gradation, form, and type) have an impact of 80%. In Libya, there are

In the north region there is a qualitative aggregate. In the middle region there is an average quality score of aggregate, but the quality is so rareness in the southern region. As these regions cover various traffic conditions, climate and subgrade layer, a change in these factors can lead to diversity in pavement properties in these regions. In particular, if the same standard specifications are used in asphalt pavement construction projects throughout the country. In addition, the lack of good-quality materials and high temperature in some areas can lead to higher costs. In fact, the suitable pavement construction depended on, the selection of materials, proper techniques and equipment, and careful attention to details in the implementation process (Huber, 2013).

6.6.6 Construction Control

Monitoring of mix design (aggregate skeleton, OBC, mixing temperature and compaction method) has an impact of 78%. The mixing procedure can have a significant effect on the viscosity of asphalt binder and the behaviour of the final product during the paving process. Controlling the amount of asphalt and mixing temperature during mix design procedures are very important for producing an acceptable mixture. This reduces the aging of the asphalt binder (oxidation) and giving a homogeneous coated mixture, since the proper content of asphalt is critical to obtaining the desired content of voids in the compacted mixture. The number of air voids affects pavement properties such as the durability, flexibility, stability, and susceptibility to moisture damage. A change in the content of asphalt can lead either to a dry mixture, which can lead to premature ravelling and cracking, or in rich mixtures that can lead to permanent deformation (Xu, & Chang, 2016).

6.7 Result of Rutting Test and Questionnaire Survey

In this experiment, Table 6.2 shows the aggregate gradation which used in these mixes, specimens had been tested by using bitumen binder B60/70 and the other specimens by bitumen binder PG 70-10. The obtained results presented at Table 6.3 and Table 6.4 and illustrated in Figure 6.1. In questionnaire survey, factors affecting the quality of the road surface were found and evaluated on a scale, depending on their impact. The obtained results of the questionnaire survey presented at Table 6.1.

Table 6.2 Aggregate Gradation for Laboratory Mix Design

Sieve size mm	%Lower Limit	%Upper Limit	% Passing
28	100	100	100
20	95	100	98
14	67	90	85
10	52	75	68
5	34	55	44
2.5	24	45	26.8
1.25	16	39	17.6
0.63	9	31	13.3
0.31	6	23	10.8
0.16	4	15	8.6
0.08	3	8	5.8

6.8 Summary and Conclusion

There are many aspects that contributed to increase the productivity. Road contractors were surveyed for factors that control the performance of the asphalt roads. Factors affecting the quality of the road surface were found and evaluated on a scale, depending on their impact. Eq. (6.1) shows how to calculate the effect of each of these factors. The results obtained from the questionnaire and laboratory experiments showed that, each area has own characteristics and requirements in the asphalt mix design.

The questionnaire survey concluded that some factors have more impact on the pavement performance which is owner experience and technical staff, asphalt characteristics, updating and development of asphalt mix design methods, lack of data collection by authorization agencies, construction and compaction process, and mentoring and controlling mixing procedure.

Appendix II shows an example of questionnaire survey. Rutting is one of the main distresses occurring in asphalt pavements in Libyan weather and badly affects the ride ability. This study showed that in rutting tests, most of the permanent deformation occurs in the upper four inches of HMA. Table 6.3 and Table 6.4 shown that the mixes using the asphalt binder (PG 70-10) showed better resistance to rutting than the mixes using the asphalt binder (B 60/70).

Mixes with asphalt binder PG (70-10) and compacted with SGC have shown more superior than mixes with asphalt binder (60/70) for all stages of the tests. The use of an overly sensitive asphalt binder to high-temperature changes in Libya is highly recommended. This research leads to a better understanding of (ACP) performance and, so, to improve the properties of asphalt pavement, increase the service life and reduce the cost of maintenance.

Table 6.3 Rutting Analyzer Test Results

No of Cycles	% Rut of Samples with Bitumen PG70-10	% Rut of Samples with Bitumen B60/70
1000	5.4	5.7
3000	5.9	6.2
10000	5.9	7.2
30000	7.0	8.7

Table 6.4 Rutting Test Result for Whole Cycled

Specimen description			Cold cycle	Number of cycles (cumulative) at 65 °C				Rutting at 30000 cycles (mm)
Binder type	Sample no	Sample height	1000	1000	3000	10000	30000	
PG 70-10	Si	107.65	0.02	0.05	0.06	0.06	0.07	6.9
	Sii	108.45	0.03	0.05	0.05	0.05	0.06	6.5
Average		108.05	0.03	0.05	0.05	0.05	0.06	6.7
B (60/70)	Si	104.45	0.02	0.06	0.06	0.07	0.08	7.8
	Sii	103.75	0.02	0.05	0.06	0.07	0.08	7.5
Average		104.1	0.017	0.05	0.06	0.07	0.08	7.7

CHAPTER 7

PERFORMANCE TESTING OF ASPHALT PAVING MIXTURES FOR HOT AND ARID CLIMATE USING TENSION-COMPRESSION TEST

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7.1 Abstract:

In the presented work, cyclic tension–compression complex modulus tests were performed on an asphalt mix specimen. This work is a part of experimental research to enhance the modification of the traditional Marshall mix design (MMD) method for asphalt mixture in hot and arid (HA) climates such as Libya. Laboratory experiments were conducted on two different asphalt mixes, one using MMD, and the second using modified Marshall mix design (3M) method.

All specimens had the same mixtures of aggregate gradation incorporated with two asphalt grading namely Asphalt cement binder (B60-70) and Performance grade asphalt binder (PG70-10) and two different compaction methods.

This modification is based on the incorporation of two factors, the new asphalt binders (performance grade) and the Superpave gyratory compactor (SGC) into the traditional MMD method. Thus, the results of this test will give a more accurate representation of the absolute value of the tension-compression complex modulus test $|E^*|$ that defines the elastic properties of a linear viscoelastic material subjected to a sinusoidal loading. In addition, 2-complex

modulus (E*) and phase angles ($\emptyset_E$) in the test have been measured at temperatures of -25, -10, -5, 10, 25, 35, and 54ºC as well as frequencies of 25, 10, 5, 1, 0.5 and 0.1 Hz. The value of the dynamic modulus reflects the stiffness of the mixture and its resistance to deformation at a designated frequency and temperature.

The results show an improvement of the $|E^*|$ in the modified 3M mix over the traditional MMD mix. The 3M method using asphalt binder PG 70-10 and gyratory compactor (SGC) as in Superpave Mix Design (SMD) method, improves the $|E^*|$ of the asphalt mixture in HA climate. As well, intrinsic characteristics related to binder properties, aggregate gradation, and compaction method in HA climate have the most significant effect on the predicted $|E^*|$.

Keywords: complex modulus, frequencies, temperatures, Hot and arid climate, phase angles, Asphalt mixture.

7.2 INTRODUCTION

Insertion of the properties of the asphalt mixture into a new design procedure being developed is a big task. The linear viscoelastic (LVE) behaviour is commonly characterized using cyclic tension–compression complex modulus tests (Perraton et al., 2016). The complex modulus (E*) is defined as the ratio between the axial stress and the axial strain and it is calculated at each frequency and temperature where E* is the norm of the complex modulus and $\emptyset_E$ is the phase angle (Nguyen, Di Benedetto, & Sauzéat, 2015).

In fact, for most of the bituminous materials, the time temperature superposition principle (TTSP) is verified in the linear and nonlinear domains (Nguyen et al. 2012). Therefore, it is possible to generate master curves at one reference temperature (T_0) by shifting experimental data on the frequency axis. The variation of the shift factors with temperature can be described with the Williams Landel Ferry (WLF) as in equation (7.1) (Gudmarsson et al. 2015).

$$log\ a_T \frac{-C_1(T-T_0)}{C_2\ (T-T_0)} \qquad (7.1)$$

where

C_1 and C_2 are the two constants of the WLF, and T_0 is the reference temperature.

Due to the HA climate, pavements are subjected to severe conditions such as rain, cold, dry winds, and severe changes in temperature from 0 ºC to over 54 ºC which lead to complicated behavior of the asphalt pavement (Hall et al., 2011). Hot-mix asphalt (HMA) is a viscoelastic material: at high temperatures it behaves as a viscos (μ) material and as a elastic at low temperatures, which is characterized by a certain level of rigidity of an elastic solid body (Zhao et al., 2012; Yusupov et al., 2019).

On the other hand, it flows and dissipates energy by frictional loss as a viscous fluid (Pellinen and Witczak 2002; Yi et al. 2014). As with any viscoelastic material, the hot mix asphalt response to stress depends on both temperature and loading time (Bazzaz et al. 2018). At high temperatures or with slow moving loads, the hot mix asphalt may exhibit a purely viscous flow (Bagampadde, Kaddu, and Kiggundu 2013).

Pavement temperatures and materials are perhaps the most important elements for an asphalt mixture design and influence almost all the important properties of HMA mixtures. Therefore, the following research will adopt a new asphalt binder, PG, which should be appropriate to the climatic conditions and new compaction method (SGC) to improve the complex modulus of the asphalt mixture based on MMD method in HA climate.

7.3 OBJECTIVES

Tension-Compression complex modulus tests of asphalt mixture is largely dependent on the aggregate gradation, air voids, asphalt binder properties, and test conditions. The objectives of this paper are as follows:

- First, the purpose of this test is to improve the dynamic modulus of the asphalt mixture based on MMD method in HA climate.

- Second, to demonstrate the difference in Tension-Compression complex modulus test results between two asphalt mixes that were tested at the same frequency and temperature.

- Third, to show the influence of various variables on the tension-compression test, rheology, and complex modulus of two different asphalt mixtures under the HA climate.

Finally, it concludes by presenting the relation between asphalt binder, traffic load, and temperature on the test results.

7.4 Background

The AASHTO 2002 design guide aims to introduce more rigorous measures of performance into hot mix asphalt mixtures and pavement design procedures. NCHRP project I -37A is producing the new 2002 design guide for New & Rehabilitated Pavements. In 1999, the NCHRP panel for Project 1-37A selected complex modulus (CM) for this purpose. The selection was based on a paper authored by Witczak (1999) which compared CM to an Indirect Diametral Test (MR) and both test procedures have been in use by the research community for years (Nasr and Pakshir 2019; Singh, Zaman, and Commuri 2011).

Overall, the most current methods of asphalt mix design almost entirely rely on the volumetric composition of asphalt mixtures. The Materials Testing System (MTS) machine has developed test method LC 26-700 for determining the complex modulus of asphalt mixtures (Dehdezi et al., 2011). A repeatability study was also conducted to describe the quality of the test and the influence of air voids change on the complex modulus of asphalt mixes. There are various tests to characterize bituminous mixtures. These tests can be divided into two main categories: homogeneous and heterogeneous tests (Castillo, Gamez, & Al-Qadi, 2019). In this study, the complex modulus is observed in homogenous tension-compression tests. The AASHTO provisional test standard TP62-03 is performed at temperatures of -10, 4.4, 21.1, 37.8 and 54 ºC and frequencies of 25, 10, 5, 1, 0.5 and 0.1 Hz are specified for loading the sample at each temperature.

The recommended protocol is a stress-controlled version of the complex modulus test in which the sinusoidal (haversine) cyclic load applied to the specimen is adjusted so that the specimen is subjected to axial strains. The strain level range should be within 50-150 micro strain. Experience with the |E*| test procedure and the hot asphalt mixes being tested is required in order to select the proper stress level that complies with the sample strain limitation. According to the current test protocol, the stress level should be selected from a certain range set for each test temperature (Loulizi et al. 2006).

7.5 Laboratory Experiments

In this study, the complex modulus of two asphalt mixtures is observed in homogenous tension compression tests. In fact, the complex modulus is measured at different frequencies and temperatures. This test is usually performed at control strain of 50×10^{-6}m/m, based on experience and to make sure that it is well below the limit of 50×10^{-4}m/m to avoid fatigue cracking (Ameri, Yeganeh, and Valipor 2019).

7.5.1 Methodology

In this work, Figure 7.1 illustrates flow chart of the laboratory experiments as follow:

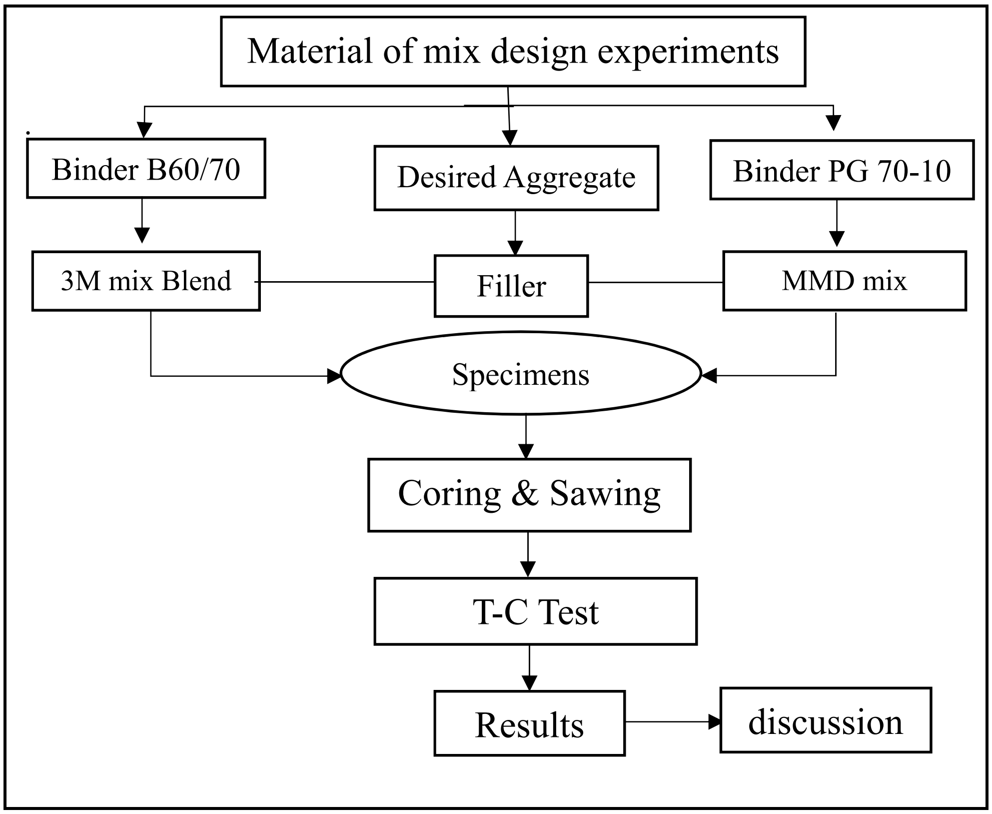

Figure 7.1 laboratory experiments

7.5.2 Materials for Laboratory Experiments

7.5.2.1 Coarse and Fine Aggregates

The gradation limits for this study were prepared as specified by LC 26 – 44, Quebec Specification. Indeed, the combined aggregates have been shipped from Libyan quarries. Figure 7.2 shows the mixes combined of coarse and fine aggregates. A smooth curve has shown an appropriate gradation of the different sizes of aggregate.

Figure 7.2 Different sizes of aggregates

7.5.2.2 Asphalt Cement

Table 1 and Figure 7.3 show the characteristics of both asphalt binder B60/70 and performance grade PG70-10 that are used in this research. The features of the asphalt cement rely highly on its temperature. At high temperatures, the binder behaves as a viscous material (plastic) at a load that exceeds its viscosity at a certain temperature (N. Tetteh, 2018).

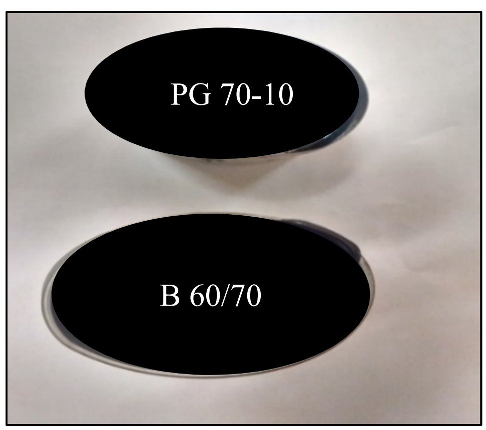

Figure 7.3 Two types of asphalt binders (PG 70-10 & B 60/70)

This behaviour in HA climates can be a contributing element to insufficient performance of the asphalt concrete pavement (ACP). The PG characteristics are supposed to be based on an expected 1-day minimum and 7-day maximum pavement temperature; loading time regarding traffic loads are specified in the PG binder specifications to ensure the proper selection for the asphalt mix design (K. El Atrash & G. J. Assaf, 2018).

Table 7.1 Data Sheet Properties of bitumen grades

Binder Properties	PG 70-10	B 60/70	Standard Specification
Specific Gravity @ 25 ˚C	1.029	1.01/1.05	ASTM D70, T228
Penetration @ 25 °C.	-	60/70	ASTM D 4402, T316
Softening Point °C.	-	49/56	ASTM D36-06
Dynamic Shear. 70°C. G*/sinδ. kPa	1.14	-	ASTM D7175-15, T315
Ductility @ 25 °C.	-	100 min	ASTM D113
Flash point °C	230 min	250 min	ASTM D92. T48
Mass Loss %	1.00 max	0.2 max	ASTM D113-99, T51-09
Creep Stiffness. 0°C. S. MPa	300 max	-	ASTM D6648-01, T313
Drop in penetration after heating PCT	-	20 max	ASTM D6/D5 9.3
Solubility in Trichlorethylene	99 min	99.5 max	ASTM D2042-15, T44

7.5.2.3 Mineral Filler

Figure 7.4 shows a picture of the filler material, the material used in this research as a filler was a limestone dust that is available and cheap. However, the amount of the filler material in the bitumen mixture should be in the range of 0.6 to 1.2 by weight and this material must be dry, free of the contaminated materials, and capable of passing through a 75 μm sieve (A. M. Mohammed & A. T. Fadhil, 2018).

Figure 7.4 Limestone dust (Filler Material)

7.5.3 Sample Preparation

The AASHTO TP 62-07 and ASTM D 3497-79 (2003) test methods call for the use of a shear gyratory compactor (SGC) for preparing the specimens used to determine the dynamic modulus of asphalt mixes Tension-Compression Test (F. Gong, Y. Liu, X. Zhou, & Z. You, 2018). Two cylindrical specimens, 75-mm by 150-mm, were prepared and compacted in the laboratory using Marshall hammer and SGC. They were then cored to a 75-mm diameter and saw cut to a final height of 150 mm.

The air voids were measured on the finished test specimens. Adjustments were made to the number of gyrations during compaction to achieve about 4.0, 4.5 and 5.0% air voids for mixes with 3M method and 4.0, 4.1 and 5.0% air voids for mixes with MMD. This sample preparation procedure was done to make four samples for the two mixes. Table 7.2 and Table 7.3. show the parameters obtained in these experiments

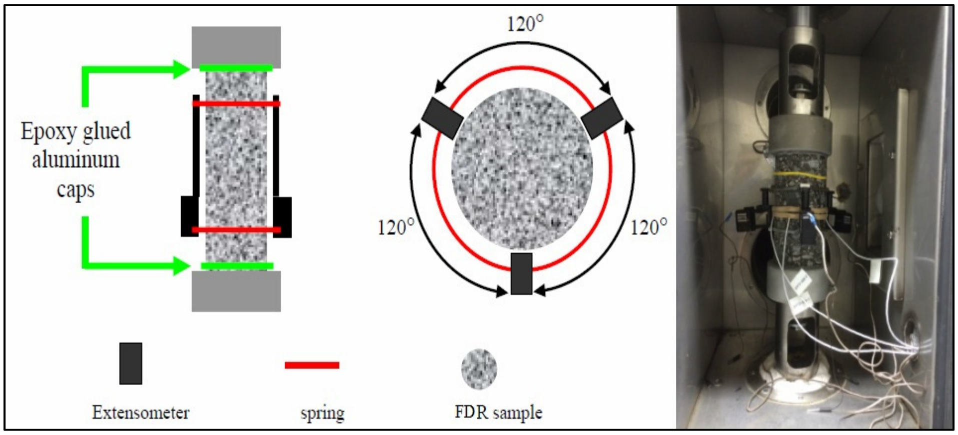

Figure 7.5 Complex Modulus Test setup and MTS Machine
Taken from Gandi, A., Carter, A., & Singh, D (2017)

7.5.4 Tension-compression test

This homogeneous test can be carried out in stress or strain-controlled conditions (Corradini, et al., 2017). Fig. 7.5 shows the uniaxial tension-compression complex modulus test setup. It was developed in the Département de Génie Civil et Bâtiment (DGCB) of the École Nationale des Travaux Publics de l'État (ENTPE) (H. Baaj, 2002). The data at any temperatures should be shifted according to log time until the curves merge into smooth curve. The master curve allows you to compare asphalt mixes that have been tested at different frequencies and temperatures (Sanditov, & Razumovskaya, 2018).

Figure 7.6 T- C complex
modulus test setup.

7.6 Results and Discussion

In this experiment, a Tensile-compression (T-C) test was performed on a cylindrical specimen. The results obtained from this test reflect the behavior of these materials under different frequencies and temperatures. Comprehensive testing of the complex modulus was performed on two samples for each mixture 3M and MMD mix. The calculation of air voids (Va) in specimens is shown in Table 7.2. These data show the changes in magnitude (or amplitude) and phase of a sine wave.

This study was conducted with 8 different test temperatures to produce a master curve. Fig. 7.7 and Fig. 7.8 present respectively the isothermal curves of the norm of complex modulus based on the frequency and the temperature for both mixes. It can be observed that the norm of complex modulus increases when the frequency increases and decreases when the temperature increases in both mixes. As well, the viscoelastic linearity limit varies with equivalent temperature-frequency.

Many studies confirmed that Time Temperature Superposition Principle (TTSP) can be applied with good approximation to bituminous materials, in the small strain domain (strain amplitudes lower than 100 μm/m). However, the results show that the behavior of 3M mix is more reliable than MMD mix under these conditions. The results of E* are shown in Table 7.3, the range of the measured complex modulus of 3M mix is between 765 MPa and 43,654 MPa and the phase angle ranged from 0.73 to 36.14 degrees, which is near to elastic.

In the same way, the complex modulus measured between 922 MPa and 38709 MPa, and the phase angle from 0.87 to 99.99 degrees for MMD mix, which exceed the range of phase angle between 0 and 90. The master curves of the norm complex modulus and shift factors obtained during the master curve construction related to frequency and phase angle of both mixes are presented in Fig. 7.9 and Fig 7.10, while Fig. 7.11, and Fig. 7.12 show the master curve related to frequency and complex modulus. The complex modulus test results for both mixes MMD using S-B 60/70 and 3M using S-PG 70-10 are presented in Table 7.3.

The values of the coefficients, C_1 and C_2, are given in Table 7.4, corresponding to each mix. The main curves obtained in this study of the complex modulus to various mixes were examined at a reference temperature (T_0) set at 15 ° C. The curves of the complex modulus on the Cole-Cole plane are presented in Fig. 7.13, and Fig. 7.14.

These figures show an example of a Cole-Cole plane. The storage modulus (E_1) is plotted on the real axis (X-axis), and the loss modulus (E_2) is plotted on an imaginary axis (Y-axis). The unit curve obtained in the Cole-Cole plane shows the effect of the principle of time-temperature superposition (TTSP) in the Linear Viscoelastic (LVE) region. Fig. 7.15, and Fig. 7.16 show the black curves.

This approach allows us to evaluate the quality of test data at medium and low temperatures. Clarification in black space (|E*| versus ϕ) allows us to better compare the experimental values and the values obtained from the model for low modulus values; some scattered results can be observed, which means that the black curve is not unique.

7.7 Summary and Conclusion

In conclusion, the conventional asphalt mixes with MMD and asphalt binder B 60/70 which were used in this study did not perform well the Cole-Cole plane and Black space diagram and thus yielded inadequate results. On the other hand, the mixes that were designed with 3M method using the asphalt-binder PG 70-10 manifested proper performance as expected.

However, it was found that the tension-compression property of asphalt mixture is improved in 3M over the traditional Marshall mix design MMD method using impact compaction and B60/70; this improvement will enable the low-cost preparation of hot mix asphalt in hot and arid weather such as that found in most of the developing countries. The results show the difference in T-C, phi, and CM of two different asphalt mixes, 3M and MMD, which were tested at the same frequency and temperature. The proper selection of the asphalt binder, aggregate gradation, and compaction method can improve the pavement tension-compression properties of the asphalt mixture in HA climate.

TABLES:

Table 7.2 Calculation of air voids (Va) in complex modulus specimens

Compaction method	Calculation of air voids (Va) in complex modulus specimens						
	Sample No	wt of dry samples (g)	wt of samples in water (g)	wt of SSD. (g)	G_{sb}	G_{mm}	% Va
Marshall hammer	S1-B 60/70	1662.800	1015.200	1663.700	2.564	2.513	4.1
	S2-B 60/70	1662.600	988.000	1663.100	2.463		4.1
SGC	S1-PG70-10	1684.100	1001.450	1684.600	2.465	2.515	4.0
	S2-PG70-10	1667.800	1018.250	1668.300	2.566		4.0

Table 7.3 Dynamic modulus fitted values at T ºC

Temperature (°C)		Frequency (f_r(Hz))	3M-PG 70-10		MMD-B 60/70	
			|E*| (MPa)	$\emptyset_E C^{\circ}$	|E*| (MPa)	$\emptyset_E{}^{(\circ)}$
Temp 1	-34.68	0.01	41308	2.49	34916	4.13
	-34.67	0.03	41070	181.36	35001	2.47
	-34.93	0.10	43114	91.95	36024	2.59
	-35.20	0.30	43654	1.38	36812	1.53
	-34.91	1.00	44103	1.16	37456	1.25
	-35.07	3.01	44437	0.98	38115	1.14
	-35.07	10.13	45316	0.73	38709	0.87
Temp 2	-25.29	0.01	33034	2.12	28213	5.23
	-25.35	0.03	35768	3.83	29083	5.05
	-24.63	0.10	37111	3.14	31686	3.85
	-24.80	0.30	38825	2.93	32895	2.60
	-24.86	1.00	40110	2.20	33944	2.57
	-25.11	3.00	41086	2.03	34877	2.10
	-25.28	10.06	42450	1.52	36226	1.53
Temp 3	-14.89	0.01	25231	7.18	20742	7.47
	-14.36	0.03	27405	9.38	22881	6.18
	-15.35	0.10	30182	5.69	24585	5.73
	-15.12	0.30	31655	4.73	26419	5.22
	-15.28	1.01	33853	4.49	28404	4.51
	-15.27	3.02	35604	3.89	29906	4.04
	-15.14	10.04	37477	3.16	31874	3.09
Temp 4	-5.07	0.01	15606	14.22	12873	11.42
	-4.89	0.03	17394	11.22	14809	10.96
	-4.03	0.10	19544	10.31	17061	9.49
	-4.10	0.30	22476	8.60	19066	8.07
	-4.09	1.00	25108	8.17	21070	7.43
	-4.15	3.01	27563	6.86	22939	6.99
	-4.64	10.17	30237	5.96	24996	6.00

Table 7.3 (Continued)

Temp 5	5.10	0.01	6791	22.64	6743	18.28
	5.12	0.03	8885	19.88	8334	15.44
	5.01	0.10	11227	17.08	10199	14.63
	5.07	0.30	13600	14.66	12064	12.67
	5.02	1.01	16229	13.16	14017	11.11
	5.01	3.01	18805	11.48	15953	10.56
	5.04	10.03	21657	9.83	18254	9.23
Temp 6	15.24	0.01	2204	31.43	2905	25.56
	15.24	0.03	3149	30.05	3932	23.48
	15.23	0.10	4531	27.25	5167	21.09
	15.22	0.30	6147	25.36	6583	19.09
	15.27	1.01	8297	22.42	8304	17.09
	15.30	3.02	10562	19.24	10098	15.47
	15.19	10.05	13375	16.33	12242	13.51
Temp 7	25.26	0.01	765	31.88	1129	28.60
	25.24	0.03	1032	34.06	1545	28.43
	25.21	0.10	1552	34.70	2175	27.25
	25.27	0.30	2305	33.59	2966	25.57
	25.22	1.01	3471	31.44	4092	24.12
	25.19	3.01	4905	28.96	5391	22.29
	25.21	10.07	6999	25.58	7134	19.93
Temp 8	35.00	1.01	1359	36.14	922	29.99
	34.98	3.01	2026	35.74	1297	29.92
	34.98	10.05	3164	34.26	1865	29.43

Table 7.4 William, Landel & Ferry (WLF) τ's quadratic fitted values

Temp. (°C)	3M-PG 70-10		MMD-B60/70	
	aT (WLF)		aT (WLF)	
-34.93	790751.3798		34052011.47	
-25.05	17167.86149		289528.6379	
-15.06	769.5616324		2716.423572	
-4.42	41.25788985		44.00281822	
5.05	3.255295136		1	
15.24	0.324691906		0.032696996	
25.23	0.040702925		0.001507265	
34.99	0.006587013		0.000102941	
Parameters C_1 & C_2	C_1= 19.49	C_2 =197.80	C1= 29.57	C2 =192.73
$T_0 C^{\circ}$	4.40		5.05	

Figures

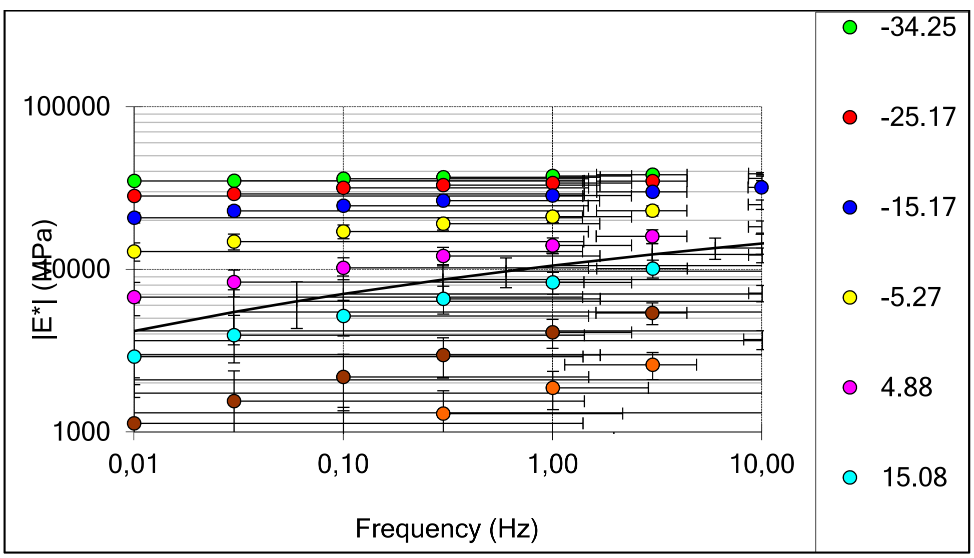

Figure 7.7 3M Graphic of isotherm curves of the norm for complex modulus

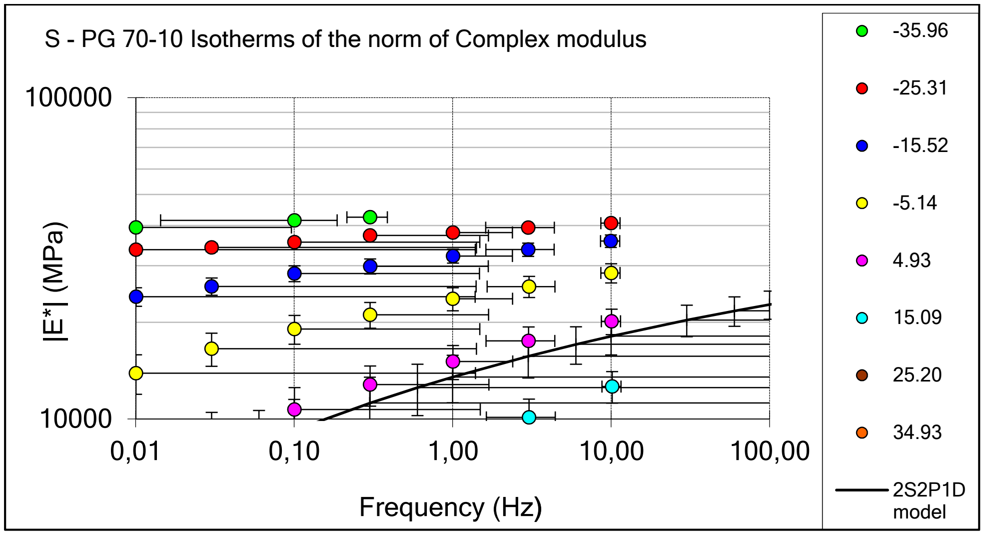

Figure 7.8 3M Graphic of isotherm curves of the norm for complex modulus

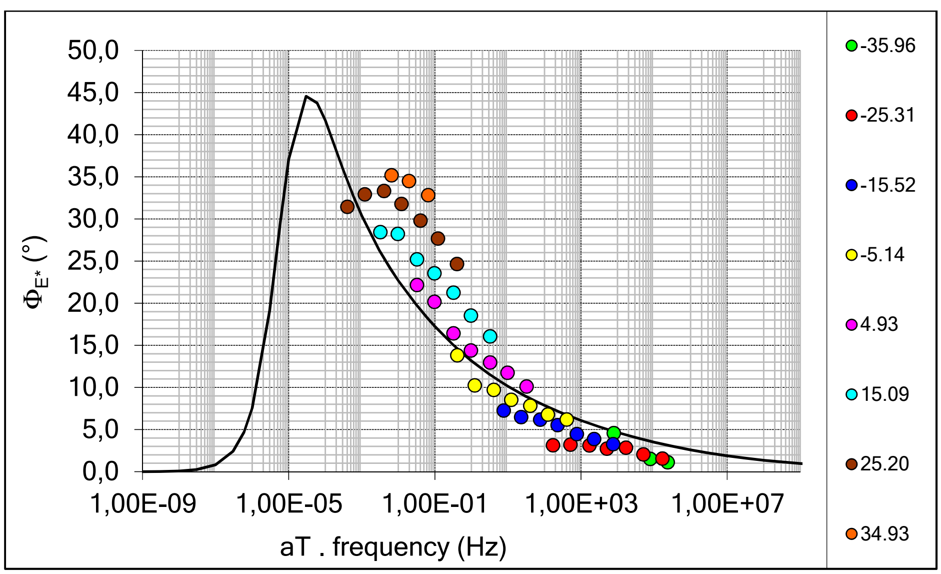

Figure 7.9 Master curve of the phase angle for MMD asphalt mixture

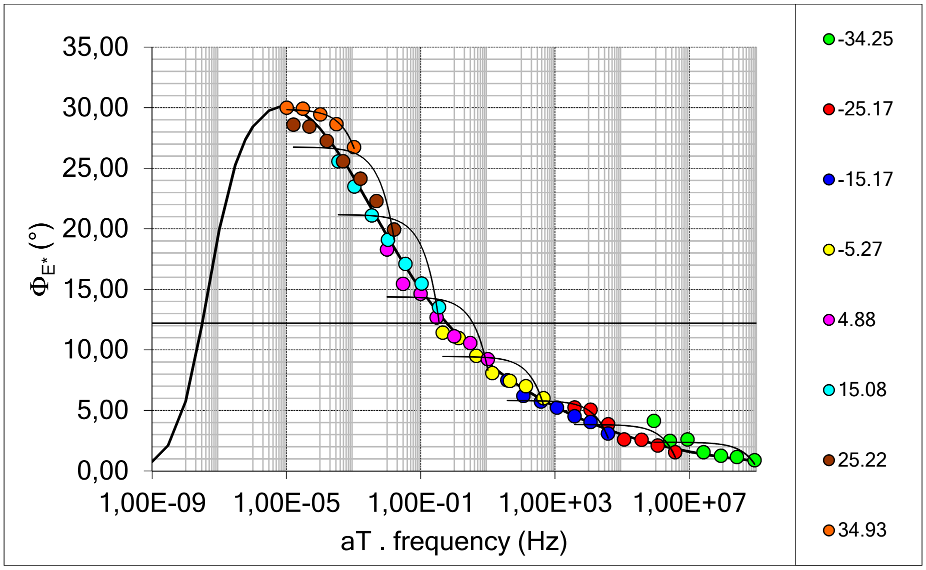

Figure 7.10 Master curve of the phase angle for 3M asphalt mixture

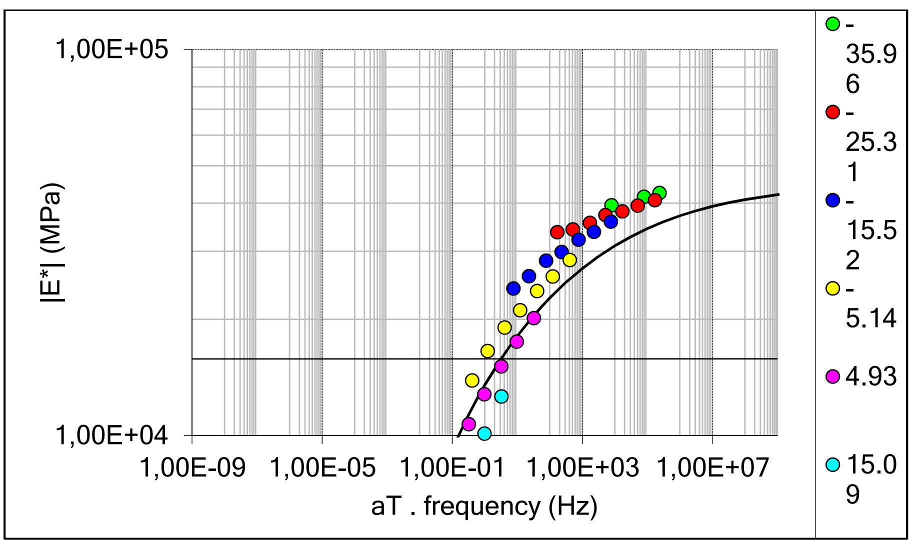

Figure 7.11 MMD Master curve of the norm for asphalt mixture

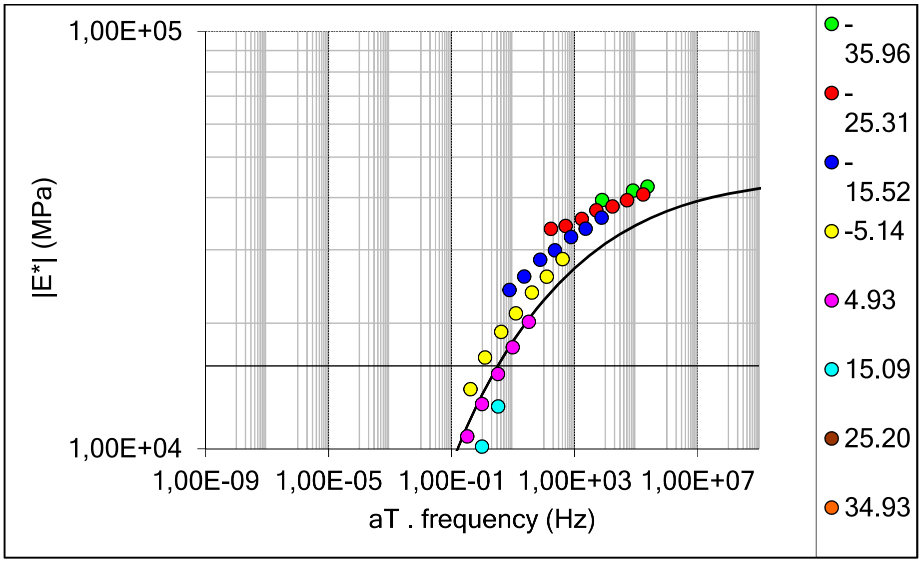

Figure 7.12 3M Master curve of the norm for asphalt mixture

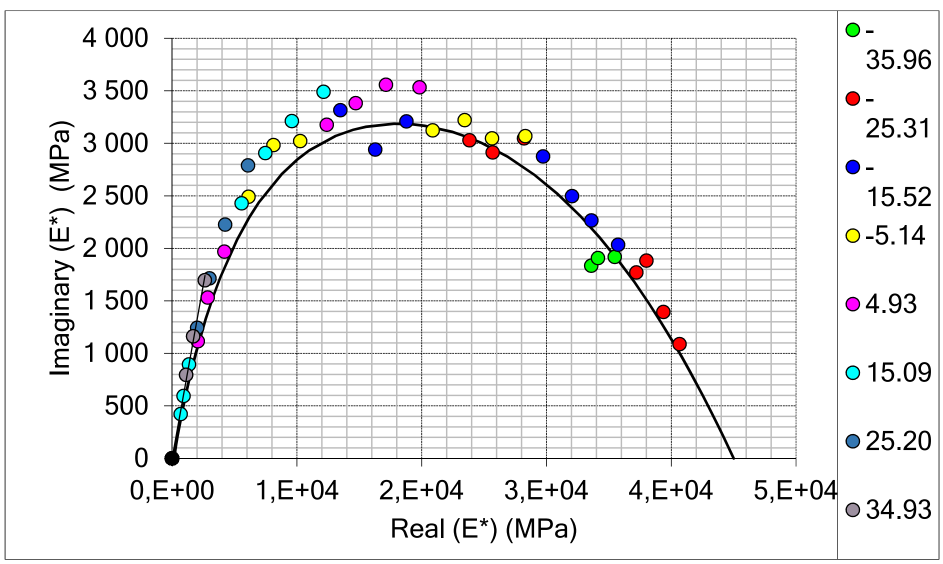

Figure 7.13 Graphic of Complex Modulus in Cole-Cole axes for MMD mixture

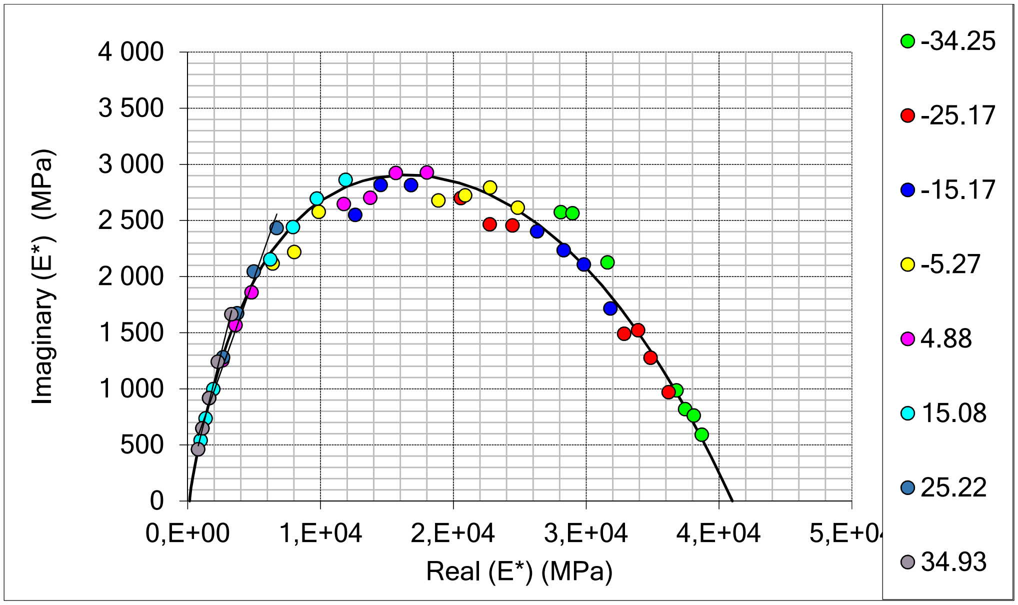

Figure 7.14 Graphic of Complex Modulus in Cole-Cole axes for 3M mixture

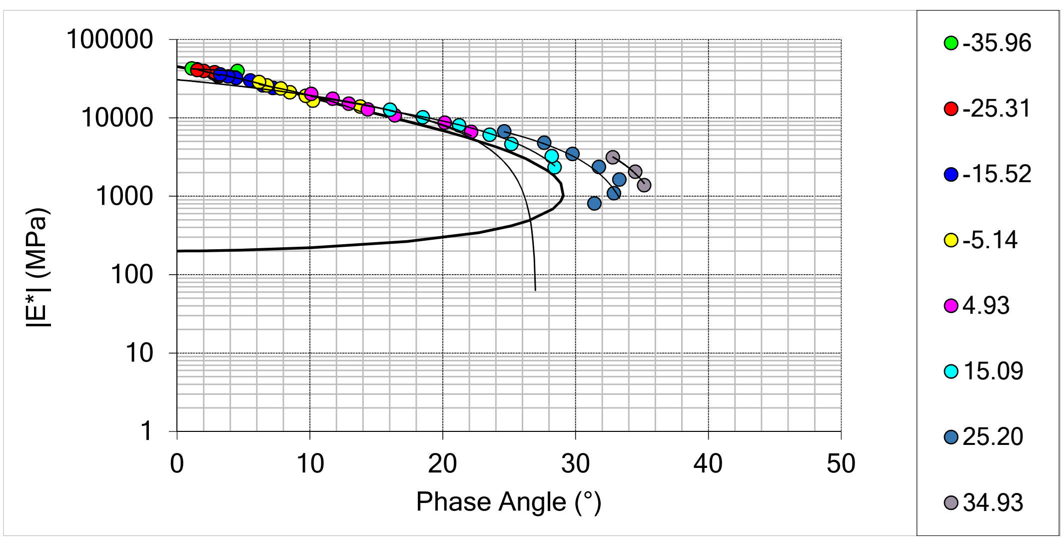

Figure 7.15 Graphic of Complex Modulus in Black space for MMD mixture

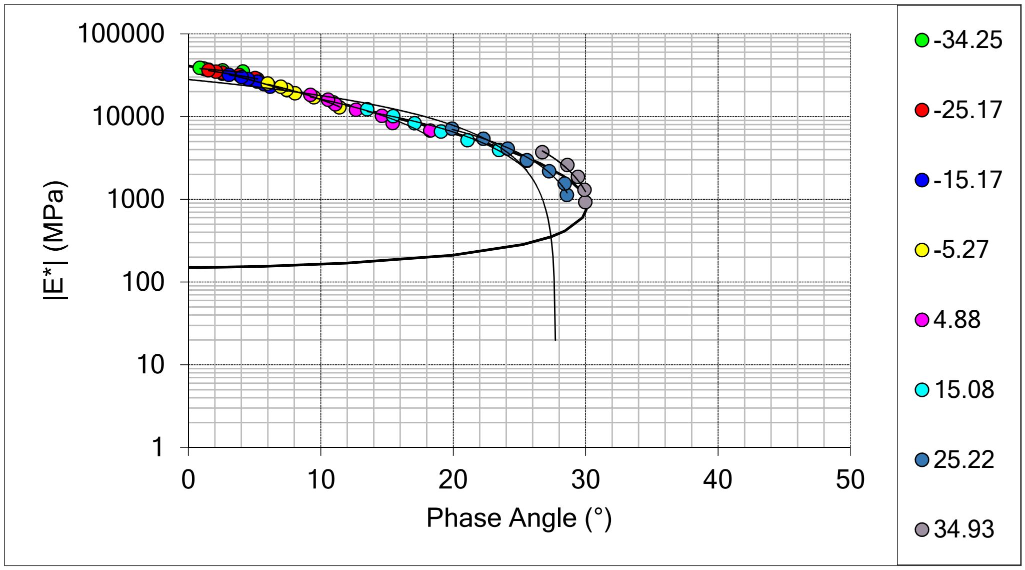

Figure 7.16 Graphic of Complex Modulus in Black space for 3M mixture

CHAPTER 8

AN ASSESSMENT OF THE SUITABILITY OF MARSHALL AND SUPERPAVE ASPHALT MIX DESIGNS IN RELATION TO THE WEATHER CONDITION IN LIBYA

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8.1 Abstract:

Asphalt mixtures for asphalt concrete (AC) pavement are prepared from aggregates, sand, filler, and bitumen; the proportioning all its components is particularly important to obtain best performance. The concept of asphalt mix design is to obtain suitable air voids in the asphalt mixture after compaction. The asphalt mix design should be an advanced method involving several factors that have an effect on the performance of the AC pavement. Many of hot weather regions are using the Marshall mix design method to obtain appropriate mixtures for their asphalt roads. This is an empirical design method that does not replicate the compaction, selection of asphalt binder and climate prevailing in the region.

In this paper, the suggested solution is to improve the traditional Marshall mix design (MMD) method based on the Superpave mix design (SMD) method to consider various factors such as the asphalt binder and the environmental conditions on the performance of the asphalt pavement in hot and arid (HA) climate. This is based on several of Laboratory mix design trials of asphalt-aggregate blends. Through the analysis and discussion of the obtained results, an improvement of the traditional Marshall mix design method was achieved. This is based on

incorporation of new asphalt binder (*performance grade*), and new compaction method using gyratory compactor (SGC) as in SMD. It was found that the improvement of the traditional Marshall mix design is applicable. The incorporation of critical factors of the new asphalt binder performance grade (PG), and compaction method was very effective and led to significant improvements in terms of cost saving and pavement performance.

Keywords: - laboratory, hot climats, asphalte Pavement, Local mix design, modification.

8.2 BACKGROUND

The first formal design method for asphalt mixtures was originally developed to design sand-asphalt mixtures and later update to asphalt-aggregates [1]. The Superpave mix design method, for Superior Performing Asphalt Pavement System, was developed in the 1980s as part of the American Strategic Highway Research Program (SHRP) [2]. Superpave incorporates a new asphalt binder and compaction method considering future traffic and climatic patterns [3]. A new asphalt binder selection criterion known as the Performance Grading system (PG).

The PG concept is based on the rheological behaviour that an asphalt-binder's property should be related to the climatic conditions. Engineering properties believed to be related to the expected performance (maximum 7-day pavement temperature, 1-day minimum pavement temperature, loading duration based on truck speed, and traffic volume) are featured in the PG binder specifications to allow for a proper selection of asphalt binder [4].

Also, this research inserted a new compaction method using a Superpave Gyratory Compactor (SGC) in mix design procedure instead of old compaction methods such as Marshall and Hveem, The asphalt mixture properties, such as density and air voids, bitumen content (BC), strongly depend on the degree and the method of compaction [5].

8.3 OBJECTIVES

The main aim of this research is to improve the traditional Marshall mix design method by considering numerous factors such as the asphalt binder type and compaction based on SMD to consider the environmental conditions for the hot and arid weather.

8.4 Methodology

Two asphalt concrete mixtures of the aggregate-asphalt were conducted using the Traditional Marshall and Superpave mix design methods as a reference mixture using asphalt binder B60/70 and PG70-10, respectively. Six other mixes were conducted using Marshall mix design method incorporated with SGC and two different asphalt binder PG 70-10 and B60 /70 containing Crumb Rubber (CR).

These mixtures were evaluated per the Marshall mix design method, Complex modulus test, and Rutting test. These specimens' results were used for a comparison to the obtained results from the reference mixtures under the same of hot and arid weather conditions such as a mid-western of Libya. Figure 8.1 shows an example of laboratory experiments framework.

8.5 Mix Design Experiments

The purpose of this research is to modify the traditional Marshall mix design method using laboratory experiments to obtain an economical mixture of using SGC and two different asphalt binders PG70-10 and modified asphalt binder (B60/70 + CR). Figure 8.2 and Table 8.1 show the mixes combined of coarse and fine aggregates. A smooth curve within the appropriate gradation of the different sizes of aggregate was achieved. Laboratory experiments were conducted on five different asphalt mixtures for road research projects (Libya/Roads) that met the requirements for the characteristics of the pavement in hot and arid weather as those found in the mid-western of Libya. The results obtained are presented in Tables 8.2 To 8.7.

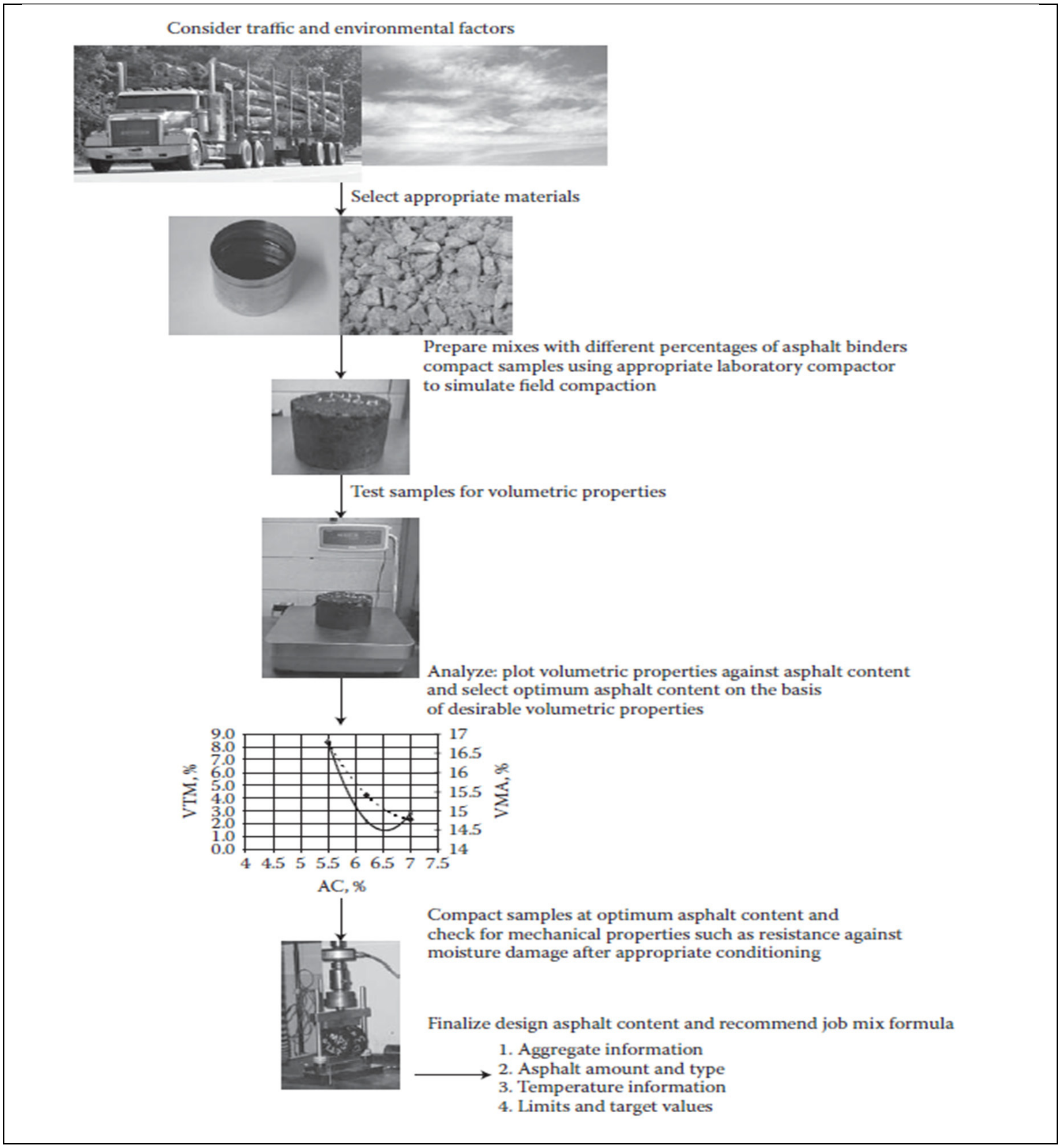


Figure 8.1 Key steps in the mixture design of the asphalt [7]

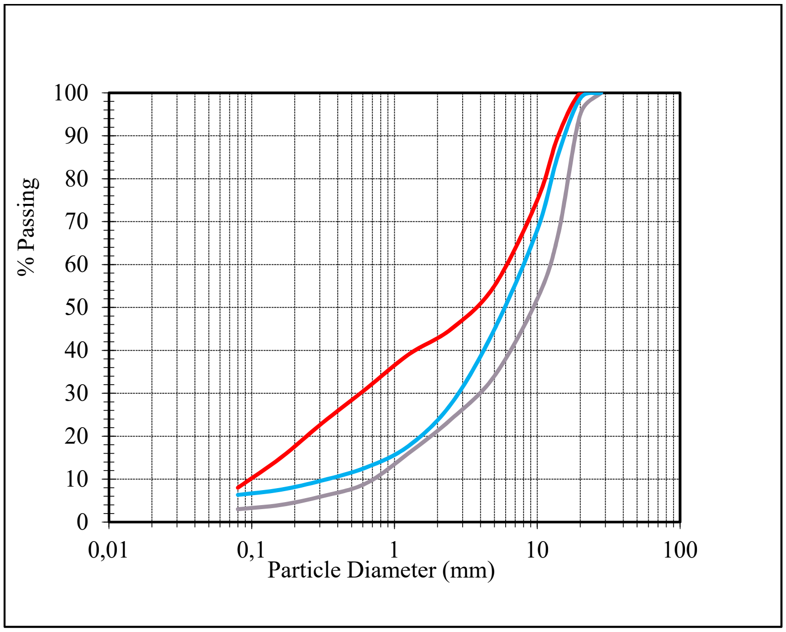


Figure 8.2 Aggregate Gradation

Table 8.1 Sieve analysis Result and aggregate gradation for laboratory mix design

Sieve size mm	% Lower Limit	% Upper Limit	% Passing
28	100	100	100
20	95	100	98
14	67	90	86
10	52	75	68
5	34	55	45
2.5	24	45	28
1.25	16	39	18
0.63	9	31	13
0.31	6	23	10
0.16	4	15	7.5
0.08	3	8	6.3

Table 8.2 Physical properties of the used asphalt cement B 60/70.

Property	Test Result	Criteria
Penetration, 0.1mm	64	60 - 70
Ductility at 25 ˚C, cm	114	100 min.
Softening Point, ˚C	55	48 – 56
Rational Viscosity at 135 ˚C, Pa.s	0.492	3 max.
Rational Viscosity at 165 ˚C, Pa.s	0.120	n/a
Flash Point, ˚C	253	230 min.
Fire Point, ˚C	310	230 min.
Specific Gravity at 25 ˚C	1.025	1.01 – 1.06

Table 8.3 Physical properties of the used asphalt cement PG 70-10

Property	Test Result	Standard Specification
Specific Gravity @ 25 ˚C	1.029	ASTM D70, T228
Penetration @ 25 °C.	-	ASTM D4402, T316
Softening Point °C.	-	ASTM D36-06
Dynamic Shear. 70°C. G*/sinδ. kPa	1.17	`ASTM D7175-15, T315
Ductility @ 25 °C.	-	ASTM D113
Flash point °C	252	ASTM D92. T48
Mass Loss %	0.90	ASTM D113-99, T51-09
Creep Stiffness. 0°C. S. MPa	250	ASTM D6648-01, T313
Drop in penetration after heating PCT	-	ASTM D6/D5 9.3
Solubility in Trichlorethylene	170	ASTM D2042-15, T44

8.6 Laboratory Experiments Results

8.6.1 Marshall Mix Design Result

In this research, different technologies and new materials have been used to improve the Marshall mix design method based on the Superpave mix design method. SHRP has shown that the compaction by the impact in the Marshall method is unrealistic compared to the compaction with the Superpave mix design method by SGC, which simulates the field density [6]. The properties of the mixture, such as density and air voids, strongly depend on the level and the method of compaction [8]. Currently, in MMD method, the asphalt binder that is used in the preparation of asphalt mixture is selected based on a penetration system which has several limitations [9]. Furthermore, the PG properties should be related to the climatic conditions [10]. In this experiment, specimens were conducted by using different binders and different method of compaction. The specimens were tested, and the results presented in Table 8.4 and illustrated in Figures 8.3 to 8.9.

Table 8.4 Laboratory Result of Marshall Mix Using B60/70

Marshall Mix Design Result Using B60/70							
OBC %	VMA %	VFA%	Va%	Flow (mm)	Stability (KN)	Complex Modulus (MPa)	Rutting 30000 cycles (mm)
4.0%	12.58	68.95	4.75	2.45	9.64	27654	7.1
4.5%	13.66	70.24	4.40	2.94	10.65	25385	7.2
5.0%	13.52	72.95	3.35	3.90	12.20	24650	7.4
5.5%	13.7	74.85	2.25	4.60	10.25	24150	7.5
Average	13.36	71.75	3.69	3.47	10.68	25460	7.3
Marshall Criteria	12 min	70 - 80	3 - 5	2 - 4	10 min	(T/C_2)	-

8.6.2 Superpave Mix Design Test Result

In this experiment, specimens were tested using bitumen binder PG70-10 and SGC. The results are shown in Table 8.5 and illustrated in Figures 8.3 To 8.9.

Table 8.5 Laboratory Result of Superpave Mix Using PG70-10

Superpave Mix Result Using PG70-10							
OBC %	VMA %	VFA %	Va %	Filler Prop.	$\%G_{mm}$ $@N_{des}$	Complex Modulus (MPa)	Rutting 30000 cycles (mm)
4.1	13.4	70.1	5.5	1.0	94.4	45316	3.0
4.6	14.2	70.3	4.0	0.9	95.9	44103	3.3
5.1	13.3	79.1	3.0	0.7	96.9	43114	4.1
5.6	13.5	80.4	1.9	0.6	97.8	42682	4.4
Average	14.01	72.47	4.94	5.04	96.3	43803	3.7
Super. Criteria	12min	65-75	4%	0.6-1.2	96.0	(T/C_2)	-

8.6.3 Modified Marshall Mix Design Result

In this experiment, specimens were conducted using modified bitumen binder B60/70 with CR and compacted by SGC. Other specimens were conducted using bitumen binder PG70-10 and compacted by SGC. The specimens were tested, and the results are presented in Table 8.5 and Table 8.6 and illustrated in Figures 8.3 To 8.9.

Table 8.6 Laboratory Result of Marshall Mix Using SGC & PG70-10

Marshall Mix Using SGC & PG70-10							
OBC %	VMA %	VFA %	Va %	Flow (mm)	Stability (KN)	Complex Modulus (Mpa)	Rutting at 30000 cycles (mm)
4.0	13.7	76.10	4.20	3.0	14.65	41308	3.2
4.5	14.1	73.65	3.85	3.3	14.80	39954	3.2
5.0	13.6	76.50	3.45	3.5	18.74	38436	4.4
5.5	13.7	78.65	3.15	3.8	15.90	46182	4.4
Average	13.8	76.22	3.66	3.4	16.00	41470	3.8
Marshall Criteria	12 min	70 - 80	3 - 5	2 - 4	10 min	(T/C_2)	-

Table 8.7 Results of Modified Marshall Mix Using SGC & binder B 60/70 with CR

Modified Marshall Mix design Using SGC & Modified asphalt with CR							
OBC %	VMA %	VFA %	Va %	Flow (mm)	Stability (KN)	Complex Modulus (Mpa)	Rutting at 30000 cycles (mm)
4.0	14.45	72.55	3.80	3.60	14.25	32667	5.1
4.5	14.2	75.10	3.35	3.65	14.50	34451	5.2
5.0	13.85	74.50	2.85	3.85	15.95	35824	5.6
5.5	13.35	77.49	2.20	4.25	13.75	31535	5.9
Average	13.96	74.91	3.05	3.83	14.61	33916	5.4
Marshall Criteria	12 min	70 - 80	3 - 5	2 - 4	10 min	(T/C_2)	-

Figures:

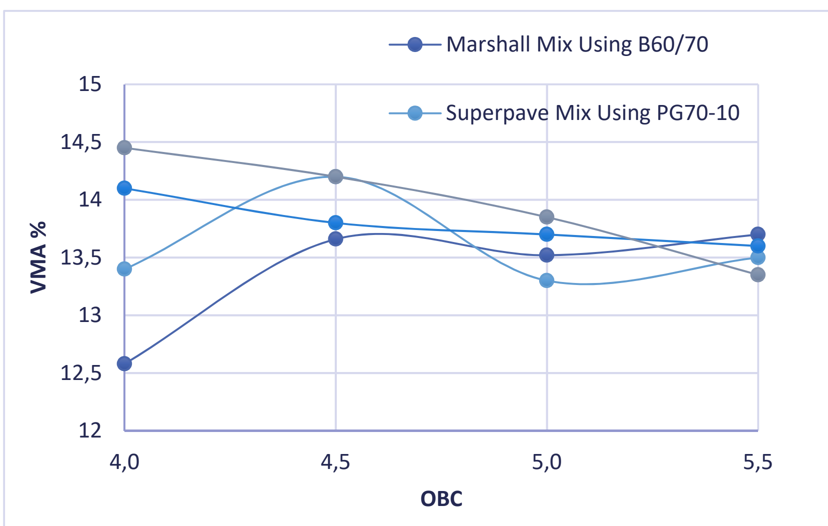


Figure 8.3 OBC % versus VMA % in four different asphalt mixtures

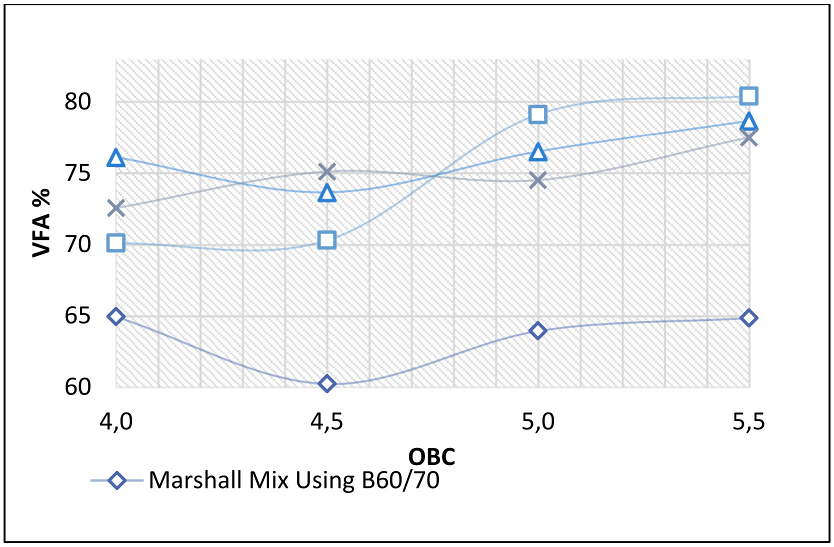


Figure 8.4 OBC % versus FVA % in four different asphalt mixtures

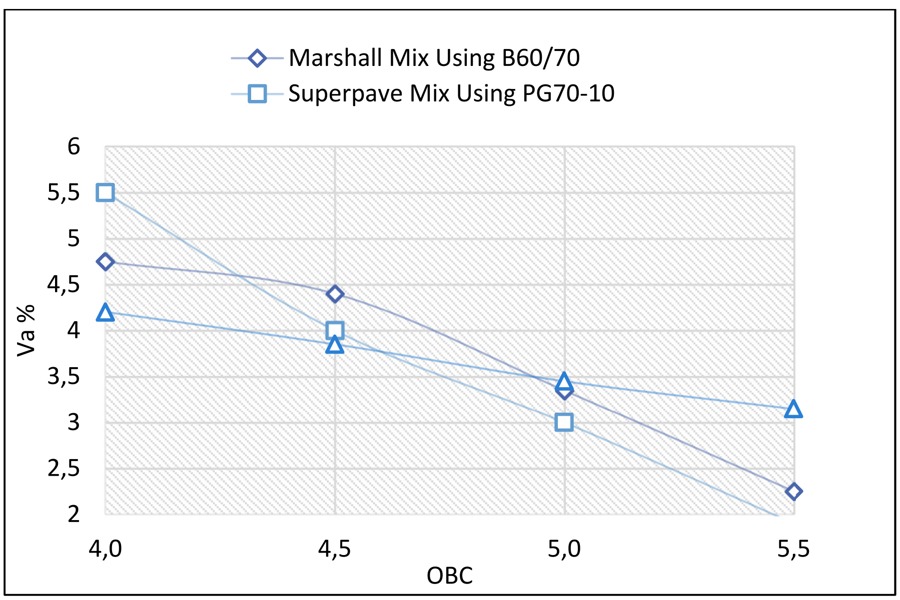


Figure 8.5 OBC % versus Va % in four different asphalt mixtures

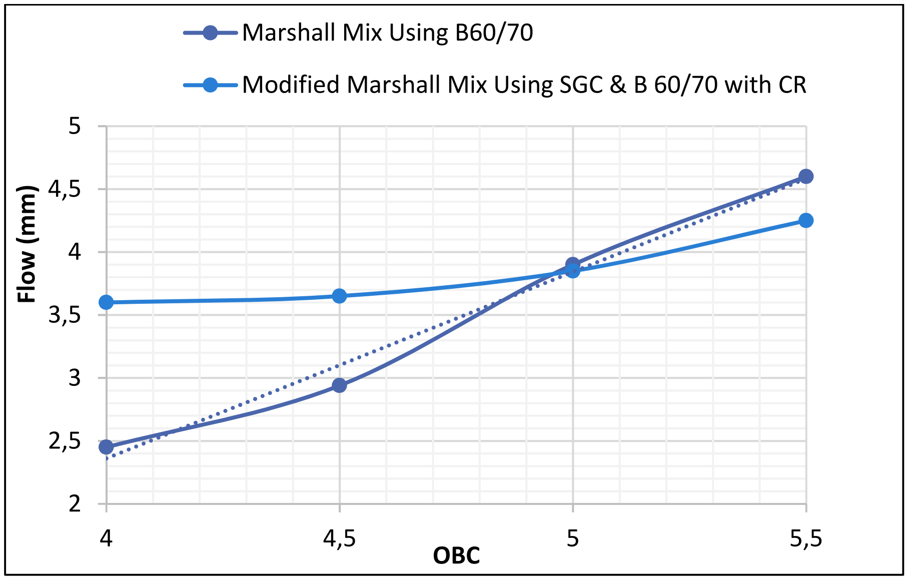


Figure 8.6 OBC % versus Flow (mm) in three different asphalt mixtures

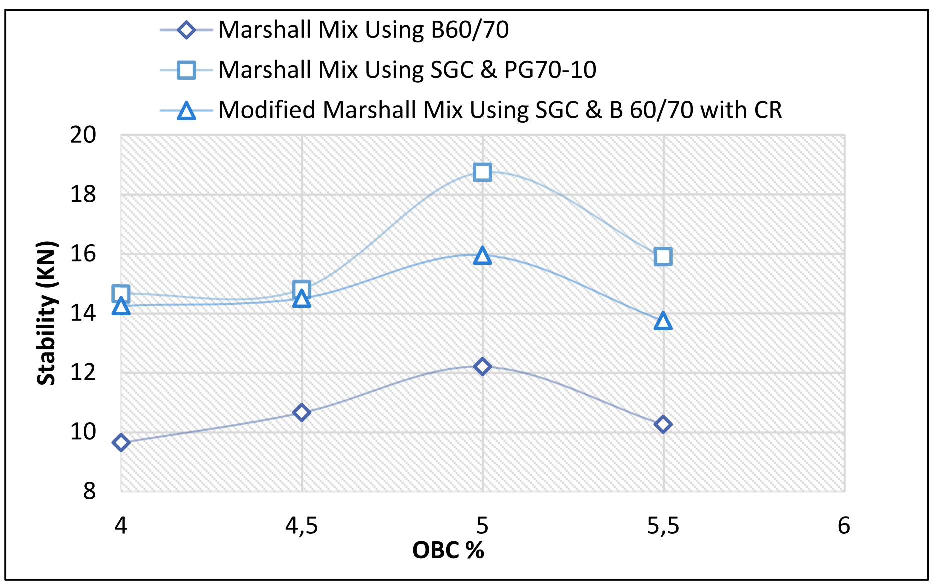


Figure 8.7 BC % versus Stability (KN) in 4 different asphalt mixtures

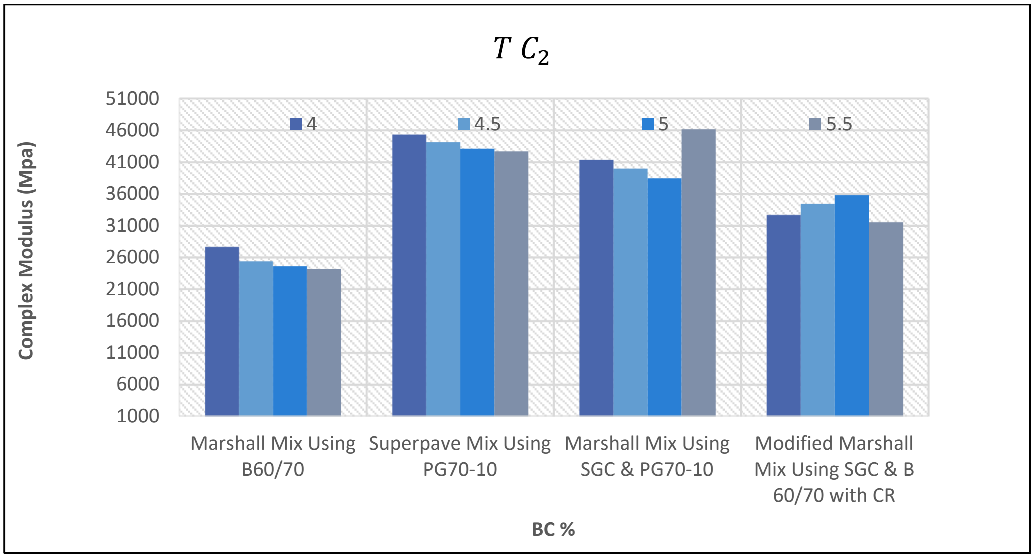


Figure 8.8 OBC % versus complex modulus (MPa) in four different asphalt mixtures

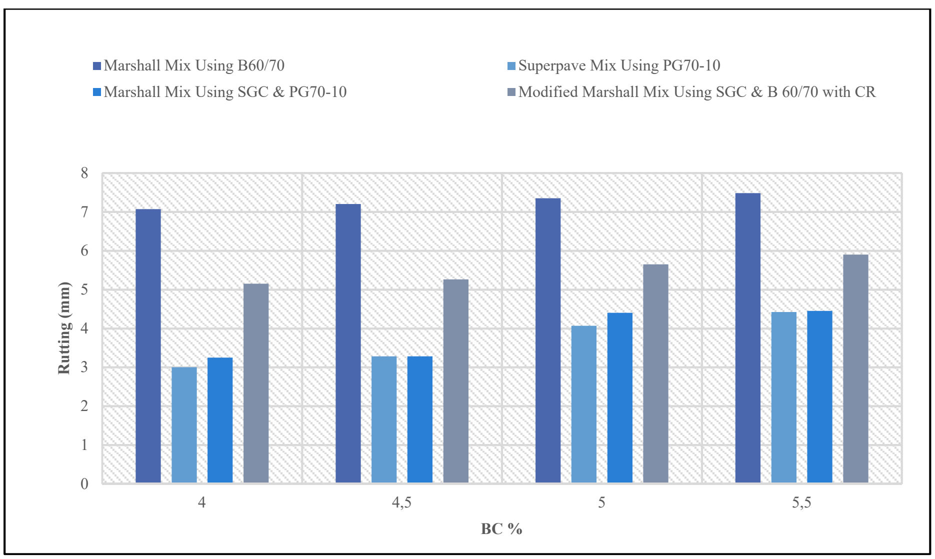


Figure 8.9 OBC % versus Rutting (mm) in four different asphalt mixtures

8.7 Finding of Results and Discussion

The results obtained show that the improvement over the traditional Marshall mix design method was achieved compared to the results achieved with Superpave mix design method. The results show that the modified mix worked much better than the traditional Marshall mix design method. The flow values of Marshall's mixtures with PG70-10 are slightly less than those of Marshall mixes with B60/70. This could be due to the differences in the binder properties, OBC%, or due to the compaction techniques used. The stability values of Marshall's mixtures with PG70-10 are better than that of Marshall mixes with B60/70. This could be due to differences in the properties of the binder and the method of compaction used. SGC rotates at a constant speed during compaction, and this characteristic provides the best orientation of the aggregate particles and aggregate interlock. This process closely simulates the field compaction. Figures 8.3 to Figure 8.9 as well as Table 8.4 to Table 8.7 illustrate the asphalt mixture properties using asphalt binder PG70-10, and SGC. This mixture showed more complex modulus, stability, and rutting resistance than the mixture using asphalt binder B60 / 70 and compacted by Marshall hammer. This experiment showed that the rutting test and volumetric properties, such as VMA%, VFA%, OBC%, and Va%, were improved. Regardless of SGC, which is the type of compaction used in this research, it is important to note that the sample should be compacted to about the same density as in the field, after several years of traffic.

8.8 Conclusions

Marshall mix design method can be also upgraded and developed for hot and arid weather. In this method, it is important to improve the asphalt binder characteristics and the method of compaction to enhance the physical and mechanical properties of the hot mix asphalt (HMA) which replicates field conditions. This modification is based on incorporating the factors of new asphalt binder (performance grade or modified asphalt) and compaction by gyratory compactor as in the Superpave mix design method into the traditional Marshall mix design method. Nevertheless, the use of mixtures having PG with characteristics of performance grade or modified asphalt and compacted by SGC relying on the Marshall mix design method have not been investigated in most of the developing countries. In conclusion, it was found that the modification of the traditional Marshall mix design is applicable and over the next few years, the proliferation of the improvement will bring growth in low-cost in the preparation of hot mix asphalt in hot and arid weather as those found in most of the developing countries. The incorporation of critical factors of the new binder and compaction method was very effective and led to significant improvements in terms of cost saving and pavement life.

CONCLUSIONS AND RECOMMENDATIONS

❖ Conclusions

- ❖ According to the analysis and discussion, all of the obtained results are based on the Superpave mix design method and its limitations.
- ❖ The existing penetration grade asphalt mixes designed for hot and arid climates do not have enough strength to maintain physical equilibrium.
- ❖ It is paramount to improve both the asphalt binder characteristics and the compaction method in the traditional Marshall mix design method to enhance the physical and mechanical properties of the hot mix asphalt. Consequently, it is essential to improve the flexibility of the asphalt mix at the lowest temperatures to prevent shrinkage, cracks, and to increase the solidity of asphalt mixture at high temperatures to prevent rutting and shoving.
- ❖ The higher asphalt-binder content found in the Marshall mix design method leads to premature pavement failure in these HA climates. In this study, the Marshall mix did not perform well for the conventional local procedures of selecting and blending the aggregate and binder.
- ❖ In this study, when the Marshall mixes were designed using the Superpave gyratory compactor, PG asphalt binders, or modified asphalt and proper aggregate graduation (source and consensus requirements), the modified mix performed similarly to the Superpave mix design.
- ❖ The asphalt-binder type, the asphalt-binder content, and the compaction method showed significant effects on the performance of the mixes, as theoretically expected.
- ❖ This could be due to differences in binder properties and between compaction techniques.
- ❖ The PG concept is based on the rheological theory that an asphalt-binder property should be related to the prevailing climatic conditions.
- ❖ The pavement temperature is directly related to major climate factors such as air temperature and solar radiations. The selection of asphalt binder should be based on the

highest and coldest expected temperatures of the pavement; otherwise, problems of premature rutting and other pavement failures would continue by using conventional grade binder B (60/70). All the results presented in the thesis show that the OBC has a direct relationship to the pavement performance; the increase in OBC leads to rutting or bleeding, and the decrease in OBC leads to cracks. The study conducted at Ash Shwarife City in Libya showed that the proper asphalt binder to produce hot asphalt mixture for this area is PG 70–10.

In parallel, the study conducted at Brak City in Libya concluded that the proper asphalt binder to produce hot mix asphalt for this area is PG 70–10. These results confirmed that in these climatic zones, the same asphalt binder is used in hot asphalt mixtures, according to the temperature and solar radiations.

- ❖ From the results obtained for this thesis, we note that there is a direct correlation between the air temperature and the pavement temperature, at the surface of the pavement as well as at different depths of pavement layers. As the air temperature rises, the temperature of the pavement rises as well.
- ❖ The use of modified mixtures or new generation methods for asphalt mix design can have a significant impact on the improvement of asphalt paving properties in HA climate. However, crucial factors which affect the pavement performance are environment, type of asphalt binder, method of compaction, and appropriate method of mix design. In this research, three asphalt concrete mixes were designed using 3M, MMD and Superpave mix design methods.
- ❖ The study has shown that a Marshall using asphalt binder B60/70 containing a percentage of Crumb Rubber (CR), and a proper aggregate gradation, performed better than traditional MMD mixes. On the other hand, the 3M mixes using PG 70-10 and SGC showed a better performance than the MMD mixes using B60/70 with a percentage of CR and compacted by SGC.
- ❖ The 3M mixes with B60/70 containing a percentage of CR and compacted by SGC, and 3M mixtures using PG 70-10 and compacted by SGC may be an appropriate choice for formulating the asphalt mixture under hot weather conditions, such as in Libya. Therefore,

it can be concluded that MMD can perform equally well if the method of compaction and the asphalt-binder selection criteria are upgraded in HA climates, such as Libya.

- ❖ Additionally, road contractors and highway engineers were interviewed for factors that affected the performance of asphalt roads. Factors affecting the quality of the pavement were found and evaluated on a scale, depending on their impacts. Eq. 6.1 shows how to calculate the effects of each of these factors. The results obtained from the questionnaire and laboratory experiments showed that each area has its own characteristics and requirements in the asphalt mix design.
- ❖ The survey results list six factors were listed with their level of influence (owner experience and technical staff; asphalt characteristics; updating and development of asphalt mix design methods; lack of data collection by authorization agencies; construction and compaction process; mentoring and controlling mixing procedure). This study showed that in rutting tests, most of the permanent deformation occurs in the upper four inches of hot mix asphalt.
- ❖ The dynamic modulus of the asphalt mixture decreases with an increase in test temperature. However, traditional MMD, with asphalt binder B 60/70 and compacted by Marshall's hammer, which was used in this study, did not show good results on the Cole-Cole plane and on the black space diagram, and thus gave inadequate results. On the other hand, mixtures developed using asphalt binder PG 70-10 and compacted by SGC demonstrated appropriate performance, as expected, which means that they do not fully comply with the principle of the time and temperature superposition (TTSP).
- ❖ The proper selection of the asphalt binder and the compaction method can improve the complex modulus of the asphalt mixture. This research leads to a better understanding of asphalt pavement performance, which can improve properties of asphalt pavement, increase service life, and reduce maintenance costs.

❖ Recommendations

This research summarized some recommendations for using asphalt mixtures in hot and arid areas. Such asphalt mixtures should use an asphalt binder which is less affected by pavement temperature changes and traffic loads. The use of an asphalt binder highly insensitive to important temperature changes in HA climates, such as in Libya, is highly recommended.

In asphalt mix design, climate factors must be considered such as air temperature and solar radiations. In fact, the asphalt binder should be selected based on the maximum and minimum temperatures of the asphalt pavement; otherwise, problems of premature rutting and other pavement failures would continue by using conventional grade binder B (60/70).

In HA climates, desert jurisdictions should be divided into temperature zones to help in the selection of the proper asphalt binder for each zone, based on the maximum and minimum pavement temperatures.

Modifying the traditional MMD method by the use of additives such as RAP, polymer (BSR), performance grade binder (PG) or rubber is strongly recommended. However, the use of mixtures having PG with characteristics of performance grades or any other additives has not been investigated. In addition, the most detailed evaluation of the gyratory compactor is needed as a tool for designing asphalt mixes in hot and arid climates, as in Libya.

The SGC method seems to be an effective field management tool, and at least as good as the MMD in many aspects. Through the analysis and discussion of the obtained results, modifying the existing asphalt mix is required to improve the asphalt binder characteristics, and the compaction method to enhance the physical and mechanical properties of the hot mix asphalt in HA climates, as found in Libya.

Consequently, it is necessary to improve the flexibility of asphalt mix at the lowest temperatures to prevent shrinkage and cracks, and increase the solidity of asphalt mix, at high temperatures to prevent rutting and shoving. However, some developing countries such as

Libya, cannot change to newer mix design methods such as SMD method. The migration is difficult and expensive, and it excludes all equipment which are currently used in laboratories.

These countries should continue to use the MMD method, but with improvements, step by step as follows:

- Adopt the Superpave PG system in the selection of asphalt binders or using additives based on the climatic zone prevailing temperatures to improve the characteristics of asphalt mixtures. This will be greatly helpful, although Libya and most developing countries import these materials from overseas because they do not produce them.

- Adopt a proper compaction method such as the Superpave gyratory compaction which achieves the density to meet field conditions.

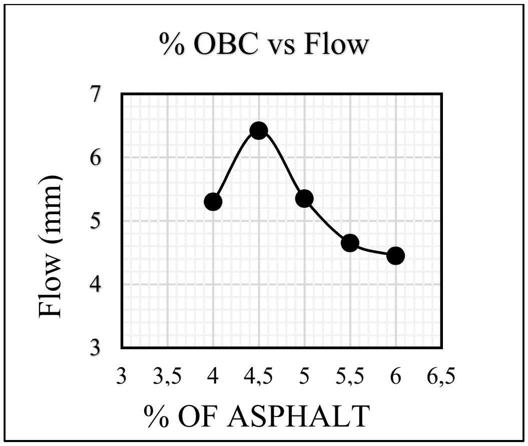
- Initiate a laboratory and field research study to practically and comparatively evaluate the asphalt mixture properties by the MMD method.

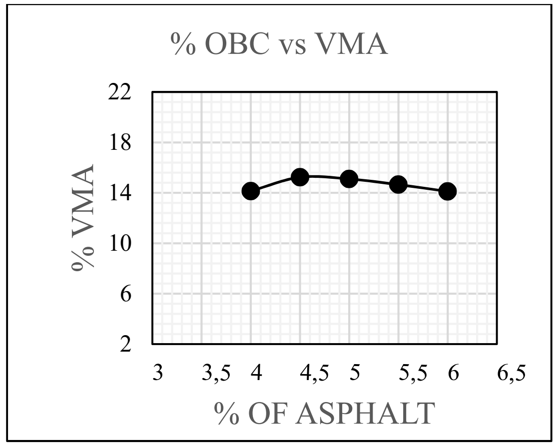
APPENDIX I

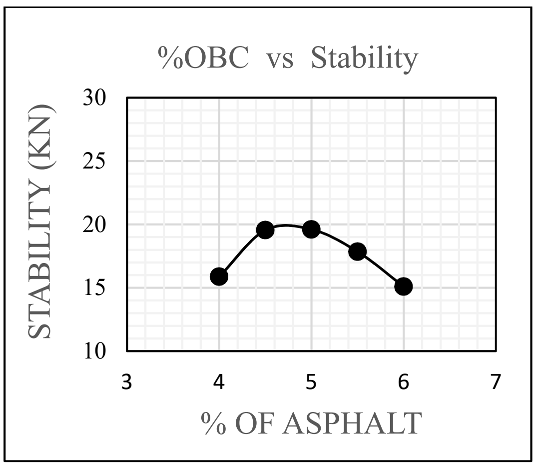
OPTIMAL BITUMEN CONTENT IN MARSHALL MIX DESIGN

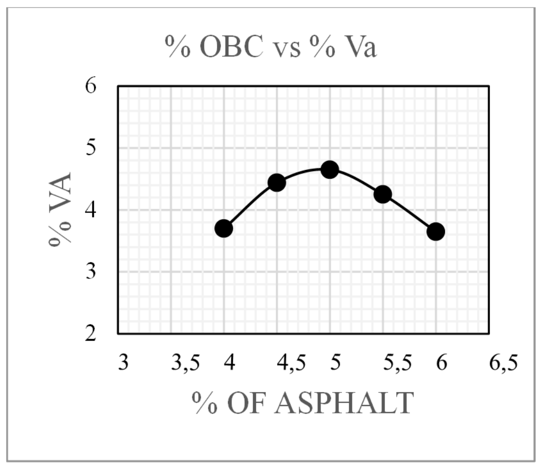
Table I.1 below shows the determination procedure of OBC

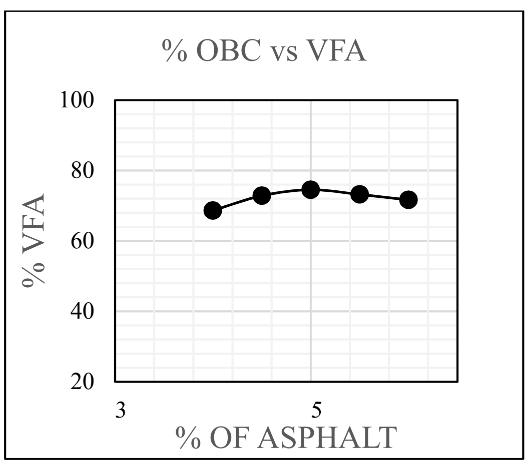
Determination of Bitumen Optimal Content by Marshall Test										
Project Name:	PhD research			Quebec Standard			Test Type: BOC			
Location:	ETS Campus			LCMB			Date: 2016-06-08			
TYPE OF MIX:	ASPHALT CONCRETE			Tested By: k.atrash			Checked By: Dr. Gabrill			
% asphalt	Hight of sample	Wt of sample in air	Wt of sample in water	Wt of sample in SSD	Bulk Spcific gravity	Stability (KN)	Flow (mm)	% Va	VMA %	% VFA
4	62.15	1164.2	680.25	1165.9	2.41	15.88	5.3	3.7	14.14	68.65
4.5	61.95	1132.2	667.5	1130.5	2.44	19.55	6.42	4.44	15.24	72.85
5	61.65	1156.1	676.4	1226	2.41	19.61	5.35	4.65	15.1	74.54
5.5	62.1	1165.2	683.2	1167.6	2.42	17.85	4.65	4.25	14.65	73.2
6	61.85	1169.5	696.4	1173.25	2.47	15.1	4.45	3.65	14.11	71.65


% OBC vs Flow
Flow (mm)
7
6
5
4
3
3 3,5 4 4,5 5 5,5 6 6,5
% OF ASPHALT


% OBC vs VMA
% VMA
22
18
14
10
6
2
3 3,5 4 4,5 5 5,5 6 6,5
% OF ASPHALT


%OBC vs Stability
STABILITY (KN)
30
25
20
15
10
3 4 5 6 7
% OF ASPHALT


% OBC vs % Va
% VA
6
5
4
3
2
3 3,5 4 4,5 5 5,5 6 6,5
% OF ASPHALT


% OBC vs VFA
% VFA
100
80
60
40
20
3 5
% OF ASPHALT

APPENDIX II

AGGREGATE GRADATION GB-20

Table II-1 GB-20 Aggregate Gradation Base on LC Method

Mix Types	**GB-20**	**ESG - 14**	**ESG - 10**	**EG - 10**	**EGA - 10**	**ESG - 5**
Sieve Size						
28 mm	100					
20 mm	95-100	100				
14 mm	67-90	95 - 100	100	100	100	100
10 mm	52-75	70 -90	92 - 100	90 - 100	90 - 100	85 - 100
5 mm	35-50	50 - 95	52 - 65	40 - 48	40 - 50	50 - 70
2.5 mm	-----	39.2	46.1	46.1	46.1	---
1.25 mm	----	25.7 - 31.7	30.7 - 36.7	30.7 - 36.7	30.7 - 36.7	---
.630 µ m	-----	19 1 - 23.1	22.8 - 26.8	22.8 - 26.8	22.8 - 26.8	---
315 µ m	-----	15.4	18.1	18.1	18.1	---
160 µ m	-----	---	---	---	---	---
80 µ m	4.0 - 8	3.0 - 8.0	4.0 - 10	4.0 - 10	4.0 - 10	4.0 - 12
Fibers	----	-----	-----	1.3	-----	-----
V_{be} (%)	10.2	11.4	12.2	12.4	14.6	14
Nb min Cl. Gran	3	3	2	2	2	2

APPENDIX III

QUESTIONNAIRE SURVEY

École de Technologie Supérieure; University of Québec

Subject: Limitation in Asphalt mix design in hot and arid climate

Full name: Talal Amhadi   Identification: Civil Engineer

Email: abinoflibay@yahoo.com   Date / 06 / 09 /2017

Question: What effect do the following factors have on the asphalt mix design in hot and arid climate?

Symbols: EE: Major Effect; E: Effect; LE: Low Effect; NE: No Effect.

Asphalt mix design problems	EE	E	LE	NE
Owner Name and Background	Y			
Type of asphalt binder		Y		
Contractor manpower and equipment capability	Y			
Qualification of owner and contractors		Y		
Upgrading of asphalt mix design methods	Y			
The amount of work subcontracted			Y	
Scarcity of data collection	Y			
Design and specification factors	Y			
Suitability of design methods in hot weather	Y			
Quality of materials used in the mix design		Y		
Type of materials (bitumen, Aggregate and Filler)			Y	
Construction control		Y		
Mentoring and controlling mixing procedure				Y

Problems encountered based on your experience:

What are the common problems of asphalt pavement in the hot and arid climate?	**EE**	**E**	**LE**	**NE**
Is rutting distress the Common distress in asphalt roads in Libya?		Y		

Give us your feedback on the pavement distresses.

The reason for the common distresses in hot and arid climate referred to the asphalt binder type, climate, material and mix design method, also, there are several other factors like owner experience, type of asphalt binder, construction time, etc.

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