COMPARISON OF FIELD AND LABORATORY SHORT TERM AGING OF ASPHALT BINDER AND MIXTURE

By

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This thesis is dedicated to my beloved family:
Seyed Mohammad Hadi Omranian,
Loabat Zarrabi
and
Seyed Arash Omranian

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In the name of God, who gave me strength and patience to completing my study.

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Strong reasons make strong actions.

William Shakespeare

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LIST OF ABBREVIATIONS

HMA	Hot Mix Asphalt
RTFOT	Rolling Thin Film Oven Test
PAV	Pressure Aging Vessel
JKR	Jabatan Kerja Raya
PG	Performance Grade
DSR	Dynamic Shear Rheometer
RV	Rotational Viscometer
VTS	Viscosity Temperature Susceptibility
FTIR	Fourier Transform Infrared Spectroscopy
XRD	X-ray Diffraction
ITS	Indirect Tensile Strength
ASTM	American Society for Testing and Materials
TFOT	Thin Film Oven Test
AASHTO	American Association of State Highway and Transportation Officials
SBR	Styrene Butadiene Rubber
MMT	Montmorillonite
OMMT	Organo-Montmorillonite
LVDTs	Linear Variable Differential Transducers
ITFT	Indirect Tensile Fatigue Test
NAT	Nottingham Asphalt Tester
SHRP	Strategic Highway Research Program
ACW	Asphalt Concrete Wearing
PWD	Malaysian Works Department
SSD	Saturated Surface Dried
OPC	Ordinary Portland Cement

STOA	Short Term Oven Aging
G_{mm}	Maximum Specific Gravity
G_{mb}	Bulk specific Gravity
UTM	Universal Testing Machine
I_{CO}	Index Carbonyl
I_{SO}	Index Sulfoxides
AC	Area of the Carbonyl Band
AS	Area of the Sulfoxides Band
ACH2	Area of the CH_2 Band
ACH3	Area of the CH_3 Band
NSRP	Non-dimensional Superpave Rutting Parameter
$\nabla\eta_A$	Non-Dimensional Viscosity Gradient
BS	British Standard
ANOVA	One-Way Analysis of Variance
P	Sample from Plant
F	Sample from Field
2HA	Artificially 2 Hours Aged Sample
4HA	Artificially 4 Hours Aged Sample
DER	Dissipated Energy Ratio
vs.	Versus

PERBANDINGAN PENUAAN JANGKA PENDEK DI TAPAK DAN MAKMAL BAHAN PENGIKAT DAN CAMPURAN ASFALT

ABSTRAK

Pengusiaan adalah satu fenomena fiziko-kimia yang kompleks yang mempengaruhi sifat reologi asfalt pengikat dan campuran asfalt dan menyebabkan kemerosotan prestasi campuran asfalt. Bagi meningkatkan prestasi turapan, pencirian asfalt pengikat dan campuran asfalt disebabkan pengusiaan jangka pendek diperlukan. Kajian ini dibahagikan kepada dua fasa. Fasa pertama adalah penilaian dan pencirian sifat reologi pengikat asfalt sebelum dan selepas pengusiaan jangka pendek. Peralatan Rolling Thin Film Oven (RTFO), Dynamic Shear Rheometer (DSR), Rotational Viscometer (RV), Fourier Transform Infrared Spectroscopy (FTIR) dan X-ray Diffraction (XRD) digunakan untuk menilai tingkahlaku pengikat asfalt lazim, pengusiaan buatan dan yang diekstrak. Fasa kedua menilai tingkahlaku campuran asfalt padat yang dihasilkan oleh Kuad Kuari Sdn. Bhd, yang terdedah kepada pengusiaan jangka pendek. Ujian kekuatan tegangan tak langsung, rayapan dinamik, modulus kebingkasan dan lesu diametral dijalankan untuk menilai dan mengenal pasti kesan pengusiaan jangka pendek di tapak, di kuari dan pengusiaan buatan bagi campuran asfalt. Semua keputusan ujian pengikat dan campuran asfalt dibandingkan untuk menilai dan mengenal pasti kesan pengusiaan jangka pendek selepas pengeluaran. Hasil kajian menunjukkan bahawa pengusiaan meningkatkan kelikatan dan pengerasan pengikat dan campuran. Keputusan ujian reologi pengikat menunjukkan bahawa pengusiaan meningkatkan modulus kompleks, faktor ubah bentuk kekal, kelikatan dan kilasan, tetapi mengurangkan sudut fasa. Keputusan FTIR menunjukkan pengusiaan hanya menjejaskan ikatan karbonil dan sulfoksida.

Daripada keputusan ujian XRD, pengusiaan hanya menjejaskan 2θ diantara 30° dan 90° dengan mengurangkan corak keamatan pengikat. Keseluruhan keputusan ujian pengikat menunjukkan bahawa spesimen yang di lazimi selama 85 minit dalam RTFO tidak mencukupi untuk mensimulasi keadaan pengusiaan jangka pendek sebenar yang berlaku di tapak yng terdedah kepada keadaan alam sekitar di Malaysia. Keputusan yang diperolehi daripada ujian campuran asfalt menunjukkan bahawa peningkatan pengusiaan menyebabkan peningkatan kekuatan tegangan tak langsung, kekukuhan rayapan dan modulus kebingkasan, tetapi mengurangkan terikan mikro kumulatif. Daripada nilai kekukuhan rayapan dan kadar terikan yang lebih tinggi, potensi ubah bentuk kekal adalah lebih tinggi pada suhu yang tinggi. Keputusan ujian lesu menunjukkan bahawa pengusiaan jangka pendek tidak mempunyai kesan ketara ke atas hayat lesu campuran. Spesimen yang diusiakan di makmal selama 2 jam di dalam ketuhar didapati mencukupi untuk mensimulasi pengusiaan jangka pendek sebenar yang berlaku semasa pengeluaran campuran asfalt di loji.

COMPARISON OF FIELD AND LABORATORY SHORT TERM AGING OF ASPHALT BINDER AND MIXTURE

ABSTRACT

Aging is a complex physico-chemical phenomenon that influences asphalt binder and mixture rheological properties causing deterioration in asphalt mixture performance. To enhance the pavement performance, characterisation of the asphalt binder and asphalt mixture due to short term aging is required. This study is divided into two phases. The first phase evaluated and characterized the asphalt binder rheological properties before and after short term aging. The Rolling Thin Film Oven (RTFO), Dynamic Shear Rheometer (DSR), Rotational Viscometer (RV), Fourier Transform Infrared Spectroscopy (FTIR) and X-ray Diffraction (XRD) tests were used to evaluate behaviour of virgin, artificially aged and extracted asphalt binders. The second phase dwelt upon the behaviour of dense asphalt mixture produced by Kuad Quarry Sdn. Bhd, after subjected to short term aging. The indirect tensile strength, dynamic creep, resilient modulus and diametral fatigue tests were carried out to assess and determine the effects of short term aging on field, plant and artificially aged asphalt mixtures. All the binder and mixture tests results were compared to evaluate and determine the short term aging effect during production. The results showed that the aging increases the viscosity and hardening of the binder and mixture. The binder rheological test results indicated that aging increased the complex modulus, rutting factor, viscosity and torque but decreased the phase angle. The FTIR results indicated that aging only affected the binder carbonyl and sulfoxides bands. From the XRD results aging affect the range 2θ between 30° and 90° by decreasing the binder pattern intensity. The overall binder results showed that the specimens conditioned for 85 minutes in the RTFO was insufficient to simulate the actual short term aging condition that took place in the field under Malaysian environmental conditions. The results obtained from the mixture tests showed that increasing aging caused an increase in ITS, creep stiffness and resilient modulus while decreasing the accumulated micro strain. Based on the creep stiffness and higher strain rate, rutting potential was more severe at high temperature. Fatigue test results indicated that short term aging had no significant effects on the mixture fatigue life. The results showed that the specimens artificially aged for approximately 2 hours in an oven was sufficient to simulate the actual short term aging that the mixture was induced during production.

CHAPTER 1

INTRODUCTION

1.1 General

Hot Mix Asphalt (HMA) is a material that has been used for road construction and consists of asphalt binder, mineral aggregate and filler. The asphalt binder glues the aggregate particles together and waterproofs the mixture. The aggregate in the mixture acts as a stone skeleton, which contributes to the mixture stiffness and stability. The filler fill up the space between aggregate to avoid their displacement and movement in the mixture. The HMA properties depend on individual component properties and their combined reaction in the mixture.

Three factors that influence asphalt mixture performance include binder temperature susceptibility, viscoelastic properties and susceptibility to aging. Asphalt binder temperature susceptibility refers to the influence of temperature on asphalt properties ranging from stiffer at colder temperature to more viscous or liquid at higher temperature. Asphalt binder is a visco-elastic material exhibiting both viscous fluid and elastic solid properties. It behaves as a viscous material at higher temperatures and as elastic material at lower temperatures, while exhibiting both characteristics at intermediate temperatures. The asphalt binder is chemically organic and reacts with oxygen present in the environment. Oxidation causes the asphalt to become more brittle, leading to oxidation hence age hardening. Oxidation occurs more rapidly at higher temperatures (Asphalt Institute, 2001).

Asphalt binder and mixture aging is one of the most important factors that contribute to shorter pavement service life. Aging can be divided into two stages. The first stage takes place during transporting, storage, and handling; followed by asphalt mixture production and construction. The second stage occurs while the pavement is in service over extended period of time. Aging is quite nominal during transportation, storage and handling. The first stage refers to short term aging, simulated using the Rolling Thin Film Oven Test (RTFOT) in the laboratory. The second stage refers to long term aging and simulated in laboratory using a Pressure Aging Vessel (PAV) on the RTFOT residue. This study focus on the effects of two short term aging duration on asphalt binder and asphalt mixture under Malaysia's environmental conditions.

1.2 Problem Statement

After several years in service, asphalt mixture started to deteriorate due to aging. Aging in itself is a complex physico-chemical phenomenon that influences asphalt binder rheological properties. Two main mechanisms of aging include loss of light oils present in the asphalt binder (volatilization) and reaction with oxygen in the environment (oxidation) causing changes in binder properties (Asphalt Institute, 2001). During production of asphalt mixtures, binders aged due to high temperature and presence of oxygen. In addition, aging continues after the asphalt pavement was constructed but it is mainly due to oxidation because of the relatively moderate pavement temperature (McGennis et al., 1994). Both short term and long term aging increase asphalt binder viscosity and mixture stiffness. Since road repair and maintenance implicates high cost and time consuming, an in depth knowledge on asphalt binder and mixture properties changes due to aging will be beneficial and useful to maintain the road at the lowest cost and optimal time.

In the United States, one of the outputs of the Strategic Highway Research Program is Superpave which proposed an improved mixture design procedure and takes into account binder aging. Superpave customised the design of an asphalt mixture for a specific location, climate, and traffic (Houston, 2007; McGennis et al., 1994). Many researchers have performed numerous chemical and mechanical aging tests to realize the aging effects but it nevertheless remains a phenomenon which is hard to comprehend. In countries with temperate climate, aging is considered as a seasonal process and generally more severe in summer than in winter (McGennis et al., 1994). The aging process proceeds at a higher rate in hot climates or during the summer months compared to the other climates due to higher temperatures (Houston, 2007). Located near to the Equator, Malaysia's climate is categorized as equatorial, being hot and humid mostly throughout the year. Hence, a more rapid aging process happened in tropical countries such as Malaysia as compared to temperate countries. However, due to the difficulties of simulating environmental conditions during production and service life of asphalt pavements, a general relationship between laboratory and field aging is difficult to obtain. According to Branthaver et al. (1993) an aging test must take into consideration the climate in which the pavement will be exposed to.

1.3 Objectives

This research was conducted to characterize the effects of short term aging on asphalt binder and asphalt mixture for pavement in Malaysia. The detailed objectives are as follows:

1. To study the effects of short term aging duration on the rheological properties of asphalt binders.
2. To compare the rheological properties of artificially short term aged asphalt binder with binder subjected to short term aging under Malaysian field and climatic conditions.
3. To evaluate the effects of short term aging duration on laboratory produced asphalt mixture performance.
4. To compare the mechanical properties of artificially short term aged asphalt mixture and mixtures produced and subjected to short term aged under Malaysian climatic conditions.

1.4 Significance of study

The primary factor affecting the durability of the asphalt mixtures is binder age hardening. Aging of the asphalt binder increases its stiffness (or viscosity) and consequential stiffening of the mixture. Age hardening can also have two effects, namely increasing the load-bearing capacity and permanent deformation resistance of the pavement by producing a stiffer material or reducing pavement flexibility resulting in the formation of cracks with the possibility of total failure (Vallerga, 1981). Aging can affect the asphalt pavements and it significantly influences the pavement life span. Consequently, aging influences the maintenance and management of the pavement network.

HMA construction is carried out at high temperatures to ensure workability of the asphalt mixture during mixing and compaction. However, producing HMA at high temperatures can result in high energy consumption, significant greenhouse gas emissions, hazardous fume, and unpleasant odours. Recently, increased environmental awareness and rising energy costs have led to the development of alternative paving materials that require lower operating temperatures; but possess similar in-service performance with the normal HMA (Al-Qadi. et al., 2012).

The study on asphalt binder rheological properties helps to design a better HMA facility that can reduce the maintenance cost and time during the pavements service life. In this research, many tests were performed to evaluate the rheological properties of the asphalt binders and mixtures before and after aging. In addition, this research was conducted to evaluate and simulate the effects of ambient conditions on short term aging for the asphalt binder and mixture during a typical road construction in Malaysia. The findings imply the need to specify a suitable laboratory short term conditioning procedure to simulate Malaysian field conditions especially the weather. The results from this study can be constructive for further research works to improve the asphalt mixture design, road construction and sustainable pavements. This study compares the aging effects on the artificial mixture produced in the laboratory and the aged mixture from the field and plant produced under Malaysian environmental conditions.

1.5 Scope of work

The scope of work is limited to a study on the effects of short term aging on asphalt binder and asphalt mixture. The aggregate type used in this study was crushed granite that is commonly used in Malaysia. The aggregate gradation conformed to the Malaysian Jabatan Kerja Raya (JKR) gradation for mix type AC14, while binder type used was a conventional penetration grade asphalt binder 80/100 (PG 64). Materials were characterised using the Dynamic Shear Rheometer (DSR), Rotational Viscometer (RV), Viscosity Temperature Susceptibility (VTS), Fourier Transform Infrared Spectroscopy (FTIR) and X-ray Diffraction (XRD) for asphalt binder and Resilient Modulus, Creep, Fatigue and Indirect Tensile Strength (ITS) for asphalt mixture.

The focus of this research is on the short term aging effects on asphalt binder and mixture properties. This study is divided into two phases. The first phase involved tests carried out on virgin, artificially aged and extracted asphalt binders. The second phase involved tests carried out on field, plant and artificially aged asphalt mixtures. All tests were being conducted to assess the characteristic of the short term aging behaviour of asphalt binder and asphalt mixture. A number of specimens were fabricated in the laboratory to compare and simulate the samples from actual field conditions.

1.6 Thesis Organization

The thesis begins with general information on asphalt binder and mixtures and highlights the research motivations. It also outlines the background, problem statement, objectives and the scope of work that need to be completed. Chapter 2 describes in detail previous studies associated with aging phenomenon and its effects on the asphalt binder and mixture. It also explains different methods used to simulate aging in the laboratory.

Chapter 3 describes the materials, tests and methods that were used for materials characterisation in the laboratory. It explains and reports the materials properties such as binder, aggregate and filler properties. Chapter 4 deliberates on the results, discussion and statistical analysis. The experimental studies are concluded in the chapter 5, where the conclusions and recommendations obtained from this research, are presented.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The word "asphalt" originated from the Greek word "asphaltos" meaning "secure". Similarly the word "bitumen" was derived from the Sanskrit word "jatu-krit" meaning "pitch creating" (Read and Whiteoak, 2003). In ancient times, asphalt was used as a mortar between bricks and stones, for ship caulking and as a water proofing material. Natural deposits (asphalt lake) in past and recently residues from refineries process are two main sources of asphalt binder. It is generally used for road paving and roofing material due to their precious engineering properties and flexibility.

HMA is a common material that has been used largely in the road construction industries. HMA consists of asphalt binder and mineral aggregate. The asphalt binder is used to glue aggregate particles together and to waterproof the mixture. The aggregate in the mixture acts as a stone skeleton to impart strength and toughness to the structure. The HMA behaviour depends on individual components properties and their combined reaction in the mixture.

Asphalt binder is a complex mixture of organic molecules and its properties change due to different factors. Asphalt binder aging is among the factors that caused shorter pavement life span. Aging affects asphalt binder rheological properties causing deterioration in asphalt mixture performance. Many tests were performed to evaluate the effects of aging on asphalt binder properties (Gandhi, 2008; Hajj et al., 2005; Siddiqui et al., 2002). To ascertain asphalt binder aging effects; the virgin, artificially aged and extracted asphalt binder were tested and comparative study between laboratory and field aging conditions were carried out.

2.2 Asphalt Binder

The American Society for Testing and Materials (ASTM) defined asphalt binder as "dark brown to black cementitious material in which the predominant constituents are bitumen that occur in petroleum processing" (ASTM, 2004). Asphalt binder is often referred to as a hydrocarbon since it is composed primarily of carbon and hydrogen atoms.

Road construction plays an essential role in the development of a sustainable infrastructure for all economies. The binder chemical component consists of approximately 80 percent by weight of carbon and almost up to 10 percent by weight of hydrogen. Other molecular compounds within asphalt binder contain heteroatoms like sulfur, nitrogen, oxygen and traces of metals like iron, nickel and vanadium, where heteroatoms can replace carbon atoms in the asphalt binder molecular structure (Jones, 1992). Asphalt binders chemistry is very different in terms of carbon and heteroatoms components. The presence of heteroatoms can make the molecule polar and consequently, react with other molecules. Both kinds and amount of heteroatoms present in the binder can be affected by the way that asphalt binder was refined from crude oils and the state of the asphalt binder aging (Jones, 1992).

There are many chemical factors at the asphalt binder molecular level which affects their physical properties (Petersen et al., 1994). Asphalt binders have many physical properties that are quite similar to polymers. The composition of a simple polymeric material consists of large molecules of similar chemical composition. In comparison with polymer, the asphalt binder material consists of relatively small molecules (Petersen et al., 1994). Asphalt ranges from non-polar hydrocarbons, which are similar in composition to waxes, to highly polar or polarizable hydrocarbon molecules consisting of condensed aromatic ring systems that incorporate heteroatoms (Robertson, 1991). When the molecules are randomized, they can move with respect to each other more easily than when they are more organized. According to Johansson (1998), asphalt binder is composed of four generic fractions namely, asphaltenes (polar), resins (polar aromatics), aromatics (non-polar, cyclic) and saturates. Figure 2.1 shows a schematic structure to describe asphalt binder components (Xu and Huang, 2010). Asphaltenes are often considered as highly polar and complex aromatic ring systems with a high concentration of polar functional groups containing heteroatoms.

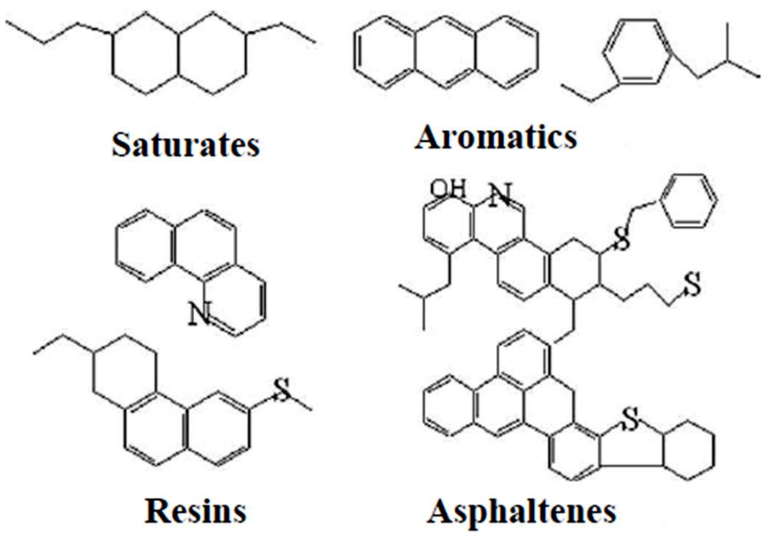

Figure 2.1: Schematic Structures for Asphalt Binder Components (Xu and Huang, 2010).

Asphaltenes play a fundamental role in the mechanical and rheological properties of asphalt binders. Important asphalt binder properties such as temperature susceptibility or sol-gel transition phenomena depend on the quantity and nature of asphaltenes. Asphaltenes are the least characterized asphalt binder component, even though a great deal of effort has been devoted to the investigation of their composition (Boduszynski et al., 1980). Resins composed of hydrogen and carbon containing small amounts of oxygen, sulphur and nitrogen. Aromatics refer to the low molecular weight naphthenic compounds with paraffinic chains, and substituted monocyclic and polycyclic aromatic hydrocarbons. Saturates comprise of straight and branch-chain aliphatic hydrocarbons, together with alkyl-naphthenes and some alkyl-aromatics. Saturates do not contain polar chemical functional groups (Johansson, 1998).

In the context of asphalt pavements, three asphalt binder characteristics are important in asphalt mixture performance: temperature susceptibility, viscoelasticity and aging. The properties of the asphalt binder are very dependent on its temperature, which means, at high temperatures, asphalt binder becomes viscous and displays plastic response. However, it becomes stiffer and behaves like an elastic solid at very low temperatures (Asphalt Institute, 1996). At high temperature, asphalt binder is subjected to rutting. The extreme stiffening of the asphalt binder at very cold temperature leads to low temperature cracking. At intermediate temperatures, asphalt binder exhibits viscoelastic behaviour and displaying characteristics of both viscous fluid and elastic solid.

The asphalt binder is chemically organic and reacts with oxygen present in the environment. Oxidation causes the asphalt to become more brittle and occurs more rapidly at higher temperatures. Age hardening leads to raveling from both fatigue and thermal cracking distresses that causes pavement failures (Chen and Huang, 2000).

2.3 Asphalt Mixture

The response of the HMA to applied load depends on the properties of the asphalt binders, the toughness and interlocking characteristics of the aggregates and fillers. Over time, asphalt pavements are subjected to surface distress such as permanent deformation, fatigue cracking and low temperature cracking. Permanent deformation or rutting resulted from the accumulation of small amounts of unrecoverable deformation that occur each time load is applied. Rutting takes place because the asphalt mixture has not enough shear strength to resist repeated heavy loads. One way to increase mixture shear strength is to use stiffer asphalt cement. Another method to increase the HMA shear strength is by selecting an aggregate with high internal friction. When a load is applied to the mixture, the aggregate particles lock tightly together and act like a large, single, elastic stone (Asphalt Institute, 1996; Sousa et al., 1991).

Fatigue cracking occurs in asphalt pavements when the reflected applied loads overstress the asphalt materials, causing cracks to form. An early sign of fatigue cracking is intermittent longitudinal cracks in the wheel path. Fatigue cracking is progressive because at some point, the initial cracks will join together, causing even more cracks to form. Fatigue cracking can be caused by repeated heavy loads, thin pavements, high deflections, poor drainage and poor construction. Methods to overcome fatigue cracking include adequately account for the number of heavy loads during design, use thicker pavements, keeping the subgrade dry, use of pavement materials not excessively weakened by moisture and use HMA that is resilient enough to withstand normal deflections (Asphalt Institute, 1996; Shu et al., 2008).

Low temperature cracking is caused by intermittent transverse cracks that occur at a surprisingly consistent spacing. Low temperature cracks form when an asphalt pavement layer shrinks in cold weather. As the pavement shrinks, tensile stresses build up within the layer. At some point along the pavement, the tensile stress exceeds the tensile strength and the asphalt layer cracks. The asphalt binder plays a key role in low temperature cracking. To overcome this problem, a softer binder that is not overly prone to aging should be used, and better control of the in-place air voids of the pavement so that the binder does not become excessively oxidized (Asphalt Institute, 1996; Jung and Vinson, 1994).

2.4 Aging

2.4.1 Asphalt Binder Aging

Binder aging is among the factors that caused shorter pavement life span. Aging effects on the asphalt binder properties, whether in the field or during accelerated laboratory aging, has received a lot of attention for many years. The first stage of short term aging occurs during transporting, storage, and handling followed by asphalt mixture production and construction. The second stage of long term aging occurs while the pavement is in service over extended time (Hintz et al., 2011). The properties of asphalt binder coating the aggregates changed during mixing, transporting, construction and during service life (Lee et al., 2008). Volatilization of asphalt binder and reaction with oxygen from the environment (oxidation) were two different mechanisms that caused property changes and led to aging of asphalt binders (Asphalt Institute, 1996). During the mixing process, binders aged due to elevated temperatures and continuous air flow. Over an extended period of time and due to oxidation, binder aging in the mixture gets more severe, caused by greater variance in air temperature (Chen and Huang, 2000; McGennis et al., 1994). The behaviour of asphalt binders is dependent on temperature and time of loading, hence time and temperature can be used interchangeably, the behaviour of asphalt at high temperature in short loading times appears to be equivalent to lower temperatures and longer loading times (Basu et al., 2003).

Three main factors causing physical aging in asphalt binder includes, change binder composition due to reactions with oxygen, decrease in maltenes content due to volatilization or adsorption and the third is slow crystallization of waxes and rearrangement of asphaltene and resin molecules (Petersen, 1984). Increase in the molecular size which results in an increase in the viscosity and stiffness of the asphalt binder, leads to failure in the field (Lee et al., 2008). Also, it was found that age hardening occurs when the naphthene-aromatics are converted to polar-aromatics and turned into asphaltenes. These changes caused an increase in viscosity and a lowering of penetration (Corbett and Schweyer, 1981). Aging increases the large molecular contents and decreases the small molecular contents, which is turn lead to an increase in the molecular weight of the asphalt binders. Other studies show that aging cause the reduction of aromatics and at the same time increases the resins and asphaltenes contents. In addition, Lu and Isacsson (2000) found that the artificial aging increases the carbonyl compounds and sulfoxides contents of conventional asphalt binders.

According to Roberts et al. (1996) six factors causing aging of asphalt binders during production and service life are oxidation, volatilization, polymerization, thixotropy, syneresis and separation. Oxidation is the reaction of oxygen and asphalt binder, where the rate of aging varies due to the asphalt binder characteristic and temperature. Volatilization is the evaporation of the lighter components from the asphalt binder and is mostly a function of temperature. It is usually not a significant factor contributing to long-term aging in the pavement, which means, that occurs more severe during the mixture production and construction (short term aging) due to high temperature. Polymerization is the combination of similar molecules to form larger molecules, causing a progressive hardening. There is no scientific evidence to show that this is a significant factor during the low temperature aging of asphalt in pavements. Thixotropy is the progressive hardening due to the formation of a structure inside the asphalt binder over a period of time, which can be ruined to a degree by reheating the material. Thixotropic hardening (also called steric hardening) is generally associated with pavements which have little or no traffic, and its amount is a function of asphalt composition. Syneresis is an exudation reaction in which the thin oily liquids are exuded to the surface of the asphalt binder film. With the elimination of these oily constituents, the asphalt binder becomes harder. Separation is the removal of the oily constituents, resins, or asphaltenes from the asphalt binder as caused by selective absorption of some porous aggregates (Roberts et al., 1996).

Binder short-term aging is simulated in the laboratory using different methods such as Rolling Thin Film Oven Test (RTFOT) and Thin Film Oven Test (TFOT). The RTFOT was conducted according to ASTM D 2872 (ASTM, 1997a) procedures, while the TFOT was conducted according to ASTM D 1754 (ASTM, 2009b) procedures. Both procedures are summarised in Table 2.1 (Shalaby, 2002). Several researchers concluded that both RTFOT and TFOT tests are not interchangeable and that the RTFOT appears to be more severe on the majority of binders than the TFOT (Zupanick, 1994). Long-term aging mainly occurs because of contact of the asphalt binders to oxygen and different environmental conditions. It is simulated in the laboratory using a Pressure Aging Vessel (PAV) in accordance to ASTM D 6521 (ASTM, 2005c) procedures. A number of other laboratory aging methods have been proposed to simulate aging. In those tests, asphalt binder aging was accelerated by increasing temperature, decreasing asphalt binder film thickness, increasing oxygen pressure, or applying various combinations of these factors. Table 2.2 briefly illustrates the different artificial asphalt binder aging methods carried out in the past (Airey, 2003).

Table 2.1: Comparison of TFOT and RTFOT Methods (Shalaby, 2002).

Parameter	TFOT (ASTM D1754)	RTFOT (ASTM D2872)
Sample placement	Steel pans	Glass bottle
Dimensions	140 mm O.D., 9.5 mm deep	64 mm O.D., 140 mm deep
Sample size	50 g per pan	35 g per bottle
Rotation	5.5 rev/min	-
Rolling action	-	15 rev/min
Forced air	-	Heated air jet
Test duration	300 min	85 min
Test temperature	163°C	163°C
Limitations	(i) Skinning, a thin crust forms on sample surface (ii) Test duration is too long for quality control/quality assurance	(i) Binder may leak from bottle particularly if polymer modified (ii) Potential for segregation in modified binders

Asphalt binder aging may be influenced simultaneously by several factors such as binder characteristics and content, nature and particle size distribution of the aggregate, air voids, production related factors, and external conditions like temperature (Lu and Isacsson, 2000). Information about the asphalt binder physical properties is essential to pavement design, which provides optimum service performance and durability. Asphalt binder consists of chemical compositions, which in turn react with atmospheric oxygen. This phenomenon leads to the hardening of the asphalt binder and causing a deterioration of desirable physical properties.

Table 2.2: Asphalt Binder Short and Long Term Aging Methods (Airey, 2003).

Test method	Temperature (˚C)	Duration	Sample size (g)	Film thickness	Extra features
Thin film oven test (TFOT) (Lewis and Welborn, 1941) and (ASTM, 2009b)	163	5 h	50	3.2mm	–
Modified thin film oven test (MTFOT) (Edler et al., 1985)	163	24 h	–	100µm	–
Rolling thin film oven test (RTFOT) (Hveem et al., 1963) and (ASTM, 1997a)	163	75m	35	1.25mm	Air flow 4000 ml/min
Extended rolling thin film oven test (ERTFOT) (Edler et al., 1985)	163	8 h	35	1.25mm	Air flow 4000 ml/min
Nitrogen rolling thin film oven test (NRTFOT) (Parmeggiani, 2000)	163	75m	35	1.25mm	N2 flow 4000 ml/min
Shell microfilm test (Griffin et al., 1955)	107	2 h	–	5 µm	–

Table 2.2: : Asphalt Binder Short and Long Term Aging Methods (continued)

Test method	Temperature (˚C)	Duration	Sample size (g)	Film thickness	Extra features
Modified Shell microfilm test (Hveem et al., 1963)	99	24 h	–	20 µm	–
Modified Shell microfilm test (Traxler, 1963) and (Halstead and Zenewitz, 1961)	107	2 h	–	15 µm	–
Modified RMFOT (Schmidt, 1973)	99	48 h	0.5	20 µm	1.04mm Φ opening
Tilt-oven durability test (TODT) (Kemp and Predoehl, 1981)	113	168 h	35	1.25mm	–
Alternative TODT (McHattie, 1983)	115	100 h	35	1.25mm	–
Thin film accelerated aging test (TFAAT) (Petersen, 1989)	130 or 113	24 or 72 h	4	160µm	3mm Φ opening
Modified rolling thin film oven (RTFOTM) (Bahia et al., 1998)	163	75m	35	1.25mm	Steel rods
Iowa durability test (IDT) (Lee, 1973)	65	1000 h	TFOT residue 50	3.2mm	2.07MPa pure oxygen
Pressure oxidation bomb (POB) (Edler et al., 1985)	65	96 h	RTFOT residue	30 µm	2.07MPa pure oxygen
Accelerated aging test device/Rotating cylinder aging test (RCAT) (Verhasselt and Choquet, 1991)	70–110	144 h	500	2mm	4–5 l/h pure oxygen
Pressure aging vessel (PAV) (Christensen and Anderson, 1992)	90–110	20 h	RTFOT or TFOT Residue 50	3.2mm	2.07MPa air
High pressure aging test (HiPAT) (Hayton et al., 1999)	85	65 h	RTFOT residue 50	3.2mm	2.07MPa air

2.4.2 Asphalt Mixture Aging

The deterioration of asphalt pavements is caused by 3 main factors: traffic, material properties and environmental factors. The magnitude of load and time of loading are two factors that deteriorate pavement life. Deterioration can be more severe when any of these parameters are increased. Materials properties depend on their types, magnitude, physical and chemical properties separately or together can affect the asphalt mixture performance and cause the deterioration of pavement life span. Environmental conditions vary due to different geographic locations and seasons. The effects of environment on the mixtures aging is a very complicated factor to evaluate. Climatic features include wind, light, temperature changes and presence of water or moisture (Houston, 2007). Figure 2.2 shows a flow chart of the different factors that affects aging (Lerfald, 2000).

The rate of oxidation is affected by factors such as asphalt binder type and thickness, environment temperature, pavement air voids and aggregate type. Aggregates influence the asphalt binder aging mechanism either physically or chemically. According to Anderson et al. (1994) and Petersen et al. (1974) aggregates, depending on their mineral composition, can absorb oily components from asphalt binder. Also, aggregates may influence the asphalt binder aging by acting as a catalyst. Aggregates can advance the formation of the oxidation products in the low polar general fractions or may absorb the highly polar fractions and cause less oxidation in the asphalt binder.

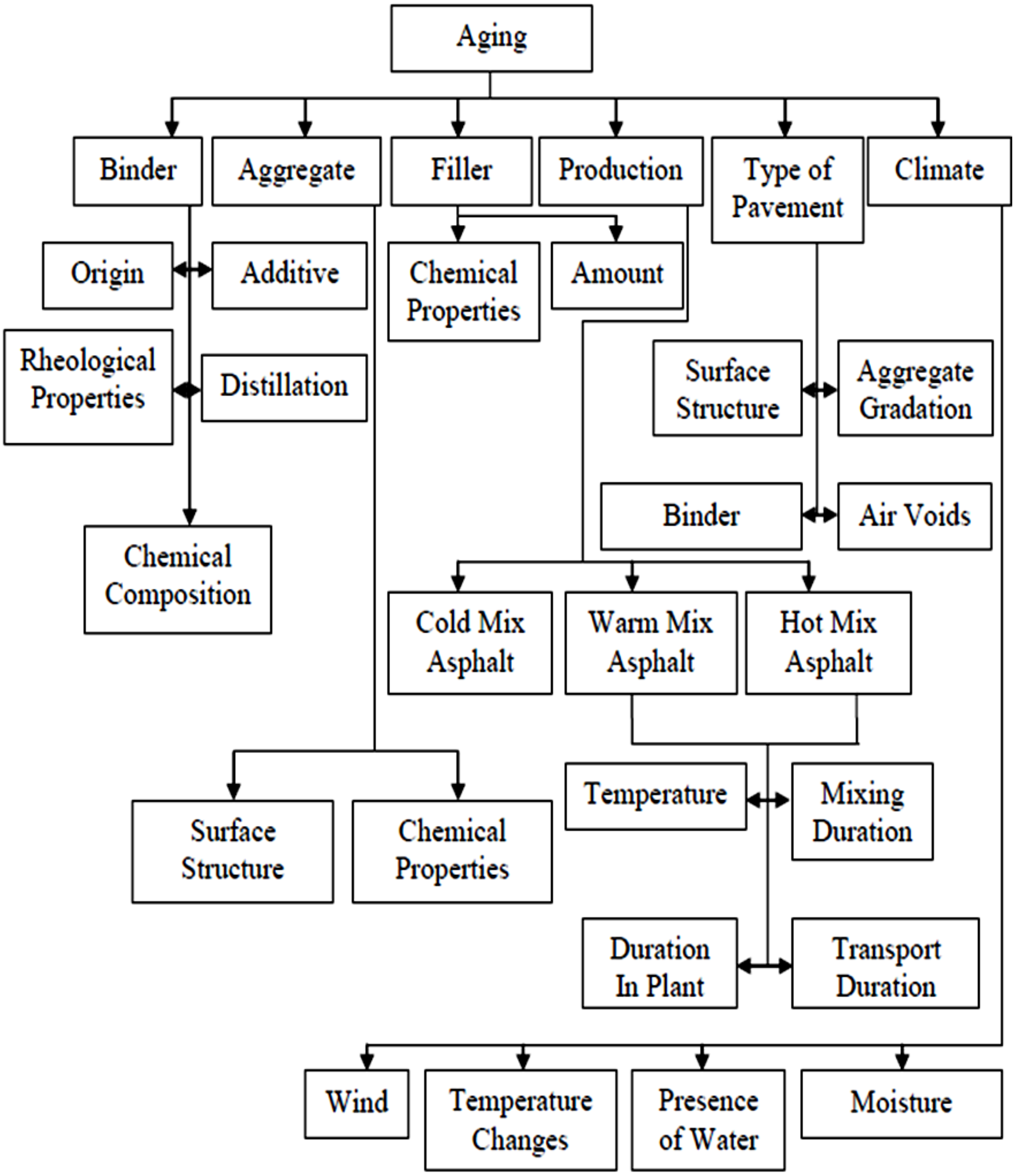

Figure 2.2: Factors Affecting Aging (Lerfald, 2000).

Anderson et al. (1994) found that aggregates with less adsorption of highly polar fractions such as quartzite has more catalytic effect on asphalt oxidation compared to more adsorption aggregates such as limestone. According to Chadbourn et al. (1999), aggregate binder absorbance depended on the air voids and pore sizes of aggregate. Aggregate with small pores had less potential to absorb asphalt binder, which caused to accelerate aging and can cause a lack in durability.

Binder film thickness plays an important function in the binder oxidation process. It was believed that thicker binder film thickness makes the binder more resistant to oxidation and hardening. Heslop (1997) stated that a thicker binder film reduces age hardening due to longer time required for oxygen to penetrate into the binder. Also, catalytic activity of the mineral aggregate surface is limited due to a thicker binder film, which completely separates the oxygen in the air and aggregate surface. Read and Whiteoak (2003) found that aging depends on the air voids. It was also stated that the binder in air proximity age faster than the binder in the core of mixtures (Read and Whiteoak, 2003). Isacsson and Zeng (1998) evaluated the air voids effects on aging of 5 binders from different sources, which were extracted from dense graded and porous asphalt mixture. It was found that the air voids has a significant effect on the aging which led to faster fracture at low temperatures. The effect of air voids was considerable due to oxidation and occurred faster in porous asphalt compared to stone mastic and dense graded asphalt mixtures. Hence, it was concluded that air voids greatly influenced the low temperature behaviour of asphalt pavements. The comparative results are shown in the Figures 2.3 and 2.4 (Isacsson and Zeng, 1998).

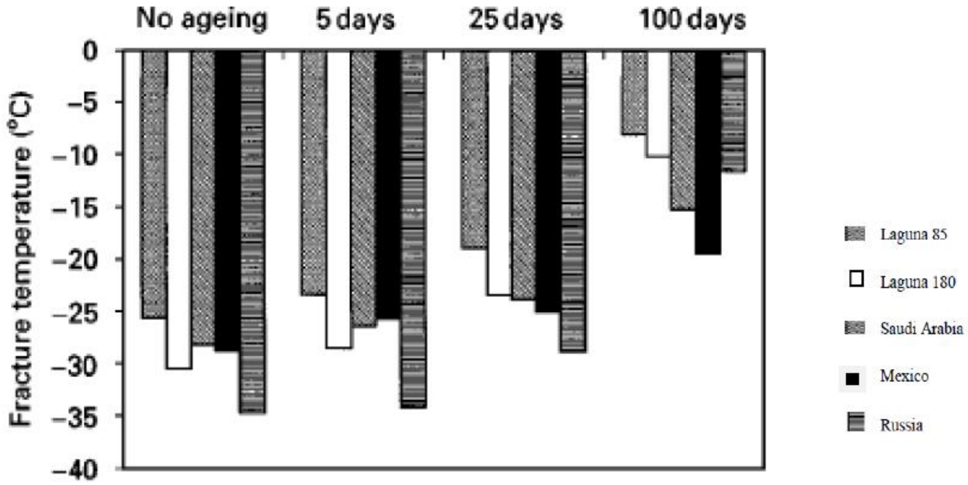

Figure 2.3: Effect of Ageing and Binder Source/Grade on the Fracture Temperature of Porous Asphalt Specimens (Isacsson and Zeng, 1998).

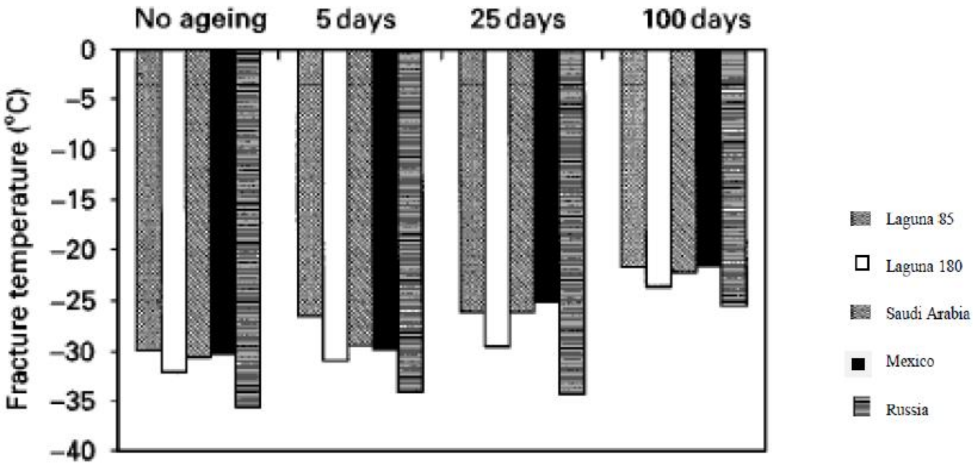

Figure 2.4: Effect of Ageing and Binder Source/Grade on the Fracture Temperature of Dense Graded Asphalt Specimens (Isacsson and Zeng, 1998).

An investigation into the changes in the mixture properties during its preparation in the laboratory is essential. To simulate the field samples mixture properties in the laboratory, samples should be produced in such a way that aging happens during production, construction and while in service. Asphalt mixture aging simulation method is mostly limited to extend heating on loose material. However recently, researchers use methods such as extended oven aging, high and low pressure oxidation and ultraviolet and infrared light treatments. The short term and long term aging mixture conditioning procedure simulates the actual aging, which occurs during production, construction and over the many years in service. Many research works on asphalt mixture aging have been tried due to the different and complicated aging effects on HMA performance. The aging methods on asphalt mixture are different compared to the aging methods on asphalt binder. Table 2.3 and 2.4 illustrate some of the methods developed to simulate short and long term aging of asphalt mixtures (Airey, 2003).

Table 2.3: Different Aging Methods for Asphalt Mixture (Airey, 2003).

Test method	Temperature (˚C)	Duration	Sample type	Extra features
Bitutest protocol (Scholz, 1995)	85	5 days	Compacted specimens	–
Short and long term aging (Kumar and Goetz, 1977)	60	1,2, 4, 6, 10 days	Compacted specimens	Air at 0.5mm of water
Oregon mixtures (Kim et al., 1986)	60	0, 1, 2, 3, 5 days	Compacted specimens	0.7MPa air
SHRP low pressure oxidation (LPO) (Bell, 1994)	60 or 85	5 days	Compacted specimens	Oxygen 1.9 l/min
Production aging (Von Quintus, 1991)	135	8, 16, 24, 36 h	Loose material	–
SHRP short-term oven aging (STOA) (Bell, 1994)	135	4 h	Loose material	–
Bitutest protocol (Scholz, 1995)	135	2 h	Loose material	–
Ottawa sand mixtures (Pauls and Welborn, 1952)	163	Various periods	50 * 50mm^2 cylinders	–
(Plancher et al., 1976)	150	5 h	25 * 40mm^2 Φ	–
Ottawa sand mixtures (Kemp and Predoehl, 1981)	60	1200 h	–	–

Table 2.4: Different Aging Methods for Asphalt Mixture.

Test method	Temperature (˚C)	Duration	Sample type	Extra features
Short term aging BRRC (Piérard and Vanelstraete, 2009)	135	2-4 h	Loose material (3cm in oven)	Stirring
Short term aging (Hachiya, 2003)	70	8 hours	Beams	–
Short term aging RILEM TG5 (De La Roche et al., 2009b)	135	4 hours	Loose material	–

Factors that cause HMA prepared in the laboratory and those produced in an asphalt plant to have different properties include variations in production methods and environmental conditions. In other words, asphalt aging during mixing, hauling and construction in the field is quite different compared to the samples produced in the laboratory. Aging is also effected by absorption of the binder into the aggregate during this process due to the different amount of asphalt binder absorbed by the aggregate pores (Chadbourn et al., 1999). Johansson (1998) stated that aggregate and particle size distribution could affect binder aging. Mixture with coarse aggregate like porous asphalt was more susceptible to aging compared to dense mixture due to the larger surface connection with oxygen present in the environment (Roberts et al., 1996). Traffic also affects pavement durability. Aging continues at a slower rate while the pavement is in service. Aging in laboratory samples are more homogeneous compared to field samples. Zapata and Raghavendra (2006) concluded that the existing Superpave binder and mixture conditioning procedure is not sufficient to exactly simulate field aging of asphalt mixtures. Raghavendra (2006)