Faculty of Engineering

FEASIBILITY STUDY ON THE COMBINATION MIX OF MICROTONOLITE AND LIMESONE FOR SURFACE WEARING COURSE

Chen Jia Chern

Bachelor of Engineering with Honours

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FEASIBILITY STUDY ON THE COMBINATION MIX OF MICROTONOLITE AND LIMESTONE FOR SURFACE WEARING COURSE

CHEN JIA CHERN

A dissertation submitted in partial fulfilment
of the requirement for the degree of
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Dedication to family and friends who provide constant support, motivation, encouragement and advice.

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ABSTRACT

Granite is the commonly used natural aggregate in asphalt concrete (AC) and it make up about 75% to 80% by volume. Due to rapid infrastructure development and road construction in Sarawak, the available material such as granite is depleting rapidly. Sarawak has rich sub-standard aggregate resources and there are possibilities that certain sub-standard aggregate such as limestone and microtonolite can be used to replace granite. The research involved the formulation of the mix proportion of AC consisting limestone and microtonolite as the aggregates, the evaluation of the mechanical performance of AC consisting limestone and microtonolite, as well as the comparison of the properties and performance of both types of AC with JKR standard. Laboratory experiments were conducted in accordance to ASTM standards in this paper to evaluate the suitability of sub-standard aggregates such as limestone and microtonolite to replace granite in flexible pavement construction. Based on the tests conducted, the physical and mechanical properties of limestone achieved the minimum requirements whereas microtonolite exceeded the maximum water absorption as stated in JKR standard requirement. This research also found that the engineering performance of limestone aggregate complied with all the specified requirements in JKR standard specification to be used in AC.

ABSTRAK

Granit adalah agregat semulajadi yang biasanya digunakan dalam turapan jalan atau konkrit asfalt (AC) dan ia membentuk sekitar 75% hingga 80% mengikut isipadu. Oleh kerana pembinaan jalan raya dan pembangunan infrastruktur yang pesat di Sarawak, bahan pembinaan yang sedia ada seperti granit berkurangan dengan cepat. Sarawak mempunyai sumber agregat sub-standard yang banyak serta berpotensi digunakan untuk turapan jalan. Agregat sub-standard tertentu seperti batu kapur dan microtonolit yang boleh diperolehi dengan mudah boleh digunakan untuk menggantikan granit serta mengurangkan kos pembinaan jalan. Penyelidikan ini melibatkan pembentukan campuran-campuran AC yang terdiri daripada batu kapur dan mikrotonolit bagi menggantikan agregat berkualiti seperti granit, penilaian prestasi mekanikal AC yang terdiri daripada batu kapur dan mikrotonolit, serta perbandingan ciri-ciri dan prestasi kedua-dua jenis AC dengan piawaian Jabatan Kerja Raya Malaysia (JKR). Dalam penyelidikan ini, eksperimen di makmal dijalankan mengikut piawaian ASTM bagi menilai kesesuaian agregat sub-standard seperti batu kapur dan mikrotonolit untuk menggantikan granit dalam campuran turapan jalan. Berdasarkan ujian-ujian makmal yang telah dijalankan, sifat fizikal dan mekanik batu kapur mampu mencapai keperluan minimum manakala bagi mikrotonolit pula keputusan yang diperolehi adalah ianya melebihi kadar penyerapan air maksimum seperti yang ditetapkan dalam piawaian JKR. Kajian ini juga mendapati bahawa prestasi kejuruteraan agregat batu kapur telah memenuhi semua kriteria dalam spesifikasi piawaian JKR dan boleh digunakan dalam AC.

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LIST OF ABBREVIATIONS

AC	-	Asphalt Concrete
ACV	-	Aggregate Crushing Value
AIMS	-	Aggregate Imaging Measurement System
AIV	-	Aggregate Impact Value
CSIR	-	Council for Scientific and Industrial Research
DTNRA	-	Department of Transport and National Roads Agency
HMA	-	Hot Mix Asphalt
IDT	-	Indirect Tensile Strength
JKR	-	Jabatan Kerja Raya/Public Works Department
JMG	-	Department of Mineral and Geoscience
LAA	-	Los Angeles Abrasion
LL	-	Lower Limit
M	-	Mix
MD	-	Mix Designation
MR	-	Mid-Range
MRWA	-	Main Roads Western Australia
NRRL	-	Norwegian Road Research Laboratory
OAC	-	Optimum Asphalt Content
PBE	-	Effective Asphalt Content
PEN	-	Penetration

PI	-	Plasticity Index
R	-	Replacement
RPM	-	Revolutions Per Minute
SG	-	Specific Gravity
SSRW	-	Standard Specification for Road Works
TMR	-	Transport and Main Roads
TRL	-	Transport Research Lab
UL	-	Upper Limit
VFA	-	Voids Filled with Asphalt
VIM	-	Voids In Mix
VMA	-	Voids In Mineral Aggregates
WC	-	Wearing Course

Chapter 1

INTRODUCTION

1.1 Background

Pavements are categorized as flexible pavement and rigid pavement. Both types of pavements have different load distribution, flexible pavement distributes the loads based on layered system whereas the slab of rigid pavement carries the load and transfers it to the underlying strata.

Flexible pavement is commonly used in Malaysia. There are several major components of flexible pavement structure, namely surface wearing coarse (WC), base, subbase and subgrade. The main materials required to produce the surface WC are asphalt, coarse aggregates, fine aggregates, and filler. Aggregates make up 75 to 80% by volume of asphalt concrete (AC) or 90 to 95% by weight of AC (FWA, 2006). Granite is the commonly used natural aggregate in AC. There are a lot of on-going and up-coming major roadwork projects in Malaysia especially in Sarawak. The major roadwork projects in Sarawak are Pan Borneo Highway, Second Trunk Road and Coastal Road. According to an online newspaper article by Borneo Post Online dated 8th March 2018, there was a lack of suitable local materials such as earth, stone and sand for the construction of Pan Borneo Highway. The amount of granite in Sarawak is depleting rapidly due to continuous and rising demand of granite in AC for road constructions. Sarawak has rich sub-standard aggregate resources and there are possibilities that certain sub-standard aggregate such as limestone can be used to replace granite.

Limestone which is largely available is prohibited to be used in AC by Public Works Department (JKR) Malaysia. Section 4.4.3.2 in Standard Specification For Road Works (JKR, 2008) shows the requirements for aggregates to be used WC and it is stated that limestone aggregates cannot be used in WC even if limestone complies with the specification. According to JKR (2008), limestone is a type of sub-standard aggregate which is not permitted to be used in because of its potential low skid resistance. Limestone is suspected to be susceptible to polishing under traffic action. However, Manglorkar (1991) conducted a research to evaluate limestones in AC WC and found that limestone aggregates can increase the stability of AC and strengthen its moisture resistance. Besides, Manglorkar (1991) also proved that some limestone aggregates had frictional resistance which was comparable to gravel aggregates. Hence, further testing was suggested to verify the physical and mechanical performance of AC consisting of sub-standard aggregates such as limestone to determine its potential use in WC.

1.2 Problem Statement

Based on JKR Standard (2008), the usage of limestone in WC is prohibited. There are a few potential problem characteristics which lead to this prohibition. Based on TRL (2002), the likely problems of limestones are low particle strength, poor grading and in-service deterioration. Other potential problems of sub-standard aggregates are high or low plasticity index (PI) fines, poor durability, poor particle shape, high mica content and high variability (TRL, 2002). Studies are required to reassess the suitability of limestone and other sub-standard aggregates in WC and to provide evidence of effectiveness of using them in WC. There are possibilities that the characteristics of sub-standard aggregates can be improved by combining two or more types of them. There is no standard specification for sub-standard aggregates or combined sub-standard aggregates in Malaysia. Further research is required to identify the opportunities to amend the standard specification to allow the usage of sub-standard aggregates under certain conditions or to identify the needs to create a standard specification specifically for sub-standard aggregates.

1.3 Significance of Study

This research contributed in the application of sub-standard aggregates in AC. This research involved the formulation of the mix proportion of AC consisting limestone as the only aggregate, the evaluation of the mechanical performance of AC consisting limestone as the only aggregate, the evaluation of the mechanical performance of AC consisting a mixture of two sub-standard aggregates as well as the comparison of the properties and performance of both types of AC with JKR standard. The significances of this study are stated below:

1. Potentially reduce the demand of granite in road construction.
2. The potential in amending the current standard to allow the usage of limestone and other sub-standard aggregates such as microtonolite.

1.4 Hypothesis

1. The optimum mix design for limestone and microtonolite AC can be achieved within the range of aggregate grading curve for ACW14.
2. Limestone AC can achieve the minimum requirements as stated in JKR Standard (2008).
3. Microtonolite can improve the mechanical performance of limestone AC.

1.5 Aim & Objectives

The aim of this research is to investigate the use of limestone and microtonolite in AC mix design. The objectives of the research are as follows:

1. To formulate the mix proportion with limestone and microtonolite in AC.
2. To investigate the mechanical properties of limestone in AC.
3. To compare the performance of limestone and microtonolite AC to JKR standard (2008).

1.6 Scope of Study

The aggregates were tested for their specific gravity (SG), aggregate impact value (AIV), aggregate crushing value (ACV) and Los Angeles Abrasion (LAA). The asphalt was tested for its softening point, fire and flash point, viscosity, SG and penetration value. Marshall samples were then produced and tested for their physical and mechanical properties using Marshall stability and flow test. The optimum mix design of limestone AC was obtained by adjusting the grading curve (trial and error and back-calculation method). Limestone was then replaced by microtonolite in three ways: replacing coarse sizes only, replacing fine sizes and full replacement.

1.7 Thesis Structure

The thesis is organized into five (5) chapters as shown below.

Chapter 1: Chapter 1 is the introduction of this study. This chapter discusses the background of this study, the motivations in this research and the potential findings.

Chapter 2: Chapter 2 is the literature review of past researches. This chapter discusses the past studies that have been done to evaluate the factors influencing performance of AC. Besides, sub-standard aggregates such as limestone was discussed in this chapter.

Chapter 3: Chapter 3 is the methodology of this study. This chapter explains the standard procedures and methods used to carry out this research.

Chapter 4: Chapter 4 contains the result and discussion of this study. This chapter discusses the experimental result obtained from this research.

Chapter 5: Chapter 5 concludes this study and makes recommendations for further studies.

Chapter 2

Literature Review

2.1 Introduction

This section reviewed the factors affecting the performance of asphalt concrete (AC) and types of sub-standard aggregate available.

2.2 Factors Affecting Performance of Asphalt Concrete

The performance of AC depends on various factors such as the morphology of aggregate, grade of asphalt, mixing and compaction temperature, and filler content. Morphology of aggregates affects the strength of interlocking force between aggregate particles. Besides, the viscosity of asphalt changes with the grade of asphalt hence affecting the performance of AC. Next, the temperature affects the workability and compactability of AC. Lastly, filler content affects the optimum asphalt content (OAC) for AC mixtures.

2.2.1 Aggregate Shape (Form, Angularity and Surface Texture)

According to Barrett (1980), the shape of a rock particle can be expressed in terms of three independent properties which are form (overall shape), angularity and surface texture. Bessa, Branco, Soares & Neto (2015) stated that a high percentage of elongated and flat aggregates in HMA may lead to a change in the designed gradation as the breakage of those particles occurs during compaction process and hence affects the performance of AC. Cui et al. (2018) conducted a research to examine the effect of limestone aggregate morphology on Marshall stability of AC. Limestone is a sedimentary rock which consists of mineral calcite, dolomite and other impurities and it can easily react with slightly acidic water. Cui et al. (2018) concluded that reasonable angularity and sphericity value ensure sufficient inter-locking of aggregate particles but the angles of aggregate will become fragile when the angularity continues to increase. Experimental data is tabulated in Table 2.1. Figure 2.1 shows the Aggregate Imaging Measurement System (AIMS) angularity criteria and Figure 2.2 shows the 2D morphology of limestone with different angularity as shown by Cui et al. (2018) in their research paper.

Table 2.1: Effect of Angularity and Sphericity on Marshall Stability for Limestone

Author(s)	Aggregate Morphology	Angularity	Texture	Sphericity	Marshall Stability (kN)
Cui et al., 2018	L1	2484	294	0.79	9.93
	L2	2827	296	0.75	11.04
	L3	3098	304	0.71	12.85
	L4	3553	297	0.60	12.73
	L5	3941	301	0.53	11.62

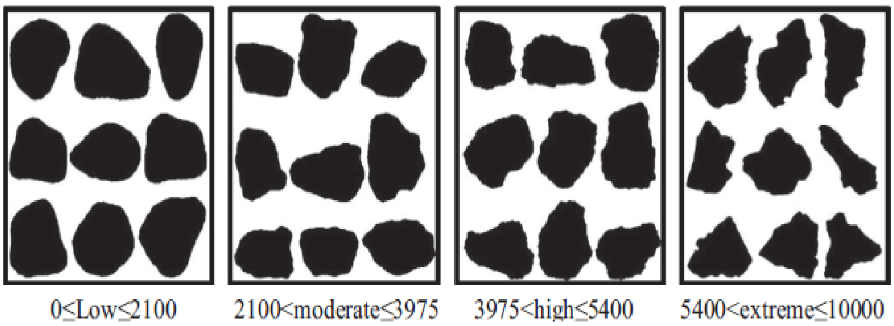

Figure 2.1: AIMS Angularity Criteria

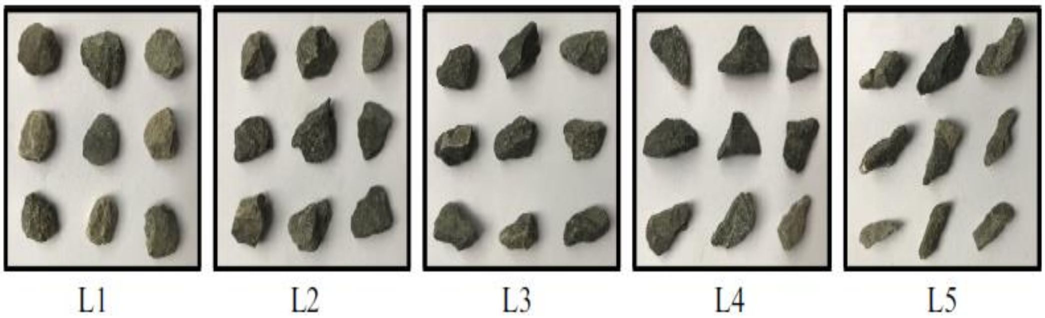

Figure 2.2: 2D Morphology of Limestone with Different Angularity

2.2.2 Aggregate Gradation

Setiawan, Suparma & Mulyono (2017) conducted a study to study the effect of aggregate gradation on the properties of AC mixtures and found that the upper limit gradation will result in higher stability and lower flow as compared to the lower limit gradation. Afaf (2014) and Elliot, Ford, Ghanim and Tu (n.d.) conducted two independent studies to evaluate the effect of gradation on Marshall Properties of AC (specific gravity, stability, flow, and air voids). Marshall Stability test was used to test and analyse the effect of gradation variation. Three gradation variations compared were upper limit gradation, mid-range gradation and lower limit gradation. Afaf (2014) and Elliott et al. (n.d.) found that the mixture with upper limit gradation has the highest stability and flow while the lower limit gradation has the lowest stability and flow. Table 2.2 shows the experimental result obtained by Setiawan et al. (2017) and Afaf (2014). The result showed the asphalt content for each gradation, Marshall stability, flow, voids in mix (VIM), voids in mix aggregate (VMA) and voids filled by asphalt (VFA).

Additionally, Kandal and Mallick (2001) conducted a study to evaluate the effect of aggregate gradation on rutting potential of AC. The aggregates used to produce Superpave gyratory samples of mixes were granite, limestone, and gravel aggregates. The gradations used were gradation above the restricted zone which is an upper gradation, gradation through the restricted zone which is a mid-range gradation and gradation below the restricted zone which is a lower gradation for typical wearing and binder courses of Alabama Department of Transportation. It was found that limestone samples with lower gradation has the highest VMA. Kandal and Mallick (2001) stated that rut depth increases with VMA.

Abo-Qudais and Al-Shweily (2007) conducted a research to investigate the effect of properties on stripping and creep behaviour of AC mixtures. Limestone and basalt were used to produce AC mixtures with upper limit, mid-range and lower limit gradations of ASTM specifications. Abo-Qudais and Al-Shweily (2007) explained AC mixtures produced with lower gradation gradation had higher air void content because it contained less fine aggregate as compared to AC samples produced with mid-range gradation. Abo-Qudais and Al-Shweily (2007) found that AC mixtures with lower limit gradation had the highest creep strain and the lowest stripping resistance whereas AC mixtures with upper limit gradation had the lowest creep strain and the highest striping resistance. It was explained that lower limit gradation contains lesser fine aggregates which reduces adhesion by fines and reduces the stripping resistance. Table 2.2 below tabulates the properties of limestone AC mixtures.

Table 2.2: Properties of AC Mixtures with Different Aggregate Gradation

Author(s)	**Gradation**	**Asphalt Content (%)**	**Stability (N)**	**Flow (mm)**	**VIM (%)**	**VMA (%)**	**VFA (%)**
Afaf (2014)	UL	5.2	1480	3.65	3.8	15.5	-
	MR	5.0	1420	3.6	3.8	14.8	-
	LL	4.8	1407	3.3	4.1	15.8	-
Setiawan et al. (2017)	UL	6.0	1978.3	3.2	3.86	16.01	75.89
	MR	6.0	1790.3	3.47	2.78	15.22	81.74
	LL	6.0	1204.67	4.53	6.88	17.97	61.74
Abo-Qudais and Al-Shweily (2007)	UL	5.6	1483	4	4.8	13.7	-
	MR	5.3	1426	4.13	4.1	13.1	-
	LL	4.2	665	3.2	12.8	16.8	-

**LL=lower limit; MR=mid-range; UL=upper limit*

2.2.3 Grade of Asphalt

AC tends to degrade in the presence of water under traffic action. Caro et al. (2008) stated that water can interact with AC in the liquid or vapour (gaseous) state which weakens the bonding between asphalt ad aggregate (Kinggundu and Roberts, 1988). Weakening of bonding can be observed through pavement distresses such as stripping.