THE EFFECTS OF NOMINAL MAXIMUM AGGREGATE SIZE ON THE PROPERTIES OF HOT MIX ASPHALT USING GYRATORY COMPACTOR

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ABSTRACT

The introduction of Superpave mix design in 1993 in the United States has categorized mixes based on the nominal maximum aggregate size (NMAS). The centerpiece of the mix design is the Superpave Gyratory Compactor (SGC). Properties of hot mix asphalt (HMA) have always been associated with pavement deformations. This study looks into the effects of NMAS on the properties of Malaysian HMA mixtures, which includes optimum bitumen content (OBC), bulk specific gravity (G_{mb}), theoretical maximum density (TMD), water absorption (WA), voids in mineral aggregate (VMA), voids filled with bitumen (VFB), and dust to binder ratio (D:B). Thus, a better understanding of the properties can reduce the pavement deformations. A total of four asphaltic concrete mix designs with different NMAS were prepared in accordance with the JKR Specification, namely AC10, AC14, AC20, and AC28. Specimens of each mix design with varying bitumen content were compacted to 75 and 100 gyrations using SGC to obtain 4±1% air voids. It was observed that as the NMAS increased, the OBC and VMA decreased. The G_{mb}, TMD, WA, and D:B showed opposite trend of the earlier properties. T-tests indicated that all properties except VMA were affected by NMAS. VMA for AC20 failed the minimum requirement initially but when calculated using the average asphalt film thickness method, it was acceptable. Different compaction efforts showed the same pattern on the properties except VFB while t-tests revealed that OBC, TMD, VMA, and D:B were significantly affected. Investigation also showed that AC20 is the best mix from the economic and durability point of views.

ABSTRAK

Pengenalan rekabentuk campuran Superpave pada tahun 1993 di Amerika Syarikat telah mengkategorikan campuran berdasarkan saiz nominal maksimum agregat (NMAS). Hasil utama rekabentuk campuran ini ialah Pemadat Legaran Superpave (SGC). Sifat-sifat campuran panas berasfalt (HMA) selalu dikaitkan dengan ubahbentuk turapan. Kajian ini melihat kepada kesan NMAS terhadap sifat-sifat campuran HMA Malaysia yang merangkumi kandungan bitumen optimum (OBC), graviti tentu pukal (G_{mb}), ketumpatan maksimum teori (TMD), penyerapan air (WA), lompang dalam agregat mineral (VMA), lompang terisi bitumen (VFB), dan nisbah debu kepada pengikat (D:B). Oleh itu, pemahaman yang lebih lanjut mengenai sifat-sifat ini dapat mengurangkan ubahbentukturapan. Sejumlah empat rekabentuk campuran konkrit berasfalt dengan NMAS yang berbeza telah disediakan mengikut Spesifikasi JKR, iaitu AC10, AC14, AC20, dan AC28. Spesimen daripada setiap rekabentuk campuran dengan kandungan bitumen yang berbeza telah dipadatkan ke 75 dan 100 legaran dengan menggunakan SGC untuk mendapatkan 4±1% kandungan udara. Apabila NMAS meningkat, dapat diperhatikan bahawa OBC dan VMA menurun. G_{mb}, TMD, WA, dan D:B menunjukkan corak yang bertentangan dengan sifat-sifat terdahulu. Keputusan ujian-t menunjukkan bahawa kesemua sifat dipengaruhi oleh NMAS kecula VMA. VMA untuk AC20 pada mulanya gagal untuk memenuhi keperluan minimum tetapi apabila dihitung dengan menggunakan kaedah ketebalan purata selaput asfalt, ianya dapat diterimapakai. Usaha pemadatan yang berbeza menunjukkan corak yang sama untuk kesemua sifat kecuali VFB manakala ujian-t menunjukkan bahawa OBC, TMD, VMA, dan D:B amat dipengaruhi. Kajian menunjukkan AC20 adalah campuran yang terbaik dari segi ekonomi dan ketahanlasakan.

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LIST OF ABBREVIATIONS

AASHTO	-	American Association of State Highway and Transport Officials
AC10	-	asphaltic concretewith NMAS of 10mm
AC14	-	asphaltic concretewith NMAS of 14mm
AC20	-	asphaltic concretewith NMAS of 20mm
AC28	-	asphaltic concretewith NMAS of 28mm
ASTM	-	American Society for Testing and Materials
D:B	-	dust to binder ratio
ESAL	-	Equivalent Standard Axle Load
G_{mb}	-	bulk specific gravity
GTM	-	Gyratory Testing Machine
HMA	-	hot mix asphalt
JKR	-	Jabatan Kerja Raya (Public Works Department)
KLIA	-	Kuala Lumpur International Airport
MDL	-	maximum density line
NAPA	-	National Asphalt Paving Association
N_{des}	-	design number of gyrations
$N_{initial}$	-	initial number of gyrations
NMAS	-	Nominal Maximum Aggregate Size
$N_{maximum}$	-	maximum number of gyrations
OBC	-	optimum bitumen content
PG	-	Performance Grade
P_s	-	percent by weight of the total amount of aggregate in the mix
$SG_{aggblend}$	-	bulk specific gravity of the combined aggregate
SGC	-	Superpave Gyratory Compactor
SG_{coarse}	-	bulk specific gravity of coarse aggregate

SG_{filler}	-	bulk specific gravity of mineral filler
SG_{fine}	-	bulk specific gravity of fine aggregate
SHRP	-	Strategic Highway Research Program
Superpave	-	Superior Performing Asphalt Pavement
TMD	-	theoretical maximum density
VFB	-	voids filled with bitumen
VMA	-	voids in mineral aggregate
VTM	-	voids in total mix
WA	-	water absorption

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CHAPTER 1

INTRODUCTION

1.1 Preamble

With the rapid growth in development and population, Malaysians are certainly heading towards a better lifestyle. The Ninth Malaysia Plan, with a bulk of the budget going to the development of infrastructure, sees a need to accommodate the basic necessities of the people in Malaysia, and road construction is one of them.

One of the basic requirements for a pavement to perform to its design life is the ability to withstand intense loading from repetitive traffic. The pavement should have sufficient thickness to deal with the stresses at the surface and at the same time, to protect the subgrade from damage. Therefore, a vital component in the process of constructing an asphalt pavement is the design of the asphalt mixture that will be used for the pavement. Beside ESALs loading, these mix designs take into account many other factors such as environmental conditions, desired surface texture, and the mix materials.

In 1987, the Strategic Highway Research Program (SHRP) was approved and established by the United States Congress as a five-year $150 million research program to improve the performance and durability of roads and to make those roads safer for both motorists and highway workers (Huang, 2004). Research on asphalt binder mixture specifications led to a new system for design of hot mix asphalt based upon mechanistic concepts. $50 million of the SHRP research funds were used for this purpose and it developed the laboratory mixture design method known as Superpave, an acronym for Superior Performing Asphalt Pavements (Lavin, 2003; Huang, 2004). Superpave directly correlates laboratory methods with pavement performance instead of relating basic physical properties and observed performance as it is with Marshall mix design method.

Superpave mix design involves three major components: the asphalt binder specification, the mixture design and analysis system. There are three levels of testing and analysis but only level one, which incorporate material selection and volumetric proportioning, are currently being practiced routinely by designers. Level two and three have additional testing machine to check the following pavement distress, namely low temperature cracking, fatigue cracking, and permanent deformation.

The key component of Superpave mix design is the Superpave Gyratory Compactor (SGC). SGC emulates the compaction done at site with its kneading action of compaction in the laboratory provided by the gyration angle. Specifications instructed that SGC are to be used with 150mm diameter mould. However, SGC is also capable of compacting smaller specimens using 100mm diameter mould but with certain limitations.

With the introduction of Superpave mix design in the United States back in 1993, it was recommended that the nominal maximum aggregate size (NMAS) to be used in categorizing the mixes. The definition of NMAS is the largest sieve size that retains not more than 10 percent of the aggregate particle in any mix designs. The other designation for classifying mix is by the maximum size which is defined as the smallest sieve size through which 100 percent of the aggregate sample particles pass.

Superpave specifications give advantages and disadvantages. Superpave is performance-based and it uses Performance Grading System (PG) for its asphalt binder grading system. Through this way, it adopts both the project temperature and traffic criteria. Even though Superpave mixtures have a high coarse aggregate content and are more difficult to work with, experience has shown that good smoothness can be obtained. Superpave mixtures tend to provide good surface drainage and result in less spray (NCAT, 1997). This results in good surface friction properties. The process of compaction by SGC is quieter as compared to Marshall hammer. This is due to the kneading action of SGC. The Superpave system can be adapted to suit the requirements of any country or region. The specification needs to include only those performance grades and requirements that are relevant to the climate and traffic prevailing in a specific region or country. Furthermore, this design method is not just restricted to high traffic freeways, but it is also applicable for low volume roads and low volume parking facilities (Cross and Lee, 2000).

The disadvantages encountered among others are the testing equipment is more complex and costly. It requires substantial capital investment and firm commitment to maintain the equipment in proper working conditions. In the USA, a complete set of Superpave bituminous binder testing equipment – including bending beam and direct tension apparatus – costs about US $100,000; the two servo-hydraulic Superpave mixture testing systems costs approximately US $400,000 (Tappeiner, 1996).

Superpave made its debut in Malaysia through the Kuala Lumpur International Airport (KLIA) project (Tappeiner, 1996; Harun, 1996). Juggling between the short period of time to complete the project and the complexity of adopting the Superpave's advanced mix design and quality control system, only the Superpave bituminous binder specifications have been included with the design and evaluation procedures similar to those described in NCHRP Report 338: *Asphalt-Aggregate Mixture Analysis System (AAMAS)* (after Tappeiner, 1996).

1.2 Problem Statement

Typically, most specifications use NMAS in its mix design. Superpave and Public Works Department (JKR) gradation limits use NMAS, even though both mix designs specified a slightly different NMAS. The design of each mix with variation in the gradation has an effect on the properties of the mix.

In a few studies conducted, NMAS is found to be linked to permeability and rutting in a pavement (Mallick *et al.*, 2003; Kandhal, 1990; Cooley Jr., Prowell, and Brown, 2002). Permeability is related to the interconnected voids that allow the water to infiltrate into the pavement. Through the research of Mallick *et al.* (2003), it was shown that voids in mineral aggregate (VMA) has a significant effect on in-place permeability of pavements and coarse-graded Superpave mixes in which with the increment of NMAS, the permeability also increases.

Rutting is normally associated with the extra compaction due to traffic loading. Lavin (2003) attributed rutting to the fact of low design air voids, excessive asphalt binder, excessive sand or mineral filler, rounded aggregate particles, and low VMA.

Each mix design has its own optimum bitumen content. The bitumen content at a fixed percent of air voids varies according to the NMAS and gradation. The bitumen content plays a significant role in calculating VMA and voids filled with bitumen (VFB). However, Kandhal, Foo, and Mallick (1998) argued that VMA should be calculated based on surface area and to have an average asphalt thickness coated on the aggregates.

Other problems related to the NMAS are workability and segregation. Smaller NMAS tends to have good workability but is more unstable while larger NMAS will cause segregation to happen. It is also interesting to note that larger aggregates are being use to minimise rutting (Kandhal, 1990).

The few phenomena described in the paragraphs above can all lead to further deterioration of a pavement. It is important to get to the root cause of it to overcome these defects. Therefore, this study that looked into the fundamental properties of Malaysian hot mix asphalt (HMA) mixes is essential to provide the knowledge and understanding of the consequences.

1.3 Aim

This study was aimed to probe the effects of nominal maximum aggregate size on the properties of hot mix asphalt compacted with Superpave Gyratory Compactor by using the Malaysian mix design.

1.4 Objectives

The primary goal of this study was to evaluate the properties of Malaysian HMA mixes prepared with different NMAS. The properties evaluated include:

(i) optimum bitumen content at four percent air voids (OBC);
(ii) bulk specific gravity of lab compacted mix, (G_{mb});
(iii) theoretical maximum density (TMD) using Rice method;
(iv) water absorption (WA);
(v) voids in mineral aggregates (VMA);
(vi) voids filled with bitumen (VFB); and
(vii) dust to binder ratio (D:B).

This study also looked into the properties of the mixes when compacted with different compactive effort. All mix designs were compacted to 75 and 100 gyrations.

1.5 Scope of the Study

In order to investigate the effects of NMAS on the properties of HMA, four types of mix designs of asphaltic concrete (AC) were prepared in accordance to the JKR Specification (SPJ rev2005). They were AC 10, AC 14, AC 20, and AC 28. All these mix designs were compacted at two different levels of compaction, i.e. 75 and 100 gyrations, simulating the Malaysian traffic loading condition.

Based on the National Asphalt Paving Association (NAPA) method, the optimum bitumen content were determined to obtain a 4% air voids for all the mixes, regardless of the layer it serves. A minimum of three bitumen content were used for each mix design, starting with median, and 0.5% before and after the median. Verification samples were done for all the OBC.

Loose samples of two for each mix design were prepared to get the TMD values. Samples were analysed based on the properties and were subsequently correlated.

1.6 Importance of the Study

The relationship between basic fundamental properties as mentioned in Section 1.4 is very much related to the behaviour of a pavement. It is from these properties that one may know the later consequences of the pavement whether it is under-designed or over-designed. A lot of researchers have used these properties to look into the deformation or on-site behaviour of a pavement (Brown, 1990; Kandhal, Foo, and Mallick, 1998; Peterson, Mahboub, and Anderson, 2004).

The JKR Specification (SPJ rev2005) differs a little bit from the Superpave gradation in terms of the NMAS used. The SPJ rev2005 uses NMAS of 10, 14, 20, and 28mm while Superpave specifies NMAS of 9.5, 12.5, 19, and 25mm. This study will be able to help the researchers and engineers understand the properties of the Malaysian mix when they are using different NMAS in their projects. As Malaysian Government has allocated the budget to have a good infrastructure, it is only proper that a study is conducted to look into the basic properties that are related to the pavement durability.

1.7 Summary

This chapter gave an overview of the study that was done. It introduced the Superpave mix design, which was the outcome of the Strategic Highway Research Program, the advantages and disadvantages of Superpave, and Superpave's debut in Malaysia. The problem that led to this study was also discussed, in which the causes of pavement deteriorations such as permeability, rutting and segregation were highlighted. Relating these deteriorations to basic properties, it will be good to know and understand the mixes used in Malaysia with different NMAS. Therefore, this study was aimed to observe the effects of NMAS on the HMA properties that were compacted with the SGC.

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