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**THE EFFECT OF MIX DESIGN SYSTEM ON STRIPPING POTENTIAL OF
HOT MIX ASPHALT MIXTURE**

AHMED MOHAMED ESARWI

A project report submitted in partial fulfilment of the requirement for the award of
degree of Master of Engineering (Civil-Transportation and Highway)

Faculty of Civil Engineering
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JUN 2008

I declare that this project report entitled “*The Effect of Mix Design System on Stripping Potential of Hot Mix Asphalt Mixture*” is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.”

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To my beloved Father and Mother.....

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ABSTRACT

Moisture damage is one of the major concerns for Hot Mix Asphalt (HMA) pavements. Although the use of high quality materials with proper design can improve the stripping resistance, the mix of insufficient compaction could be subjected to stripping. This study aims to evaluate the effects of compaction method on moisture damage of HMA as well as to determine the effects of using antistripping additives on stripping resistance. Four mixture types (ACW10 and ACW14 both with and without hydrated lime) for both of Marshall and Superpave mix design systems have been prepared according to JKR and AASHTO standards. Aggregate of (MRP) quarry and bitumen of 80/100 PEN were used in this study. The percentage of hydrated lime used was the maximum allowable percentage by JKR, which is 2% of total combined aggregate weight. The Optimum Bitumen Content (OBC) was designed and found to be higher percentage of Superpave mix design system comparing with Marshall mix design system. The OBC of each mix was used to produce six samples of $7\pm 1\%$ air voids to determine the Indirect Tensile Strength (IDT) and the Tensile Strength Ratio (TSR) of each mix for both mix design systems by means of modified Lottman test (AASHTO T 283). The results of this study show that the use of hydrated lime is effective in terms of increasing strength and adhesion bond of the mix, as well as giving acceptable asphalt film thickness. Also it has been found that the Superpave mix design system has improved the TSR values by 11.0% compared to the Marshall mix design system.

ABSTRAK

Kerosakan akibat lembapan merupakan keosahan utama bagi campuran asphalt panas. Walaupun penggunaan bahan berkualiti tinggi dibantu dengan rekabentuk campuran yang baik boleh meningkatkan rintangan terhadap lelasan namun campuran yang tidak dipadatkan dengan sempurna juga turut menyebabkan lelasan. Kajian ini dijalankan untuk mengkaji kesan kaedah mampatan terhadap kerosakan akibat lembapan dan kesan penggunaan bahan tambah lelasan terhadap rintangan lelasan. Empat jenis campuran (ACW10 dan ACW14 dengan dan tanpa kapur terhidrat) disediakan untuk campuran Marshall dan Superpave mengikut piawai yang ditetapkan dalam JKR dan AASHTO. Aggregate (MRP) dan bitumin gred 80/100 PEN digunakan di dalam kajian ini. Peratus kapur terhidrat yang digunakan adalah peratus maksimum yang dibenarkan oleh JKR iaitu 2% dari jumlah keseluruhan aggregate. Kandungan Optimum Bitumin (OBC) di ditentukan dan didapati peratus kandungan bitumin untuk campuran rekabentuk Superpave lebih tinggi berbanding campuran rekabentuk Marshall. Nilai OBC untuk setiap campuran digunakan untuk menghasilkan enam sampel dengan kandungan udara $7 \pm 1\%$ untuk menentukan nilai Indirect Tensile Strength (IDT) dan Tensile Strength Ratio (TSR) untuk setiap campuran bagi kedua-dua sistem campuran rekabentuk dengan cara ujian Lottman diubahsuai (AASHTO T 283). Keputusan kajian ini menunjukkan bahawa penggunaan kapur terhidrat adalah efektif bagi meningkatkan kekuatan dan ikatan rekatan campuran dan turut memberikan ketebalan selaput asphalt yang boleh diterima. Di dapati campuran rekabentuk Superpave telah memperbaiki nilai TSR sebanyak 11% berbanding sistem campuran rekabentuk Marshall.

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LIST OF ABBREVIATIONS

HMA	-	Hot Mix Asphalt
JKR	-	Jabatan Kerja Raya (Public Works Department)
AASHTO	-	American Association of State Highway and Transportation Official
ASTM	-	American Society for Testing and Materials
NCHRP	-	National Cooperative Highway Research Program
AASHTO T 283	-	Resistance of Compacted Asphalt Mixtures to Moisture Induce Damage
ACW 10	-	Asphaltic Concrete for Wearing course with NMAS of 10 mm
ACW 14	-	Asphaltic Concrete for Wearing course with NMAS of 14 mm
ACW 10H.L	-	Asphaltic Concrete for Wearing course with NMAS of 10 mm treated with hydrated lime
ACW 14 H.L	-	Asphaltic Concrete for Wearing course with NMAS of 10 mm treated with hydrated lime
NMAS	-	Nominal Maximum Aggregate Size
IDT	-	Indirect Tensile Strength
SHRP	-	Strategic Highway Research Program
AIMS	-	Aggregate Imaging System
Nf	-	number of gyrations at failed
Ndes	-	design number of gyrations
Ninitial	-	initial number of gyrations

Nmaximum	-	maximum number of gyrations
SGC	-	Superpave Gyratory Compactor
TMD	-	Theoretical Maximum Density
SGcoarse	-	bulk specific gravity of coarse aggregate
SGfine	-	bulk specific gravity of fine aggregate
SGfiller	-	bulk specific gravity of mineral filler
SGblend	-	specific gravity of blended aggregate
VTM	-	Voids in Total Mix
VMA	-	Voids in Mineral Aggregate
VFA	-	Voids Filled with Asphalt
NAPA	-	National Asphalt Paving Association
ESAL	-	Equivalent Standard Axle Load
OBC	-	Optimum Bitumen Content
SSD	-	Saturated Surface Dry
TSR	-	Tensile Strength Ratio

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Asphalt concrete considered as one of the primary materials used to build and maintain roadways around the world. Aggregates and asphalt are relatively cheap and abundant materials that exhibit properties such as elasticity, stability, durability, and moisture resistance when combined effectively to make Hot Mix Asphalt (HMA) pavements. Each year it becomes more important that these materials perform at higher levels to combat the effects of increased traffic and environmental effects (Lytton *et al.*, 2005).

The global increase in truck traffic volumes has raised the need for better performing pavements. Proper performance of bituminous pavements is guaranteed if all the pavement layers (surface course, base and subbase) and the subgrade can appropriately support traffic loads under all service conditions. Deterioration or loss of pavement performance has been experienced in form of rutting due to deformations in one or several layers, fatigue cracking due to repeated dynamic heavy vehicle loading, moisture damage-related distresses in the bituminous layers, surface wear in countries where studded tyres are used, and others.

Many factors contribute to the degradation of asphalt pavements. When high quality materials are used, distresses are typically due to traffic loading, resulting in rutting or fatigue cracking. Environmental conditions such as temperature and water can have a significant effect on the performance of asphalt concrete pavements as well. Moisture is the major climatic condition that adversely affects the quality of asphalt concrete (Kollipara, 2003).

The performance of HMA pavements in the presence of water is a complex issue and has been the subject of numerous research studies during the past six decades. During this period, asphalt technologists and state highway agencies have been in pursuit of a reliable laboratory test protocol to predict the asphalt pavement behavior in the field with regard to moisture sensitivity.

The infiltration of moisture into HMA pavements is one of the most common causes of degradation in pavement structures. When moisture enters the pavement structure, it can find its way between the aggregate and the asphalt cement, leading to a loss of cohesion within the pavement (Conne, 2003).

Moisture may damage asphalt concrete in three ways. The moisture may combine with the asphalt resulting in a loss of cohesion of the asphalt film. The water may also cause failure of the bond at the asphalt aggregate interface. Finally, degradation of the aggregate may result as the moisture in the asphalt concrete freezes. The loss of cohesion and the failure of the asphalt bond with the aggregate are defined as stripping (Kollipara, 2003).

Factors affecting moisture sensitivity of HMA have been identified as the type and use of the mix, the characteristics of the asphalt binder and the aggregate and environmental effects during and after construction, and the use of anti-stripping additives. Many factors are involved in moisture sensitivity of HMA, so the test method should closely simulate the real field condition to reflect these variables (Coree, and Kim, 2005).

1.2 Background

Stripping is defined as bond loss between mineral aggregate and asphalt binder and is generally caused by traffic, water, and high in-place service temperatures.

Stripping is a failure mode that can be seen through many different ways. The effects of stripping are most often very evident in surface features such as ruts or cracks in the asphalt. However, the effects of stripping can also be seen in situations where shoving of the asphalt matrix has taken place. Many factors in addition to the presence of water can contribute to stripping. Relevant factors include, but are not limited to: asphalt mix characteristics, traffic loading, and climate. However, it is believed that pavement experiences the greatest destructive effect when an interaction occurs between one or more of the aforementioned effects while moisture is present (Conne, 2003).

Stripping is one of the most difficult distresses to recognize in HMA pavements because the surface appearance can take various forms such as rutting, shoving, raveling, or cracking. Obtained cores of the pavement are considered as the only accurate way to determine whether the stripping is the cause of the distress. However, sometimes the HMA mix has become completely unbounded and cores can not be removed intact for observation (Buchanan, and Moore, 2005).

Many test methods have been developed and applied in the past to predict moisture susceptibility of asphalt mixes. The developed tests can be classified into two categories: qualitative tests and quantitative strength tests. The Boiling Water Test (ASTM D3625) and Static -Immersion Test (AASHTO T182) are qualitative tests, while the Lottman Test (NCHRP 246), Tunncliff and Root Conditioning (NCHRP 274), Modified Lottman Test (AASHTO T283), Texas Freeze-Thaw Pedestal Test, and Immersion-Compression Test (AASHTO T165) are quantitative strength tests. The strength tests allow numerical comparisons to be made between HMA mixtures (Hunter, and Ksaibati, 2002).

1.3 Problem Statement

Many state agencies have decided that moisture damage in asphalt pavements can be reduced by developing a reliable test to predict moisture susceptibility, also by adding anti-stripping agents to improve moisture stability and durability of HMA (Lytton *et al.*, 2005).

Because of the pavement design is the process of determining the combination of materials for the surface and underlying layers that is best suited for specific project conditions, choosing the suitable and effective design system is the most important for predicting the HMA performance.

Historically, highway pavements have been designed using the Marshall mix design system. The Marshall mix design procedure was originally developed in the 1940's for airfield pavements. While this mix design procedure has performed well for highway pavements for over 50 years, while in recent years highway pavements have been designed using the Superpave mix design procedure. The laboratory testing procedure currently available for testing HMA moisture susceptibility, including the AASHTO T-283 procedure, were primarily developed to determine the degree of resistance to moisture damage by a particular combination of asphalt and aggregate, compare mixes composed of different types and quantities of aggregate, or to evaluate the effectiveness of anti-stripping agents (Tunnicliff, and root, 1984).

Since the AASHTO T283 can be performed using these two methods, a study is needed to compare the results of mixes as related to stripping.

1.4 Objectives

The principle objectives of this study are stated below:

- (i)-To evaluate the effect of compaction method on moisture damage of HMA.
- (ii)-To evaluate the effectiveness of anti-stripping additive.

1.5 Scope of Study

This study covered the preparation of specimens for Asphalt Wearing Course (ACW 10 and ACW 14) of both Marshall and Superpave design systems and measuring the change of Indirect Tensile Strength (IDT) resulting from the effects of water saturation for compacted asphalt mixtures obtained from both methods of design according to (AASHTO T-283) standard. All mixes were tested with and without antistripping agent.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Both of the flexible and rigid pavements are considered as the most popular categories in use to construct highways around the world. Generally the structure of flexible pavement consists of two or more layers including subbase course, base course, and surface course, while rigid pavement structure consists of two layers, designated as the pavement slab and the subbase course, which is often omitted if the subgrade soils are granular in nature, or otherwise free-draining.

The basic idea of selecting flexible pavement materials is to use the highest quality, most load-resistant materials in the upper layers which are subjected to the highest stresses; the materials in the lower layers should provide drainage and/or to reduce the stresses on the subgrade by distributing the load over a wider area in accordance with layer theory (Cooley, and Brown, 2003).

The surface course of the flexible pavement is consisting of aggregates and asphaltic materials which can provide characteristics such as friction, smoothness, noise control, rut and shoving resistance and drainage. And it can prevent the entrance of

excessive quantities of surface water into the underlying base, sub-base and sub-grade (Rajagopal, 2004).

Generally two layers come under the term of surface course structure; Wearing Course and Intermediate/Binder Course. The wearing course is the upper layer which is directly in contact with traffic loads while the Binder course is just below the wearing course and is meant to reduce the stresses on the underlying layers (Rajagopal, 2004).

Like all other paving materials, HMA is subjected to a variety of distresses. Selecting high quality materials with proper construction will make the pavement carry the traffic without significant distresses along its design life, since the pavement approaches their design life, distresses are expected to occur as a result of the environment and repeated traffic loads. These distresses can be formed of rutting, cracking, shoving, raveling and so on. It is important to recognize the causes of these distresses in terms of finding the proper rehabilitation method. Water is considered to be one of these causes which is known as moisture susceptibility.

2.2 Moisture Susceptibility

The moisture susceptibility of an asphalt mix can be defined as its propensity to allow the infiltration of water into the matrix to form a boundary layer between asphalt cement and aggregate (Conner, 2003). This separation of the asphalt cement from the aggregate is known as stripping.

Stripping is not necessarily evident because it can manifest itself in different surface forms (Roberts *et al.*, 1991). There are a number of general stripping definitions provided by various researchers and agencies, some of them are listed in Table 2.1.

Table 2.1: General Stripping Definitions

Reference	Definition
National Center for Asphalt Technology	Weakening or eventual loss of the adhesive bond usually in the presence of moisture between the aggregate surface and the asphalt cement in a HMA pavement or mixture.
Asphalt Institute	Breaking of the adhesive bond between the aggregate surface and asphalt cement.
Hunter, E., <i>et al.</i>	Loss of integrity of a HMA mix through weakening of the bond between the aggregate and the asphalt cement.
White, T. <i>et al.</i>	Loss of the adhesive bond between the bitumen and the aggregate surface.
Kennedy, T. <i>et al.</i>	The physical separation of the asphalt cement from the aggregate produced by the loss of adhesion between the asphalt cement and the aggregate which is primarily due to the action of water or water vapor.
Tunnichiff, D. <i>et al.</i>	Displacement of asphalt cement film from aggregate surfaces by water caused by conditions under which the aggregate surface is more easily wetted by water than by asphalt
Kiggundu <i>et al.</i>	The progressive functional deterioration of a pavement mixture by loss of the adhesive bond between the asphalt cement and the aggregate surface and/or loss of the cohesive resistance within the asphalt cement principally from the action of water.

Stripping normally begins at the bottom of HMA layer and then permeates upward. Rutting and shoving developed in the wheel path is caused by gradual loss of strength over a period of years. Stripping is difficult to be recognized because the long period of time taken by stripping to appear on the surface. Also, many surface indicators are possible and may include: rutting, shoving, corrugations, raveling, and cracking. It is important to identify stripping by looking at the cross-section of the HMA mix. In some cases of stripping, the HMA mix has lost so much adhesion between the aggregate and asphalt that a core cannot be removed in one piece (Kennedy, Roberts, and Lee, 1983).

As any distress of HMA there are many possible causes of stripping. Surface drainage or sub-surface drainage is a primary contributor to stripping. The moisture can enter the HMA pavement layers from many ways: capillary action from the water table, run off from the road surface, and seepage from surrounding. If a proper drainage is absent, air voids in the HMA may become saturated with moisture, which result into increase the pressure and weakening the bond (Roberts *et al.*, 1996).

Most mix designs consist of 3 to 5 percent air void. The HMA of air void content below 5 percent is almost impervious to water. During construction, compaction control is not always very good and high air void contents are a result. Water can readily seep into the material within air void content is above 8 percent. Excessive dust coating on the aggregate can inhibit coating by asphalt and provide channels for water to penetrate through. Use of open-graded asphalt friction coarse, inadequate drying of aggregate, weak aggregate, overlays on deteriorated concrete pavements, waterproofing membranes and seal coats can reduce stripping potential (Roberts *et al.*, 1996).

2.3 Stripping Mechanisms

Many mechanisms have been proposed for stripping including detachment, displacement, spontaneous emulsification, film rupture, pore pressure, and hydraulic scouring. These mechanisms are not fully understood and there is lack of agreement regarding the relative contribution of each mechanism to stripping in particular cases (Badru, Kiggundu, and Roberts, 1988).

Stripping mechanisms in a hot-dry environment differ from the mechanisms in hot-wet, cold-dry, and cold-wet environments. It is important to understand the possible differences in the stripping mechanisms in relation to the environments, service and material conditions to be able to develop and use appropriate test methods (Fromm, 1974),(Taylor, and Khosla, 1983) and (Scott, 1978). A discussion of the hypothesized mechanisms is following:

2.3.1 Detachment

This mechanism is defined as “the microscopic separation of an asphalt film from the aggregate surface by a thin layer of water with no obvious break in the asphalt film Majidzadeh, and Brovold (1968), Rice (1958), and Asphalt Institute (1987)”. Existing of the water thin film can result from a sub monolayer of water of wet aggregate surface: the pore of wet aggregate which filled by the water may vaporize and condense on the surface; and possibly water which may permeate through the asphalt film and reach the interface region. The proposed and published indicator of this mechanism is that the asphalt film can be easily stripped off the aggregate surface (Badru, Kiggundu, and Roberts, 1988).