EVALUATION ON THE PROPERTIES OF AGGREGATE SUBJECTED TO ELEVATED TEMPERATURE USING NCAT IGNITION OVEN AND ASPHALT MIX PERFORMANCE

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SCHOOL OF CIVIL ENGINEERING
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by

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ABSTRAK

Kualiti turapan asfalt yang baik dan boleh dipercayai adalah penting untuk menyediakan permukaan jalan raya yang lancar. Turapan yang lebih berkualiti menyediakan perjalanan yang lebih selamat dan selesa untuk kegunaan harian. Keadaan permukaan jalan yang merosot mungkin disebabkan oleh agregat yang berkualiti rendah digunakan dalam penyediaan campuran asfalt. Kesan luluhawa yang berterusan pada setiap hari boleh merosakkan campuran asfalt. Oleh itu, kriteria melakukan keputusan bagi menentukan kandungan pengikat campuran asfalt menggunakan oven penyalaan NCAT adalah sangat penting sebelum meletakkan campuran. Malangnya, setelah proses pemanasan, agregat dibuang berdasarkan kritikan yang mendakwa bahawa kualiti agregat yang kurang baik bagi agregat yang dipanaskan. Oleh itu, penyelidikan ini dilakukan untuk mengukur kualiti agregat yang dipanaskan. Agregat asli dan agregat yang dipanaskan didedahkan kepada ujian makmal yang asas, termasuk ujian Graviti Tentu (SG), ujian Nilai Pecahan Agregat (ACV), ujian Nilai Lelasan Los Angeles (LAAV), dan ujian Kestabilan dan Aliran Marshall. Selain itu, kedua-dua agregat asli dan agregat yang dipanaskan digunakan untuk penyediaan campuran asfalt. Campuran asfalt ACW14 kemudiannya menjalani ujian makmal untuk menentukan Kandungan Pengikat Optimum (OBC). OBC yang dipilih adalah 5.2% untuk campuran asfalt yang disediakan menggunakan agregat asli (sampel kawalan). Sementara itu, OBC untuk campuran asfalt yang menggunakan agregat yang dipanaskan (sampel yang diubah) menunjukkan OBC adalah 5.4%. Suhu tinggi mempengaruhi kekuatan sifat turapan asfalt. Hasil kajian menunjukkan bahawa SG secara jelas, permukaan tepu kering (SSD), dan SG pukal untuk sampel yang diubah tidak mencatat perbezaan yang signifikan berbanding dengan sampel kawalan. Walau bagaimanapun, sebanyak 32.6% nilai ACV dicatatkan untuk sampel yang diubah, iaitu dua kali ganda berbanding 17.0% nilai ACV

bagi sampel kawalan. LAAV untuk sampel yang diubah jauh lebih tinggi iaitu 59.5% berbanding dengan sampel kawalan dengan LAAV sebanyak 23.9%. Nilai ACV dan LAAV untuk sampel yang diubah tidak memenuhi syarat yang telah ditetapkan. Sementara itu, nilai kestabilan puncak adalah pada 5.5% untuk sampel yang diubah dan 5.0% untuk sampel kawalan. Ini menunjukkan bahawa agregat yang dipanaskan mengalami penguraian unsur silika hingga 20% yang meningkatkan liang di dalam zarah agregat. Pori yang lebih tinggi memerlukan lebih banyak bitumen untuk mengisi kekosongan. Untuk nilai aliran, sampel yang diubah menunjukkan nilai yang lebih tinggi antara 2.9 mm hingga 4.7 mm berbanding dengan sampel kawalan yang menunjukkan julat yang boleh diterima dari 2.2 mm hingga 3.8 mm. Julat lompang udara dalam sampel yang diubah menunjukkan perbezaan yang lebih tinggi antara 2.1 hingga 10.1%. Julat lompang udara untuk sampel kawalan lebih seragam antara 3.5 hingga 6.4%. Ini menunjukkan bahawa agregat yang terdedah kepada suhu yang lebih tinggi mempunyai lebih banyak liang kerana pembakaran Silika (SiO_2) dan unsur lain dalam zarah agregat. Oleh itu, julat untuk Kokosongan yang Diisi dengan Bitumen (VFB) lebih tinggi untuk sampel yang diubah, antara 46.4 hingga 87.4%. Untuk sampel kawalan, julat VFB lebih seragam, dengan julat yang lebih rendah dari 58.7 hingga 83.2%. Secara amnya, penemuan ini memberikan pemahaman yang lebih baik mengenai kesan peningkatan suhu pada sifat agregat dan prestasi campuran asfalt. Jelas, suhu yang tinggi mempengaruhi sifat agregat. Oleh itu, agregat yang dipanaskan tidak sesuai digunakan dalam campuran asphalt yang baharu.

ABSTRACT

Good and reliable asphalt pavement quality is essential to provide smooth road surfaces. A better-quality pavement provides a safer and comfortable ride for daily commute. Deteriorated road surface conditions might be due to the poor-quality aggregate used to prepare the asphalt mixture. Daily exposure to weathering effects degrades the asphalt mixtures. Therefore, determining the binder content of the asphalt mixture using the NCAT ignition oven prior to laying the mix is vital for decision-making criteria. Unfortunately, after the heating process, the aggregates were thrown away based on the critique that claims poor aggregate quality for those heated aggregates. Therefore, this research was conducted to quantify the quality of the heated aggregates. Virgin aggregate and heated aggregates were subjected to basic laboratory tests, including specific gravity test, aggregate crushing value (ACV) test, Los Angeles Abrasion Value (LAAV) test, and Marshall Stability and Flow tests. Additionally, both virgin and heated aggregate were used to prepare asphalt mixtures. The ACW14 asphalt mixtures were then subjected to laboratory tests to determine the Optimum Binder Content (OBC). The selected OBC was 5.2% for asphalt mixture prepared using the virgin aggregate (control sample). Meanwhile, the OBC for the asphalt mixture that used heated aggregate (modified sample) showed the OBC equal to 5.4%. It was hypothesized that an elevated temperature affected the strength of asphalt pavement properties. The results indicated that the apparent SG, SSD, and bulk SG for the modified sample recorded no significant difference compared to that of the control sample. However, the ACV of 32.6% was recorded for the modified sample, which is double from 17.0% of the ACV for control sample. The LAAV for the modified sample is significantly higher (59.5%) as compared to the control sample with the LAAV of 23.9%. Both the ACV and LAAV for modified sample did not comply with the requirements. Meanwhile, the peak stability values are

at 5.5% for modified sample and 5.0% for control sample. This implies that the heated aggregate experienced the decomposition of up to 20% Silica element which increased the pores inside the aggregate particle. Higher pores require more bitumen to fill in the voids. For flow values, the modified sample indicated higher values ranging from 2.9 mm to 4.7 mm as compared to control sample that shows an acceptable range from 2.2 mm to 3.8 mm. The air voids range in modified sample show a higher difference between 2.1 to 10.1%. The air voids range for the control sample is more uniform between 3.5 to 6.4%. This implies that the aggregate exposed to higher temperature has more pores due to the burning of the Silica (SiO_2) inside the aggregate particle. Consequently, the range for the Voids Filled with Bitumen (VFB) is higher for modified sample, which is between 46.4 to 87.4%. For control sample, the range of VFB is more uniform, with lower range from 58.7 to 83.2%. In general, the findings provide a better understanding of the effects of the elevated temperature on the aggregate properties and asphalt mix performance. Clearly, the elevated temperature significantly affected the properties of the aggregates. Therefore, the heated aggregates are not suitable for use in the new asphalt mixture prepared for the wearing course.

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LIST OF ABBREVIATIONS

ACV	Aggregate Crushing Value
ACW	Asphalt Concrete Wearing
ASTM	American Society for Testing and Materials
BC	Binder Content
G_{mb}	Bulk Specific Gravity
JKR	Jabatan Kerja Raya
LAAV	Los Angeles Abrasion Value
NCAT	National Center of Asphalt Technology
OBC	Optimum Binder Content
PWD	Public Work Department
SG	Specific Gravity
SSD	Saturated Surface Dry
VFB	Void Filled with Bitumen

CHAPTER 1

INTRODUCTION

1.1 Introduction

Aggregate is one of the wide material used in construction of road. The aggregates help to withstand the traffic loads in terms of conveying the heavy loads through the aggregate skeleton towards the subgrade layer. Aggregates are utilized in both flexible and rigid pavements layers. Therefore, good aggregate properties are essential for quality asphalt pavement layers. Several tests commonly measure aggregate properties, such as Los Angeles Abrasion Value (LAAV) test, Aggregate Crushing Value (ACV) test, and Specific Gravity (SG) test. These tests are mainly conducted in accordance with the ASTM standards. In most cases, aggregate properties are performed using virgin aggregate without considering any changes in its characteristics. Therefore, the result of aggregate properties for virgin aggregate can be used as comparison with modified aggregate. For asphalt mixture, there is one test namely the National Center of Asphalt Technology (NCAT) ignition oven test that is conducted to determine binder content. This test exposed the aggregates to an elevated temperature, therefore changed the mineral contents inside the aggregate itself.

The NCAT ignition oven is being used worldwide to determine bitumen content from asphalt mixture. The NCAT ignition oven conditioned the asphalt mixture up to 538℃ to heat the loose asphalt mixture in the oven. Prior to the burning process, the loose asphalt sample is weighted according to the required amount. The NCAT ignition oven will automatically measure the sample weight loss after the burning process.

The use of NCAT ignition oven being specified for determining binder content and leave the burned aggregates and fine materials afterwards. The test time for asphalt content requires approximately 30 to 40 minutes of heating process at 538℃. This is safer as compared to the use of harmful chemical through the solvent extraction method. Ignition method is more modern than the solvent extraction method considering that there is no hazardous waste to be produced. Moreover, the solvent creates hazardous vapours that harm people and the environment. The solvent contains trichloroethane and was banned on December 31, 1995 as part of the 1990 Clean Air Act Amendments. As the result of the previous research, ignition method has been specified as a replacement for solvent extraction (Prowell and Hurley, 2005). Based on the study by Taha (2009) the ignition test method can be significantly used to determine the asphalt content and aggregate gradation of asphalt mixture. Compared to solvent extraction test method, the ignition method is faster, safer, and cost saving. Ignition method also has significantly lower deviation of the measured asphalt content from the true asphalt content so that it can give a higher degree of accuracy and precision.

Previous study by Mallick et al. (1998) indicated that the heating process caused significant effects on the aggregate properties. The granite aggregate decreased slightly in bulk specific gravity values after the burning process. Additionally, Hall and Williams (1999) reported a slight decrease in the SG of the aggregate after the heating process. The researchers also discovered that the gradation of the asphalt mixture remained similar without any significant changes. Therefore, this research looks forward to testing the granite aggregates that are available in Malaysia and assess whether high temperature effects on aggregate properties and asphalt mix performance are significant or not.

1.2 Problem Statement

The influence of aggregate properties contributes to composition in asphalt mixture performance. Aggregate with low toughness unable to resist crushing and disintegration during mixing, placing, and compacting under repetitive traffic loading. The effect of high temperature contributes to high porosity aggregate. Moreover, the aggregate with high porosity permits the aggregate to absorb excessive asphalt and form a bond between the particle and the asphalt. A degree of porosity is desired, but highly absorbent aggregates are not used.

The effects of re-using aggregates that were subjected to the elevated temperature for the granite aggregates are not well reported. In the context of highway engineering, the effects of changing aggregate properties for the ACW14 asphalt mixture due to the elevated temperature are not properly documented and discussed among the practitioners. Understanding the effects of using the heated aggregate in the asphalt mixture associated with the Public Work Department (PWD) gradation of ACW14 is important for sustainable construction practices. If the results for asphalt mixtures prepared using the heated aggregate is encouraging, then re-using and recycling of the aggregates are possible. The amount of heated aggregate that can be reused was measured automatically using NCAT ignition oven with the difference of 0.01 grams from the initial weight. In other word, the NCAT ignition oven can produce up to 4000 grams of aggregate and asphalt binder per test which subsequently to total of 100 kg was collected from contractors. Therefore, the amount of heated aggregate produced was enough to be recycle and reuse in this study.

1.3 Objectives

This research studies and compares the properties of aggregates and the associated asphalt mixture performance using both virgin aggregate and aggregate that is subjected to the elevated temperature using NCAT ignition oven. The objectives of the research are listed as the followings:

1. To characterize the physical and mechanical properties of virgin aggregate and aggregate exposed to elevated temperature.
2. To assess the Marshall Stability and Flow for asphalt mixtures prepared with virgin aggregate and aggregate subjected to elevated temperature.
3. To evaluate and compare aggregate properties and the performance of asphalt mixtures prepared with the virgin aggregate and aggregate that is subjected to elevated temperature.

1.4 Scope of Work

This research studies the engineering properties of the virgin aggregates and aggregates that are heated to an elevated temperature of 538°C. The virgin granite type aggregates are obtained from Kuad Quarry in Penanti, Bukit Mertajam, Pulau Pinang. However, the leftover of the asphalt mixture samples brought in by the contractors for the NCAT ignition oven test are collected and stored for this research. Therefore, there are some discrepancies in term of the source of the aggregates between the virgin and heated aggregates. However, the aggregate type used are still the same with virgin aggregate.

Apart from getting the properties of the aggregates, this research also evaluates the properties of asphalt mixtures that are prepared using the virgin aggregate and aggregate that is subjected to an elevated temperature. The asphalt mixture gradation for wearing course, ACW14 from the Malaysia Public Works Department (JKR) is implemented throughout the research. The aggregates are subjected to the SG test, ACV test, and LAAV test to characterize their unique properties. Meanwhile, the compacted asphalt specimens are subjected to the Marshall Stability and Flow tests. Eventually, the results for both virgin and heated aggregates are compared to assess if there is any significant difference in term of aggregate and compacted asphalt Marshall sample properties.

1.5 Significance of Study

This research provides an insight on how the properties of aggregates change when subjected to the elevated temperature. This research helps researcher to understand how the elevated temperature will change the basic properties of granite type aggregates. Additionally, the research provides important information on how the changes of aggregate properties effect the findings from standard laboratory tests such as the SG, ACV, LAAV and the Marshall Stability and Flow test. The findings help in term of decision making, whether the aggregate can be recycled and reused for asphalt pavement layer. Recycling and reusing of the existing aggregate resources will avoid sudden depletion of the valuable raw materials quantities. Furthermore, the amount of the aggregates that are thrown away after the NCAT ignition oven test will substantially reduce. The amount of NCAT ignition sample can be up to 4000 grams per test. The waste from NCAT ignition oven test that contain aggregate and binder content can be recycled rather than being thrown away. This mitigation can hugely reduce the leftover from NCAT ignition oven if the test was carried out in the large scale purposes.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Aggregate is a mineral material such as sand and crushed granite that are used with a binding medium to form a compound mixture. In pavement engineering, aggregates are also used for base and subbase layers of flexible pavement system. For asphaltic mixture, determination of the binder content is a must to ensure quality pavement layer. Thus, the asphaltic mixtures are subjected to the NCAT ignition test. This chapter summarizes the current and previous studies that are related to the NCAT ignition method, common material used in our country and brief information of the aggregate property tests. There are several uncertainties of using heated aggregate might affect the aggregate properties as well as asphalt mix performance.

2.2 The NCAT ignition Method

The NCAT developed the ignition method to determine bitumen content from loose asphalt mixture samples. The test requires calibration of the NCAT ignition oven to ensure accurate estimation of the binder contents. The NCAT ignition oven heated the loose asphalt mixture at about 538°C throughout test duration. The initial mass of the specimen is determined, and the elevated temperatures accelerates the heating process thus causes mass loss for the asphalt mixture. It will take around 30 to 40 minutes for a complete cycle and the lower test temperature may excessively increase the test time (Brown and Mager, 1996). Based on previous study, the results showed that the test time decreased greatly when the temperature was increased up to 535°C and the test time reduced slightly when temperature being increase above 550°C (Taha, 2009).

An elevated temperature can cause changes in the physical properties of mineral aggregates that are commonly used in asphalt mixtures (Devecseri, 2010). This method of testing is an optional approach of determining bitumen content from asphalt mixture. The used of ignition oven for extracting asphalt mixture is an alternative method that replace the harmful chemical solvent as extracting and also harmful for both human being and the surrounding environment. The chemical solvent is difficult and costly in obtaining and disposing it (Brown and Murphy, 1994). Moreover, the research shows that the ignition method can determine the asphalt content with greater precision than the solvent extraction method. Besides, the ignition method is relatively inexpensive because there are no associated costs for disposal of hazardous solvents (Brown et al., 1995).

2.3 The Effects of Elevated Temperature Exposure on the Aggregates

This sub-chapter describes the effects of the elevated temperature exposure on the basic engineering properties of the aggregates. The aggregate that undergoes ignition process will tend to break easily and become more porous. Mallick et al. (1998) studied the effects of the ignition furnace on bulk specific gravity of the aggregate under ignition oven. The study showed that the aggregate properties were significantly affected. For granite aggregates, the bulk specific gravity values of coarse aggregates slightly decreased after the burning process. Hall and Williams (1999) investigated the effects of the ignition method on physical properties of aggregate including specific gravity. However, the researchers found no significant changes in aggregate gradation after ignition. But a slight decrease in specific gravity of coarse aggregate was measured after the aggregate was subjected to the elevated temperature. Prowell and Carter (2000) studied the ignition effect on the aggregate properties, bulk specific gravity and gradation of the aggregate extracted using the ignition furnace for typical aggregate. The researchers reported that there was no significant difference between virgin and aggregates recovered from the ignition oven.

Moreover, the LAAV and the ACV somehow showed a significant impact due to elevated temperature. The high temperature is believed to be related to the increased aggregate breakdown as measured by gradation, LA Abrasion and Micro Deval tests. The significant increase in the LAAV by the ignition method might result from micro-cracks in the aggregates induced while burning in the ignition oven (Thakur et al., 2011). Besides, the aggregate crushing index is rising when the temperature increases gradually (Wang Li et al., 2017). This method uses a very high temperature oven to burn off the asphalt by comparing the behavior of material before and after the burn off. High temperatures can cause changes in the physical properties of mineral aggregates that are commonly used in asphalt mixtures causing faults in the results of the binder analysis (Devecseri, 2010). Therefore, high temperature on aggregate will significantly affect the amount and effectiveness of asphalt binder in asphalt mixtures.

Temperature is an important parameter that being considered during testing process. Every testing material might be subjected to certain elevated temperature to obtain a specific test result. High and low temperatures are required to mix, dry, and cool the materials. Higher temperature will increase the amount of mass losses. Li Yu et al., (1992) showed that samples with different binder content will be completely burned at 485°C and higher. Tested aggregate using NCAT ignition oven might crack and loosen its strength. However, a study by Prowell and Carter (2000) stated that there is no significant difference between virgin aggregate and aggregates subjected to ignition oven.

2.4 Common Material used in Asphalt Mixture

In this research, the selected gradation for asphalt mixture is ACW14 used for wearing course following the JKR Standard Specification for pavement work (JKR, 2013). The gradation is used to prepare sample for testing the asphalt mix performance. The aggregates, filler and bitumen are mixed accordingly.

2.4.1 Granite Aggregate

Granite is commonly used as aggregate in any construction work such as building and foundation. A good quality of aggregate material is undoubtedly the fundamental of construction work. These granites are crushed materials that are broken down into different sizes for construction applications. Granites are one of the best performing construction materials available. The physical properties of coarse aggregates were determined according to ASTM C127 (2015) and ASTM C131/C131M (2014). Based on the previous study, granite aggregate showed higher mechanical properties as compared to the limestone and quartzite material at various temperatures ranging from 25℃ to 650°C (Tufail *et al.*, 2017).

The chemical composition of granite aggregate contains more silica element. Table 2.1 shows the chemical composition of granite aggregate with higher amount of Silica (SiO_2) in its composition (Baker, 2017). This fact suggested that the granite aggregate is able to withstand excessive force, provided the shape is not flaky and elongated even at the elevated temperatures. However, exposure to the elevated temperature may decompose some of the natural element in the aggregates thus create more pores.

Table 2.1 Chemical composition of Granite Aggregate (Baker, 2017)

Element	Chemical composition of granite aggregate (%)
Silica (SiO_2)	70-77
Alumina (Al_2O_3)	11-14
Potassium oxide (K_2O)	3-5
Soda (Na_2CO_3)	3-5
Lime	1
Iron (Fe_2O_3)	1-2
Iron (FeO)	1-3
Magnesia (MgO)	0.5-1
Titania (TiO_2)	0.38
Water	0.03

2.4.2 Hydrated Lime as Mineral Filler

Hydrated lime is mainly composed of Calcium Hydroxide $Ca(OH)_2$. The hydrated lime is an additive for asphalt mixtures to increases asphalt mixture durability. Hydrated lime is also known to reduce chemical aging of the bitumen while stiffens the mastic better than normal mineral filler (Mouillet *et al.*, 2014). Addition of the hydrated lime within bitumen improves the moisture resistance of the asphalt mixture (Huang *et al.*, 2005). Therefore, chemical interaction between hydrated lime and the acidic moieties of bitumen tends to improve aging resistance and adhesion of the asphalt mixture.

2.5 Engineering Properties of Aggregate and Asphalt Mixture

2.5.1 Specific Gravity

Specific gravity test was used to determine the specific gravity and water absorption of aggregate. Adequate amount of absorption of water is essential to ensure enough bitumen for the aggregate to absorb during asphalt mixing. A good quality of aggregate will tend to have lower absorption of water to reduce excessive amount of asphalt binder needed when mixing the asphalt. However, this research involves aggregate subjected to high elevated temperature that could change the specific gravity and increase absorption in aggregate itself. From previous study, Hall and William (1999) found that there is a slight decrease in specific gravity of coarse aggregate was measured after the aggregate was subjected to elevated temperature.

Another study showed that aggregate subjected to an ignition oven could lower its specific gravity while increasing the absorption (Kowalski *et al.*, 2010). This prove that the aggregate uses more asphalt binder when mixing the asphalt to fulfil the amount of binder needed. Moreover, Mallick and Brown (1999) found that the bulk specific gravity values of coarse aggregate decreased after burning granite aggregate.

2.5.2 Aggregate Crushing Value Test

Aggregate Crushing Value (ACV) test is a well-known method to determine the aggregate crushing value using compressive testing machine. The compressive load simulates the loading from traffic wheel loads on pavement structure. If the aggregate is weak, the stability of pavement structure will be affected as well as damaging the pavement structure.

Moreover, high temperature significantly effects the aggregate properties and asphalt mix performance. Researchers found that the ACV was increased when the temperature gradually increased (Xia et al., 2019). A high percentage of the ACV affected the strength of aggregate and less resistance to crushing under repetitive traffic exposure.

A study by Ahmad et al., (2004) found that virgin aggregate shows a lower value in the ACV as compared to aggregate exposed to the elevated temperature. The study concluded that the virgin aggregates have higher strength on resisting crushing under traffic loads.

2.5.3 Los Angeles Abrasion Value

Abrasion is related with the resistance of aggregate against wear, grabbing and degradation. The principle of Los Angeles abrasion test in basically to find the percentage wear due to relative rubbing action between aggregates and steel balls used as abrasion charge. Previous study by researcher reported a significant increase in the LAAV for aggregate exposed to the elevated temperature due to the formation of micro cracks in the aggregates while burning in the ignition oven (Thakur *et al.*, 2011).

Granite had the lowest abrasion resistance but the highest impact resistance, indicating that this has the highest strength among other aggregate types (Tufail *et al.*, 2017). However, under elevated temperature, cracks are gradually generated and the cracking density, intracrystalline crack length and crack width of aggregate increased.

2.5.4 Marshall Stability and Flow

The Marshall Stability and Flow tests assess the performance of the designed samples whether it meets the PWD's requirements or not. The Marshall stability test determines the capability of the compacted asphalt mixture to hold the loading before cracked or failed. Meanwhile, the flow test represents the deformation of the sample under loads and it indicates the flexibility of the asphalt pavement. Table 2.2 summarizes the reference for the stability and flow values as well as other parameters.

(JKR/ SPJ/ 2008 - S4). The Stability, S for wearing course should be more than 8000 N and the Flow (F) value must be within 2.0 to 4.0 mm for conventional asphalt mixture.

Table 2.2 PWD's ACW14 Requirements for Asphalt Mix Design (JKR/ SPJ/ 2008 – S4)

Parameters	**Specified Value**
Optimum Binder Content	4.0% - 6.0%
Stability,S	>8000N
Flow, F	2.0 – 4.0 mm
Stiffness	>2000 N/mm
Air Voids	3.0% - 5.0%
Voids Filled with Bitumen	70% - 80%

The Optimum Binder Content (OBC) of asphalt mixture and binder types is determined from the relationships between mixture volumetric and strength properties with variations in binder contents. However, the aggregate that being subjected to high temperature tends to affect the performance of asphalt. High temperature can cause changes in the physical properties of aggregates that are commonly used in asphalt mixtures causing faults in binder analysis (Devecseri, 2010). This study shows that high elevated temperature affects the binder content needed in asphalt mixture.

2.6 Summary

Evaluation on the properties of aggregates subjected to the elevated temperature involves several tests on aggregate and asphalt mixtures. From the previous study, high temperature somehow affected the aggregate properties as well as asphalt mixture performance. High temperature effect can increase the absorption of aggregate while changing the adequate amount of bitumen needed in asphalt mixture. Moreover, the ACV value was reported an increase, as well as increasing percentage of the LAAV after the heating process of aggregates. The heated aggregates used in asphalt mixture surely will influence the Marshall Stability and Flow results. Proper justification can be made once all the required tests are completed.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter describes the methodologies associated with the laboratory tests conducted in this research. Asphalt mixtures are prepared using the ACW14 gradation based on the JKR/SPJ 2008-S4 specification. The laboratory tests evaluate both virgin and heated aggregates at current conditions. Due to the unprecedented COVID-19 pandemic, there is limited time for students to conduct laboratory tests. Therefore, the short-term and long-term conditioning of the specimens are not included in this research. Figure 3.1 shows the flowchart that explains the research methodology. The previous study was reviewed, followed by gathering important information regarding this research. Then, preparation of material for testing aggregate properties and asphalt mix performance was conducted. Moreover, modified aggregate can be compared with virgin aggregate, and further justification can be made.

The virgin aggregate and the heated aggregate are subjected to a few basic laboratory tests, namely specific gravity test, aggregate crushing value test and Los Angeles Abrasion Value test. Next, the virgin aggregate and the heated aggregates are used to prepare asphalt mixtures and eventually prepared as the compacted Marshall specimens. The compacted asphalt specimens are subjected to the Marshall Stability and Flow test to assess the asphalt mixture performances. The results between those two asphalt mixture types are compared and evaluated based on the JKR/SPJ 2008-S4 specification.

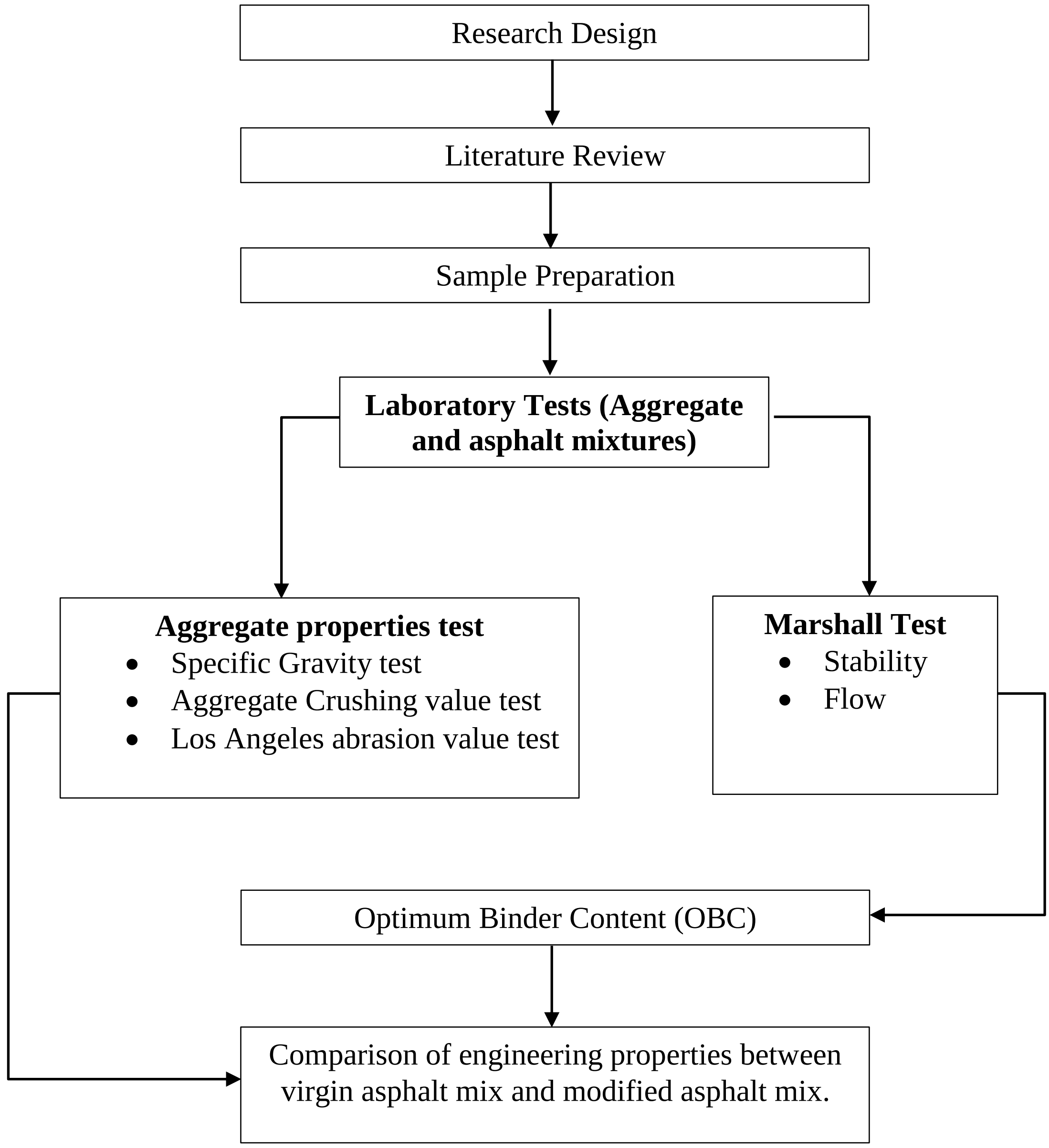

Figure 3.1 Flowchart of Study

3.2 Preparation of Materials

Proper preparation of the material is important before testing. Some material requires a specific preparation process before testing for research purposes, such as control sample aggregate with 10 mm sieve size and above need to be washed before batching process. Furthermore, heated aggregate was kept in a specific container to avoid any influence from surrounding that can affect its behaviour. The sieve analysis process was used to obtain aggregate and mineral filler in a specific sieve size. In this study, aggregate was subjected to elevated temperature then being tested to characterize its aggregate properties and asphalt mix performance. The granite type of aggregate was selected, and the preparing process was conducted.

3.2.1 Aggregate Gradation and Batching Process

The aggregate type used throughout the research is granite. The aggregates were sieved and separated into the respective aggregate size ranges. Prior to the asphalt sample preparation, the virgin aggregates from the container were cleaned and stored nicely. On the other hand, the aggregate particles subjected to the NCAT Ignition test were collected and kept in a specific container. These aggregates were then sieved and kept according to the respective sieve sizes as in Plate 3.1. These aggregates were sieved and batched to 1150 grams for each specimen in accordance with the Public Work Department of Malaysia's (PWD Malaysia) and by referring to JKR/SPJ/2008 for road works. Table 3.1 shows the gradation for ACW14 from the JKR/SPJ/2008. Each specimen was batched precisely to ensure standard height of all specimens.

Plate 3.1 Aggregates according to standard sieve sizes

Table 3.1 ACW14 Aggregates Gradation for Asphaltic Concrete (JKR/SPJ/2008)

Mix type	Wearing Coarse
Mix Designation	ACW14
BS Sieve Size	% 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 um	12-24
150 um	6-14
75 um	4-8
Pan	0

Table 3.2 shows the range of percentage passing by weight, weight of aggregates, and the cumulative weight of aggregate. The percent passing of the aggregates correspond to the median percentages of the given ranges. Weight of the aggregate is based on the retained aggregate weight. Finally, the cumulative weight is calculated from the weight of the aggregates. A single batch with approximately 1150 gram is required to produce compacted asphalt specimen with 65 mm in height and 100 mm diameter.

Table 3.2 Aggregate grading according to each sieve size

BS Sieve size (mm)	**Range of Percentage passing by weight**	**Median (%)**	**Mix Design of AC14**	**Weight of aggregate**	**Cumulative Weight of Aggregate (g)**
20 mm	100	100	0	0	0
14 mm	90-100	95	5	57.5	57.5
10 mm	76-86	81	14	161	218.5
5 mm	50-62	56	25	287.5	506
3.35 mm	40-54	47	9	103.5	609.5
1.18 mm	18-34	26	21	241.5	851
425 um	12-24	18	8	92	943
150 um	6-14	10	8	92	1035
75 um	4-8	6	4	46	1081
Filler (pan)			4	46	1127
Hydrated Lime			2	23	1150

3.3 In-Laboratory Aggregate Property Tests

3.3.1 Specific Gravity Test

Specific gravity (SG) or relative density is the ratio of the density (mass of a unit volume) of a substance to the density of a given reference to the density of water. The test procedures commonly refer to the ASTM C127 (2015) specifications. The test normally conducted in three different states, which are apparent SG, Bulk SG and Saturated Surface Dry (SSD) SG. Using these three weights in different condition allow the calculation of water absorption too.

In this research, aggregates with 10 mm and 20 mm were washed to discard any fine aggregate particles clinging to the retained coarse particles. The aggregates were then submerged underwater for around 15 hours to ensure the void in the aggregate filled with water. Then, aggregate with water permeable voids was measure inside the wire basket. The measure was taken during the submerging aggregate to avoids losses void filled with water inside the aggregate particle. While submerging inside the water basin, the basket was shake a bit to release any entrapped air before weighing. Thus, SSD SG can be obtained. The test was carried out to measure the volume of the aggregate particle and the volume of the water permeable voids as express in Equation 3.1.

Furthermore, the test for Bulk SG was carried out. The submerging aggregate was taken out and placed on a wet towel. The surface of the aggregate was wiped using a wet towel by rolling the aggregate from side to side. The weight for the Bulk SG condition of aggregate was measured. Using a wet towel ensures the weight for aggregate without water on the surface while not affecting the void filled with water inside aggregate. It is usually expressed as the mass of a unit volume of aggregate, including water permeable voids, at a specified temperature divided by the mass of an equal volume of gas-free distilled water at the specified temperature as in Equation 3.2.

Then, the aggregate was left inside an oven at 110ºC for 24 hours. The tray was coated using aluminium foil as in Plate 3.2 to avoid contact with the rusty tray and the specimen. Apparent SG of the coarse aggregate can be obtained by weighing the dried aggregate. This is to ensure that only the volume of the aggregate particle was measured without including the volume of water permeable voids as expressed in Equation 3.3.

Plate 3.2 Dried aggregates for SG test

Absorption was determined after apparent SG, SSD SG and Bulk SG were obtained. The aggregate absorption was determined using Equation 3.4. When the absorption is higher, it is not economical because more binder required to account for the high aggregate absorption. According to JKR Specification-2005, the absorption percentage must not exceed 2% to indicate good absorption of aggregate.

$$Relative\ Density\ (SDD) = \left[\frac{(W_3 - W_5)}{(W_3 - W_5) - (W_1 - W_2)}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots Eq\ 3.1$$

$$Relative\ Density\ (OD) = \left[\frac{(W_4 - W_5)}{(W_3 - W_5) - (W_1 - W_2)}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 3.2$$

$$Apparent\ Relative\ Density\ (OD) = \left[\frac{(W_4 - W_5)}{(W_4 - W_5) - (W_1 - W_2)}\right] \ldots\ldots\ldots..\ldots Eq\ 3.3$$

$$Water\ Absoprtion\ (\%) = \left[100 \times \frac{(W_3 - W_4)}{(W_4 - W_5)}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots Eq\ 3.4$$

Where, W_1 = Mass of basket + mass of aggregate in water (g)

W_2 = Mass of empty basket in water (g)

W_3 = Mass of aggregate (SSD) + tray (g)

W_4 = Mass of aggregate (oven dry) + tray (g)

W_5 = Mass of tray (g)

3.3.2 Aggregate Crushing Value Test

The ACV test was carried to measure the aggregate crushing value for an aggregate. Thus, aggregate should be strong enough to resist crushing under compressive load. Aggregate with low ACV is preferred. Test was carried out to determine either heated aggregate can resist compressive load according to the specification by JKR/SPJ. This test was following BS 812-110 (1990) for Aggregate Crushing Value Test. The aggregate was prepared with total of 6.5 kg with ranging from 12.5 mm to 10 mm sieve size. The aggregate passing 12.5 mm sieve and retained on 10 mm sieve was selected for the ACV test. Sample with 2.75 kg each was tested using aggregate crushing machine with a maximum load of 400 kN. The load is applied at 0.67 Newton per minute.

A steel cylinder was required, and the aggregate specimen was filled inside the steel cylinder placed on a base plate. Then, the compressive testing machine can apply load at a uniform loading rate. The surface of the aggregate must be in dry condition before testing. The test sample of aggregate filled the cylindrical with three layers tamped each layer 25 times using the tamping rod. Once the third layer is tamped, the tamping rod was used as a straight edge level of the aggregate at the top of the cylindrical measure.

Then, the cylinder of the test apparatus is placed in position on the base plate. The cylinder with the test aggregate and the plunger in position was placed in the compression testing machine. Load is then applied through the plunger at a uniform rate of 400 kN per minute until achieving a total load of 400 kN, and then the load was released. The aggregate that has been tested was removed from the cylinder and sieves on a 2.36 mm sieve size. The percentage of aggregate passing the 2.36 mm sieve size was determined. Two repetitions of the test for every type of specimen were carried out, and the average value was considered.

Basically, aggregate crushing value was defined as a ratio of weight of fines passing the 2.36 mm sieve size to the total weight of the sample expressed as a percentage as shown in Equation 3.5.

$$Aggregate\ Crushing\ Value\ (ACV) = \left[\frac{100 \times W_1}{W_2}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots Eq\ 3.5$$

Where, W_1 = Total weight of dry sample

W_2 = Weight of the portion of crushed aggregate passing 2.36 mm sieve size.

3.3.3 Los Angeles Abrasion Test

Loss Angeles Abrasion Value test measures the degradation of standard grading of aggregate when subjected to abrasion and impact in rotating steel drum. The abrasion test normally to determine the relative quality, toughness and durability of aggregates subjected impact and abrasion. The standard test method by referring ASTM C131 (2014). Aggregate was prepared between 12.5 mm and 9.5 mm sieve size. The combination for this aggregate with a total of 5 kg ($W_{initial}$) which is 2.5 kg each sieve size. These sample then being placed in L.A. Abrasion Machine.

The test was carried out based on Grading B using 12 steel ball. A total of 4 sample have been prepared and the rotary drum machine being set up to 500 number of revolutions at rotation speed of 30 to 33 rpm. The sample aggregate was separated into aggregate passing the 1.70 mm (No. 12) sieve and aggregate retained on the 1.70 mm (No. 12) sieve size measured as final sample mass (W_{final}).

The parameter measured in the Los Angeles Abrasion test are expressed as a percentage by weight. Equation 3.6 is used to calculate the LAAV.

$$LAAV = \left[\frac{W_{initial} - W_{final}}{W_{initial}} \times 100\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 3.6$$

Where: $W_{initial}$ = original sample mass (g)

W_{final} = final sample mass (g)

Plate 3.3 Aggregate after undergoing the LAAV test

3.4 Asphalt Binder Penetration Test

The penetration test is used to determine the penetration grade and the consistency of the asphalt binder (Plate 3.4). The depth to which the needle penetrates the asphalt binder describes the consistency of the asphalt binder. The deeper the penetration, the lesser the viscosity of the asphalt binder. A penetrometer with a standard needle is required for this test. Then, the penetration test is carried out under the following conditions: a load of 100 grams, a test temperature of 25°C, and a loading time of 5 seconds. The test is conducted according to ASTM D5 (2013). The test is carried out for 2 times repetition with 5 points penetration each. Location of penetration