THE EFFECT OF COMPACTION TEMPERATURES ON THE MARSHALL PROPERTIES OF ASPHALTIC CONCRETE

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CIVIL AND ENVIRONMENTAL ENGINEERING

UNIVERSITI TEKNOLOGI PETRONAS

SEPTEMBER 2016

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By

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17384

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

SEPTEMBER 2016

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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AZREE FAREES BIN ZAINAL ARIFFIN

ABSTRACT

Asphaltic concrete can caused significant problems if using an inappropriate compaction temperature. Asphalt mixture usually loses their temperature during transportation and when laying down to be compacted. Temperature controls asphalt mixture viscosity which affect its ability to coat and provide adequate lubrication for aggregates and slides with each other and pack into dense mass during compaction. Compaction is one of major issue and an important criteria for asphaltic concrete process. At road construction site in Malaysia, the lowering compaction temperature are caused by transportation of mix, weather, and other factor that cannot be minimized. The importance of compaction temperature is significant as it determine the performance of asphalt concrete, effecting the fatigue, permeability, rutting and durability. The main objective of this study is to determine the effect of compaction temperature on the Marshall Properties of Asphaltic Concrete. There will be eight different compaction temperatures of asphaltic concrete to be studied, each with four samples of asphaltic concrete that will be tested in the laboratory. In this study, the material that is used for HMA is of nominal maximum size of aggregates of 14 mm (AC 14). The mixture of HMA is prepared in accordance to the specification by JKR standards. With JKR (Jabatan Kerja Raya Malaysia) Standards Specification for Road Works Flexible Pavement, the aggregates were selected with the standard sampling method and aggregates gradation values. Besides that, Penetration Grade 80 – 100 for bitumen were used according to JKR Standards. The samples were tested using Marshall Test and the results will be compared to the JKR standards and requirement.

ACKNOWLEDGEMENTS

First and foremost, Alhamdulillah, God who Most Merciful and Most Gracious by giving me the opportunities and strength in pursuance of knowledge and grant me a good health and wealth.

I would like to express my profound gratitude to my supervisor Ass. Prof. Dr Madzlan Bin Napiah for his supervision, incessant advice, guidance invaluable help and patience during the course of this research. His knowledge and idea have been great value for me and has had remarkable influence on my entire project.

Ultimately, I wish to express special thanks and appreciation to my parents, Zainal Ariffin Bin Mohd Zabidi and Zainun Binti Shaffian for their unconditional support and love. I would like to thank Muhamad Azim Fitri Bin Abdul Muis, Fadia Dyni Binti Zaaba and Fahad Saad Seif Alazmi for all their support, help, interest, valuable hints and motivations.

I also want to thank Mr. Nura Bala, postgraduate students who has provided guidance and shared information regarding the project. Recognition is also due to all of the laboratory technicians, Mr Azran and Mr Iskandar who patiently provided assistances on the experimental portion of this study and who provided assistance, valuable discussion and cooperation on the experimental work of this research.

Finally, I wish to extend my warmth thank to my friends who has helped me with my work and constant support for me to finish the project. I also would like to thank everybody who had helped me directly and indirectly towards the accomplishments of this study.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

These days, lower mixing temperature has become a trend in the operation of asphalt plant. There is one major reason why mixing at lower temperature has been chosen, by conserve the energy required to produce the mixture. It means that at lower mixing temperature, it will result in lower operating cost. Besides that, there is also a drawbacks from overheated the mixtures by volatile emissions emanating to the environment.

In recent years, researcher has tried to improve the pavement performance to solve some issues that occurs in highway roads. The issues that usually occurs are, thermal cracking, rutting, fatigue cracking, abrasion, stripping cause, aging and creep deformation. These issues would lead the road pavement to fail. Among all these issues, rutting has considered as the most common problems in road pavements. With the high traffic nowadays and environmental effects, causing the road pavement to rut.

Asphalt concrete is a uniformly mixed combination of course aggregate, fine aggregate, filler material, binder and other material. Asphalt concrete can be categorized into different types such as Mastic Asphalt Concrete, Hot Mix Asphalt Concrete, Natural Asphalt Concrete, Cold Mix Asphalt Concrete, Warm Mix Asphalt Concrete, and Cut Back Asphalt Concrete. Mostly used in this country, this research will be focus on Hot Mix Asphalt Concrete (HMA).

The most widely implemented type of asphalt concrete in road construction worldwide and Malaysia is Hot Mix Asphalt Concrete (HMA). With popularity as paving material with high skid resistance, low maintenance cost and high comfort ability, it is being preferred by most of highway engineers as premier paving product and it is available anywhere at any cost.

The combination of uniformly mixed aggregate and asphalt cement coating is what the HMA paving made of the term “hot mix” and it is comes from aggregate and asphalt cement dried and heated for proper mixing and workability and mix together with desired temperature [1].

To produce good quality HMA, the one major and important criteria is compaction temperature. The compaction temperature will control the viscosity of asphalt cement that affect the coating ability, and the lubrication for the aggregates.

The design of asphalt mix will be based on Jabatan Kerja Raya Malaysia (JKR) standards. The road builders in constructing road used this standard as their guide. This research is to determine the effect of compaction temperature on the Marshall Properties of Asphaltic Concrete and the investigation is held in the laboratory.

1.2 Problem Statement

At road construction site in Malaysia, the lowering of compaction temperature are caused by weather, transportation of mix and other factors. The importance of compaction temperature is significant as it determine the performance of asphalt concrete, effecting the fatigue, permeability, rutting and durability. Asphaltic concrete can caused significant problems if using an in correct compaction temperature. This study will determine the effect of compaction temperature on the Marshall Properties of Asphaltic Concrete.

1.3 Objectives

The main objective of this study is to determine the effect of compaction temperature on the Marshall Properties of Asphaltic Concrete. This study produced asphalt concrete in different value of compaction temperature. A part from that, this study aims to analyses the optimum compaction temperature for the asphalt concrete from the investigation in the laboratory.

1.4 Scope of Works

With a lot of type of aggregates that have being used in road construction, this study covered only for granite. Most road construction in Malaysia, primarily used granite as their aggregates type. In this study, the material that is used for HMA is of nominal maximum size of aggregates of 14 mm (ACW 14). The mixture of HMA is prepared in accordance to the specification by JKR standards. HMA were compacted at different temperature to determine its effect on the Marshall Properties.

Determination of the aggregates properties is the earliest work that has been done for this project. With JKR (Jabatan Kerja Raya Malaysia) Standards Specification for Road Works Flexible Pavement, the aggregates were selected with the standard sampling method and aggregates gradation values. Besides that, Penetration Grade 80 – 100 for bitumen were used according to JKR Standards.

A number of laboratory tests already be carried on aggregates which is the granite in order to determine its mechanical and physical properties according to the ASTM and BS Standards. Below are the test included to determine the properties of the aggregates:

a. Specific Gravity and Water Absorption.
b. Los Angeles Abrasion Test.

Besides that, some tests also already been carried on to determine the properties of the bitumen according to the standards set out in the JKR Specifications. Below are the tests on bitumen:

a. Standard Penetration Test.
b. Softening Point Test (Softening Point).

There are eight different compaction temperatures of asphaltic concrete has been studied, each with four samples of asphaltic concrete that already be tested on Marshall Test in the laboratory.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The performance of Hot Mix Asphalt (HMA) are depending on the mixing and compaction temperature of HMA. In achieving complete aggregate coating and adequate field density it will need the aid of appropriate compaction temperature and mixing.

Compaction below the standard compaction temperature may bring reverse effect on HMA properties. Moisture damage of HMA with low temperature referred as striping and this problem become prevalent in recent years [1]. If the subgrade is weak, it will bring to the pavement to settle and the surface to crack. Air entering the surfacing mix oxidizes the asphalt cement causing the surface to weaken and crack extensively [2].

2.2 Compaction Temperature

One of the important factor in the design and following production of asphalt mixtures is compaction. The major controlling elements in this procedure is the compaction temperature for HMA. The workability of the asphalt mixture will be dependent on the compaction temperature.

Compaction temperature is very crucial to asphalt mix. To preserve a minimum compaction temperature, the time of how long it takes to cool from the lay down must be alert. Besides that, it will not be effective if any attempt to compact the asphalt mixture normally in low temperature. Further compaction may fracture the aggregate in the mix, decreases pavement density and frustrating the purpose of compacting [2].

It's recommended that a compaction temperature between 135 and 150°C. Use of a 150°C compaction temperature can result in design binder contents that are as much as 0.5% lower than if compacted at 135°C [3].

If asphalt mixtures cooler than desirable temperature, a variation in mix temperature (temperature differentials) can cause poor mix compaction leads to non-uniform densities [4]. Loss of fatigue life and serviceability of the pavement will occur by the low density.

The compaction temperatures can leads to the decrease in achievable density. Laboratory study showed that an increase in air void content and a decrease in stability with lower compaction temperatures. Compared to a sample compacted at (135°C), a sample compacted at a temperature of (93°C) contained more than double the percent air voids and at (65°C), the air void content quadrupled. Stabilities performed on these samples typically show a decrease in stability with decreasing compaction temperature and the resulting increase in air voids [2].

Large numbers of asphalt concrete paving projects have experienced a cyclic occurrence of low-density pavement areas [5]. The "cyclic segregation", is prematurely failed by fatigue cracking, raveling, or both. The "cyclic segregation" phenomenon in asphalt pavements has been studied [2].

In this study the effect of different compaction temperature on the Marshall Properties of asphalt concrete were investigated. Also there is eight different compaction temperature of asphalt concrete, each with four samples are studied.

2.3 Hot Mix Asphalt (HMA)

HMA contains two important elements which are asphalt and aggregate material. Asphalt plays an important role of binding aggregates together in a HMA mixture [7]. The asphalt and aggregate are blended together in accurate proportion and it will determines the effect of compaction temperature on Marshall Properties of the mix and on how the mixtures performance as a completed and finished asphalt concrete. Term of “hot mix” comes from aggregate and asphalt cement dried and heated for proper mixing and workability and mix together with desired temperature [1].

2.4 Aggregate

Referred as granular material, mineral aggregates, and rock, aggregates is used as graduated particles and fragments in the Hot Mix Asphalt Concrete. Aggregate makes up 90-95% by weight and 75-85% by volume of most pavement structures. Rock can be classified into three general types; sedimentary, igneous, and metamorphic [1]. In the manner of each type is formed, the classification is based upon.

Aggregates and binder are the HMA component. The aggregate are based on gradation and is divided as coarse aggregates, fine aggregates and filler material which is based on the criteria set in JKR standards [7]. Sieve analysis on the distribution of particle by percentage retained is done the get the aggregate gradation. Aggregates that retained above 1.18 mm seize size will be considered as course aggregates and the particle that pass through it is considered as fine aggregates. A part from that, particle that passes 75 micro meter sieve size is considered as filler material which obtained in the pan.

Aggregates characteristics play a crucial role in road construction. Mineral aggregates may consist of minerals materials such as gravel, sand and crushed stoned that are combined with a binding medium such as the bitumen to produce a compound materials such as the bituminous mixtures [10]. From the base, to the pavement of the road, aggregates is the major material that builds up the structures.

In hot mix asphalt (HMA), aggregates are combined with an asphalt binding medium to form a compound material. By weight, aggregates generally constitutes for between 92 and 96 percent of the cost of the HMA pavement structure.

The characteristic of the aggregates play a significant role in a bituminous mixture. Size and shape of the aggregates, pore volume and size, surface area, acidity and alkalinity, surface charge or polarity, chemical constituents at the surface and as well as the absorption size surface density are some of the widely cited characteristics that play a major role in contributing of a good engineering properties of the bituminous mixture [10].

In twentieth century, as materials specifications for HMA have formalized and customs and also practices within the local industries, so highway engineers all over the world have followed the same economic dictate of using local materials wherever they have proved to be suitable [11]. The materials selection need to fulfil some requirements for pavement which are:

a. To provide an even, non-skidding and good riding quality surface;
b. To resist wear and shearing stress by traffic;
c. To be capable of surviving a large number of repeated loaded without distress;
d. To prevent water from penetrating into the under laying pavement layers; and
e. To withstand adverse environmental conditions

As the scope of study for this project is being narrowed to aggregate that widely used in the local country, only granite will be take into consideration.

2.4.1 Granite

Granite came from the igneous rock group and the minerals that are found in granite are primarily plagioclase feldspars, quartz, potassium or K-feldspars, micas and homblende. Quartz is usually considered as the last mineral to crystallize as well as filling the extra spaces of other minerals.

The properties such as hardness, least of chemical reactivity and near lack of cleavage contribute to the significant amount if it’s durable properties. The quartz usually in grey color, but it is actually colorless and is actually reflecting and fusing the colors of black and white minerals surrounding it. Granite as the same as the case in limestone aggregates, their properties are significantly affected by its chemical composition.

Granite is a common and widely occurring type of intrusive, felsic, igneous rock. Granite occurrence is nearly always massive, hard and tough and therefore it has gained widespread use as a construction stone. Furthermore, the porosity and permeability of granite is almost negligible; its range between 0.2 to 4.0 percent only.

Additionally, granite has high thermal stability which means granite shows no changes with the change in temperature. Also, granite is impervious to weathering, either from the temperature changes or air borne chemicals. From the mentioned properties of granite, it seems that granite is perfect as an aggregate in hot mix asphalt.

2.4.2 Physical Properties of Granite

Granite is an acidic crystalline igneous rock with a relative density of 2.65-2.75 kg/cubic meter. The hardness of the granite vary accordingly to the composition and as well as with the proportion and type of feldspar present in the granite [9].

The porosity and permeability of granite are typically low due to the development of slow and complete crystallization of the molten magma. The porosity of granite is consistently low with the values only on the order of 0.1 to 1.2 percent being characteristics.

The compressive strength of the granite is between the ranges of 140 to 210 N/mm^2. As a crystalline, granite has low permeability when fresh, even though weathered rocks are usually much more permeable.

2.4.3 Aggregates Gradation

Aggregate gradation is very significant to bituminous mixture design. Variation in the aggregate gradation of the hot mix asphalt (HMA) mix can significantly affect the measured asphalt content [12].

Asphalt content must be controlled in HMA mixes to obtain optimum serviceability and durability. A HMA pavement can ravel and/or crack if it's deficient in asphalt content by as little as 0.5 percent where as 0.5 percent excessive asphalt content can cause flushing and rutting.

Coarse HMA mixes tend to segregate because it holds less asphalt cement by weight compare to the fine aggregate fraction [12]. Segregation causes variation of coarse and fine aggregate gradation in HMA samples; consequently affect the measured asphalt contents. If an ideal aggregate gradation and accurate optimum asphalt content is combined together, road pavement can achieve maximum serviceability and durability.

2.5 Aggregate Characterization in Relation Bitumen – Aggregate Adhesion

2.5.1 Mineralogical Composition

The aggregate mineralogy can affect the adhesion in the bituminous mixtures. Generally, the mineralogy of the aggregates affect the rate if attraction of the aggregate between the water and bitumen. Besides that, the mineralogical composition also affect the surface texture of the aggregate. The mineralogical composition of the aggregates depend on the origin of the rocks and their groups either igneous, sedimentary or metamorphic [15].

2.5.2 Surface Energy

Directly related to the chemical and mineralogical composition is the surface energy of the aggregates. The intermolecular forces at the surface of the aggregates are able to interact with the molecules from the bitumen which will result in an adhesive bond. Different chemicals have different types of bonding mechanism for interaction with the molecules in the bitumen. For instance the polar molecules on the surface of the aggregates are more able to interact with the functional groups in the bitumen. Non-polar molecules at the surface are more able to interact with non-polar molecules in the bitumen [16].

2.5.3 Surface Texture

In the stage of mixing the asphalt mixture, the surface texture of the aggregates influences a proper coating of the aggregate and the bitumen binder. The smooth surface structure is considered as easy to be coated with a proper binder films, however, the mechanical bond is less compared to the rougher surface aggregates. Rougher surface has larger surface area per unit mass which result in stronger adhesive bond between the bitumen binder and aggregates [16].

2.5.4 Shape and Angularity

Same cases as the surface texture, the shape of the aggregates also affects the coating process of the bitumen binder and the aggregates during the mixing process. Rounder particles are considered easy to be coated compared to the angular shaped aggregates. However, during the service life, the angularity may offer good points of anchoring for the bitumen binder to improve the adhesion. It is known however, the increase in angularity will also increase the probability of the puncturing the bitumen film. This way the water can easily penetrate the layer of the adhesive bond in the bituminous mixture and can probably cause stripping [17].

2.5.5 Porosity and Pore Size

A rougher surface structure is resulted from the pore size distribution in which many pores are located at the surface of the aggregates. The larger the surface area per unit mass to ensue stronger adhesive bond in the bituminous mixture. The high porosity on the aggregates' surface also affect the absorption of bitumen binder at the same time.

The absorbed bitumen will be forced and locked in the pores, another cause of strong adhesion. However, the amount of absorbed bitumen in the pores of the aggregates would not be available for a proper coating the exterior of the aggregates. This would result with an extra amount of bitumen added during the mixing stage [16].

2.6 Filler Material

An important element of bounding the aggregates and asphalt in asphaltic concrete is filler material. The material that retained in pan during sieve is usually defined as filler material. The filler material that mostly used in asphalt concrete is river sand, quarry dust or Ordinary Portland Cement (OPC) [7].

As the role to bond aggregates and asphalt together, filler material is added in the mixtures of HMA. Filler material will contribute as a bondage material which to bond the aggregates and fills the pores in the mixture. To have a better asphalt mixture, the filler material is changed with other material available such as Ordinary Portland Cement (OPC), hydrated lime or carbide lime.

Normally, river sand is used as filler material because of availability of material and in terms of cost effectives. Other filler such as limestone also used in the mix. Besides that, filler material such as carbide lime from industrial waste could be proven as sufficient or more than capable of improving the normal mixture of HMA. Carbide lime or also known as calcium carbide is a product of excessive coke with quicklime in the presence of oxygen in an oxygen-thermal furnace.

Mineral filler shall be incorporated as part of the combined aggregate gradation. It shall be of finely divided mineral matter of hydrated lime (calcium hydroxide). At the time of mixing with bitumen, the hydrated lime shall be sufficiently dry to flow freely and shall be essentially free from agglomerations.

Not less than 70% by weight shall pass the BS 75 um sieve. The total amount of hydrated lime as mineral filler shall be limited such that the ratio of the combined coarse aggregate, fine aggregate and mineral filler of the final gradation passing 75 um sieve to bitumen, by weight, shall be in the range of 0.6 to 1.2.

As a guide, the total amount of hydrated lime shall be approximately 2% by weight of the combined aggregates. The hydrated lime shall also be treated as an anti-stripping agent. If hydrated lime is not available, ordinary Portland cement shall be used as an alternative.

2.7 Bituminous Material

Generally, binders are selected based on some simple tests and other site-specific requirements. These tests could be different depending of the type of binder viscosity, penetration grade, cutback, emulsion, modified binder etc. For most of these tests, the test conditions are pre-fixed in the specification.

Temperature is an important parameter which affects the modulus as well as the aging of binder [13], [14]. For this study, bitumen 80p is used as the binder.

In Malaysia, bitumen 80/100 is the most widely used based on the specification set by JKR. The penetration refers to the hardness of the bitumen at 25°C and is described in bitumen 80 PEN.

The higher the prefix numbers the softer the bitumen. This is due to the visco-elastic rheology property of bitumen. Bitumen 80 penetration is a visco-elastic material and may exhibit either elastic or viscous behavior, or a combination of both, depending on the temperature and time over which the bitumen is observed.

Bitumen will show liquid-like viscous behavior on a long time scale or at higher temperatures, but solid-like elastic behavior at short times/low temperatures [13].

2.8 Marshall Mix

The Marshall Properties stability and flow test provides the performance prediction measure for the Marshall Mix design method. The stability portion of the test measures the maximum load supported by the test specimen at the loading rate of 50.8 mm/minute. Basically, the load is increased until it reaches a maximum then when the load just begins to decrease the loading is stopped and the maximum load is recorded [6].

During the loading, an attached dial gauge measures the specimen's plastic flow as a result of the loading. The flow value is recorded in 0.25mm increments at the same time the maximum load is recorded [6].

The analysis shall conform to the requirements of the appropriate type of mix as given in Table 4.3.5 in JKR Manual as shown in Table 2.1 below:

Table 2.1: Test and Analysis Parameters.

Parameter	Wearing Course
Stability, S	>8000 N
Flow, F	2.0 – 4.0 mm
Stiffness, S/F	>2000 N/mm
Air Voids in Mix (VIM)	3.0% - 5.0%
Voids in aggregate filled with bitumen	70% - 80%

CHAPTER 3

METHODOLOGY

3.1. Determination of Aggregate Properties

3.1.1 Specific Gravity and Water Absorption Test

The specific gravity of an aggregate is considered to be a measurement of the strength or quality of the material. Aggregates with low specific gravity are usually weaker compared to the aggregates with high specific gravity. It is because aggregates with high water absorption value are porous. The test will be carried out according to the ASTM Designation: C 127-88.

Several method of obtaining the particle density of the aggregates are specified which include the measurements of the mass of the sample in air and in water. Particle density of also known as specific gravity can be defined on an oven-dried basis, on saturated surface-dry basis or as an apparent particle density.

The oven dried is the most commonly used for road engineering construction. The amount of water absorption is normally measured at the same time as the particle density. The value can be obtained through the difference in mass of before and after drying the sample at 105± 5ºC for 24 hours.

3.1.2 Los Angeles Abrasion Test

Los Angeles Abrasion test is one of the common test used to indicate the aggregates' toughness and abrasion characteristics. In order to produce a high quality HMA, it is important for the aggregates used to have high resistance to crushing, degradation, and disintegration.

Premature structural failure or a loss of skid resistance may occur due to the insufficient of the resistance of the aggregates to abrasion and polishing. Other than that, poor resistance to the abrasion would also produce an excessive dust during the production of HMA which will result in possible environmental problems as well as mixture control problems.

Aggregates used in pavement should durable so that they can resist crushing under the roller. Many abrasion test have been developed in order to evaluate the ease (or difficulty) with which aggregate particles are likely to wear under attrition from traffic. The aggregate abrasion test and the accelerated polishing test are two such tests most widely accepted.

In the experiment, the standard L.A abrasion test subjects a coarse aggregates sample to abrasion, impact and grinding which occur in a rotation steel drum containing specified number of steel spheres.

The Los Angeles abrasion test is carried out in a sample of aggregate all retained on the No. 4 ASTM sieve. In this test, 12 steel balls of 44-48 cm diameter are introduced in a steel cylinder fitted with an internal shelf and rotated at 30-33 rpm for 500 revolutions.

The result of the test is expressed as the percentage by mass of material passing a No. 12 ASTM sieve (equivalent to a No. 10 BS sieve) after test. Two versions of the test are specified in the ASTM designations, one for course and the other for fine aggregates (Khairul Azri, 2010).

Suggested maximum Los Angeles abrasion values were 40 for bituminous materials and 50 for concrete aggregates. Typical Los Angeles abrasion value for coarse aggregate is 20% or lower. Aggregate with abrasion value over 50% are not suitable for road pavements.

3.2 Determination of Bitumen Properties

3.2.1 Standard Penetration Test

The test will be carried on to determine the grade of bitumen. The penetration will determine the consistency of the bitumen for the purpose of grading. In this test, a needle of specified dimension will be allowed to penetrate into a sample of bitumen with a known load (100g), at a fixed temperature of 25ºC in a duration of five seconds. Therefore, the softer the bitumen, the greater the penetration of the needle.

3.2.1 Ring and Ball Test (Softening Point)

The Ring and Ball test will be carried on to determine the consistency of penetration or oxidized bitumen. Same as the penetration test, the procedure for carrying out this test should be precisely followed in order to obtain an accurate result. The step preparing the sample, the rate of heating the sample and the accuracy of the temperature measurement are important.

In this test, a steel ball will be placed upon the bituminous materials and the water is the heated at the rate of 5ºC increase per minute. At the temperature where the softened bituminous materials first touched the metal plate ate a specific distance below the ring will be recorded as the Softening Point of the sample.

3.3 Gradation Limit

Gradation:

Table 3.1: Gradation Limits for Asphaltic Concrete (Table 4.3.3, JKR Manual).

Mix Type	Wearing Course
Mix Design	ACW 14
B.S Sieve Size	Percentage Passing By Weight
20.0 mm	100
14.0 mm	90 - 100
10.0 mm	76 – 86
5.0 mm	50 – 62
3.35 mm	40 – 54
1.18 mm	18 – 34
425 µm	12 – 24
150 µm	6 – 14
75 µm	4 – 8
Pan	0

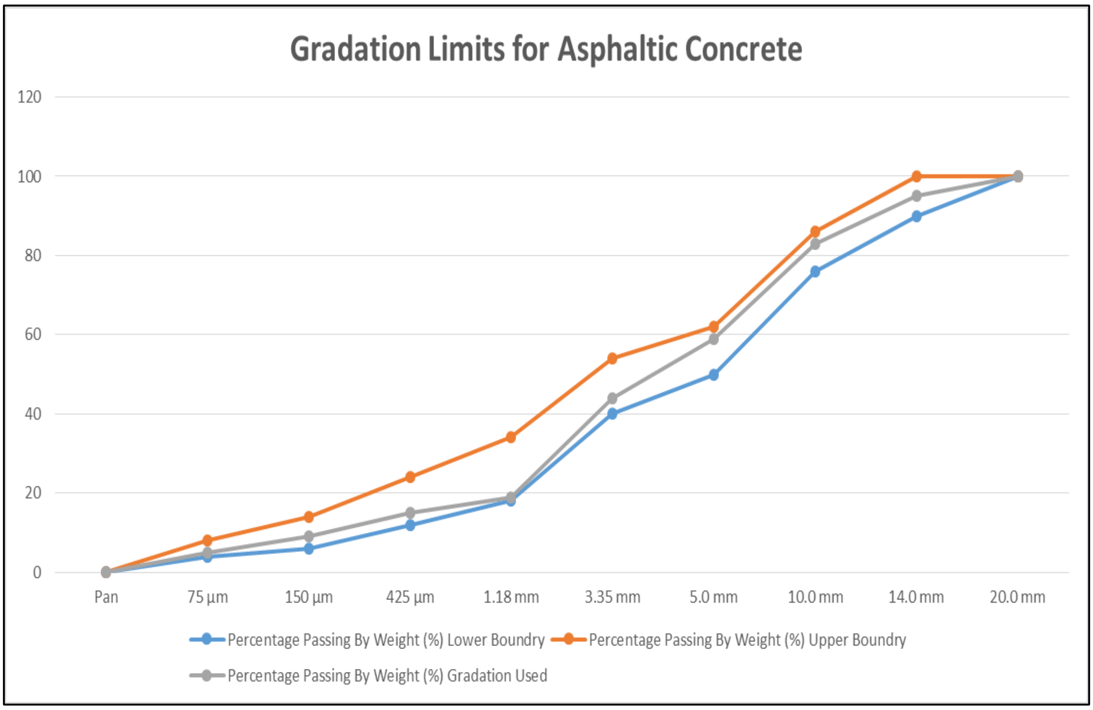

Figure 3.1: Gradation Limits for Asphaltic Concrete Graph.

3.3.1 Sieve Analysis

Sieve analysis test is used to determine the particle size or gradation of the coarse aggregate and fine aggregate. Basically the grain size characteristics of the aggregate is evaluated by sieve analysis. This test is done by using mechanical sieve shaker. Place the aggregate on the top and then the machine would shake the aggregate and then the aggregate would be separated based on its size which is done by different sieves sizes under each other.

Starting from the top of the machine, there would be the largest sieve size and then ending up with the smallest sieve size. The aggregate should be dry and with a known weight. After the separation the weight of each particles on each sieve, particles should be measured and compare to the total aggregate weight.

The percentage retained by weight on each sieve size can be found after we measure all particles that retained from each sieve. After getting the percentage we could draw a graph to show the cumulative percentage.

3.4 Marshall Mix Design

In order to design bituminous mix by laboratory procedures, with aim of producing the required density and engineering properties, it is desirable to prepare specimens which reproduced, as closely as possible, the material that will be used. The packing characteristics of the aggregate significantly influence the mix properties which cannot be assessed from grading curves, as these assume uniformity of particle shape, surface roughness and specific gravity.

Compactions of asphalt concrete mixture at eight different temperatures (160, 150, 140, 130, 120, 110, 100, and 90°C) were considered. 32 samples were tested, four samples for each temperature will be considered.

All materials are batched and kept in an oven at 150°C. The mixer is also heated to the same level of temperature, therefore great care should be exercised when handling the hot material and equipment.

The batched granular material (plus filler) should be placed in the mixer and mixed dry for 1 minute, then the 5% of bitumen should be added to the aggregate. Mixing should continue until all particles are coated with bitumen.

The material should also be compacted in 100 mm diameter steel moulds. The mould also need to be heated up according the compaction temperature. After filling the mould with the appropriate amount of material, the operator should make sure that it is evenly distributed in the mould. This is done by tamping the material (using steel rod) 15 times around the edges and 5 times in the center.

At this stage, the sample is ready for compaction using the Gyratory Testing Machine which is set to the following standard conditions:

a. Axial load = 0.7MPa
b. Angle of Gyration = 1°
c. No. of Revolutions = 200

When the samples have cooled down to room temperature (24 hours), they are extruded from the moulds. The weight of each samples in and water and its height should be taken (for density calculation).

3.5 Marshall Stability and Flow

The test were carried out to measure the resistance to plastic flow of cylindrical specimens of the bituminous mixtures loaded in the lateral surface by means of the Marshall apparatus. There are several factors should be determined with varying compaction temperatures in order to get the optimum bituminous mixture for stability, durability, flexibility as well as fatigue resistance.

The factors are:

a. Marshall Stability.
b. Flow.
c. Density.
d. Air Voids.
e. Voids Filled with Bitumen.

The Marshall Stability of the bituminous mixture is defined as the maximum load carried by the mixes at a standard temperature of 60ºC. The flow value is the deformation at which the specimen undergoes during loading up to the maximum load. The flow will be measured in 0.25mm units. The aim of the test is to get the optimum binder content for the type of aggregate mix used and the expected traffic intensity.

3.6 Data Analysis

Once all the samples had been tested in the laboratory, the data were analyses to see the real impact of compaction temperature on Marshall Properties on asphaltic concrete. The relationship between the data were gathered and conclusion will be made.

The list of relationship between the data are listed below:

a. Compaction Temperature VS Marshall Stability.
b. Compaction Temperature VS Flow.
c. Compaction Temperature VS Density.
d. Compaction Temperature VS Marshall Stiffness.
e. Compaction Temperature VS Air Voids.
f. Compaction Temperature VS Void in Aggregates Filled with Bitumen (VFB).
g. Compaction Temperature VS Void in Mineral Aggregates (VMA).

3.7 Project Key Milestone

Event or Deliverable	Target Date	Responsibility
Preliminary works	Week 1 – 8	Understand and do some research to gather information that are related to the project. Present the information to the supervisor to discuss further actions.
Submission Extended Proposal	Week 7	Complete the Extended Proposal and hand it to supervisor
Proposal Defense	Week 11	Student must present their project to the examiner and supervisor
Submission of Interim Report	Week 14	Student must submit the Interim Report to the supervisor

Table 3.2: FYP 1 Project Key Milestones.

Event or Deliverable	Target Date	Responsibility
Lab works	Week 1 – 2	Preparing the samples for the lab works and prepared a schedule for the lab works and testing specimens.
Lab works	Week 3-8	Completed the Progress Report and submitted to the supervisor
Submission of Progress Report	Week 9	Student must present their project to the examiner and supervisor
Pre-Sedex Presentation	Week 10	Student prepared a poster for Pre-Sedex presentation.
Submission of Final Report	Week 11	Student must complete the thesis and submit the final report to the supervisor.
Final Viva	Week 13	Student must prepare presentation slides for viva and must submit the hardbound thesis.

Table 3.3: FYP 2 Project Key Milestones.

3.8 Project Gantt Chart

Table 3.4: Project Gantt Chart.

	FYP 1 (SEMESTER 1)	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
TASK 1	Topic Selection														
	Information Gathering														
	Extended Proposal														
	Data Gathering														
	Proposal Defense														
	Laboratory Experiment														
	Analyses the Laboratory Data														
	Submission of Interim Report														
	FYP 2 (SEMESTER 2)	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
TASK 2	Laboratory Experiment														
	Progress Report														
	Analyses the Laboratory Data														
	Submission of First Draft Report														
	Oral Presentation														
	Submission of Dissertation (Hardbound)														

CHAPTER 4

RESULT AND DISCUSSION

4.1 Physical Properties of Aggregates

4.1.1 Specific Gravity and Water Absorption Test Result

The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. The specific gravity test help in the identification of stone. Water absorption gives an idea of strength of aggregate. Aggregates having more water absorption are more porous in nature and are generally considered unsuitable unless they are found to be acceptable on strength, impact and hardness test.

The aggregates tested for this project is granite and the value are presented as below. Sand was used as a fine aggregates and its properties was determined prior to mixing with bitumen so that it can confirm to JKR standard.

Table 4.1: Particle Density (Specific Gravity) & Water Absorption Result.

Materials	**Bulk Specific Gravity**	**Bulk SSD Specific Gravity**	**Apparent Specific Gravity**	**Water Absorption (% of dry mass)**
Granite	2.61	2.66	2.90	1.15
Sand	2.60	2.61	2.63	0.55

In the Table 4.1 above, the granites gave the water absorption value of 1.15%. The JKR manual specifies that the water absorption value of an aggregate should be less than 2% in order to be used in the road constructions.

Therefore, the granite used for this project have met the requirements in terms of water absorption capacity. The fine aggregates used for the project was found to have a value of 0.55% which also meets the JKR standard. The bulk specific gravity of granite is 2.61. Granite has high specific gravity value because the structure of granite is well packed.

4.2 Mechanical Properties of Aggregates

4.2.1 Los Angeles Abrasion Test Result

The Los Angeles (L.A.) abrasion test is a common test method used to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate in HMA must resist crushing, degradation and disintegration in order to produce a high quality HMA. The Los Angeles values for each granite for this project are as below:

Table 4.2: Los Angeles Abrasion Result for Granite.

		1	**2**
Mass of aggregates retained on No.4 ASTM sieve	(kg)	5.0	5.045
Mass of material passing No.12 ASTM sieve	(kg)	0.715	0.765
Los Angeles Abrasion Value	M_2/M_1 $x\,100$	14.3 %	15.2 %

The test is carried out to measure the resistance of the aggregates to abrasion. From the results obtained, granite has low LA abrasion value. The result demonstrated that granite resistance to abrasion is high.

Aggregates with higher abrasion value are not desirable to be used in the road works as they provide less resistance against skidding. The JKR specification stated that the LA value of an aggregate to be used in road construction should be less than 60% and it can be concluded that granite as aggregates meet the requirements.

4.3 Properties of Bitumen

The bitumen used for this project is the bitumen Penetration Grade of 80-100. Two tests are allocated in order to investigate the properties of the bitumen. The tests are, Standard Penetration Test and Ring and Ball Test (Softening Point)

4.3.1 Standard Penetration Test Result

The standard penetration test is used to determine or measure the consistency of the bitumen. The higher the values of penetration indicates the softer the consistency. The method is used widely all over the world in order to classify bituminous materials into different grades.

In warmer regions, lower penetration grades are preferred and in colder regions bitumen with higher penetration values are used. Depending upon the climatic conditions and type of construction, bitumen of different penetration grade are used. Commonly used grades are 30/40, 60/70 and 80/100. The results of the standard penetration for this project are as below:

Table 4.3: Standard Penetration Test Result.

Standard Penetration Test				
Temperature: 25 °C		Load: 100g		Time: 5 seconds
Sample No.	Determination 1	Determination 2	Determination 3	Mean
A	88	88	87	88
B	86	87	85	85

The table above confirmed that the bitumen which going to be used for the samples in this project is an 80/100 bitumen. Both samples obtained the same results between 80 and 100, thus the results are valid.

4.3.2 Ring and Ball Test (Softening Point) Result

Softening point test was conducted to determine the softening point of bituminous binder. A total of 2 samples were tested. The results of the test are shown in table below:

Table 4.4: Ring and Ball Test (Softening Point) Result.

Softening Point Test (Softening Point)			
Sample No.	Ball 1	Ball 2	Mean
A	51.8	52.1	51.95
B	48	49.3	48.65

The results obtained from this experiment shows two mean values of 51.95°C and 48.65°C which when averaged equals in 50.3°C and not more than 52°C. According to the Manual on Pavement Design, the requirement for softening point of bitumen Grade 80/100 the softening point value should not be less than 45°C and not more than 52°C. Based on the results, both sample A and B, the softening value comply with the standard, therefore, it can be taken into consideration.

4.4 Laboratory Investigation Result

4.4.1 Effect of Compaction Temperature on Marshall Stability

The indicator of resistance against the deformation of the asphalt concrete is Marshall Stability. To evaluate the resistance of the deformation of the tested samples, Marshall Stability values are calculated. A higher value of Marshall Stability indicates a stiffer mixture and, hence, indicates that the mixture is likely more resistant to rutting and shoving.

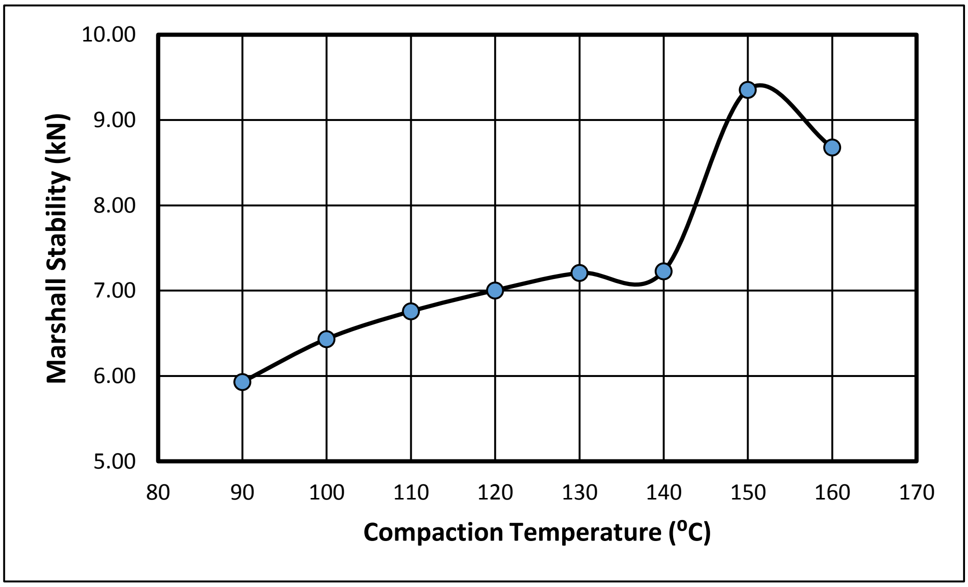

Figure 4.1: Relationship between Compaction Temperature and Marshall Stability.

Marshall Stability value in (kN) is studied as function of compaction temperature in (^{0}C) that relation has been plotted as shown in Figure 4.1. Its shows that as the compaction temperature decrease from (150^{0}C to 140^{0}C) the stability values is sharply decrease, and as the compaction temperature decrease from (140^{0}C to 90^{0}C) the stability values is gradually decreases.

Where, the value of Marshall Stability at compaction temperature (150^{0}C) is about 29% higher than if compared at (140^{0}C), and 34% if compacted at (120^{0}C) and 38% if compacted at (110^{0}C), while it increases to 56% if compacted at (90^{0}C). This is because at high temperature the bitumen viscosity is so low that cause good lubrication of aggregate particle and this cause better interlock between particles during compaction.

From compaction temperature (160^{0}C to 150^{0}C) the stability values is also sharply decrease as it shows that the compaction temperature at 150^{0}C is the optimum compaction temperature. Referring to JKR standards, the Marshall Stability value need to be more than 8kN and only Marshall Stability value of compaction temperature at 160^{0}C and 150^{0}C conformed to the requirement.

4.4.2 Effect of Compaction Temperature on Flow

To find out the effect of different Compaction Temperature in (^{0}C) on the Flow values in (mm). Figure 4.2 below has been plotted. It is shown that the flow value is about the same for compaction temperatures ranges between (160 to 110^{0}C), then as the compaction temperature decrease from (110^{0}C to 90^{0}C), the flow values increase.

This is attributed to that, at low temperature the percentage of voids of total mixture is high than at higher temperature. This causes air space for the aggregate particle to deform and this increases flow value. Referring to JKR standards, the Flow value need to be in ranges of (2.0mm – 4.0mm) and only Flow values of compaction temperature at 160^{0}C to 110^{0}C conformed to the requirement.

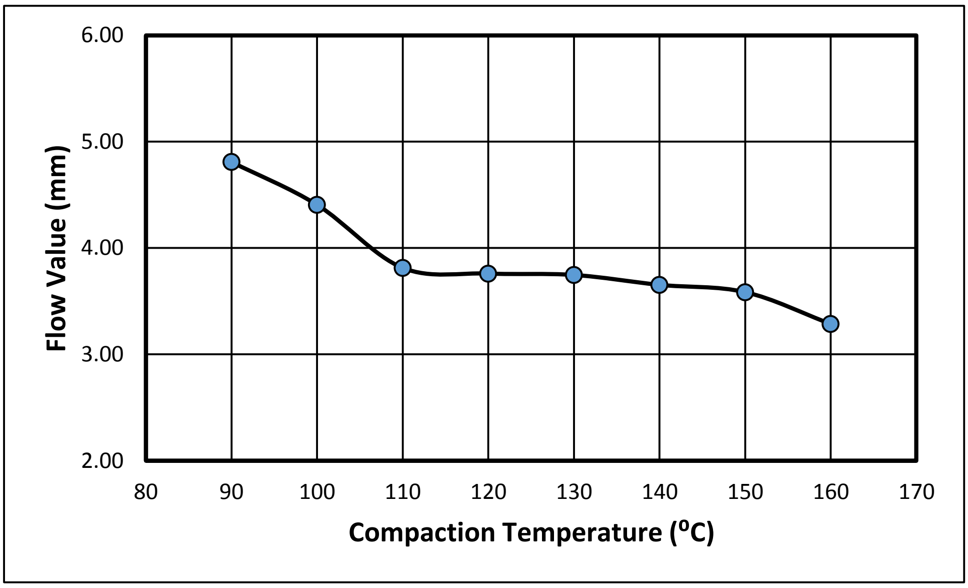

Figure 4.2: Relationship between Compaction Temperature and Flow.

4.4.3 Effect of Compaction Temperature on Density

Relationship between Compaction Temperature in (°C) and Density in (kg/m^3) has been plotted in Figure 4.3 below. It is found that when compaction temperature decreases from (160°C to 140°C) the density values is sharply decreases. This reflects that the asphalt mixture is more workable due to low viscosity of bitumen which lubricated aggregate particle well at that range of temperature.

At compaction temperature from (140°C to 100°C) the density constantly decreases. This is because the bitumen viscosity may increase which cause decrease in density with the same trend. As the compaction temperature decreases from (90 °C), the bitumen viscosity is so high that the asphalt mixture is not workable, so the density is at the lowest value.

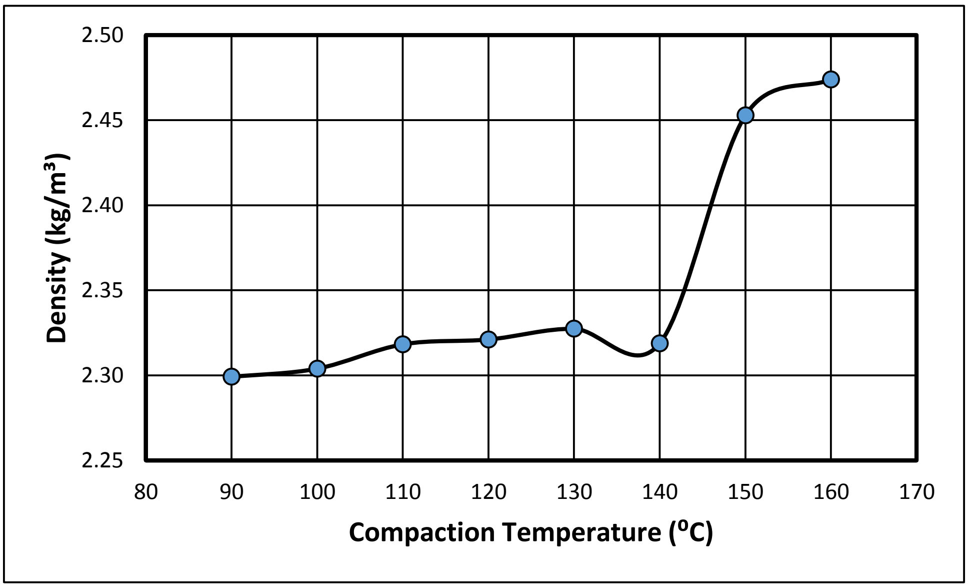

Figure 4.3: Relationship between Compaction Temperature and Density.

4.4.4 Effect of Compaction Temperature on Marshall Stiffness

Values of Marshall Stiffness versus different compaction temperatures are shown in Figure 4.4 below. It is clear that the Marshall Stiffness value is sharply decrease from compaction temperature (150°C to 140°C). The value is constantly decreased as the compaction temperature decrease for temperature ranges from (140 to 110°C).

As the compaction temperature decrease from (110°C to 90°C) the Marshall Stiffness values sharply decrease. This is attributed to that at high compaction temperature the bitumen viscosity is low and the asphalt mixture is workable and compacted well. Referring to JKR standards, the Marshall Stiffness value need to be in more than 2kN/mm and only Marshall Stiffness values of compaction temperature at 160°C and 150°C conformed to the requirement.

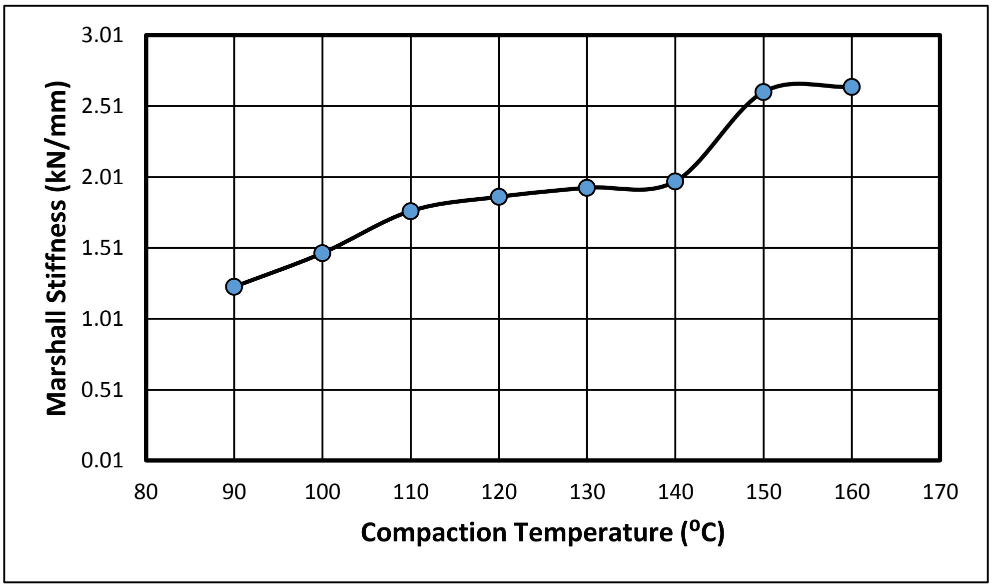

Figure 4.4: Relationship between Compaction Temperature and Marshall Stiffness.

4.4.5 Effect of Compaction Temperature on Air Voids

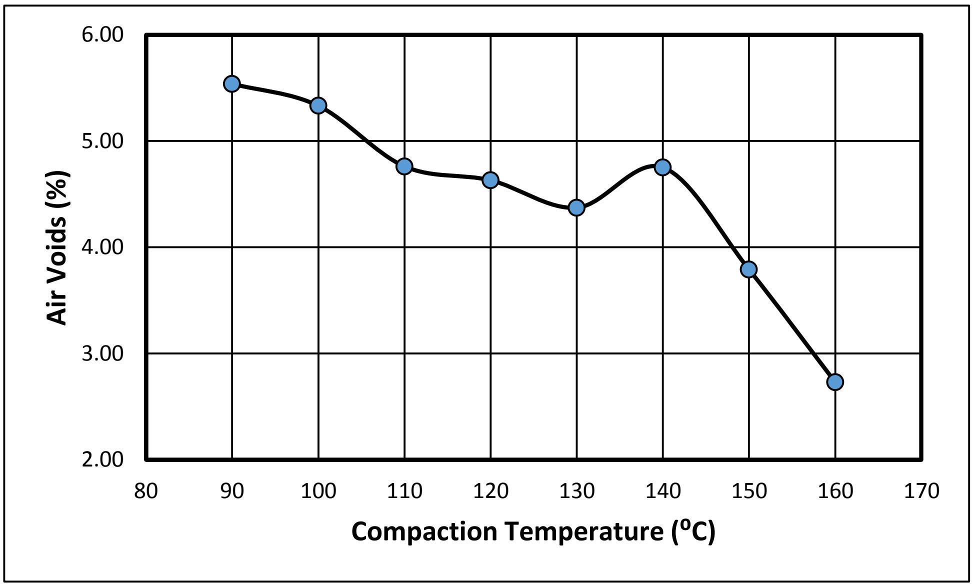

Figure 4.5: Relationship between Compaction Temperature and Air Voids.

Figure 4.5 above shows the porosity results of the mixtures. These results are aligned with the density results where increasing in the density will produce lesser porosity. Voids in the total mix is the parameter which indicates the porosity of the mixture.

If the amount of air voids in the mixture reaches above the required quantity, it may introduce cracking in the mixture as there is no sufficient bitumen to coat all the aggregate surface. If too low air voids are present, there would not be enough room to contain the bitumen thus resulting in bleeding or plastic flow of bitumen which is termed as rutting.

Therefore, referring to JKR standards, the Air Voids value need to be in ranges of (3.0% – 5.0%) and only Air Voids values of compaction temperature at 150^0C to 110^0C conformed to the requirement.

4.4.6 Effect of Compaction Temperature on Voids Filled with Bitumen (VFB)

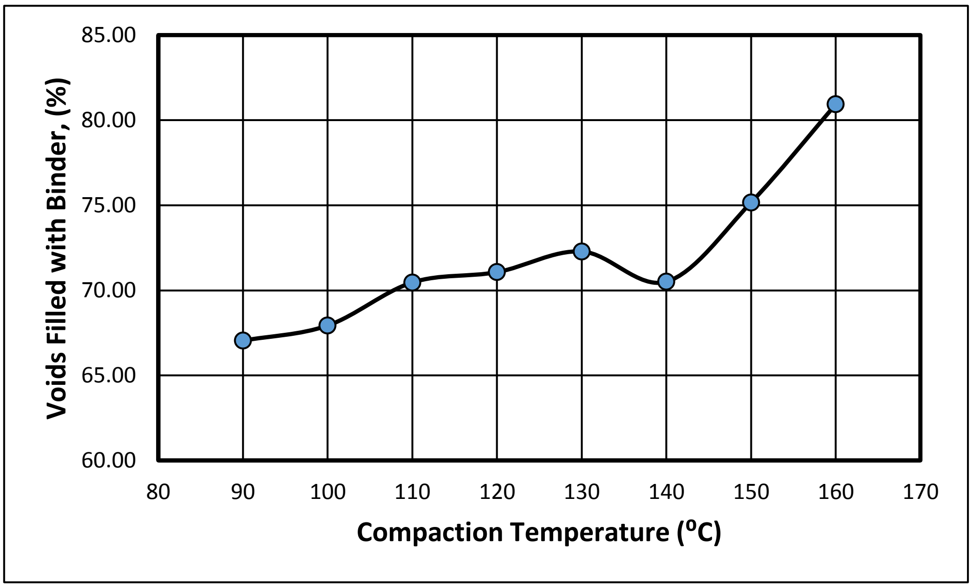

Figure 4.6: Relationship between Compaction Temperature and Voids Filled with Bitumen (VFB).

From Figure 4.6 above, it is shows that at high compaction temperature, more voids in aggregates is filled with bitumen and as we go down to the lower compaction temperature, less voids in aggregates is being filled with bitumen and it reflects that there is more empty voids at lower compaction temperature.

Referring to JKR standards, the Voids Filled with Bitumen value need to be in ranges of (70% – 80%) and only Voids Filled with Bitumen values of compaction temperature at 150^{0}C to 110^{0}C conformed to the requirement.

4.4.7 Effect of Compaction Temperature on Voids in Mineral Aggregate (VMA)

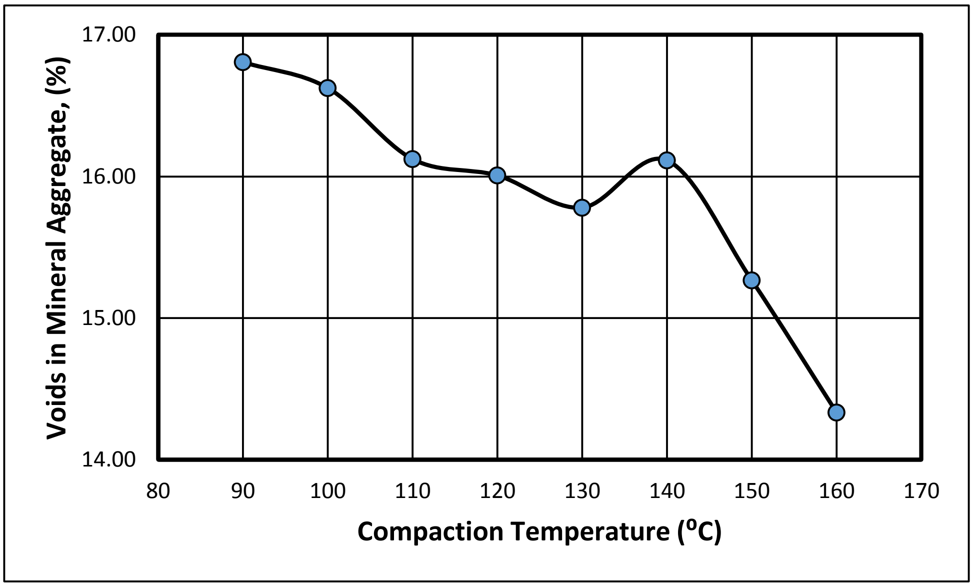

Figure 4.7: Relationship between Compaction Temperature and Voids in Mineral Aggregate (VMA).

Figure 4.7 above shows that as compaction temperature decreases, the VMA values increases. The value of percentage VMA was (16.12%) at 110^{0}C, and increased to (16.81%) at 90^{0}C. As the compaction temperature increase, the value slightly decrease.

This can conclude that the changed in percentage VMA are significantly affected at compaction temperature less than 110^{0}C. This may be attributed to that the asphalt specimen is difficult as the temperature decrease because bitumen viscosity is significantly increases.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

At the end of this study, the effect of compaction temperature on the Marshall Properties of asphaltic concrete already be determined. This study focused on the effect of different compaction temperature on the Marshall Properties of asphaltic concrete that were studied and tested at the laboratory. There are different results as the compaction temperature will be vary.

The data that has been gained from the laboratory experiment are analyzed to catch the effect of compaction temperature on the Marshall Properties of asphaltic concrete. With following the JKR standards, the result of this study can be contributed back to the industry by providing the necessary result that can help the industry to a better system and also increase the efficiency. It is found that the optimum compaction temperature for the asphaltic concrete is at 150^{o}C.

5.1.1 Physical Properties of Aggregates

1. Specific gravity of granite is 2.61.

2. Water absorption of granite is 1.15.

5.1.2 Laboratory Investigation Results

It concluded that the compaction temperature really impact/effect the Marshall Properties of asphaltic concrete.

The effect of compaction temperatures on the Marshall Properties of asphaltic concrete has been found.

The conclusion can be summarized as follow:

1. The Marshall Stability value shows that as the compaction temperature decrease from (150^{o}C to 140^{o}C) the stability values is sharply decrease, and as the compaction temperature decrease from (140^{o}C to 90^{o}C) the stability values is gradually decreases. Where, the value of Marshall Stability at compaction temperature (150^{o}C) is about 29% higher than if compared at (140^{o}C), and 34% if compacted at (120^{o}C) and 38% if compacted at (110^{o}C), while it increases to 56% if compacted at (90^{o}C). From compaction temperature (160^{o}C to 150^{o}C) the stability values is also sharply decrease as it shows that the compaction temperature at (150^{o}C) is the optimum compaction temperature.
2. The Flow value is about the same for compaction temperatures rages between (150 to 110^{o}C), then as the compaction temperature decrease from (110^{o}C to 90^{o}C), the flow values increase.
3. It is found that when compaction temperature decreases from (160^{o}C to 140^{o}C) the density values is sharply decreases. At compaction temperature from (140^{o}C to 100^{o}C) the density constantly decreases. As the compaction temperature decreases from (90 ^{o}C), the bitumen viscosity is so high that the asphalt mixture is not workable so, the density is slowly decrease.
4. Marshall Stiffness value is sharply decrease from compaction temperature (150^{o}C to 140^{o}C). The value is constantly decreased as the compaction temperature decrease for temperature ranges from (140 to 110^{o}C). As the compaction temperature decrease in from (110^{o}C to 90^{o}C) the Marshall Stiffness values sharply decrease.

5. Air Voids results are aligned with the density results where increasing in the density will produce lesser porosity. Voids in the total mix is the parameter which indicates the porosity of the mixture.

5.1.3 JKR Requirement Results

The laboratory results shall conform to the JKR requirement and the conclusion as compared to the requirement can be summarized as below:

1. The Marshall Stability value need to be more than 8kN and only Marshall Stability value of compaction temperature at 160^{o}C and 150^{o}C conformed to the requirement.
2. The Flow value need to be in ranges of (2.0mm – 4.0mm) and only Marshall Flow values of compaction temperature at 160^{o}C to 110^{o}C conformed to the requirement.
3. The Marshall Stiffness value need to be in more than 2kN/mm and only Marshall Flow values of compaction temperature at 160^{o}C and 150^{o}C conformed to the requirement.
4. The Air Voids value need to be in ranges of (3.0% – 5.0%) and only Air Voids values of compaction temperature at 150^{0}C to 110^{0}C conformed to the requirement.
5. The Voids Filled with Bitumen value need to be in ranges of (70% – 80%) and only Voids Filled with Bitumen values of compaction temperature at 150^{0}C to 110^{0}C conformed to the requirement.

5.2 Recommendations

This project should continually offer in the future. This research should be done much detail in order to have the precise value. More study can be continued from this research to find its fatigue and tensile value.

It would be strongly recommend that the optimum allowable temperature for compaction must not less than 150^{o}C for laboratory uses. For future study, the percentage of bitumen content can varies followed by JKT standards of (4.0% - 6.0%) for AW 14.

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