# EFFECTS OF ANTI-STRIPPING ADDITIVES ON THE MOISTURE SENSITIVITY OF ASPHALT MIXTURES SUBJECTED TO SEVERAL CONDITIONING METHODS

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# ABSTRAK

Pelucutan adalah mod lazim yang mengakibatkan berlakunya kerosakan turapan di Malaysia. Ini adalah disebabkan oleh penyusupan air yang berlebihan ke dalam turapan asfalt lalu mempercepat proses kerosakan pada permukaan dan lapisan bawah turapan. Tough Fix dan ZycoTherm merupakan bahan anti-pelucutan yang biasanya digunakan di negara Jepun dan India. Untuk mengatasi masalah pelucutan, Tough Fix dan ZycoTherm telah digunakan. Selepas tambahan bahan anti-pelucutan, asfalt campuran didedahkan pada keadaan kelembapan yang berbeza. Kaedah-kaedah kelembapan ini bertujuan sebagai simulasi kepada keaadaan sebenar di tapak dengan mengambil kira faktor penuaan dan kelembapan. Kaedah kelembapan terdiri daripada kaedah lazim, kerosakan akibat kelembapam, perubahsuaian Lottman, percepatan vakum saturator makmal dan perendaman air. Ciri-ciri kejuruteraan asfalt campuran dinilai dari segi tegangan kekuatan tidak langsung dan modulus berdaya tahan. Bahan anti-pelucutan di dalam asfalt campuran telah menunjukkan potensi bagi meningkatkan ketahanan turapan terhadap kerosakan yang dipengaruhi oleh pelbagai keadaan kelembapan. Meskipun demikian, ZycoTherm menunjukkan kesan yang ketara di antara bahan anti-pelucutan yang digunakan. Analisis terhadap agregat pada asfalt campuran juga dijalankan untuk mengenalpasti punca kehancurannya. Selain daripada bentuk dan kualiti agregat, orientasi agregat juga merupakan salah satu faktor yang menyebabkan ketidakselarasan kekuatan tegangan tidak langsung pada asfalt campuran.

# ABSTRACT

Stripping is the most common cause of pavement distress in Malaysia. This could be attributed to the excessive infiltration of water into asphalt pavements which accelerate damage in both surface and subsurface layers. To minimize the problem, Tough Fix and ZycoTherm, which are currently used in Japan and India as anti-stripping agents and warm compaction additive respectively, were adopted. Each additive was incorporated in asphalt mixtures and then subjected to several moisture conditioning methods. To simulate the actual condition on site, moisture conditioning methods were carried out in a combination of aging and moisture intrusion. Different levels of moisture conditioning methods, ranging from unconditioned, moisture induced damage, modified Lottman, accelerated laboratory vacuum saturator and water immersion; were carried out to evaluate the engineering properties of asphalt mixtures in terms of indirect tensile strength and resilient modulus. From the mixture performance test results, mixtures prepared with ordinary portland cement (OPC), Tough Fix and ZycoTherm showed the potential to improve pavement resistance to pavement distresses such as moisture damage, permanent deformation and cracking. The effects of ZycoTherm on the ITSR, MR, fracture energy, workability, CEI and percentage of adhesive failure; were found to be significant. Analysis of fractured aggregate was one of the highlights of the study. Broken aggregates were extracted from the asphalt specimens to investigate the sources of failure. Apart from poor aggregate shapes such as flaky and elongated particles, aggregate orientation was one of the factors causing inconsistency of indirect tensile strength for certain specimens.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| ALVS | Accelerated Laboratory Vacuum Saturator |
| CEI | Compaction Energy Index |
| HMA | Hot Mix Asphalt |
| ITS | Indirect Tensile Strength |
| ITSR | Indirect Tensile Strength Ratio |
| JKR | Jabatan Kerja Raya |
| LTA | Long Term Aging |
| MR | Resilient Modulus |
| OPC | Ordinary Portland Cement |
| TF | Tough Fix |
| WMA | Warm Mix Asphalt |
| WZ | Warm Compaction Additive |
| WI | Workability Index |

# CHAPTER 1

# INTRODUCTION

## 1.1 General

In Malaysia, asphalt mixture is the most commonly used material for asphalt pavement construction. Asphalt is produced using aggregates mixed with binder and filler. A properly designed asphalt pavement is able to support loads, ranging from passenger cars to heavy truck, as well as provide smooth and durable road condition to road users. However, asphalt pavement is vulnerable to surface or structural damage due to increased temperature or frequent intense rainfall events.

Stripping as a result of moisture damage in asphalt pavement, is the most widely cause of pavement distress in Malaysia (Rosli et al., 2015). Stripping takes place when the asphalt binder separates from the aggregate surface due to the infiltration of water, resulting in loss of mixture strength and durability. As a result, stripping resistance in asphalt mixture is essential to mitigate asphalt pavement from stripping. High stripping resistance of asphalt pavement is always correlated with several key elements such as the usage of anti-stripping agents, aggregate type, proper compaction temperature, high quality material and adequate air voids (Graf, 1986).

A number of researchers such as Hesami et al., (2013), Schmidt and Graf (1972) and Baig et al., (2015) showed that the use of anti-stripping agents in asphalt mixture is able to reduce the potential of stripping and thus extend the asphalt pavement service life. In accordance with this, the effectiveness of Tough Fix and ZycoTherm which are currently used in Japan and India respectively, as anti-stripping agents and warm compaction additive are investigated.

In Malaysia, hydrated lime is the anti-striping agent specified by Jabatan Kerja Raya (JKR) specification for roadworks (JKR, 2008). To evaluate the potential of better quality anti-stripping agents as the alternative to hydrated lime, three mixtures incorporating ordinary portland cement (OPC) as filler, Tough Fix as anti-stripping agents and ZycoTherm as warm compaction additive are evaluated.

In real life, pavements are subjected to both moisture conditioning and long-term aging simultaneously. Ageing on asphalt mixtures tends to highly stiffen the bitumen due to both air oxidation and loss of more volatile components, while moisture conditioning decreases its stiffness. Therefore, laboratory works are performed to investigate on the combined effects of both aging and moisture conditioning on stiffness properties of both HMA and WMA. Evaluation on the effectiveness of different anti-stripping agents allow the best type of anti-stripping agent to be applied in future mix design. Hence, pavement with better stripping resistance can be provided.

## 1.2 Problem Statement

Road infrastructure is essential to ensure rapid development of a nation. As a result, construction of high quality and durable road pavement is always a concern for highway authorities in Malaysia.

HMA, which is the popularly used road pavements material in Malaysia, has been severely affected by various types of pavement distress which cause descending serviceability of the pavement structure. Continuously increasing in surrounding average temperature leads to the ageing on asphalt pavement, subsequently increase the stiffness of asphalt mixtures. It is important to consider on the stiffness properties of asphalt mixture as it is not desirable in terms of durability since excessive long-term stiffness can lead to premature fatigue and cracking failure.

Apart from aging, stripping is one of the most common cause of pavement distress in Malaysia. Stripping occurs when there is excessive presence of water that contributes to the weak bonding between binder and aggregates. In addition, intrusion of moisture into the asphalt mixture decreases its strength and leads to poor road pavement quality. More attention should be given to the problem as it may give rise to road hazards which consequently increase road accidents.

Anti-stripping agents is one of the key elements to minimize stripping problem. Previous studies such as Anderson et al., (1982) and Ibrahim and Mehan (2015) were conducted to determine the effectiveness of anti-stripping agents. However, there is still a gap of knowledge in understanding more on other sources of anti-stripping agents. Therefore, this study emphasises on the effectiveness of asphalt mixture incorporating OPC, Tough Fix and ZycoTherm.

## 1.3 Objectives

The objectives of this research are outlined below:

1. To investigate the combined effects of aging and moisture conditioning on the indirect tensile strength and stripping resistance of asphalt mixtures incorporating OPC, Tough Fix and ZycoTherm.
2. To quantify the percentage of failure on asphalt mixtures attributed to adhesion and cohesion via image analysis.
3. To investigate the types of failure on broken aggregates when subjected to indirect tensile strength test.

## 1.4 Scope of Work

The scope of work focuses on studying the stripping resistance of asphalt mixtures incorporating different anti-stripping agents when subjected to several moisture conditioning methods. OPC, Tough Fix and ZycoTherm were used as anti-stripping agents and warm compaction additive respectively to produce HMA at 160ºC and WMA at 140ºC in accordance to JKR Malaysia aggregate gradation specification for AC14 (JKR, 2008). A conventional asphalt binder grade 80/100 was incorporated in specimens' preparation. To ensure the accuracy, at least three specimens were prepared for each mixture and then subjected to five moisture conditioning methods. Provided that the pavement is simultaneously subjected to long-term aging and moisture intrusion, apart from modified Lottman, moisture conditioning methods such as accelerated laboratory vacuum saturator plus long-term aging, moisture induced damage plus long-term aging, water immersed plus long-term aging were included. Several tests were then conducted to assess the performance of the asphalt mixtures, including indirect tensile strength test, resilient modulus, image analysis and analysis on fractured aggregates. Through the analysis, results such as workability, compaction energy index, fracture energy, indirect tensile strength ratio, types of failure on broken aggregates and image analysis of specimens were obtained.

## 1.5 Importance of the Research

There are many factors causing damage to the road pavement throughout the years and one of the most common causes is stripping. The intrusion of moisture into asphalt pavement contributes to the weak bonding between the asphalt mixtures and hence, weakens the strength of pavement and shortens its service life.

Stripping problem becomes worse when it comes to the raining season or improper drainage design in which the pavement is continuously subjected to both aging and moisture intrusion. To provide a better solution towards this problem, evaluation on the effectiveness of OPC, Tough Fix and ZycoTherm were carried out. From the investigation, different levels of moisture conditioning methods reflects the actual conditions on site and show the worst case scenario. By incorporating OPC, Tough Fix and ZycoTherm in the asphalt mixtures, potential of these additives as an alternative to hydrated lime was defined.

The research is important because the outcome can be taken as a guide in future mix design to solve stripping problem. Higher strength and more durable pavement can provide better road condition, while ensuring safety of road users.

## 1.6 Dissertation Outline

This dissertation is divided into five chapters. Chapter 1 presents an overview on HMA, WMA and stripping problem in Malaysia. The chapter briefly explains the problem statement, objectives of the study, scope of work and importance of the research.

Chapter 2 describes an overview of the moisture sensitivity of asphalt mixtures, moisture conditioning methods, anti-stripping agents and moisture sensitivity tests. This chapter also discusses the combined effects of aging and moisture intrusion on the asphalt mixtures. An overview of previous studies on the tests, performance and potential challenges of anti-stripping additives sourcing from other countries are summarized in this chapter.

Chapter 3 explains the materials used in this study, including asphalt binder, aggregates and additives for both HMA and WMA. The sample preparation method, moisture conditioning methods and test procedures are outlined in this chapter. The analysis methods on the laboratory results are also included in this chapter.

Chapter 4 discusses the result of specimens incorporating OPC, Tough Fix and ZycoTherm. It assesses the results of compaction energy index, indirect tensile strength, workability, resilient modulus, image analysis and analysis on fractured aggregate of three mixtures when subjected to several moisture conditioning methods. The overall performance of asphalt mixtures incorporating different anti-stripping additives are evaluated in this chapter.

Chapter Five presents the conclusions and recommendations for future works from this study.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview

Sustainable road construction has become a major concern of highway authorities in recent years. However, the performance of HMA in the presence of water is a complex issue and has been the subject of numerous research studies during the past six decades (Solaimanian et al., 2003). According to Kandahl (1992), excessive water in asphalt pavement shows a condition in which the asphalt binder loses its ability to bond to the aggregate and the pavement material loses its structural integrity. These manifest in the form of alligator cracking, potholes and surface revelling, damage in both surface and subsurface layers. With respects to this, many studies were conducted to introduce new technologies or alternative materials in road construction to mitigate the problem. Meanwhile, different anti-stripping agents and warm mix asphalt (WMA) were introduced in road construction.

This chapter deliberates on the most common cause of pavement distress in Malaysia which is stripping. The distress is also known as moisture damage. The presence of water in pavements can be detrimental if it is combined with other factors, for instance, freeze-thaw cycle and the physical and chemical properties of the asphalt and the aggregates, mixture properties, and external factors which include construction, traffic, and environmental factors (Larry, 2003). Therefore, previous studies on asphalt incorporating different additives, effects of aging and moisture damage on asphalt mixture are also verified.

## 2.2 Moisture Damage of Asphalt Mixtures

According to Solaimanian et al., (2003), moisture has become a major concern in building asphalt concrete pavements for many years. It has been found that many pavements experience premature rutting, ravelling and wear. Distress and deterioration in large number of pavements as a result of moisture damage is an indication of how the moisture can severely damage the asphalt pavement. Moisture damage can be generally classified in two mechanisms which are loss of adhesion and loss of cohesion (Lottman, 2001).

According to Epps et al., (2001), the loss of adhesion is due to water trapping between the asphalt and the aggregate which subsequently strip away the asphalt film. On the other hand, the loss of cohesion is due to a softening of asphalt concrete mastic. These two mechanisms being interrelated a moisture damaged pavement may be a combined result of both mechanisms. Furthermore, the moisture damage causes the changes in asphalt binders, decreases in asphalt binder content to satisfy rutting associated with increases in traffic, changes in aggregate quality, increased widespread use of selected design features, and poor quality control.

According to Hicks (1991), factors affecting moisture sensitivity of HMA include 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. There are a lot of factors that might influence moisture sensitivity of HMA, so the test method should closely simulate the real field condition to reflect these variables. Under the real traffic conditions, water damage in asphalt pavement occurs when repeated traffic loading is applied to a saturated pavement, inducing water movement or pressure transients in the void structure of HMA. Stuart (1990), summarise the factors influencing moisture damage in Table 2.1.

Table 2.1 : Summary of Factors Influencing Moisture Damage

| Factor | Desirable Characteristics |
|---|---|
| (1) Aggregate | |
| Surface Texture | Rough |
| Porosity | Depends on pore size |
| Mineralogy | Basic (pH=7) aggregate are more resistant |
| Dust Coating | Clean |
| Surface Moisture | Dry |
| Surface Chemical Composition | Able to share electrons or form hydrogen bonds |
| Mineral Filler | Increase viscosity of asphalt |
| (2) Asphalt Cement | |
| Viscosity | High |
| Chemistry | Nitrogen and phenols |
| Film Thickness | Thick |
| (3) Type of Mixture | |
| Voids | Very low or very high |
| Gradation | Very dense or very open |
| Asphalt Content | High |
| (4) Environmental Effect during Construction | |
| Temperature | Warm |
| Rainfall | None |
| Compaction | Sufficient |
| (5) Environmental Effects after Construction | |
| Rainfall | None |
| Freeze-Thaw | None |
| Traffic Loading | Low traffic |

## 2.3 Moisture Sensitivity Tests

According to Williams and Breakah (2009), pavement design should include moisture damage evaluation as a design parameter to ensure a more durable pavement construction. The development of moisture sensitivity test of asphalt mixtures began in the 1930s (Terrel and Shute, 1989). Numerous methods have been developed to determine if a bituminous mixture is prone to damage due to moisture. According to Terrel and Al-Swailmi (1994), several methods which have received the most attention in the United States are outlined below:

(i) Indirect tensile test or indirect tensile stiffness test with Lottman conditioning

(ii) Indirect tensile strength test with Tunnicliff and root conditioning

(iii) AASHTO-T283 (AASHTO, 2011) which combine features of the above tests (commonly referred as the modified Lottman Test)

(iv) Immersion–compression test

(v) Boiling water tests

(vi) Freeze-thaw pedestal test

### 2.3.1 Modified Lottman

Modified Lottman is a combination of the Lottman and the root-Tunnicliff tests. According to Kiggundu and Roberts (1988), this test is the most accurate test method currently available for predicting moisture damage in HMA mixtures. According to Aschenbrener (2002), modified Lottman test is the most commonly used test among the US state highway agencies. The study was conducted where six specimens were produced with air voids between 6% to 8%. The high percentage of air voids helps to accelerate moisture damage on the cores. Two groups of three specimens were utilized. The first group was the control group. The second group was saturated to between 55%

and 80% with water and was placed in the freezer at –18°C for 16 hours to 18 hours. The frozen specimens were then moved to a water bath at 60°C for 24 hours. After conditioning, the resilient modulus test and indirect tensile strength (ITS) test were then performed. According to Roberts et al., (1996), a minimum tensile strength ratio of 0.7 is usually specified to distinguish between moisture sensitive and moisture insensitive mixtures.

According to Buttlar and Roque (1992), ITS test was fully developed for HMA in the mid 1990's through the research efforts put together during Strategic Highway Research Program (SHRP). The research was finalized in form of a standard for testing and analysis, namely AASTHO T-322 (AASHTO, 2004).

In the ITS test, an increasing load is applied along a diametrical plane to the cylindrical specimen to maintain a constant rate of vertical deformation until the specimen fails. The evaluation of indirect tensile strength of both field and lab specimens within the AASHTO standard was derived from an extension of the simple plane stress formula first developed by Hertz in 1881. The latter is given in Equation (2.1).

$$S_t = \frac{2 \text{ x } P}{\pi \text{ x } b \text{ x } D} \tag{2.1}$$

where,

$S_t$ = Tensile strength of specimen

P = Failure load for specimen

b = Thickness of specimen

D = Diameter of specimen.

In the AASHTO-T322 (AASHTO, 2004), a "first failure load" is used in the calculation of the tensile strength of HMA instead of peak load. This concept was proposed by Buttlar and Roque (1992), to define tensile strength as the stress state is at