Task 409: Collaborative Research into the Next Generation of Asphalt Surfacings

Sub-Task 2: Influence of Oxidative Hardening and UV Light on Ageing of Thin Surfacings

Project Report

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1 INTRODUCTION

The high level objectives of Highways England are value for money, driving innovation and improving efficiency. As such, there is now greater emphasis on asphalt surfacings to deliver cost reduction as well as environmental benefits.

The main element of this project is to review surfacing materials worldwide with the view to understanding and developing requirements for materials which offer significantly enhanced durability and optimised noise and skid resistance characteristics. Thin Surface Course Systems (TSCS) are currently the preferred type of surfacing on the Strategic Road Network, introduced on UK roads in the late 1990's. Previous research has shown that these materials can be very durable and last up to 16 years, even on roads with high traffic levels.

Hot rolled asphalt was widely used on the Strategic Road Network prior to the introduction of TSCS and it is estimated that these surfaces last on average for 20 years and examples exist where the material has been in service for more than 25 years, even in areas with very high traffic levels. However, hot rolled asphalt materials generate higher traffic noise levels than thin surfacings, which can be significant in areas where the residential dwellings are near the Strategic Road Network.

Highways England, Mineral Products Association and Eurobitume UK commissioned AECOM (formerly URS) on 21 January 2015 to deliver a collaborative research into next generation of asphalt surfacing. This study was awarded under Highways England Framework for Transport Related Technical, Engineering Advice and Research – Lot 2: 4/45/12 with Package Order Reference – 409 (4/45/12) ARPS.

This project provides a fundamental review of surfacing materials and considers the development of materials that take the durability aspects of hot rolled asphalt and combines them with noise reduction properties of thin surfacing while maintaining safety characteristics (including skid resistance and spray reduction).

The primary objective of the collaborative research is "to ensure that asphalt surfacings continue to deliver value for money on the strategic road network and to maximise the benefit from innovation".

This work was been divided into the following sub-tasks:

- Sub-Task 1: a review of surfacing materials worldwide with a view to understanding and developing requirements for materials which offers significantly enhanced durability and optimised noise and skid resistance characteristics.

- Sub-Task 2: a review of ageing of thin surfacing materials through environmental exposure, such as oxidation and ultraviolet (UV) light.

This report presents findings from Sub-Task 2, whilst those from Sub-Task 1 are reported separately.

2 AGEING OF ASPHALT MATERIALS

In recent times, concerns have been raised about the performance of Thin Surface Course Systems (TSCS) which led to the review of existing standards and specifications to identify critical factors and measures that will enhance the durability of these materials. Failure mechanisms of TSCS can be categorised into five major groups (UKRLG – UK Roads Liaison Group, 2006):

1. Internal failure mechanisms: these comprise of bitumen properties, aggregate properties, mix design stability, aggregate/bitumen affinity.
2. Traffic loadings that include static and dynamic traffic loads.
3. Environmental factors that take into account water saturation, temperature variations, humidity, precipitation, freeze-thaw cycles, ageing due to oxidisation and UV light.
4. Substrate strain loading – The vertical and horizontal strains experienced by the TSCS due to traffic loadings on the pavement.
5. Interface shear stress due to reduced surface thickness of the TSCS which results in an increase in the horizontal shear stress at the base of the surface layer due to traffic loading.

The durability of TSCS is based on the asphalt specification and industry practice. The asphalt mixture should be designed for the required performance, properly compacted and bonded and be laid on roads where bottom-up fatigue cracking is not the defining failure mechanism. Nicholls et al., (2010) reported that the most common categories of defect for TSCS occur as a result of a combination of the factors listed above. The most common defects were identified as fretting, cracking and delamination. These defects mostly took place within months or years in service. Exposure of asphalt surfacing to variations in environment conditions plays a role in these defects (Ayar et al., 2016). This exposure may result in progressive ageing in service, which can impact rheological properties of the asphalt surfacing and consequently the rheology of the bituminous binder or the bitumen in the asphalt surfacing. Therefore, it is considered important to understand the ageing characteristics of bitumen and bituminous binders.

The rheological properties of bitumen change with time resulting in an increase in viscosity and stiffness of the bitumen which alters its performance. This phenomenon is termed “ageing”. Age hardening is the result of compositional changes in the bitumen. This is characterised by the asphalt mixture becoming more brittle with its ability to support traffic induced stresses and strains decreasing. This could result in cracking damage to the bound layer of the pavement (Wu, 2009).

Excessive age hardening weakens the adhesion between the bitumen and aggregate resulting in loss of materials (Wu, 2009). Petersen (1984) outlined three fundamental composition-related factors which govern the changes that could cause bitumen hardening in pavements:

- Loss of oily components of bitumen by volatility or absorption;
- Change in chemical composition of bitumen molecules from reaction with atmospheric oxygen;
- Molecular structuring that produces thixotropic effects (steric hardening).

Ageing is more predominant in TSCS due to the reduced thickness of the surfacing layer and at the surface of the pavement. The amount and rate of ageing is a factor of temperature, exposure to oxygen, chemical composition and structure of the bitumen. Other factors include porosity, depth of the surfacing layer and the local climatic condition as emphasised by Petersen (2009). Anderson et al., (1994) stated that temperature is a significant factor in the ageing process as it softens the bitumen. Due to the softening, the volume of the bitumen increases which leads to higher porosity facilitating interaction with oxygen. This results in acceleration of the chemical reaction resulting in age hardening of the bitumen.

Changes in the rheological, mechanical and chemical properties of bitumen and asphalt mixture can be quantified by means of ageing indicators as proposed by Hagos (2008). The ageing indicators commonly used in practice could either be empirical parameters describing changes in binder property (such as penetration, softening point or viscosity), fundamental properties describing changes in the viscoelastic behaviour of the bitumen or a measure of the change in the chemical composition of the bitumen with specific focus on the colloidal structure after ageing has started.

In the current study, specific interest was aimed to understand in situ ageing of thin asphalt surfacing through environmental exposure due to oxidation and UV light.

3 AGEING DUE TO OXIDATION

3.1 Introduction

Bitumen is a complex mixture mainly consisting of hydrocarbon molecules. Oxidation is considered to be a major cause of bitumen ageing resulting in the deterioration of asphalt performance properties over time. Oxygen from the environment diffuses into the bitumen resulting in chemical changes that cause hardening of the bitumen (Anderson et al., 1994). Oxidation makes the bitumen harder and more brittle due to increasing viscosity and/or stiffness of the bitumen. This has an adverse effect on the pavement thereby increasing the risk of cracking (Redelius, 1998).

There are laboratory test methods and specifications which aim to simulate oxidative hardening of bituminous binders used in hot mix asphalts, such as:

- Rolling Thin Film Oven Test (RTFOT) in accordance with EN 12607-1 to simulate short-term ageing (CEN, 2014);
- Pressure Ageing Vessel (PAV) in accordance with EN 14769 to simulate long-term ageing (CEN, 2012);
- The Rotating Cylinder Ageing Test (RCAT), originally developed by the Belgian Road Research Centre, now published as EN 15323 (CEN, 2007);
- Standard 'Short Term Ageing Test' and the Modified Ageing Rolling Thin Film Oven Test, specified in Clause 955 of the UK's Manual of Contract Documents for Highway Works (MCHW), for binders used in asphalt manufacturing or other Hot Mixed Materials (DfT, 2008).

At the point of writing this report, a standard method for accelerating oxidative ageing of laboratory manufactured asphalt mixture was being developed and is referenced in; prEN 12697-52.

The next section presents the mechanisms surrounding oxidative hardening of bituminous binders and how they may affect the fractional composition and rheology of the binders, and consequently, the performance of the asphalt mixtures.

3.2 Fractional Chemical Changes Due to Oxidation

The key compositional molecules of bitumen react through chemical ageing, triggered by oxidation (Traxler, 1961; Petersen, 2009). Ageing due to oxidation behaviour is usually assessed based on the characteristics of the bitumen alone. This is done by taking into account the fractional composition of the bitumen. The fractional chemical changes that occur in the bitumen due to oxidative ageing are introduced and highlighted below.

The fractional chemical composition of bitumen is usually classified based on contents of its Saturates, Aromatics, Resins and Asphaltene (SARA) fractions. The SARA fractions are distinguished from one another based on their solubility which broadly correlates with molecular weight and polarity.

Saturates

Saturates are non-polar viscous oils composed of straight and branched aliphatic hydrocarbons. The components include both waxy and non-waxy saturates. Saturates comprise 5 to 20% of the bitumen.

Aromatics

Aromatics are dark viscous liquids. They are “weakly” polar-acting as the dispersion medium for the peptised asphaltenes. Aromatics have the lowest molecular weight amongst other fractions. The average molecular weight ranges from 300 to 2,000. They constitute about 30 to 60% by mass of the total bitumen.

Resins

Resins are dark coloured and are very polar in nature which makes them highly adhesive. They are dispersing agents for the asphaltenes. Resins have a relatively high molecular weight ranging from 500 to 50,000. They comprise of 15 to 55% of the mass of the bitumen as stated by (Asphalt Institute and Eurobitume, 2011).

Asphaltenes

Asphaltenes are black or brown amorphous solids containing carbon, hydrogen, nitrogen, sulphur and oxygen. Trace elements including nickel and vanadium might be present depending on bitumen source (Airey, 2003). Asphaltenes are considered to be highly polar aromatic materials with a tendency to interact and associate. They have fairly high molecular weights ranging from about 1000 to 100,000. The asphaltene content has a large effect on the rheological characteristics of bitumen. Increasing the asphaltene content produces harder bitumen with a lower penetration, higher softening point and consequently higher viscosity. Generally, bitumen contains 10 to 20% asphaltenes (Srivastava and van Rooijen, 2000).

Fractional chemical compositions are obtained by using solvent precipitation and adsorption chromatography. Oxidation causes these fractional chemical compositions to change as described below. Figure 1 depicts the changes in the fractional chemical composition of the bitumen (Chipperfield et al., 1970).

Saturate fractions of bitumen generally remain unchanged due to their low reactivity to oxidation (Lesueur and Youtcheff, 2013). Part of the aromatics change in such a way that if a compositional analysis is conducted, there is a decrease in the aromatic content with most converted into resins (WRI, 2011).

Elemental analysis of the asphaltene content showed an increase in oxygen content during ageing (Tallafigo, 1993). The rate of asphaltene formation was found to be linear with time as observed through laboratory experiments and field conditions (Lamontagne et al., 2001).

Lesueur, (2009) quantified this by stating that the asphaltene content increased by about 1-4% continuously due to oxidation of the polar resins. This increase results in the hardening of the bitumen characterised by a reduction in the penetration, increase in the softening point and viscosity of the bitumen.

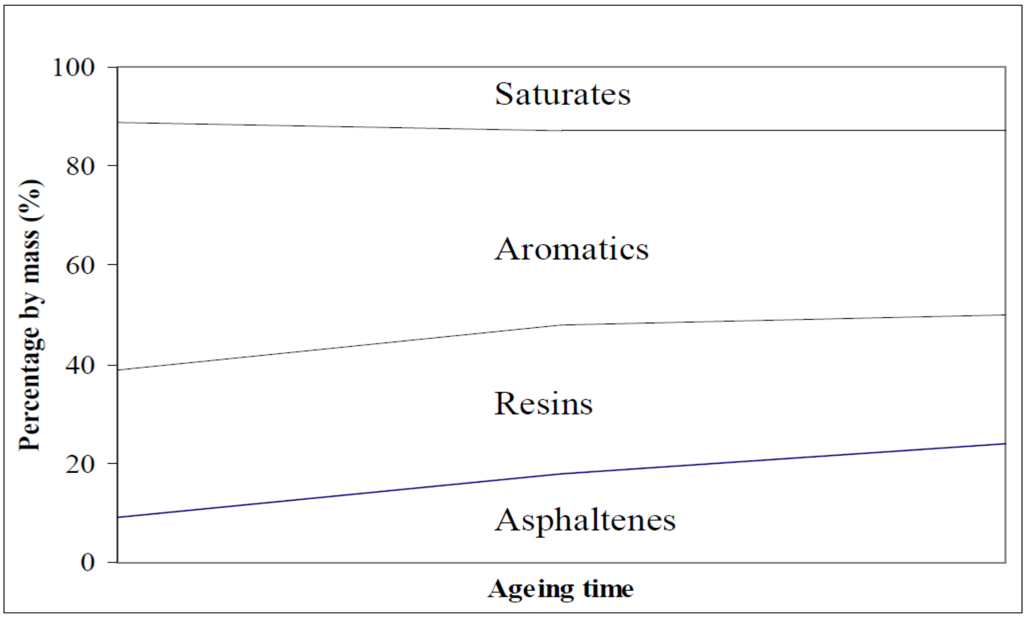

Figure 1: Changes in Fractional Chemical Composition (Chipperfield et al., 1970)

Srivastava and Van Rooijen (2000) had an alternative view with respect to evaluating the properties of aged bitumen using SARA fractional compositions alone as this could be misleading especially with the ‘new combination of resins’ formed having reduced its natural adhesive properties.

Herrington et al., (2005) emphasised this point further stating that assessing the oxidative behaviour of the bitumen alone fails to fully account for how the asphalt mixture reacts to oxidation. Oxidation produces polar functional groups in asphalt molecules. This provides a different method for assessing the changes that occur during oxidation. These molecular changes due to oxidative ageing are discussed below.

3.3 Molecular Changes Due to Oxidative Ageing

Figure 2 shows the key molecular changes and formation groups formed during oxidative ageing which include sulphoxides, anhydrides, carboxylic acids and ketones. The oxidation reaction in asphalt can be tracked by measuring changes of these products.

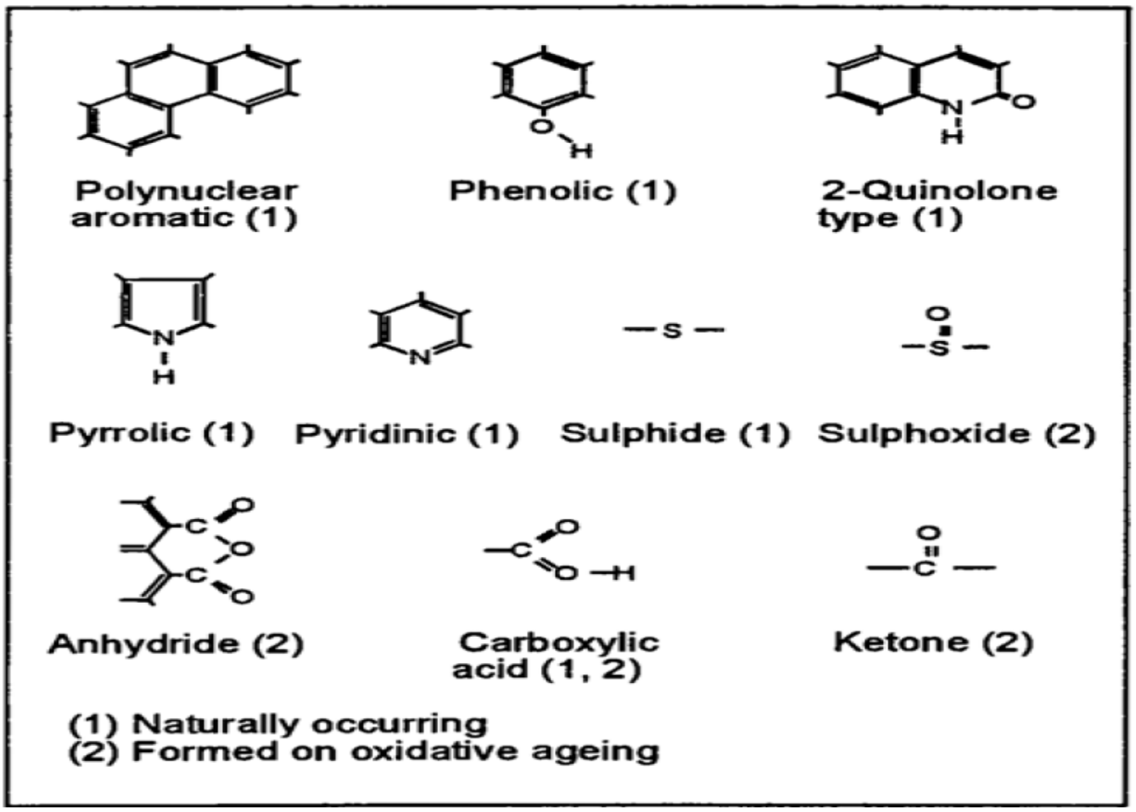

Figure 2: Molecular Products Formed Due to Oxidation (Petersen, 1984)

The anhydrides, carboxylic acids and ketones are widely classified as 'carbonyl functional groups'. These products form at different rates. Ketones and sulphoxides are the major oxidation products.

Sulphoxides generally form first with a rate that slows considerably after a short period. The carbonyls form slowly at first but with a relatively stable rate over time given constant temperature/pressure conditions (Petersen et al., 1994).

Under non-steady state conditions, rates of oxidation are dependent upon the rate of diffusion and the availability of oxygen to the system. Non-polar fractions are converted into polar fractions which lead to an increase in the viscosity of the binder.

The sum of the ketones and sulphoxides formed indicates the relative oxidation of the binder (Van Vliet et al., 2012). It should be noted that relative sensitivity to the viscosity increase is highly dependent on the source and properties of the bitumen.

Petersen (1984) conducted detailed studies highlighting and quantifying the specific changes that occur during oxidation of bitumen. As detailed in Wu (2009), tests conducted on four bitumens sourced from different crude oils aged under the same conditions resulted in the following findings.

Ketones and sulphoxides are the major products formed during oxidative ageing. Sulphoxides are formed rapidly and are thermally unstable components. Anhydrides and carboxylic acids are formed in smaller amounts. The results of their research are presented in Table 1

Table 1: Quantification of the Molecular Changes Due to Oxidative Ageing (Wu, 2009)

Bitumen	Concentration (moles/litre)				Average Hardening Index[b]
	Ketones	Anhydride	Carboxylic Acid[a]	Sulphoxides	
B-2959	0.50	0.014	0.008	0.30	38.0
B-3036	0.55	0.015	0.005	0.29	27.0
B-3051	0.58	0.020	0.009	0.29	132.0
B-3602	0.77	0.043	0.005	0.18	30.0

Note: Column Oxidation: 130°C, 24 hours, 15µm film

(a) Naturally occurring acids have been subtracted from reported value

(b) Ratio of viscosity after oxidative ageing to viscosity before oxidative ageing

Petersen (1984) showed that sulphoxides are generated from the oxidation of organic sulphides that exist in the complex bitumen molecules. Carbonyl functional groups are usually found to be in the most polar fractions (Wu, 2009).

During oxidation, the bitumen exhibits a high reactivity with oxygen resulting in the rapid formation of both ketones and sulphoxides (Liu et al., 1996 and Petersen et al., 2006). Table 2 shows the formation of carbonyl functional groups. The data in Table 2 shows that concentration of ketones formed on oxidative ageing is highest in the asphaltene and polar aromatic fractions. The ketones and sulphoxides can be established using Fourier Transform Infra-Red Spectroscopy (FTIR).

The presence of these oxidative products formed may attract moisture which can adversely affect the adhesive properties of the bitumen (Curtis et al., 1989). The freeze-thaw tolerance of bitumen can also be affected which could accelerate failure modes such as fretting and cracking of TSCS. The rates (kinetics) of chemical oxidation and viscosity increase are influenced by the bitumen composition, the oxidation products formed, temperature, oxygen partial pressure and physicochemical effects (Petersen et al., 1996).

Table 2: Carbonyl Functional Groups (Petersen, 1984)

Fraction	Concentration (moles/litre)		
	Ketones	Anhydride	Carboxylic Acid
Saturate	0.045	0.010	Trace
Aromatic	0.32	0.017	-
Polar Aromatic (Resins)	1.48	0.088	-
Asphaltene	1.82	0.080	-
Whole Bitumen	1.02	0.052	0.007

3.4 Temperature, Transportation and Other Factors

It is commonly known that bitumen is exposed to different kinds of temperature stresses that arise during production, transportation and installation of the asphalt. Srivastava and Van Rooijen (2000) stated that when bitumen was kept in storage towers at high temperatures, very little oxidation occurred. They further explained that this was due to the fact that the surface of the bitumen exposed to oxygen was relatively small in relation to the volume of the bitumen.

Further to this, Srivastava and Van Rooijen (2000) suggested that during plant mixing at high temperatures, the fractional chemical composition and the viscosity of the bitumen changed significantly and a further ageing could have taken place when the loose hot asphalt mixture was being delivered to the site. In this situation, thin bitumen film coating the loose hot asphalt mixture would have been exposed to air for a prolonged duration during delivery and installation.

In addition to the above, if the surfacing layer had considerably low air voids, the rate of ageing will be slower and oxidative ageing will be more controlled occurring mostly at the top 1 cm of the surfacing layer (Petersen, 2009). Other critical factors influencing ageing include the aggregate gradation, aggregate to aggregate contact, bitumen content, bitumen film thickness, mixing time, type of mixing plant, air void content and the temperature difference between aggregate and bitumen. Irrespective of the ageing resistance of the bitumen, the degree and rate of oxidation largely depends on temperature, time, bitumen film thickness and level of exposure to oxygen (Srivastava and Van Rooijen, 2000).

4 AGEING DUE TO ULTRA-VIOLET LIGHT (UV)

4.1 Introduction

Most of the ageing occurring on the road is still regarded as thermally induced (Lu et al., 2008). It must be noted that UV and thermal ageing are two different types of ageing. Bitumen has different sensitivities to UV and thermal radiation. Penetration values, softening point and ductility of UV-aged bitumen vary in comparison to thermally aged bitumen (Tan et al., 2007). The rate of thermal ageing of bitumen approximately doubles for every 10°C rise in temperature as stated by Durrieu et al., (2007).

The influence of UV light is often ignored in laboratory simulations of ageing due to the fact that UV light radiation only affects the first one to two microns of the bitumen's surface. Tan et al., (2007) stated that UV radiation causes significant ageing of bitumen due to gradual degradation over a period of time which influences its performance contributing to a decrease in the durability of the pavement. Wu et al., (2009) confirmed that UV light ageing changes the rheological parameters of the bitumen. Wu et al., (2009) stated that this type of ageing can be reflected from Fourier Transform Infra-Red (FTIR) spectra in terms of characteristic peaks of the carbonyl groups and sulphoxides.

4.2 Typical Tests for UV Ageing

Over the years, various tests and methods for assessing the effects of UV light have been developed. Traxler (1963) used actinic light to simulate the photochemical ageing of bitumen. The data showed that photochemical reaction has a significant effect on thin films of bitumen (3 microns) but that the effect decreases for thicker films. Edler et al., (1985) developed a weatherometer to simulate climatic conditions on the road, with part of the test comprising UV light treatment. The weatherometer consists of a cabinet housing a revolving sample holder, a temperature controlled environment, an ultraviolet light source and a sprinkling device. The test consists of ageing 100 micron bitumen films, coated on 50 mm by 50 mm glass plates, at 65°C during a 2 hour cycle comprising a 102 minute cycle of UV light only and 18 minutes of UV light and water spray at a pressure of 300 kPa. Test durations of 32.5 hours, 73.5 hours, 7 days and 14 days were used.

Kuppens et al, (1997) used a special climate chamber (oven) to simulate the ageing of porous asphalt under Dutch climatic conditions. The procedure consists of subjecting bitumen, over a 24 hour period to 16 hours of UV light at 50°C, 4 hours rain with NaCl at 40°C, 1 hour water at 20°C and 2 hours dry at -20°C. The procedure attempts to simulate both field ageing and water damage and can be repeated as often as required. However, evaluation of the procedure showed a very poor correlation with field performance.

Das et al., (2014) performed ageing experiments in which bitumen samples were exposed to air and UV conditioning for 30 days, after which they were washed with distilled water. It was noted that prior to and after washing and conditioning, the samples were examined using the Atomic Force Microscopy (AFM). The AFM is able to analyse interactions of the individual components of bitumen microstructure with the interface of solid particles. Following their investigation, it was concluded that UV ageing can create water soluble film which means that over time, the mastic films would get thinner making infiltration of water a greater problem. This coupled with the increased brittleness results in susceptibility to the ageing of the asphaltic mix resulting in the unexpected deterioration of the overall structure (Varveri et al., 2015).

4.3 Effects of UV Ageing

UV light radiation increases energy levels leading to carbon-carbon chains which break and combine with oxygen occurring at a natural pace over the service life of the pavement.

These reactions make the surface harder which in turn initiates cracks in the asphalt pavement. (Fernandez-Gomez et al., 2013) illustrated this point further stating that UV light is known to increase the oxidation process. The UV light catalysed reaction occurs rapidly and generally takes place within the top 5μm of the exposed binder film as bitumen is a good light absorber. Yamaguchi et al., (2004) concurred stating that the level of degradation by UV light has an effect on the bitumen film and this process is accelerated with an increase in temperature. This was demonstrated by a series of tests that showed that the degree of degradation worsens towards the surface of the asphalt layer and increases rapidly in the thickness range below 200 μm.

Montepara et al., (2006) in their research subjected bitumen to a UV ageing chamber at a frequency band between 180 and 315 μm for a maximum period of 420 days. The chemical evolution and the variation of its physical properties were evaluated at 20 day intervals. Volatilization and oxidation were also detected to be taking place in the binder. Figure 3 highlights the hardening of the bitumen as a function of exposure time to UV light.

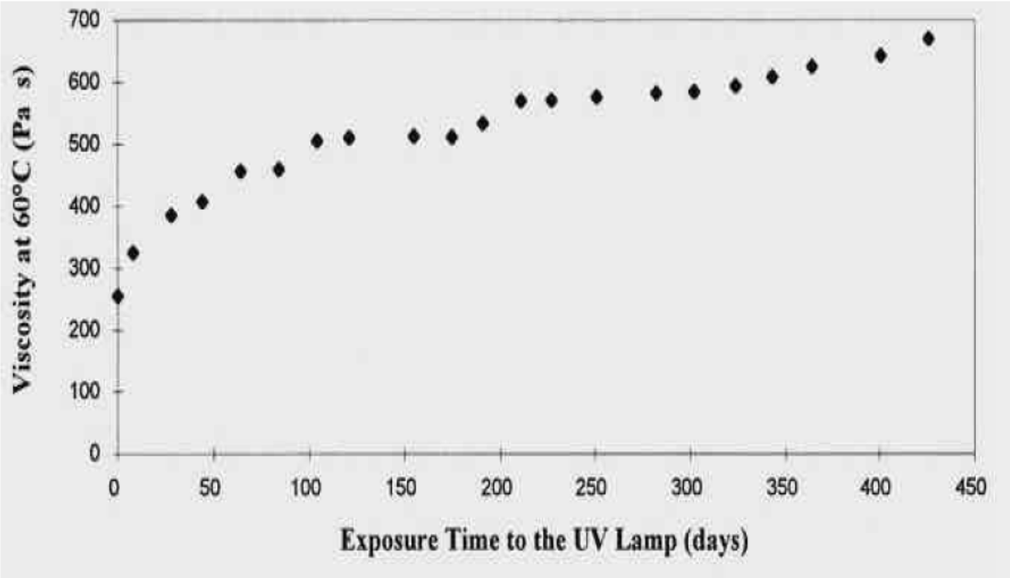

Figure 3: Changes in Viscosity as a Function of Exposure Time to UV Light (Montepara et al., 2006)

Saez-Alvan et al., (2003) stated that the softening point and viscosity increased due to UV light exposure. It was further explained by Montepara et al., (2006) that the hardening of the bitumen as a function of exposure time to UV light is due to the joint occurrence of volatilization, oxidation and polymerization. Whilst most researchers agreed about the occurrence of volatilization and oxidation, there were controversies regarding any presence of polymerization in bitumen.

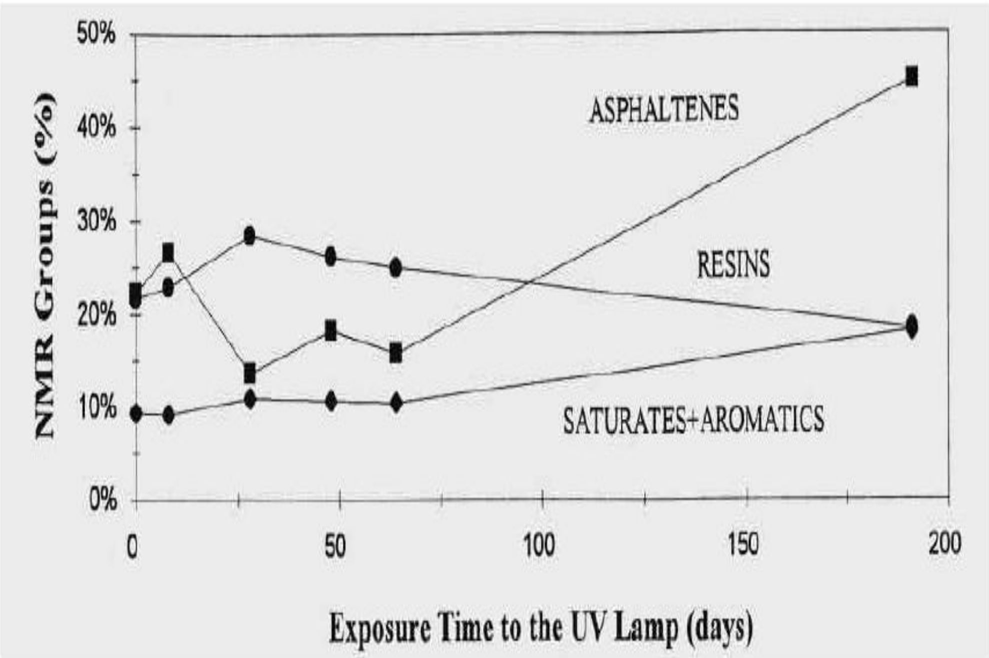

Figure 4: Changes in Fractional Compositions on Exposure to UV Light (Montepara et al., 2006)

Figure 4 shows the hypothesis that upon UV ageing; there is an increase in the asphaltenes and a decrease in resins and aromatics. The effects of different UV absorbers (octabenzone and bumetrizole) on the physical properties and photostability of bitumen were investigated by (Feng et al., 2013). Thin layer chromatography with flame ionisation detection techniques was used to analyse the effects of UV absorbers including its ageing characteristics. The work of Feng et al., (2013) indicated that bitumen ductility was significantly enhanced by adding a small amount of UV absorbers of which octabenzone was optimally performing in comparison to bumetrizole. The addition of octabenzone resulted in an increase in the aromatic content which had an influence on the viscosity and fluidity of the bitumen (Leiva-Villacorta et al., 2013). The influence of UV absorbers on bitumen photo-stability was seen to be dependent on bitumen origin and the type of UV absorber. Bitumen from different origins showed specific selectivity for different UV absorbers as discussed in Fernandez-Gomez et al., (2013).

Lu et al., (2014) investigated the influence of using Layered Double Hydroxides (LDHs) on the fatigue properties of the asphalt mixture and its purported use as an ultraviolet light resistant material. The findings showed that UV light influenced the properties of the bitumen. LDHs have the effect of acting as a physical shield against UV light and could be used as alternative modifiers in the bitumen to protect against the adverse influence of UV light on the asphalt pavement. Carbon black was used in research conducted by Yamaguchi et al., (2004) to examine its effect as an inhibitor to protect against the ultraviolet degradation of the asphalt pavement. The results are presented in Figure 5. The results show that an increase in film thickness resulted in a decrease in the dynamic complex modulus (G*) while an increase in film thickness resulted in the increase in the phase angle (δ). This shows a reduction in stiffness and brittleness of the bitumen with an increase in bitumen film thickness.

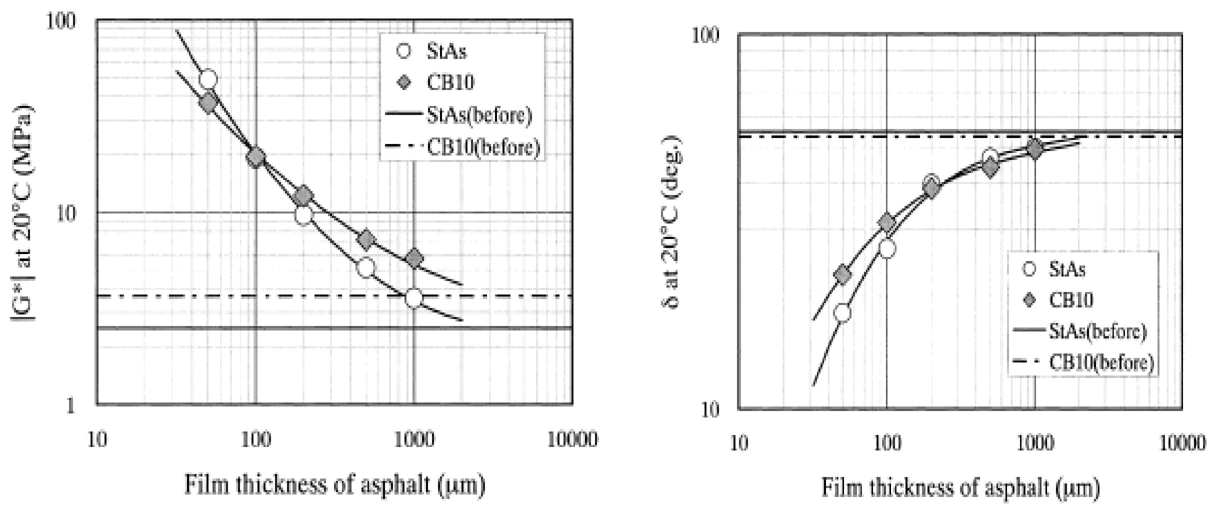

Figure 5: The Influence of UV Light on Film Thickness of Bitumen (Yamaguchi et al., 2004).

Yamaguchi et al., (2004) showed that the G* of bitumen with 10% carbon black (CB10) was higher than the standard bitumen (StAs) with 90 dmm penetration and a softening point of 46°C. The results show equivalent performance between StAs and CB10 at bitumen film thickness of 100 µm. the decrease in δ was smaller for CB10 in comparison to StAs in the film thickness range below 200 µm. The result shows the positive influence of carbon black in preventing photo-degradation of bitumen through UV light.

In summary, results from the research conducted by Yamaguchi et al., (2004) showed that thinner film thicknesses resulted in higher values of G* and an increase in the carbonyl index of the bitumen which indicates increased oxidative degradation facilitated by UV light on the bitumen especially in the bitumen film thickness below 200 µm. UV light has an adverse influence on the surfacing of the pavement structure which should not be totally ignored as it accelerates the rate of oxidation which results in eventual deterioration of the pavement. Increasing the bitumen content and/or decreasing the air void contents in asphalt mixtures are considered to be effective in increasing the film thickness of the bitumen as this has a positive influence on preventing the adverse effects of UV light on the pavement.

5 OVERALL SUMMARY

This report presented a review into the ageing of thin asphalt surface course systems due to oxidative hardening and UV light. Thin asphalt surface courses are prone to ageing due to the reduced thickness of the surfacing layer and location at the top of the pavement. The amount and rate of ageing is a factor of local climatic condition (such as temperature, exposure to oxygen, UV light), chemical composition and structure of the bitumen and characteristics of the asphalt mixture (such as porosity and depth of the surface course).

The discussion has highlighted the role of UV light in facilitating the formation of carbonyl bonds due to oxidative ageing which subsequently altered the structure of bitumen and resulted in the hardening of the bitumen over a period of time. Furthermore, bitumen has different sensitivities when exposed to UV light and thermal ageing. These sensitivities can be reduced by increasing binder content or bitumen film thickness in asphalt mixtures.

Overall, the long-term ageing of the bitumen contained in the surface mixtures of bituminous pavements is predominantly due to oxidative effects but often coupled with other factors (such as exposure to UV light) which may adversely affect the durability of the surface course. In most cases, the reactions are irreversible and may alter the chemical stability and physical characteristics of the binder which over time changes its adhesive properties. In this context, the principal problem is mostly with the increased stiffness of the binder and the reduced ability to accommodate imposed stresses which may lead to failure. Therefore, selecting a bituminous binder with good resistance to oxidative ageing should be considered as an important part of asphalt mixture design.

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