THE EFFECTS OF MICRO AND NANO SIZE BAUXITE PARTICLES IN MODIFIED ASPHALT BINDERS AND ASPHALTIC MIXTURES

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DEDICATION

I would like to dedicate my appreciation to Allah Almighty for his grace, guidance and protection during my Ph.D. study.

Specially dedicated to

My parents

My wife

My lovely brothers and sisters

My love to you will always remain and thank you for your support, guidance, patience and joy that make this experience complete.

Thank you for your sacrifices, prayers, understanding, and continuous support I wouldn't make it without you.

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“May Allah bless us all to achieve excellence in life”

ABSTRACT

Yearly increasing of traffic volume has caused congestion on road pavement and it's likely to effects the pavement performance such as reduce in strength and loss structural integrity. Due to these phenomena, road construction industry need to focus how to improve the characteristics of asphalt mix in order to reduce the pavement deteriorations. This study aims to evaluate the effects of Malaysian Micro bauxite powders (MBP) and Nano bauxite powders (NBP) with 3%, 5% and 7% by mass of bitumen. Conventional bitumen 80/100 penetration grade was used as the base binder. The modified asphalt binder was evaluated on the fundamental physical properties. Performance of modified asphalt mixtures prepared with MBP and NBP were evaluated for resilient modulus, dynamic creep and rutting susceptibility. In this study, the size of MBP and NBP used were less than 75 μm and in ranges of 10 nm to 20 nm, respectively. The result shows that the addition of 7% MBP and NBP in asphalt binder have decreased the penetration value and increased the softening point by 18.6% and 23.6%, and 6.5% and 10.8%, correspondingly. This indicates that incorporation of 7% MBP and NBP in asphalt binder are capable to increase the stiffness of asphalt binders compared to virgin binder. However, the modified asphalt binder with 5% MBP and NBP exhibit higher complex modulus (G^*) and phase angle (δ) compared to the modified binder with 7% MBP and NBP regardless of test temperature. Thus, incorporation of 5% MBP and NBP in asphalt binder give a higher value of $G^*/\sin \delta$ which result higher binder stiffness to resist the rutting. In addition, the resilient modulus of modified asphalt mixture incorporation of 5% MBP and NBP for unaged and short-term aged tested at 25°C and 40°C have increased by 16.5% and 14.4%, and 19.9% and 18.7%, respectively. The permanent deformation and rutting of asphalt mixture incorporated with 5% MBP and NBP consistently resulted lowest values for both unaged and short-term aged compared to the other specimens. It can be concluded that the incorporation of 5% MBP and NBP in virgin asphalt binder give the best performance of the modified asphalt mixture.

ABSTRAK

Peningkatan jumlah lalu lintas tahunan telah mengakibatkan kesesakan di jalan raya dan memberikan kesan terhadap prestasi turapan seperti mengurangkan kekukuhan dan integriti struktur. Disebabkan oleh fenomena ini, industri pembinaan jalan raya perlu memikirkan bagaimana untuk meningkatkan ciri-ciri campuran asfalt yang boleh mengurangkan kemerosotan turapan tersebut. Kajian ini bertujuan untuk menilai kesan penggunaan serbuk bauksit Mikro (MBP) dan serbuk bauksit Nano (NBP) di Malaysia yang mengandungi 3%, 5% dan 7% dari berat bitumen. Bitumen konvensional 80/100 gred penusukan digunakan sebagai bahan pengikat asas. Bitumen terubahsuai dinilai pada sifat fizikal asas. Prestasi campuran asfalt terubahsuai yang dicampurkan dengan MBP dan NBP dinilai terhadap modulus keanjalan, rayapan dinamik dan kecenderungan terhadap perpaluhan. Dalam kajian ini, saiz MBP dan NBP yang digunakan adalah kurang daripada 75 µm dan dalam lingkungan 10 nm hingga 20 nm, masing-masing. Hasil kajian menunjukkan penambahan 7% MBP dan NBP dalam asfalt terubahsuai telah menurunkan nilai penusukan dan meningkatkan titik pelembutan sebanyak 18.6% dan 23.6%, dan 6.5% dan 10.8%, masing-masing. Ini menunjukkan bahawa penggunaan 7% MBP dan NBP meningkatkan kekakuan asfalt berbanding pengikat asal. Walau bagaimanapun, asfalt terubahsuai yang mengandungi 5% MBP dan NBP mempamerkan modulus kompleks (G*) dan sudut fasa (δ) yang lebih tinggi berbanding asfalt terubahsuai yang mengandungi 7% MBP dan NBP tanpa mengira suhu pengujian. Oleh itu, penggunaan 5% MBP dan NBP memberikan nilai yang lebih tinggi keatas nilai G*/sinδ dan mampu menjadi penghalang perpaluhan. Di samping itu, modulus keanjalan campuran asfalt terubahsuai mengandungi 5% MBP dan NBP dalam keadaan asal dan pengusiaan jangka pendek diuji pada $25^{o}C$ dan $40^{o}C$ menunjukkan peningkatan sebanyak 16.5% dan 14.4%, dan 19.9% dan 18.7%, masing masing. Dapat disimpulkan bahawa perubahan bentuk kekal dan perpaluhan campuran asfalt terubahsuai mengandungi 5% MBP dan NBP menghasilkan nilai terendah terhadap keadaan asal dan pengusiaan jangka pendek berbanding spesimen lain serta berprestasi menjadi campuran asfalt terubahsuai terbaik.

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LIST OF ABREVIATIONS

A	-	Aging
AI	-	Aging Index
AASHTO	-	American association of state highway and transportation officials
ASTM	-	American society for testing and materials
CGN	-	Compaction Gyration Number
DSR	-	Dynamic Shear Rheometer
DG	-	Dense-Grade
ESALs	-	Equivalent Single Axle Loads
G_{sb}	-	Bulk specific gravity of aggregate
G_b	-	Specific gravity of asphalt
G_{se}	-	Effective specific gravity of aggregate
G_{mb}	-	Specific gravity of aggregate
G_{mm}	-	Maximum specific gravity of paving mixture
HMA	-	Hot Mixture Asphalt
MBP	-	Micro Bauxite Powder
MSCR	-	Multiple Stress Creep Recovery
MT	-	Mixing Temperature
$N_{initial}$	-	Compaction parameter
N_{design}	-	Compaction parameter
$N_{maximum}$	-	Compaction parameter
NAPA	-	National Asphalt Pavement Association
NBP	-	Nano Bauxite Powder
OAC	-	Optimum asphalt content
P_{be}	-	Effective asphalt content, percent by total weight of Mixture
P_b	-	Asphalt percent by total weight of mixture
PG	-	Performance Grade

RTFO	-	Rolling Thin Film Oven
RV	-	Rotational Viscometer
SHRP	-	Strategic Highway Research Program
SMA	-	Stone Matrix Asphalt
SGC	-	Superpave Gyratory Compactor
TSR	-	Tensile Strength Ratio
UTM	-	Universal Testing Machine
VFA	-	Voids Filled Asphalt
VMA	-	Voids Mineral Aggregate
VTM	-	Voids in Total Mixture

LIST OF SYMBOLS

F	-	Recovered angle
FTS	-	High Failure Temperatures of short-term-aged asphalt binder
FTU	-	High Failure Temperatures of unaged asphalt binder
G*	-	Complex shear modulus
G*/sin δ	-	Superpave™ rutting factor
G’	-	Elastic component or storage modulus
G’’	-	Viscous component or loss modulus
Jnr	-	Creep compliance
MR	-	Resilient modulus
PI	-	Penetration Index
S.P	-	Softening Point
γ	-	Ratio of the strain
δ	-	Phase angle
Σ	-	Constant applied load

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CHAPTER 1

INTRODUCTION

1.1 Preface

The asphalt binder and asphalt mixes need to be improved to reduce and prevent distresses. Several possible ways are used to improve the performance of asphalt binder and mixture used in the surfacing course of road pavements. At the present time, researchers of asphalt and engineers are still looking for solutions, taking into considerations the most important user requirements in terms of economy and safety of highway construction (Musbah *et al*., 2016).

Furthermore, road pavement is subjected to external loads including mechanical loading induced by heavy traffic and thermal loading induced by thermal changes (Soltani *et al*., 2015). Similarly, in order to assure positive performance of pavements, highway agencies stipulate the use of specific materials for highway pavement construction. Asphalt modifiers have been used in road construction industry as early as in1950s, which have improved the performance of asphalt pavements by inceasing resistance to pavement distresses (Roberts *et al*., 1991). A precedent study by Kedarisetty *et al*., (2016) noted that unconventional modified asphalt binder and mixtures materials have been successfully applied on road construction to reduce the pavement structure failures, and are playing an increasingly important role in the asphalt industry. More importantly, the modified asphalt mixes are able to mitigate the damage caused by pavement distress with less maintenance. The goal of improving bitumen properties and the functional modified bitumen system is based on the fine dispersion of rheological bitumen for which the chemical composition of bitumen is important. A great deal of research has been conducted to understand the road performances of asphalt binders and mixtures. Some researchers reported that the bitumen modifiers such as fillers, extenders polymer, fibers, oxidants, and nano materials had been used for several years in asphalt mixing to increase the pavement performance.

In recent years, modifiers material known as mineral fillers has been increasingly practised on asphalt binder modification preparations. Mineral fillers are found to have great effects and improved the performance of pavements. Mineral fillers play a critical role in the performance of asphalt mixes. Several types of mineral fillers are used worldwide. The addition of fillers to asphalt has shown to be beneficial with an improvement in the properties of the binder, as well as resistance to the permanent deformation and rutting potential of asphalt concrete mixtures, improving their performance. In general, filler material produces benefits to asphalt binder and asphalt mixes properties. Firstly, it is able to improve the storage stability in modified asphalt binder. Secondly, it can reduce the moisture susceptibility of modified asphalt binder. Thirdly, it can improve the properties of asphalt which lead to improving the durability of asphalt pavements and the maintenance cost and energy consumption.

Nanotechnology is very small particles of material, nanotechnologies are new materials that recently become popular and one of the large and important parts of research and development worldwide (Mahshid *et al*., 2012). In pavement modification materials, nano- modifiers such as nanoceramic powder, nano aluminum oxide, nanosilica, carbon nanotube and nanoclay have been successfully used to improve asphalt binder properties. Previous studies reported that using nano-modifiers in asphalt binder and asphalt mixture improved the properties of asphalt at low and high temperatures, reduced the moisture damage, and improved the durability of the asphalt mixture, reducing the costs of maintenance and saving energy (Yang and Tighe, 2013; Hainin, Matori, and Akin, 2014; Mubaraki *et al*. 2016; Hussein *et al*., 2017).

1.2 Problem statement

The increasing demands for effective road construction materials especially in developed countries have resulted in searches for binders with improved performance relative to normal penetration grade bitumen. Efforts to obtain improved binder characteristics have led to the evaluation, development and use of a wide range of bitumen modifiers, which enhance the performance of the conventional bitumen and hence, decrease life cycle costs, and increase the pavement durability (Albrka *et al*., 2014).

Several research teams around the world have worked on evaluating the benefits of binder modification on pavement performance. Wekumbura *et al*., (2007) mentioned that the most common modes of pavement distress are cracking and rutting due to heavy vehicles' static loads, long traffic durations, and climatic factors such as temperature and moisture.

The Public Works Department Malaysia (PWD) conducted a study in 2003 and found that the volume of expenditure on road maintenance increased over a year (Harahap, 2005). Pavement structure layers must be able to withstand the different climatic conditions, existing heavy loads and expected future loads for an acceptable period of time. According to Aman (2013), the durability of asphaltic concrete is greatly influenced by the environmental changes between day and night, as well as between hot and cold temperatures throughout the year. High temperatures can soften the bitumen and consequently reduce the stiffness of asphaltic concrete, making the mix more susceptible to rutting. Low temperature can increase the stiffness of bitumen and reduce the flexibility of the asphaltic concrete, hence, inducing fatigue failure. Thus, high temperature stiffness and low temperature flexibility are important properties in bituminous mixtures respectively to avert rutting and cracking.

Shafabakhsh and Ani (2015) reported that rutting, which is one of the major distresses in asphalt pavement, is the accumulation of permanent deformation in asphalt caused by repeated loads at high working temperatures. Rutting affects the pavement ride quality and can cause uncontrollable vehicle sliding with a high potential for traffic accidents, especially when it rains (Msallam *et al*., 2017).

Therefore, there is a need to improve the asphalt binder by adding some modifiers such as fillers and nanomaterial. These types of modifiers have an important role in the performance of asphalt pavement. Depending on their characteristics to fill the voids and modify the asphalt mixture, the micro and nano materials can mitigate pavement distresses. Besides smelting and manufacturing its own aluminium, Malaysia also exports bauxite to China, Malaysia's largest export destination. In order to meet the strong demand from this country, Malaysia had to double and tripled the production of bauxite in order to meet the demand. But the country is selling off its resources on the cheap way so Malaysia should follow a new way to preserve its valuable mineral resources for domestic industry. Thus, this study was conducted to modify the asphalt binder and mixture with a new local material (bauxite) which can enhance the pavement design life and reduce the road maintenance cost. In addition, this study was conducted to evaluate the effects of Malaysian bauxite powder in micro and nano sizes on the performance of the asphalt binder and mixture.

1.3 Research aim and objectives

The aim of this research was to evaluate the effects of Malaysian bauxite powder in two sizes (micro and nano) on the performance of modified asphalt and asphalt mixes. In order to accomplish this aim, the following objectives were addressed:

i. to assess the effects of micro and nano bauxite powder as modifiers on the binder's physical and rheological properties.
ii. to evaluate the effects of aging condition on the modified asphalt binder by using micro and nano bauxite powder.
iii. to identifying the effects of micro and nano bauxite powder in asphalt mixtures as modifiers on the rutting behavior potential.
iv. to investigate the effects of aging condition on the modified asphalt mixes by using micro and nano bauxite powder, and
v. to compare the results of micro and nano bauxite powders in terms of their influence on the performance of asphalt binder and asphalt mixture.

1.4 Scope of the research

This research focused on experimental work investigating the impacts of both modifiers on asphalt binder and asphalt mixes. Penetration test, softening point test, ductility test and viscosity test were performed to investigate the physical properties. The mixed design and the compaction condition study were conducted using Superpave mix design. Based on this design, the volumetric properties and the optimum asphalt content (OBC) were determined. Subsequently, the performance tests of asphalt mixes were conducted. These tests included dynamic creep, resilient modulus and wheel trucking test. In addition, the Dynamic Shear Rheometer (DSR) were used to evaluate the rheological of the base asphalt and modified asphalt binder.

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