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EFFECT OF CRUDE PALM OIL
(CPO) AS AN ALTERNATIVE ADDITIVE TO THE BINDER IN
ASPHALT MIXTURE

MOHAMAD KHAIDIER BIN MOHD RAFFI

Thesis submitted in fulfillment of the requirements
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ABSTRAK

Asfalt campuran suam (WMA) yang dihasilkan pada suhu yang lebih rendah daripada panas-campuran asfalt (HMA) untuk mengurangkan suhu asfalt untuk tujuan kos tenaga boleh disimpan. Suhu pengeluaran untuk memanaskan campuran asfalt biasanya sekitar 130 ° C hingga 150 ° C. Objektif kertas kajian ini memberikan potensi kajian selain minyak sawit mentah (CPO) sebagai bahan tambahan untuk asfalt campuran turapan. Jumlah reka bentuk campuran konkrit asfalt dengan tambahan 0.5% daripada CPO telah disediakan mengikut spesifikasi JKR. Penggredan digunakan adalah AC 14 untuk menentukan kawalan kandungan asfalt optimum. Pencampuran dan pemadatan suhu telah dipilih di 120,130,140ºC. Semasa pencampuran, yang telah ditentukan kandungan asfalt optimum iaitu 5% dan 0.5% daripada CPO OAC ditambah ke dalam campuran konkrit asfalt. Semua sampel campuran adalah berdasarkan Kaedah Campuran Marshall. Dalam kajian ini, sifat-sifat isipadu seperti lompang dalam jumlah campuran (VTM), lompang dipenuhi dengan asphalt (VFA), ketumpatan pukal (Gmb) dan lompang dalam agregat mineral (VMA) telah dikaji. Dalam kajian ini, penambahan kandungan minyak sawit mentah (CPO) adalah alternatif kepada asfalt konvensional kerana ia boleh dihasilkan pada suhu rendah kira-kira 120 ° C.

ABSTRACT

Warm mix asphalt (WMA) produced in the lower temperature than Hot-mix asphalt (HMA) to reduce the temperature of asphalt for purpose of energy costs can be saved. The production temperatures for warm-mix asphalt are normally around 130°C to 150°C. The objective of this research paper presents a study potential of addition Crude Palm Oil (CPO) as additive to asphalt pavement mix. A total of asphaltic concrete mix designs with 0.5% addition of CPO were prepared in accordance with the JKR Specification. The gradations used are AC 14 to determine the control optimum asphalt content. The mixing and compaction temperatures were selected at 120,130,140°C. During mixing, the determined optimum asphalt content which is 5% and 0.5% of CPO of OAC added into asphaltic concrete mix. All the mix samples were based on the Marshall Mix Design Method. In this study, the volumetric properties such as voids in Total Mix (VTM), voids filled with Asphalt (VFA), bulk density (Gmb) and voids in mineral aggregates (VMA) were investigated. In this study, addition of Crude Palm Oil (CPO) content is an alternative to the conventional asphalt as it can be produced at lower temperatures of about 120°C.

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LIST OF ABBREVIATIONS

AC10	asphaltic concrete with NMAS of 10mm
AC14	asphaltic concrete with NMAS of 14mm
WMA	Warm mix asphalt
HMA	Hot mix asphalt
PM	Particulate matter
CPO	Crude Palm Oil
JKR	Jabatan Kerja Raya
CO2	Carbon Dioxide
NOx	Nitrogen Oxide
SO2	Sulphate Dioxide
CO	Carbon Oxide
DAT	Dispersed Asphalt Technology
SSD	Saturated Surface Dry
LA	Los Angeles
VTM	Voids in Total Mix
AASHTO	American Association of State Highway and Transportation Official
VMA	Voids in Mineral Aggregates
VFA	Void filled Mineral Asphalt
ASTM	American Society for Testing and Materials
MS	Malaysia Standard
Gm	Specific Gravity of Mix
VS	Versus

CHAPTER 1

INTRODUCTION

1.1 Introduction

Asphalt mixture is composite material commonly technology used in road construction industry like surface of roads, airport runway, parking lots and etc. To provide the best performance to different sectors, many varieties of asphalt mixes can be offered. There are three different type of asphalt mixture carry out in pavement construction which Hot Mix Asphalt (HMA), cold mix asphalt and Warm Mix Asphalt (WMA). Warm Mix Asphalt (WMA) is the one of the most popular paving material used on site nowadays because of it's a uniformly mixed combination of coarse aggregate, fine aggregate, asphalt binder and other type of asphalt mixture (Ezree, 2014).

Paving and compaction during process of pavement production of hot mix asphalt must be performed during the asphalt sufficiently hot. Production of HMA resulting high energy (fuel) used that cause high cost of production and greenhouse effect. The WMA introduce to the process of pavement production at lower temperature where according to Asphalt Institute, this technology is produced at temperatures of approximately 25–30°C less than HMA due to chemical composition changes during the mixing process which warm-mix asphalt are normally around 130°C to 150°C compared to HMA which is around 160°C and above.

Several laboratory studies have been conducted on mixes containing the warm asphalt additives. However, it is a known fact that the properties of the aggregates and the binders used can also affect the properties of the mixtures. Thus, a thorough understanding of the properties and performance of WMA is necessary in order to implement it successfully, especially, since it is an emerging technology. The significance of this research was to investigate the effects of different aggregate and binder sources on the properties of WMA and to study the properties of the binders containing the warm asphalt additives in great detail. This is important as not much research has been conducted to investigate the effects of adding the warm asphalt additives to the binders to date. Also, binders behave differently at different temperatures, and thus, it was important to study the properties of the binders containing the warm asphalt additives at high, mid-range and low temperatures (Gandhi, 2008). Another importance of this research was to evaluate the aging characteristics of the warm asphalt binders and mixtures. Since the first warm asphalt field trial was conducted as recently as 1999, the long term performance and the aging characteristics of the WMA are not known in great detail. This research addresses some of the issues related to the aging of WMA.

WMA innovation appears to be quite promising. It consumes 30% less energy, reduces carbon dioxide emission by 30%, and reduces dust emission by 50-60% compared to hot mix asphalt (Das *et al.*,2008). This WMA innovation result in reduction of production temperatures, less releasing carbon dioxide, aerosols and vapours thus reduce odour emission from plants. This can summarize that WMA technology show significantly reduced the cost of production and as a powerful tools to achieve sustainability.

1.2 Problem Statement

Production of hot mix asphalt (HMA) need high energy which mean hot temperature needed for compaction and paving. The heat release during production will cause heat trapped by the greenhouse gases in the atmosphere leads to more heating and consequently, resulting higher temperature of the earth (Goh, 2011). Nevertheless, without this natural effect, the earth's surface temperature would dramatically decrease below freezing temperature. The past study stated that this effect can be linked directly to the increasing of greenhouse gases such as carbon dioxide, methane and nitrous oxide from human activities. Hence, this will aggravate the global warming that cause's climate change and rising of the sea levels. Global warming is primarily an important issue to be concerned of for the sake of us and our children in the future. The highlighted major problem statement is stated below:

- The high temperature can emitted the pollution dust, particulate matter (PM), fumes and variety of gaseous to environment such as carbon monoxide, nitrogen oxides and sulphur dioxide. These gases contribute to the global warming problems.
- High temperature mixing cause an increasing energy usage which is high burner fuel required to heat aggregates.

1.3 Objective

The main objective of the research project was to evaluate the effects of the warm asphalt additive which crude palm oil (CPO) on the properties of asphalt binders and mixtures. The specific objectives of the research project included the following.

- To determine the properties of mix design with addition of CPO through Marshall Test.
- To determine the physical properties (Stability and flow value) at different temperature for asphalt mixture with and without the addition of CPO.

1.4 Significance of Study

The significance of this research will be as follows:

- Allows significant lowering of the production and paving temperature by reducing the viscosity of bitumen and/or increasing the workability of mixture
- Lowering the greenhouse gas emissions, lowering energy consumption, improved working conditions, better workability and compaction without compromising the performance of asphalt.
- Another aspect that will be investigated is the characteristics of the warm asphalt. While it is important to study the effects of various factors affecting WMA, it is also important to investigate the effects of aging on the properties of WMA and the warm asphalt binder. Since the aging of warm asphalt mixtures and binders have not been studied in great detail, it is proposed to study the effects of aging on warm asphalt mixtures and binders in this research study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Asphalt mixture is the most common paving material used around the world because of its uniformly mixed combination between coarse and fine aggregate, asphalt binder, filler and other type of mixture materials. Nowadays, warm mix asphalt technology is getting more attention around the world and this opportunity lead to an increasing of research to determine the possibility of this innovation. WMA can be produced at lower temperature without fundamentally affecting the quality of mixes. Instead of improving energy efficiency by reduction of temperature of production, odour emission from plants also can be reduce to improve the air quality. There several technologies that have been developed and used in production of WMA which is addition of additive .Crude palm oil seem to be quiet potential to be an additive in asphalt mixture to produce WMA. In this research, crude palm oil was used as additive to achieve warm mix asphalt.

2.2 Advantages and Disadvantages of WMA

WMA technology has always been recognized among local authorities, researchers and pavement industries. WMA shows great potential in advantages compared to HMA. WMA promise several advantages including some aspects of the benefits which are environmental benefits, economic benefits, construction benefits, and recycling benefits.

Generally, electricity, fossil fuels, mining, iron and steel, chemical industrial, paper and also asphalt mixing are considered as the energy-intensive industries. Asphalt mixing can be considered as one of the most energy-intensive process compared to the other industrial activities. During the mixing process, the energy consumed was about 60% of the total energy required for the construction and maintenance of a given road over a typical service life of 30 years (Ezree, 2014). Thus, a significant advantage of WMA is the reduction mixing and compaction temperature. The processes of WMA reduce about 20°C to 40 °C lower than standard HMA process. Lowering of temperature result the reduction of energy (fuel) usage and indirectly decrease the odour emission which related to the fuel use. According to the Bitumen Forum (D'Angelo, 2008), there are virtually no asphalt emissions at temperatures below 80°C. At about 150°C, the emissions recorded were only about 1mg h-1 whereas significant emissions were recorded at 180°C. Certain pollutant like CO2, NOx and SO2 significantly drop connected to the WMA temperature production. Table 2-1 shows the reduction of emissions due to the implementation of WMA technology.

Air Pollutant Gaseous	Reduction Measured as Compared to HMA
CO2	15 to 40%
SO2	18 to 35%
NOX	18 to 70%
CO	10 to 30%
Dust	25 to 55%

Table 2.1: Emission reduction when implementation of WMA

Reduction of emissions can be beneficial to the workers that exposed to the fumes which is produced during asphalt paving process. The less of emission will lead to the improvement of working conditions that will negatively affected by emissions. Workers' exposure to emission is more critical for paving project in closed area like tunnels. Hence, the use of WMA processes can effectively reduce the production of these fumes which consequently reducing exposure to many people especially the paving crews, contractors, local authorities and also the public.

Studies conducted at National Center for Asphalt Technology (NCAT) (Hurley and Prowell, 2005) indicate that as the mixing temperatures are reduced for WMA, the mixes show increased tendencies towards rutting and moisture susceptibility. This is as a result of the aggregates used in the mix not drying completely. Thus, the WMA producers should seek the right balance between lowering the mixing temperatures, using sufficient amount of anti-stripping agents and sufficiently drying the aggregates used in the mixes.

2.3 Available Warm Asphalt Technologies

WMA was first developed and used in Europe through four distinct technologies, all of which are proprietary. All of this availability of several proprietary chemicals and processes has been tested to produce warm asphalt which is possible to produce warm asphalt without affecting the properties of the mix. Some of the most common processes / chemicals available today are as described below.

2.3.1 Asphamin®

Aspha-Min® as known as zeolite which is a Sodium – Aluminum – Silicate a finely granulated which has been hydro thermally crystallized. Contains about 21% crystalline water by weight and is added to the mixture at a rate of 0.3% by weight of the mixture. A synthetic zeolite is added at the plant at the same time as the binder during mixing. By adding it to the mixture at the same time as the binder, a very fine water spray is created as all the crystalline water is released, which causes volume expansion in the binder, thereby increasing the workability and compatibility of the mixture at lower temperatures. It has been reported, by the manufacturer, that a reduction of about 25 to 30 °C (40 to 50 °F) has been observed (Gandhi, 2008). The zeolite releases internal water to microscopically foam the binder, decreasing the viscosity of the binder and increasing the workability of the mix and enhance compaction of asphalt.

2.3.2 Evotherm™

Evotherm is a water-free uses a chemical additive technology and a "Dispersed Asphalt Technology", (DAT), delivery system. The producer states that by using this technology a unique chemistry customized for aggregate compatibility is delivered into a dispersed asphalt phase (emulsion). It is designed to allow the production and compaction of high quality asphalt pavements at reduced temperatures which is reported that field testing demonstrated it is about 50 to 90°F lower than conventional hot mix asphalt (HMA). Evotherm WMA enables asphalt to better aggregate coating at reduced temperatures while also lubricating the mix to improve workability, adhesion, and improved compaction without change in materials or job mix formula required. Evotherm improves adhesion at the asphalt-aggregate interface thereby addressing water sensitivity issues. Mixes made with Evotherm consistently achieve roadway densities more easily than conventional HMA. Evotherm was created to suit all types of asphalt binders including neat, polymer modified, rubberized asphalt, and PPA modified.

2.3.3 Foamed Asphalt

Combining hot asphalt binder with small amounts of cold water formed foamed asphalt. When the cold water injected into the hot asphalt binder it turns to steam, which trapped into tiny asphalt binder bubbles and resulting in spontaneous foaming. However it is only last for less than a minute and the asphalt continue to its original properties. In order to produce foamed asphalt, the bitumen has to be incorporated into the aggregates while still in its foamed state (Muthe, 1998). This process makes it possible to produce the asphalt mixture at temperatures between 100°C and 120°C (212 and 250 °F) and compact it at 80 to 110°C (175 to 230 °F) *(Koenders et al. 2000)*. The manufacture claims that this process can reduce the fuel consumption by as much as 11% *(Astec Inc., 2007)*.

2.3.4 Sasobit®

Sasobit is a fine crystalline long chain aliphatic hydrocarbon (chain lengths of 40 to 115 carbon atoms) manufactured from coal gasification by using the Fischer – Tropsch process. It also known as wax which is not that naturally found in liquid asphalt. Sasobit is available in a solid form which is a prill (about 5mm in diameter), small prill (1mm in diameter), and flaked form (3mm in diameter). Sasobit can be define as an 'asphalt improver' because of ability to lower the viscosity of the asphalt binder and acts as flow modifier. By lowering in viscosity allows working temperatures to be decreased by 18°C - 54°C (Hurley and Prowell, 2005). During in its liquid state, this modification allows aggregate to move more freely in the binder. When Sasobit cools and crystallizes it forms a uniform network structure in the binder that lead to the added stability. Throughout the production of HMA, Sasol recommends that Sasobit can be added at a rate of 0.8 percent or more by mass of binder, but not exceeding 3 % (Arshad, *et. al*, 2012).

2.4 Crude Palm Oil (CPO)

Crude Palm oil is edible oil extracted from the pulp of fruit of oil palm which is natural oils. Crude palm oil is the purified and organic oil that is extracted from the kernel. As with all crude oils, CPO has non-glyceride components such as trace metals, kernel shell pieces and products of oxidation. When a palm kernel is harvested, smashed and heated, 'cloudy' oil first produced. What comes out of this initial process is crude palm oil, which is much thicker, lumpier and full of many inedible components. Crude palm oil goes through a purification phase to remove the unwanted components to smooth out the oils. No chemical process included in the process and it still remains natural and organic oils.

2.5 CPO as new additive in WMA technologies

Malaysia is the one of world's leading producer and exporter of palm oil products with a reputation for quality and consistency. According to The Star Online (2013), in 2012, Malaysia, the world's second largest producer of palm oil produced 18.79 million tonnes of crude palm oil on roughly 5,000,000 hectares (19,000 sq mi) of land. Therefore, it is easy to find CPO resources compare to other additives. CPO has high oxidative stability characteristic. In pursuit of green technology, high attention has been compensated to the environment. As such, the reduction in emission of carbon dioxide for preventing global warming is becoming an international interest. This carbon dioxide emission reduction draws attention because of a possibility of creating a commercial value called carbon emission rights in addition to the prevention of global warming (Hwang, et al, 2011). Provide a low of carbon, CPO have high potential to be new additive to achieve the high characteristic of WMA due to capable of reducing mixture and compaction temperatures of the WMA and the decrease of carbon emission rights in addition to avoiding of global warming.

2.6 Bitumen

Bitumen is a dark-colored solid, semi-solid, viscous, nebulous, and cementitious material available in different forms, such us rock asphalt, natural bitumen, tar and bitumen derived from oil, which is referred to as petroleum bitumen. Bitumen is a composite material with a complex response to stress characteristic. The response of bitumen to stress is dependent on both temperature and loading time and the degree to which their behaviour is viscous and elastic is a function of both temperature and loading time (Zaumanis, 2010). Bitumen behaves as viscous liquid at high temperatures and when at very low temperatures or short times of loading they behave as elastic solids (Whiteoak, *et al,* 2003). Shifting bitumen's visco-elastic characteristics in manufacture and in-service temperatures is one of the main parts of the WMA technologies.

Addition of additives in bitumen modification or reduction of the bitumen viscosity in production and paving temperatures results in reduction of the temperature in which bitumen is still workable. Therefore, it is important to have solid knowledge about bitumen properties and their influence on the visco-elastic behaviour of binder in order to determine the right production and paving temperature and predict asphalts behaviour for long term in-service life.

2.7 Temperature

Consistency at low temperature is an issue of WMA carrying out in countries with cold winter climate. Thus, temperature play main role in implementing WMA technology. Experiments have shown poorer low temperature behavior (increased brittleness) of organic WMA technology, because of crystallization of the waxes (Hurley et al., 2006). This should be taken into account when choosing WMA technology and the amount of additives in the mix.

2.8 Measurement of Compaction

In asphalt asphalt mix design, the essential property to evaluate the mix is the volumetric properties. Marshall and Superpave mix design endorsed the volumetric properties either for laboratory compacted samples or on-site cored samples. The fundamental volumetric properties of a compacted asphalt mixture are air voids, voids in mineral aggregate, voids filled with bitumen, and effective bitumen content (Lavin, 2003). Other volumetric properties can be further elaborated in Figure 2.4.

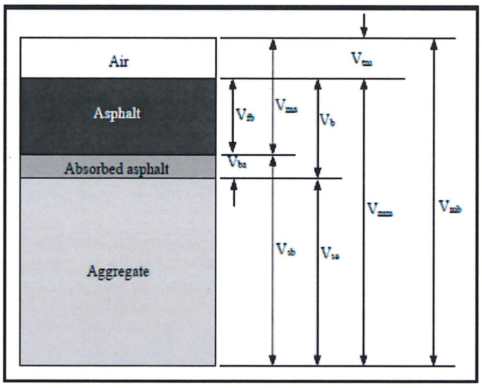

Figure 2.1: Volumetric diagram

As such, volumetric properties are based on weight-volume relationships. This can be traced to the contribution of Mc Leod (1956) where he pointed out that the design and analysis of asphalt paving mixtures should be based on volumetric properties instead of using the basis of weight as have been practiced widely at that time. Most specifications in those days tended to specify a range of asphalt content by weight along with grading bands or limits for the aggregate, which in effect required a design on the basis of weight. The most serious problem concerning the design of bituminous paving mixtures in Canada is found to be the coarse and fine aggregate combinations, which resulted in a too densely graded mix. He developed the volumetric criteria such as VMA, VFA, and volume of air voids and reported that it contain errors when calculated by weight (Kandhal, Foo, and Mallick, 1956). reported that McLeod worked with Marshall hammer of 75 blows, and recommended that the VMA should be restricted to a minimum value of 15%, the volume of air voids (within the VMA) should lie between 3 to 5%, which in turn restricted the volume of asphalt binder in the compacted mixture to a permissible minimum of 10% by volume. This automatically established minimum asphalt content of about 4.5% by weight (10% by volume). High air voids lead to permeability of water and air resulting in water damage, oxidation, and cracking. Low air voids lead to rutting and shoving of the asphalt mixture (Brown, 1990).

2.9 Viscosity

Viscosity change (reduction on high temperatures and for some additives increasing at low temperatures) of the binder is the main principle that makes it possible to produce asphalt at lower temperatures with sufficient aggregate coating and with no loss of workability in paving temperature (Zaumanis, 2010). It is important to determine the temperature ranges for compaction and mixing of mixtures between the temperature and viscosity relationship for binder.

2.10 Specific Gravity

Specific gravity is a ratio of the mass of a material of a given volume to the weight of an equal volume of water, both at same temperature. The specific gravity of a material is used to bridge the gap between weight and volume relationship in asphalt mixture design. Lavin (2003) stated five different types of specific gravity measurements used in the volumetric analysis of asphalt mixtures:

- Apparent specific gravity, Gsa: the ratio of the mass in air of a unit volume of an impermeable aggregate or stone at a stated temperature.

- Bulk specific gravity, Gsb: the ratio of the mass in air of a unit volume of a permeable (including both permeable and impermeable voids) aggregate at a stated temperature.

- Effective specific gravity Gse: the ratio of the mass in air of a unit volume of permeable (excluding voids permeable to the asphalt binder) aggregate at a stated temperature.

- Bulk specific gravity of the compacted asphalt mixture, Gmb: the ratio of the mass in air of a unit volume of a compacted specimen of an asphalt mixture at a stated temperature.

- Theoretical maximum specific gravity of an asphalt mixture, TMD: the ratio of the mass in air of a unit an uncompacted or loose asphalt mixture at a stated temperature. It is also known as the Rice specific gravity, named after James Rice, the developer of the test procedure to measure the maximum specific gravity.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The purpose of this study was to look into the effectiveness of CPO as partial replacement as additive for binder in asphalt mixture in different temperature. This study used the Superpave method as published by National Asphalt Paving Association along with the Public Works Department of Malaysia's specifications (JKR/SPJ/2008-S4) for the different type of mixes. The type of mixes that were designed are AC14. The specimens were subjected to compaction by the Marshall Compactor given 50 blows each top and bottom surfaces. Specimens were prepared in two phase where phase one is preparation of control samples with fixed temperature, 160°C for mixing and compaction. For phase two, specimens by addition of 0.5% CPO were prepared with three different temperature which are 120, 130, 140 °C for mixing and 10 °C were reduced during compaction.

All tests were conducted at Universiti Malaysia Pahang's Transportation Laboratory. Tests were conducted on the aggregates, bitumen, and compacted mix in order to obtain the properties of all the mixes.

3.2 Operational Framework

The laboratory work consisted of two phases of tests with the first being tests done prior to mixing and second series being the tests done on prepared specimens. The tests to be conducted for the first series are sieve analysis, and determination of specific gravity for aggregate. LA abrasion test was conducted to determine the percentage wear of aggregates which reflects their resistance to degradation. Aggregate blending satisfying the JKR gradation limits were used. Subsequently, the process of specific gravity determination for coarse and fine aggregate took place. Bitumen of 80-100 PEN was used in this study. Softening point test and penetration of bituminous test were conducted.

The second phase involved the mix design. A total of 15 specimens for control and 15 modified specimens were prepared. The sample preparation incorporates specifying the mixing and compaction temperatures, sample shot-term aging, and determining the optimum bitumen content. The specimens is measured and weighed in air, water and saturated surface dry (SSD). A few testing will be carried out for the asphalt mix which includes density and void analysis (ASTM D2726), Marshall Stability and flow test (ASTM D4123) to determine the bulk specific gravity of the mix, voids in total mix (VTM), voids in mineral aggregates (VMA) and voids filled mineral asphalt (VFA), stability and flow values. The general procedures for laboratory work are illustrated in Figure 3.1.

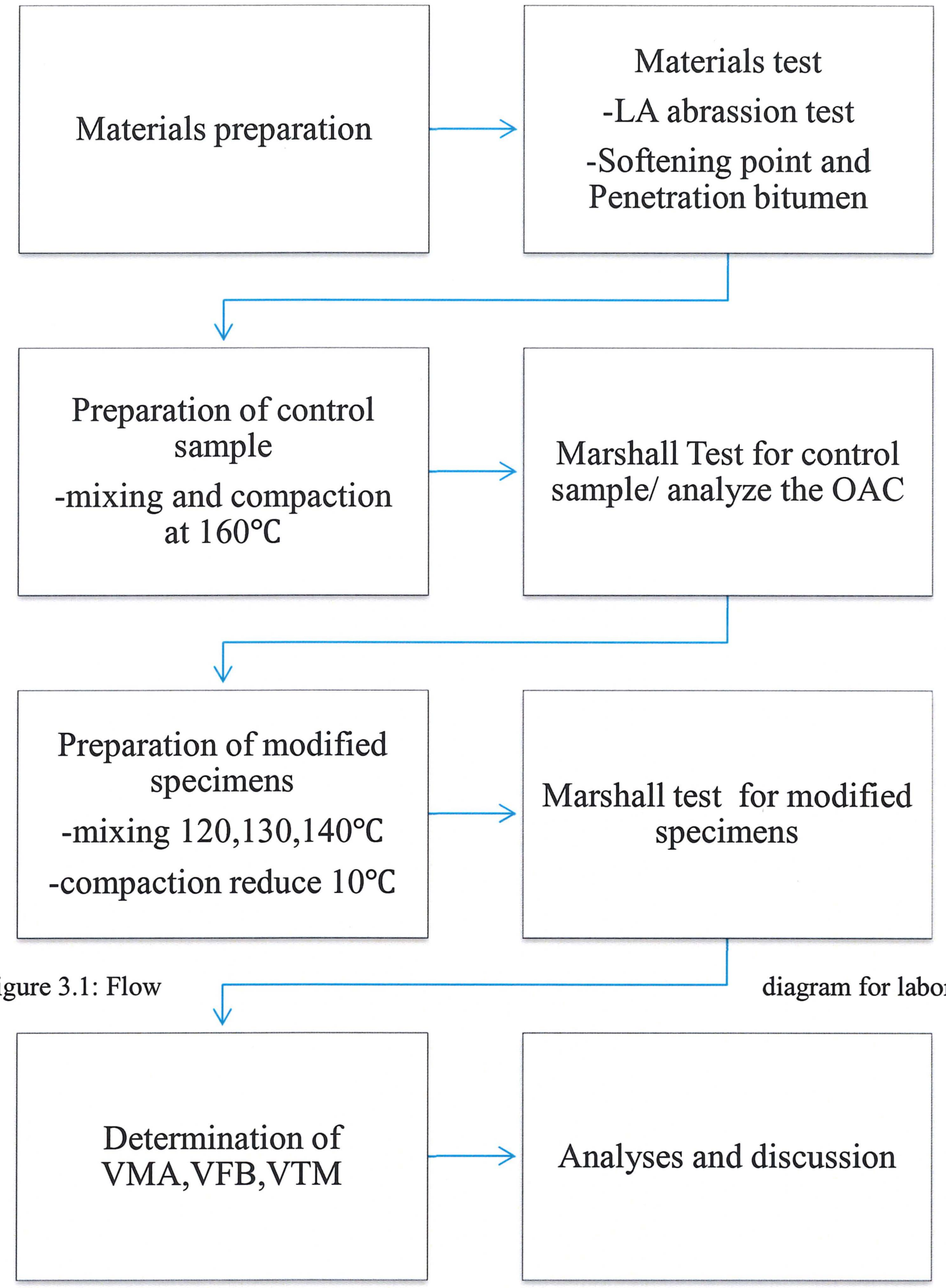

Figure 3.1: Flow diagram for laboratory analysis process

3.3 Preparation of Asphalt Mix

Materials that are going to be used for this study are aggregate, bituminous binder, filler, and crude palm oil (CPO). All materials are to be prepared in accordance with the Standard Specification for Roadworks published by JKR (JKR/SPJ/2008-S4).

3.3.1 Aggregates

According to JKR/SPJ/rev2005, aggregate for asphaltic concrete shall be a mixture of coarse and fine aggregates, and mineral filler. The individual aggregate shall be of sizes suitable for blending to produce the required gradation of combined aggregates.

Course aggregates shall be screened crushed hard rock, angular in shape and free from dust, clay, vegetative and other organic matter and other deleterious substances. The LA abrasion value when tested in accordance with ASTM C131 shall be not more than 25%, the weighted average loss of weight in magnesium sulphate soundness test when tested in accordance with AASHTO Test Method T 101 shall be not more than 18%, the flakiness index when tested in accordance with MS 30 shall be not more than 25%, the water absorption when tested in accordance with MS 30 shall be not more than 2% and the polished stone value when tested in accordance with MS 30 shall be not less than 40%.

Fine aggregate shall be clean screened quarry dust. Fine aggregate also mustn't be non-plastic and free from clay, loam, aggregation of material, vegetative and other organic matter, and other deleterious substances. It is also must follow the physical and mechanical quality requirements; where the sand equivalent of aggregate fraction passing the No. (4.75 mm) sieve when tested in accordance with ASTM D 2419 must not less than 45%, angularity when tested in accordance ASTM C 1245 shall not less than 45%, and the water absorption when tested in accordance with MS 30 shall not be more than 2%.

3.3.2 Mineral filler

Mineral filler used for this study was limestone, which was sufficiently dry and essentially free from agglomerations and effect to the properties of mastics. The mineral filler also served the purpose as an anti-stripping agent and that of filling voids in coarser aggregates, which increases the density, stability and toughness of a conventional bituminous paving mixture (Lee, 1964).

3.3.3 Bituminous Binder

Bituminous binder used for asphaltic concrete was bitumen of penetration grade 80-100, which accommodated to MS 124. The specific gravity for bitumen was 1.03.

3.4 Aggregates blending

Aggregates blending is the process that intermixing two or more aggregates to produce a combination with improved grading or other properties. In specific, it is the process of proportioning the aggregates to obtain the desired gradation that were well within the range of the gradation limits. Table 3.1 shown the gradation limits for the mixes that were prepared as specified by JKR/SPJ/2008-S4. In this study, the mixes that be prepared are AC 14. The mixes combined coarse aggregates, fine aggregates and mineral filler and shall produce a smooth curve within the appropriate gradation envelope.

Mix Type	Wearing Course	Wearing Course	Binder Course
Mix Designation	AC 10	AC 14	AC 28
BS Sieve Size (mm)	Percentage Passing by Weight		
28.0			100
20.0		100	72 - 90
14.0	100	90 - 100	58 - 76
10.0	90 - 100	76 - 86	48 - 64
5.0	58 - 72	50 - 62	30 - 46
3.35	48 - 64	40 - 54	24 - 40
1.18	22 - 40	18 - 34	14 - 28
0.425	12 - 26	12 - 24	8 - 20
0.150	6 - 14	6 - 14	4 - 10
0.075	4 - 8	4 - 8	3 - 7

Figure 3.2: Gradation limit for asphaltic concrete

3.5 Determination of Specific Gravity for Aggregate

The specific gravity of an aggregate provides a mean of expressing the weight-volume characteristics of material. Specific gravity for coarse and fine aggregate was determined separately. By coarse aggregate, it is the aggregates that are retained on the 4.75mm sieve while fine aggregates are those that passing 4.75mm sieve.

3.5.1 Coarse Aggregate

The procedure for determining specific gravity for coarse aggregate was in accordance with AASHTO T 85 and ASTM C 127. The apparatus needed were:

(i) Balance that is accurate to 0.5g of the sample weight;
(ii) Sample container;
(iii) Water tank; and
(iv) Sieves of 4.75mm sieve.

The procedure for determining specific gravity for coarse aggregate was as follow:

I. The aggregate was weighed and washed so as to clean it from dust.
II. The aggregate was soaked in water for 24 hours.
III. After 24 hours, the aggregate was weighed together with the water and the mass is recorded as 'A'.
IV. The aggregate was dried with a damp towel until it was saturated surface dry and was weighed again. The mass of aggregate was recorded as 'B'.

V. Subsequently, the aggregate was dried in an oven for 24 hours at 110±5°C and cooled before weighing for the third time and the mass of aggregate was recorded as 'C'.

VI. Specific gravity for coarse aggregate was determined with the following formula:

$$\text{Specific Gravity (Coarse Aggregate)} = \frac{C}{B-A} \quad 3.1$$

Where,

A = Weight of aggregate in water, g

B = Weight of saturated surface dry aggregate in air, g

C = Weight of oven dry aggregate, g

3.5.2 Fine Aggregate

The procedure for determining specific gravity for fine aggregate was in accordance with AASHTO T 84 and ASTM C 128.

The apparatus needed were:

(i) Balance having the capacity of 1kg with the accuracy of 0.1g;

(ii) Pycnometer;

(iii) Mould in the form of a frustrum of a cone with dimensions as follow: 40±3mm inside diameter at the top, 90±3mm inside diameter at the bottm, and 75±3mm in height; and

(iv) Tamper weighing 340±15g and having a flat circular face 25±3mm in diameter

The procedure for determining the specific gravity of fine aggregate were as follow:

(i) A ¾ filled pycnometer was weighed and recorded as 'A'.

(ii) The water was poured away until the pycnometer is left to about ¼ filled. About 500g fine aggregate was added in and shake well to get rid of the air.

(iii) Again, the pycnometer is filled with water until the original level of ¾ of its volume. The pycnometer was weighed and record as 'B'.

(iv) The aggregate was dried in an oven until the aggregate achieve a constant weight. The oven dry aggregate was weighed and recorded as 'C'.

(v) The aggregate was mixed with water until the aggregate sticks together. Then, the cone test was performed. If about 1/3 of the aggregate slumps after 25 light drops of tamper about 5mm above the top surface of the fine aggregate in a cone, the aggregate is saturated surface dry. The weight of saturated surface dry aggregate was weighed record as 'D'.

(vi) Specific gravity for fine aggregate were determined with the following formula:

$$\text{Specific Gravity (Fine Aggregate)} = \frac{C}{D-(B-A)} \qquad 3.2$$

Where,

A = Weight of pycnometer filled with water,g

B = Weight of pycnometer with water and aggregate, g

C = Weight of oven dry aggregate in air, g

D = Weight of saturated surface aggregate

3.6 Marshall Mix Design

The Marshall Mix design method provides the performance prediction measure for the Marshall stability and flow test. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is assigned as stability. During the loading, a connected dial gauge measures the specimen's plastic flow (deformation) due to the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded. The important steps involved in the marshal mix design are summarized next.

3.6.1 Specimen preparation

About 1200g of aggregates and filler is heated at different temperature of 120, 130 and 140□ about 24 hours. Bitumen are heated to a temperature of same as heated aggregates. The heated aggregates and bitumen are thoroughly mixed together at temperature 120, 130 and 140□. Then, the mix is placed in a preheated mould and compacted by a hammer with 75 blows on either side at temperature of reducing 10□ from mixing temperature. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness. The prepared mould is loaded in the Marshall test setup as shown in the Figure 3.6.1.

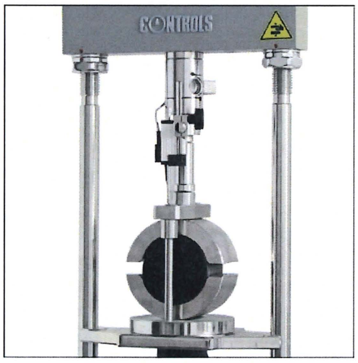

Figure 3.3: Marshall test setup

3.6.2 Apparatus

The apparatus needed for producing specimens were:

(i) Sieve shaker;

(ii) An oven to heat up the aggregates, bitumen and compaction mould;

(iii) Marshall mould to heating aggregates;

(iv) Container for heating bitumen;

(v) Mixing work;

(vi) Thermometer readable to 200□ for checking and maintaining the temperature during mixing and compaction;

(vii) Paper disc for compaction;

(viii) Water bath for curing the specimens;

(ix) Marshall Compression Machine;

3.6.3 Procedures

The procedure for specimen preparation listed below:

1) The aggregate about 1200g, graded according to ASTM or BS standard are over dried at 120, 130, and 140 for 24 hours.

2) The required quantity of asphalt is weighed our and heated to a temperature 110,120, and 130 for 24 hours.

3) The thoroughly cleaned mould is heated on a hot plate or in an oven to a temperature 120-140. This mould is 101.6mm diameter high and provided with a base plate and extension collar.

4) A crater is formed in the aggregate, the binder poured in and mixing carried out until all the aggregate is coated. The mixing temperature shall be within the limit set for the binder temperature.

5) A piece of filter paper is fitted in the bottom of the mould and the whole mix poured in three layers. The mix is then vigorously trowel 15 times round and the perimeter and 10 times in the center leaving a slightly rounded surface.

6) The mould is placed on the Marshall Compactor and give 75 blows either sides.

7) The specimen is then carefully removed from the mould after 24 hours and then marked.

8) The measure and weighed in air, water and saturated surface dry (SSD).

3.6.4 Properties of Mix

The properties that are of interest include the theoretical specific gravity Gt, the bulk specific gravity of the mix Gm, percent air voids Vv, percent volume of bitumen Vb, percent void in mixed aggregate VMA and percent voids filled with bitumen VFB. These calculations are discussed next. To understand these calculation a phase diagram is given in Figure 3.4.

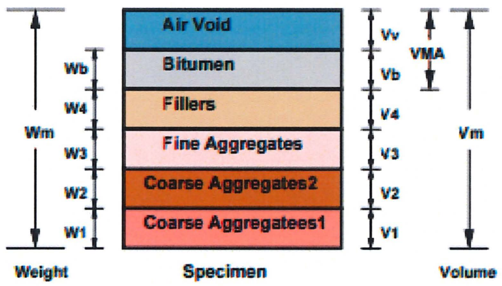

Figure 3.4: Phase diagram of bituminous mix

3.6.4.1 Theoretical specific gravity, Gt

Theoretical specific gravity Gt is the specific gravity without considering air voids, and is given by:

$$Gt = \frac{W1 + W2 + W3 + Wb}{\frac{W1}{G1} + \frac{W2}{G2} + \frac{W3}{G3} + \frac{W4}{G4}} \qquad 3.3$$

Where,

W1 = the weight of coarse aggregate in the total mix,

W2 = the weight of fine aggregate in the total mix,

W3 = the weight of filler in the total mix,

Wb = the weight of bitumen in the total mix,

G1 = the apparent specific gravity of coarse aggregate,

G2 = the apparent specific gravity of fine aggregate,

G3 = the apparent specific gravity of filler

Gb = the apparent specific gravity of bitumen

3.6.4.2 Bulk Specific Gravity of Mix, Gm

The bulk specific gravity or the actual specific gravity of the mix Gm is the specific gravity considering air voids and is found out by:

Bulk Density, d = Gm x ρw

$$Gm = [\frac{W_D}{W_{SSD} - W_{sub}}] \qquad 3.4$$

where,

W_{SSD} = the surface dry mass (g),

W_D = the weight of mix in air, Wsub is the weight of mix in water,

Note that Wm -Ww gives the volume of the mix. Sometimes to get accurate bulk specific gravity, the specimen is coated with thin film of paraffin wax, when weight is taken in the water. This, however requires to consider the weight and volume of wax in the calculations.

3.6.4.3 Voids in Total Mix (VTM)

The percentage of air voids in the mix is determined by firstly calculating the maximum theoretical density and then expressing the difference between it and the actual bulk density as a percentage of total volume.

$$VTM = \left[1 - \left(\frac{d}{TMD}\right)\right] x\ 100 \quad 3.5$$

$$TMD = G_{mm} x\ \rho_w \quad 3.6$$

$$G_{mm} = \left\{\frac{1}{\left[\left(\frac{1-P_b}{G_{se}}\right)+\frac{P_b}{G_b}\right]}\right\} \quad 3.7$$

Where:

d = bulk density,

ρ_w = density of water,

G_{mm} = maximum theoretical Specific Gravity of the mix,

TMD = maximum theoretical density (g/cm^3),

P_b = asphalt content, percent by weight of the mix,

G_{se} = effective specific gravity of the mix, G_b= Specific Gravity of asphalt cement

3.6.5 Voids in filled with Asphalt (VFA)

The volume of void in mineral aggregate VMA is an important factor for the mixture design.

$$VMA = 100\ x\ \{1 - [G_{mb}(1 - P_b)/\ G_{sb}]\} \quad 3.8$$

Where:

G_{mb} = bulk Specific Gravity of the mix

P_b = asphalt content, percent by weight of the mix

G_{sb} = bulk Specific Gravity of the aggregate

3.7 Summary

In this chapter, methodology were described that will be used for the study. All the data were obtained through laboratory testing. Tests that were conducted are dry and washed sieve analysis, aggregate blending, determination of specific gravity for coarse and fine aggregate, determination of bulk specific gravity, determination of theoretical maximum density, and finally, determining the properties. The properties include bulk specific gravity, theoretical maximum density, optimum bitumen content, voids in mineral aggregate, and voids filled with bitumen.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The aim of this study was to look into the effects of crude palm oil as additive to the properties of hot mix asphalt when designed with the Malaysian Standard Specification for Road Works (JKR/SPJ/2008-S4) but at the same time adopting the Superpave method as published by the National Asphalt Paving Association. The methodology used for this study has been discussed in Chapter 3.

This chapter presents the experimental results obtained in this study. First, the binder properties and the effects of the CPO on the binder properties are discussed. Rheological properties of the binders with and without the warm asphalt additives were measured at specific temperatures which are for control sample is 160°C and for modified asphalt mixture are 120, 130 and 140 °C. In addition, the binders were heated in the laboratory at 140°C freshly and the CPO was in sealed containers at room temperature to prevent oxidation and premature aging. Second, the properties of the modified asphalt mixture were evaluated, and compared with the properties of the control sample. Results of each procedure in determining the properties are presented in this chapter and will be further analyzed and discussed in depth.

4.2 Determination of Bulk Specific Gravity of Aggregate

The specific gravity test has been carried out for all the materials used in the study, including aggregates, mineral filler, and bitumen. The aggregates were divided into coarse and fine with the earlier defined as aggregates larger than 4.75mm and the latter being defined as aggregates smaller than 4.75mm until 0.075mm. This categorization is in accordance with ASTM standard. In this study, the specific gravity for the aggregates has been determined based on the gradation of AC14.

4.2.1 Specific Gravity of Bitumen

The bitumen provides the cohesive forces that hold the aggregate particles together. The cohesive forces grow with increasing bitumen viscosity. In this study, bitumen of 80/100 PEN has been used. Based on previous studies conducted at Transportation and Highway Laboratory of Universiti Malaysia Pahang, the specific gravity of bitumen is taken as 1.03. This value was used in the determination of effective specific gravity of aggregate.

4.2.2 Bulk Specific Gravity of Aggregate

The bulk specific gravity test is used to determine the specific gravity of a compacted sample by determining the ratio of its weight to the weight of an equal volume of water. The bulk specific gravity of aggregate, known as specific gravity of aggregate blend, studies conducted at the Transportation and Highway Laboratory of Universiti Malaysia Pahang has found that specific gravity of aggregate is 2.46.

4.3 Result and Discussion of the Properties

In this chapter, the results of properties obtained from the tests and study are shown. 0.5% CPO were substituted to optimum asphalt content which is 5.0% which become 4.5% bitumen + 0.5% CPO from total weight of aggregate. Each samples where mixed and compacted with 120, 130 and 140□.

4.3.1 Marshall Mix Design for Control

The procedure and requirements of JKR/SPJ/2008-S4 is taken into consideration for preparing three samples at different bitumen content within the range shown in Table 4.1 which are 4.0, 4.5, 5, 5.5 and 6.0 % at AC 14 gradation mix design at mixing temperature of 160 °C accordance with ASTM D 1559 using 75/blows face compaction standard at temperature 145 °C. All bitumen contents shall be in percentage by weight of the total mix. Each specimen tested to determine the bulk specific gravity, the stability and flow value. After completed the test, void and specific gravity analysis be carried out to determine percentage air voids in the compacted mix (VIM), the compacted aggregate filled with bitumen (VFA), the percentage of voids in total asphalt mixture (VTM), the percentage of voids in mineral aggregate (VMA).

Bitumen content	Stability (kN)	Flow value (mm)	Bulk sp. Gravity g/cc	Vv%	VFB%	VMA%
4.0%	9.654	3.397	2.104	9.718	47.654	17.889
4.5%	12.611	3.603	2.147	7.258	56.467	16.640
5.0%	15.984	3.984	2.193	4.661	69.599	15.308
5.5%	13.106	3.884	2.234	2.249	84.803	14.178
6.0%	11.017	3.529	2.242	1.261	91.219	14.322

Table 4.1: Average Marshall Results showing average properties of mix for each bitumen content (%).

4.3.2 Optimum Asphalt Content

In order to obtain homogeneous mix and to achieve the required standards for attaining the quality and characteristics for pavement construction based on the JKR/SPJ/2008-S4, which are the average of bulk specific gravity, stability, flow, VFB and VIM obtained be plotted separately against the bitumen content and a smooth curve drawn through the plotted values.

The mean optimum asphalt contents were determined by averaging five bitumen contents so determined as follows;

(i) Peak of curve taken from the stability graph,

(ii) Flow equals to 3mm from the flow graph,

(iii)Peak of curve taken from the bulk specific gravity graph,

(iv) VFB equals to 75% for wearing course, from the VFB graph,

(v) VIM equals to 40% for wearing course from the VIM graph.

The results are shown in figure form.

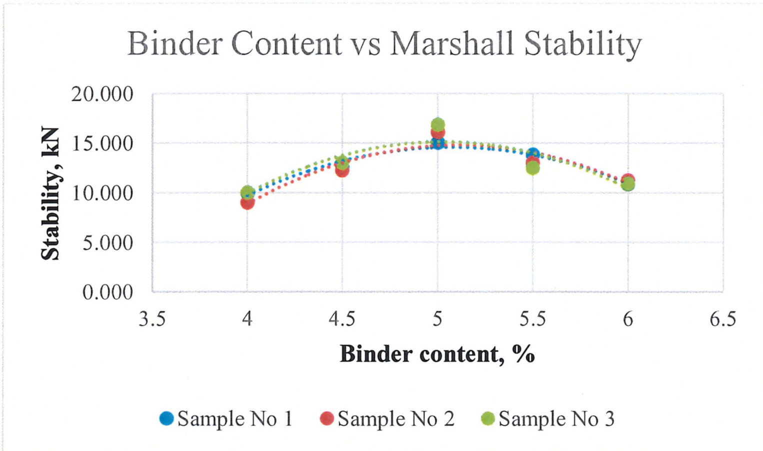

Figure 4.1, Stability, kN v/s Binder content, %

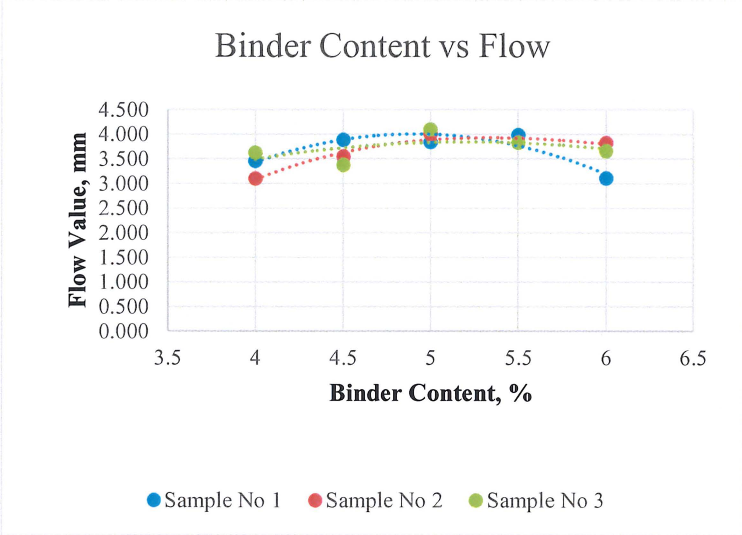

Figure 4.2, Flow value, mm v/s Binder content, %

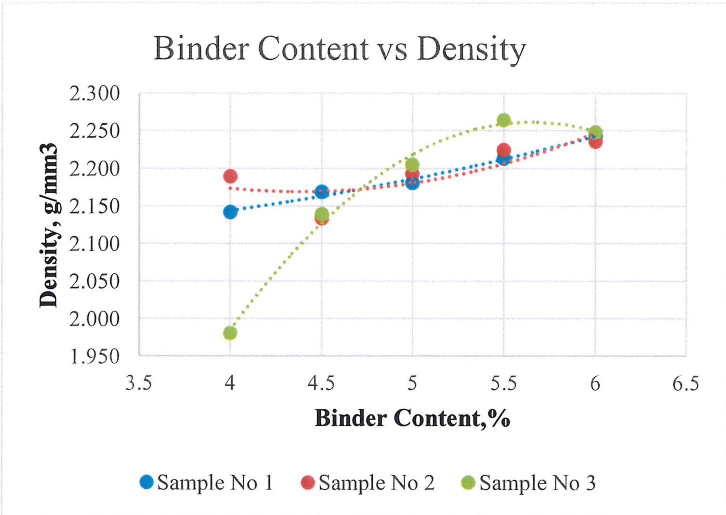

Figure 4.3, Density, g/mm3 v/s Binder content, %

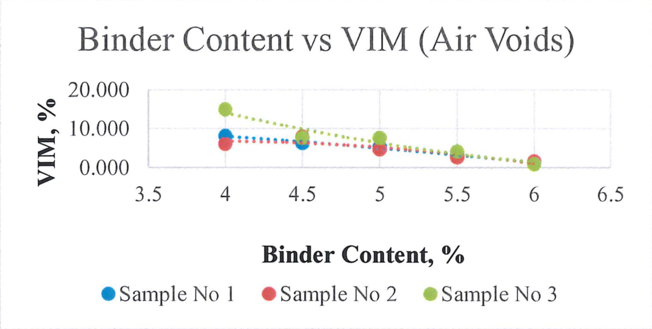

Figure 4.4, VIM, % v/s Binder content, %

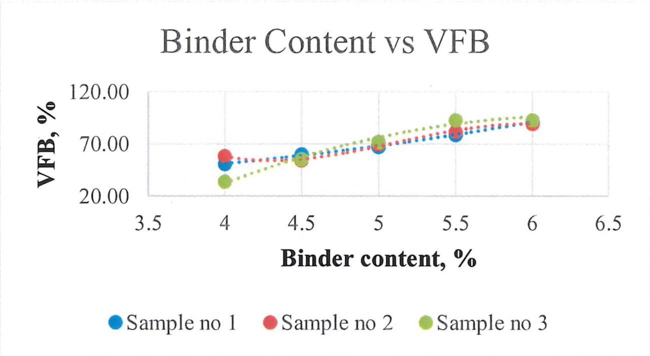

Figure 4.5, VFB, % v/s Binder content, %

From the graphs, volumetric and mechanical properties of Marshall Specimens, obtained at varying indicates the mean of optimum asphalt content of 5.0% based on the JKR/SPJ/2008-S4 with respect to the mean optimum content as followed maximum stability curve which is laid at 5.0% bitumen content, flow equals to 3mm from the flow at 4.0%, maximum bulk specific gravity at 5.5%, VFB equals to 75% at 5.5, VIM equal to 4.0% at 5.0%. Calculation determine OAC shown as below:

$$OAC\% = \frac{5+4+5.5+5.5+5}{5} = 5.0\% \qquad 4.1$$

4.3.3 Marshall Mix Design of Addition CPO

Basic characteristics of laboratory WMA specimens were measured that include mixing and compaction temperature; theoretical maximum specific gravity; bulk specific gravity; and air void. To evaluate fundamental engineering properties and performance related characteristics of laboratory specimens, analysis and results are discussed in this section. Average properties of mix result test for each temperatures which are 120, 130, and 140□ shown in Table 4.2.

Temperature □	Stability (kN)	Flow value (mm)	Bulk sp Gravity g/cc	Vv%	VFB%	VMA%	Stiffness kN/mm	VIM %
120	7.91	3.86	2.27	6.79	59.49	16.71	2.07	4.73
130	8.14	3.37	2.27	6.78	59.95	16.70	2.43	4.71
140	8.36	3.01	2.25	7.56	56.75	17.40	2.92	5.52

Table 4.2: Average Marshall Results showing average properties of mix with 0.5% modified binder.

4.3.3.1 Effect of CPO on Stability

The stability value with and without addition of CPO are shown in Figure 4.6. As we can observed from this graph, the addition of CPO did not give any significant effect on the stability. The increasing of stability value can be observed caused by increasing in temperature.

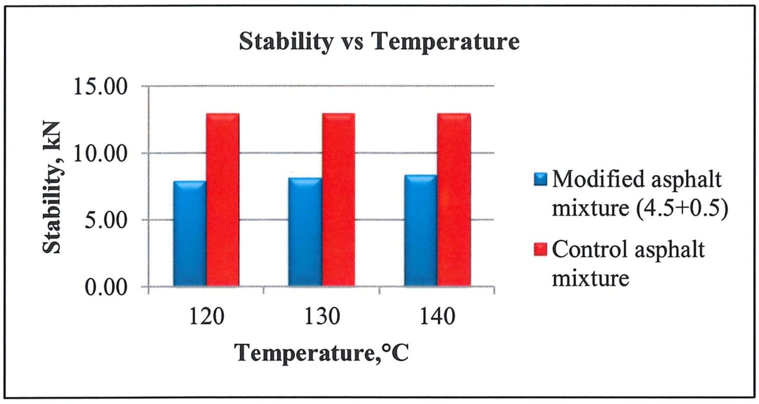

Figure 4.6: Stability, kN vs Temperature, □

It's shown that as the temperature increased from (120 to 140 □), the stability value slightly increase in stably manner. This is because at high temperature the bitumen viscosity is so low that cause good lubrication of aggregate particle and causing good interlock between particles during compaction.

4.3.3.2 Flow Value

Figure 4.7 shown the flow value vs temperature with and without addition of CPO. As we can see, temperature increase, the flow values decrease. This is attributed to that, at law temperature the percentage of voids of total mixture is high than that at higher temperature. This causes air space for the aggregate particle to deform and this increases flow value.

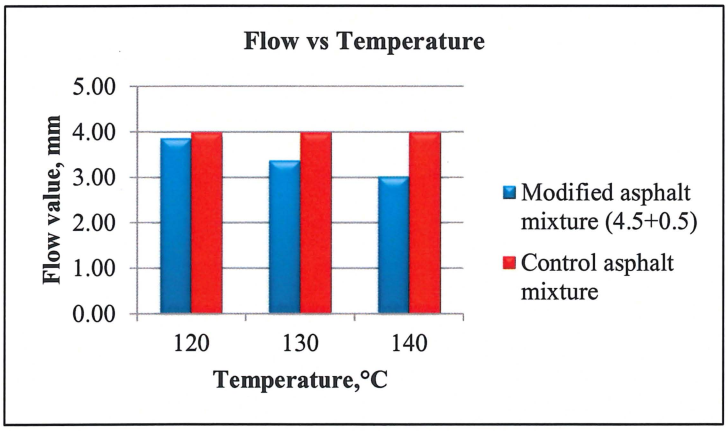

Figure 4.7: Flow values in (mm) versus temperature, □

4.3.3.3 Marshall Stiffness Value

Values of Marshall Stiffness versus different temperatures with and without addition of 0.5% CPO are shown in Figure 4.8. It is clear that the Marshall Stiffness value is slightly increased as the temperature increased for temperature ranges from 120 to 140 □. This is attributed to that at high compaction temperature the bitumen viscosity is low and the asphalt mixture is workable and compacted well.

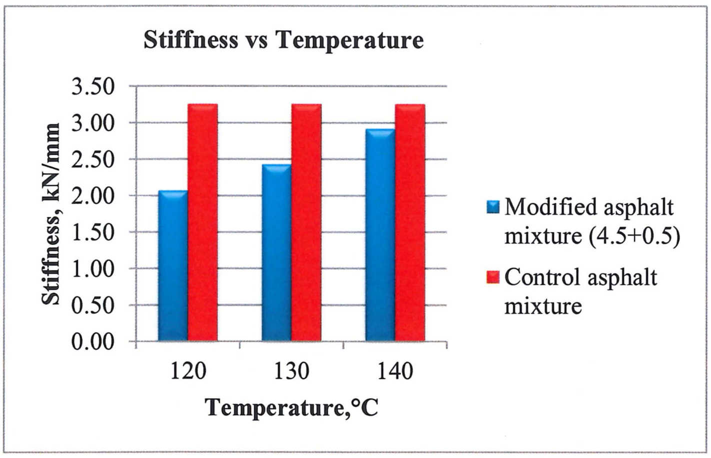

Figure 4.8: Stiffness, kN/mm versus temperature, □

4.3.4 Voids Filled with Bitumen

Looking at Figure 4.9, the addition of CPO has no significant impact on VFB of samples is well within the given range of 60-55%. The computation of VFB is dependent on VMA and bitumen content. As put forth by (Abdullah, Obaidat, and Abu-Sa'da, 1998) the conclusion of Lees in 1987, air voids in mineral aggregates and voids filled with bitumen are merely physical parameters with no direct engineering significance. In the example given, it was mentioned that strength, flow, permeability to air, and permeability to water of two mixes of identical air voids may not necessarily identical.

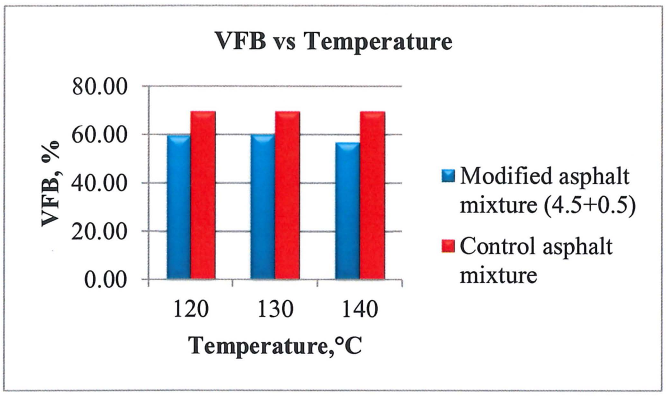

Figure 4.9: Void Filled with Bitumen, % versus Temperature, □

4.3.5 Comparison between WMA and HMA Production Temperature for Addition 0.3% and 0.5% Dosage of CPO to the Binder

In this section, parameter for two different dosage of modified bitumen which is 0.3% and 0.5% of CPO for different temperature of production have been compared according to the specification of JKR/SPJ/2008-S4. The table below show analysis parameter of modified bitumen specimens at different temperature according to the specification of JKR/SPJ/2008-S4.

Parameter	Wearing Course	Binder Course	Modified Bitumen (0.3%)		
			120 □	130 □	140 □
Stability, S	>8000N	>8000 N	8240 N	8330 N	8850 N
Flow, F	2.0 – 4.0mm	2.0 – 4.0 mm	4.61 mm	5.10 mm	4.15 mm
Stiffness, S/F	>2.0 kN/mm	>2.0kN/mm	2.01 kN/mm	1.64 kN/mm	2.14 kN/mm
Air Voids in Mix (VIM)	3.0 – 5.0 %	3.0 – 7.0 %	8.31%	7.85%	7.58%
Voids aggregate filled bitumen (VFB)	70 – 80 %	65 – 75 %	48.42%	50.00%	50.57%

Table 4.3: Analysis parameter for 0.3% modified bitumen specimens at WMA production temperature according to the specification of JKR/SPJ/2008-S4

Parameter	Wearing Course	Binder Course	Modified Bitumen (0.5%)		
			120 □	130 □	140 □
Stability, S	>8000 N	>8000 N	7910 N	8140 N	8640 N
Flow, F	2.0 – 4.0 mm	2.0 – 4.0 mm	3.86 mm	3.37 mm	3.00 mm
Stiffness, S/F	>2.0 kN/mm	>2.0 kN/mm	2.07 kN/mm	2.30 kN/mm	2.92 kN/mm
Air Voids in Mix (VIM)	3.0 – 5.0 %	3.0 – 7.0 %	4.73 %	4.71 %	5.51 %
Voids in aggregate filled with bitumen (VFB)	70 – 80 %	65 – 75 %	59.49 %	59.95 %	56.75 %

Table 4.4: Analysis parameter for 0.5% modified bitumen specimens at WMA production temperature according to the specification of JKR/SPJ/2008-S4

Parameter	Wearing Course	Binder Course	Modified Bitumen (0.3%)		
			150 □	160 □	170 □
Stability, S	>8000 N	>8000 N	10450 N	9660 N	10070 N
Flow, F	2.0 – 4.0 mm	2.0 – 4.0 mm	4.87 mm	4.21 mm	3.98 mm
Stiffness, S/F	>2.0 kN/mm	>2.0 kN/mm	2.75 kN/mm	2.59 kN/mm	2.24 kN/mm
Air Voids in Mix (VIM)	3.0 – 5.0 %	3.0 – 7.0 %	9.53%	7.41%	6.13%
Voids in aggregate filled with bitumen (VFB)	70 – 80 %	65 – 75 %	64.25%	62.48%	59.50%

Table 4.5: Analysis parameter for 0.3% modified bitumen specimens at HMA production temperature according to the specification of JKR/SPJ/2008-S4

Parameter	Wearing Course	Binder Course	Modified Bitumen (0.5%)		
			150 □	160 □	170 □
Stability, S	>8000 N	>8000 N	10150 N	10550 N	10100 N
Flow, F	2.0 – 4.0 mm	2.0 – 4.0 mm	4.87 mm	4.21 mm	3.98 mm
Stiffness, S/F	>2.0 kN/mm	>2.0 kN/mm	2.10 kN/mm	2.53 kN/mm	2.54 kN/mm
Air Voids in Mix (VIM)	3.0 – 5.0 %	3.0 – 7.0 %	3.76 %	3.57 %	4.43 %
Voids in aggregate filled with bitumen (VFB)	70 – 80 %	65 – 75 %	63.38 %	64.02 %	60.57 %

Table 4.6: Analysis parameter for 0.5% modified bitumen specimens at HMA temperature production according to the specification of JKR/SPJ/2008-S4

From the analysis parameter according to JKR/SPJ/2008-S4, it was observed that the almost all the values is comply with the specification but for 0.5% modified bitumen at 120□, stability value almost achieve 8.0 kN and for void in aggregate filled with bitumen (VFB) not achieve 70-80%. Therefore, the mix design procedure must be repeated using different laboratory design mix aggregate gradation limit. Compared to the stability values at WMA production temperature, increasing the dosage of CPO will lower the stability values but at HMA production temperature, both modified bitumen had almost similar stability values. Thus, it can be conclude that the HMA temperature of production of mixes containing the CPO does not have major effects on the stability value. At WMA production temperature, increasing the temperature will increase the value of stability, therefore the temperature is the major factor effect for the stability of the mixes.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The analyses presented in the Chapter 4 presents the pattern of the mix asphalt mixes properties, which include optimum bitumen content, stability and flow value, bulk specific gravity, stiffness, voids in mineral aggregate, and voids filled with bitumen, The following conclusions can be drawn from the study.

1. As the dosage of CPO increase, the stability value is decrease. It can be summarize that addition of CPO reduce the viscosity of binder. The binding force of an asphalt mixture is called cohesion. Cohesion increases as the viscosity the binder increase up to certain point and past that point resulting loss of interparticle friction.

2. It is noted that, the addition of CPO not giving major effect to the properties of asphalt mixture. Usually temperature playing important role in effecting the properties of asphalt mixture.

3. The introduction of CPO as alternative organic additive to warm mix asphalt wouldn't improve the asphalt mix design properties. It is appeared that it is reduced about 35% of Marshall Stability value compared to the control.

As an overall conclusions, this thesis was fulfilling the entire objective which are to determine the properties of mix design with addition of CPO, the physical properties (Stability and flow value) at different temperature for asphalt mixture with and without the addition of CPO. Crude Palm Oil (CPO) shown insignificant performance but still satisfied the JKR specification except VFB,% which is nearly satisfied.

5.2 Recommendations

Utilization of Crude Palm Oil is still in research and not fully bring new outcome for manufacture technology and industry. However, regarding to this research, there are some improvements need to be done to ensure the result precisely obtained and accurately executed in the future. Below are some recommendations for further study in the future.

1. A series of investigation on the characteristic of the CPO in term of viscosity test, binder aging characteristic, and penetration modified bitumen (addition of CPO into bitumen).
2. Evaluating the creep test and indirect tensile test on the asphalt mixture to get precise and accurate strength performance.
3. Perform the moisture sensitivity test to determine the loss of strength due to the presence of moisture in term of a tensile strength ratio (TSR).

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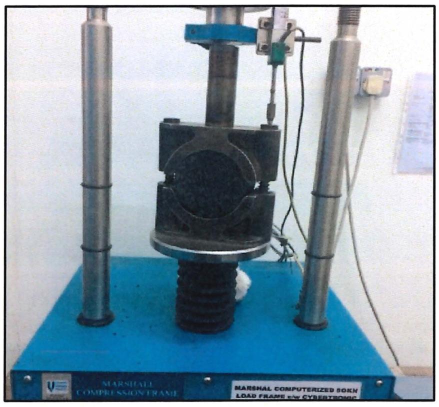
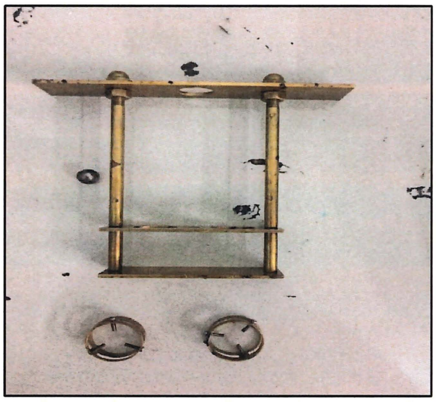
APPENDIX I: PHOTOS OF LABORATORY WORKS

Aggregates and bitumen manually mixed

Compacted specimens

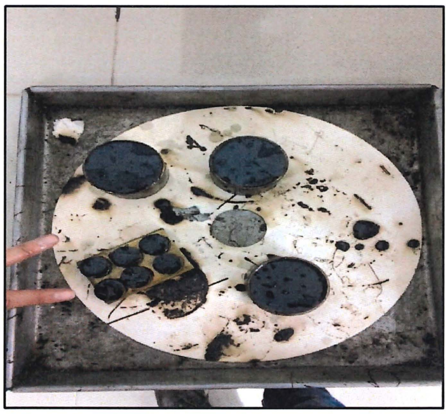


Marshall Test



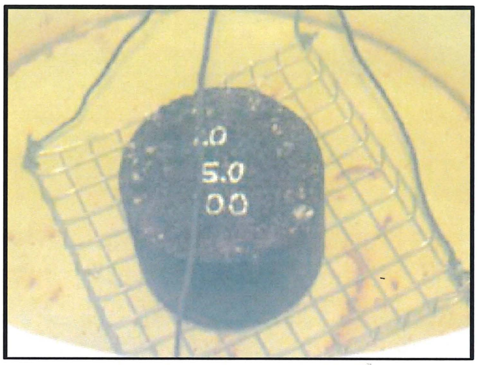
Softening Point Apparatus

Aggregate in Mould for Heating



Bitumen Penetration Test

Dry Sieve



Sample Being weighed in water during determination of bulk specific gravity of mix