ASSESSMENT OF THE EFFECTIVENESS OF ASPHALT PAVEMENT PRESERVATIVE MATERIALS

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ABSTRACT

Historically, maintenance work of motorways and the trunk road network in the UK involved removal of defective asphalt layers and replacement with new improved or equivalent performing material. However, this approach has been revisited due to a significant cut in the budgets available to maintain and preserve the road networks following the recent decision from the UK government to reduce public spending. In recent times, some departures have been allowed to permit multiple-layered surface dressings, microsurfacings and some trial applications of asphalt pavement preservative materials (PPMs) to extend the life of asphalt, but there is little objective evidence to confirm the effectiveness of PPMs, previously termed rejuvenating agents. This paper presents a recently completed initial study, funded by the Highways Agency in the UK, to assess the effectiveness of different treatments, including solvent based rejuvenators and polymer modified bituminous emulsion sealers. Laboratory accelerated ageing tests were carried out on short-term aged bitumen, prior to treatment, after treatment with medium-term ageing and after long-term ageing, to simulate 3 to 5 years and 5 to 10 years of in-service asphalt binder ageing. This study using rheology testing found that the effectiveness of PPMs to preserve the properties of treated aged binder is affected by the type of PPM and the extent of binder ageing. The new protocol developed during this study is able to rapidly identify different PPM products by their ageing characteristics and indicates when re-treatment might be required.

Keywords: maintenance, ageing, sustainability, sealer, rejuvenator

1. BACKGROUND

Given the current financial constraints on highway budgets there is a need to extend the lives of roads to maintain the asset at minimal current cost. Preservative materials are being promoted for this purpose and various claims are made as to the effectiveness of each system. Performance of these materials is difficult to quantify. Test methods that are currently being used to evaluate the potential for rejuvenation or preservation generally consider the properties of a recovered binder from aged asphalt before and after treatment. The main problems are selecting a representative surface layer asphalt sample and the binder recovery process. The claimed penetration of the preservative is typically 5mm to 10mm below the road surface; it is recognised that such thin slices of asphalt taken from cores or from the road surface as samples for test and the solvent method of recovery of the treated aged binder, introduce many variables. The properties of the recovered binder do not reflect the increased oxidation at the surface compared to the body of the asphalt material and they do not indicate how the treated asphalt will subsequently age. Binder film thickness and air voids have a major impact on asphalt ageing; adding binder and sealing the asphalt surface against air and moisture is an important aspect. An ageing test is needed to rapidly assess preservative material and provide a means of product identification, which eventually could be correlated to performance on the road.

2. PAVEMENT PRESERVATIVES

There are a number of definitions associated with pavement preservation; for example, the Federal Highways Administration (FHWA) Pavement Preservation Expert Task Group in the US has defined it as “a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations”. In general Pavement Preservation is considered to represent a proactive approach to maintaining existing highways; this includes routine maintenance, preventive maintenance and minor remedial work.

In the UK, suppliers of pavement preservation materials joined together under the umbrella of the Road Surface Treatment Association (RSTA) and formed an informal group known as the Pavement Preservation User Group (PPUG). Amongst the pavement preservation materials marketed in the UK, some products are known to incorporate a “rejuvenating agent”. There are a number of pavement preservation systems that claim to have the ability to extend the service life of a distressed surface course simply by preserving its condition and protecting it from rapid deterioration. These products are sometimes referred to as “sealers”. These systems include mist spray application of premium/intermediate grade bitumen emulsion followed by gritting application or are conventional surface dressing products. Other than providing a seal and better appearance of the new surface, these spray sealers are not claimed or thought to rejuvenate the existing surfacing.

3. AGEING OF BITUMEN

3.1 Rejuvenation Process

“*Due to oxidation and to the direct influence of sun, salts, acids and oils, the bitumen in the asphalt surface of a road ages rapidly. At the same time the road surface is subject to increasing heavy mechanical forces from the passing traffic. As a result the bitumen loses its flexibility and adhesive capacity and it becomes brittle.”* These statements have been used by many pavement preservation material suppliers to present their business case that, in order to preserve their service life, road surfacings require treatment (preservation) after 3-5 years from opening to traffic, and repeated applications are recommended to further extend the service life.

A range of rejuvenating agents are readily available on the market, such as aqueous acrylic emulsions modified with epoxy resin, coal tar emulsions, maltene (oil) based emulsions and modified Gilsonite based systems, cut back with a hydrocarbon solvent. Rejuvenators can be applied directly without disturbing the existing bituminous surface (cold application), although preheating of the existing surface may be required in some cases (hot application). It is claimed that these rejuvenators can penetrate into the existing surface to a depth of up to 12mm, rejuvenating, binding, sealing and consolidating it; however, data from Vallerga [1] suggested that the effective depth of rejuvenation was only up to 9mm. Furthermore, based on the work on the hard shoulder of US 99 at Lodi in August 1961, Vallerga found that only cationic “maltene” rejuvenator penetrates and more effectively restores the penetration of the aged bitumen, whilst bitumen emulsion appeared to have less effect.

There are many bitumen emulsions being marketed that claim rejuvenation capability; however, Browridge [2] stated that *“if the (bitumen) emulsion breaks or cures on the pavement surface then it is sealing, not rejuvenating”*. He further argued that engineered cationic emulsion containing maltene saturates (light fractions), which is wax free, should be used as the base medium for rejuvenator. This engineered emulsion would have better ability to penetrate (‘diffuse’) into the bitumen film that is being rejuvenated, through its solvency effect with the binder; the molecular composition of the maltene base oil used in the formulating provides this solvency without the use of distillate or solvents.

In general, the following criteria have been adopted as measures of the effectiveness of a bitumen rejuvenator, specifically its ability to:

- Restore the binder rheology, e.g. increase the penetration value, reduce viscosity or reduce stiffness in the top portion of the pavement surfacing where rejuvenator was applied;
- Seal the pavement against ingress of moisture and air, reducing the risk of stripping and/or slowing down oxidative hardening of the upper layer and below;
- Improve the durability and extend the service life of the treated surface course due to any or a combination of the above.

Effect on Early Life Friction

Many reports highlight a short-term reduction in friction following the application of preservation materials. The use of small chippings has to some extent reduced the problem. A novel approach is to add filler to the preservation system to provide some form of slip resistance; one of the samples tested in this study incorporated added filler.

3.2 Developing Preservative Ageing Profile Test Method

The first step was to determine how to age a commonly used asphalt binder in a controlled reproducible manner providing a thin film so that the effect of adding a preservative could be assessed using rheological properties.

Various ageing test methods were considered including the Pressure Ageing Vessel (PAV) Test (EN 14769: 2005) and the Rotating Cylinder Ageing Test (RCAT) (EN 15323: 2007). Most preservatives are promoted as being effective if applied long before the asphalt has come to the end of its life so PAV was thought to be too severe and was also rejected for solvent based preservatives for safety reasons. Only the RCAT could provide a profile (by sampling at intervals), but the process is slow (several days for each sample) and large sample volumes were not required for examining binder rheological properties using a Dynamic Shear Rheometer (DSR). Solvents again would prove difficult to handle and adding the preservative to a film of aged bitumen at ambient temperature to try to simulate on-site conditions would be difficult.

It was decided to use the Ageing Profile Test that had been developed for hot polymer modified bituminous binders by adapting the well-established Short Term Ageing Test (ASTM Rolling Thin Film Oven Test (RTFOT)). The so-called modified RTFOT method is published in the UK Department for Transport Specification for Highway Works (SHW) Volume 1, 900 Series, as Clause 955, and has been shown to provide results equivalent to conventional RTFOT and PAV85 for different types of binders including polymer modified binders after only 8 hours, **see Figure 1**.

'Short Term Ageing Test'	→	Modified Ageing RTFOT (Ageing Profile)
163 °C Air 45 minutes Stainless steel screws PTFE bottles **'Short Term Aged Binder'**	→	135 °C Air 4 hours 8 hours – **'Aged Binder'** 22 hours Stainless steel screws PTFE bottles

Figure 1: Clause 955 Modified RTFO Ageing Test for Hot Mix Asphalt Binders

This research work was carried out at the URS Scott Wilson laboratories by Hill et al [3] and it was considered favourite to provide a rapid method for the production of a reasonably thin film of aged bitumen for preservative assessment. Increasingly, polymer modified bituminous binders are being used in asphalt surface courses; the modified RTFOT is being adopted because skinning is prevented by the constant stirring of the binder. The conventional RTFOT would need a much higher temperature, to ensure a rolling film of binder; the high temperature greater than 180 °C is known to degrade polymer binders.

The SHW test method also has clauses to recover and age bituminous emulsion binders and cut-back binders. It was felt that these could be adapted to cope with solvent based preservatives with low flash points and polymer modified bituminous emulsion sealers currently being used.

In order to assess the effect of Pavement Preservation Material (PPM) on binders used in surfacing materials, a suite of laboratory testing was developed. To provide a means of comparison and to identify PPMs a 40/60 paving grade bitumen was selected for use as the binder to be aged and rejuvenated (hereafter the "base binder" or B50), to represent a most commonly used binder in asphalt surfacings in the UK including Hot Rolled Asphalt, generic Stone Mastic Asphalt and Thin Surfacing materials. Although any typical asphalt binder including polymer modified binders may be selected for test. The base bitumen (40/60pen) referenced B50 and five typical PPMs were selected for the laboratory testing referenced D, E, F, H and I. Some were solvent based “rejuvenators” and some polymer modified bituminous emulsion “sealers”. One PPM sample F was an emulsion and sample G was supplied as the base binder of F and it was felt useful to test both to determine that the recovery protocol for the emulsion did not affect the results.

4. RISK ASSESSMENT

As a part of routine practices, COSHH and Risk Assessments were carried out on the samples, which incorporate either emulsion or solvent based bituminous materials. Review of the Manual Safety Data Sheets for these products suggest some samples were relatively volatile and have low flash point. This resulted in initial risk levels being considered High to Medium.

In order to further assess the safety aspect of the test program, initial trials were carried out in stages within a confined environment at high temperatures (i.e. oven), prior to starting the Main Test Programme. These trials concluded that introducing a flow of nitrogen (to replace air within the Rolling Thin Film oven), with an active extraction in place, was able to reduce the level of risk from High/Medium to Low; this approach was subsequently adopted in the Main Test Programme.

5. METHODOLOGY

The literature review highlights the fact that any rejuvenation process would mostly take place by diffusion or gradual absorption of the applied rejuvenator into the binder film of the surface course downwards. This process is very slow and subject to many variables such as surface temperatures, porosities and residual binder properties. Furthermore, successful preservative treatment should not only rejuvenate or restore the properties of aged binder but ideally it should be able to favourably control the subsequent rate of age-hardening such that it is at least similar to, or better than, that of the aged binder. These considerations make it almost impossible to simulate this rejuvenation process in a laboratory before any further assessment of the effectiveness of the process can be made. For this project, a simplified approach was adopted incorporating the use of a control binder B50, subjected to an accelerated ageing condition, before and after being treated with PPMs. As stated in the previous section, PPMs could be emulsion or solvent (“cut-back”) based.

Clause 955 of SHW contains a procedure for recovering emulsion and cutback bitumen (i.e. bitumen incorporating hydrocarbon solvent) and a subsequent accelerated ageing protocol on the binder residue after recovery. The protocol is being revised, because the microwave procedure is no longer used and PAV ageing for emulsions is under review in Europe because it is not thought to simulate in service ageing of emulsion systems. Clause 955 adopts polytetrafluoroethylene (PTFE) in place of the traditional glass bottles used in the standard RTFOT (BS EN 12607-1) and introduces a stainless steel screw in each PTFE bottle, to stir and homogenise the binder sample during ageing. For this study, a new set of aluminium containers, internally coated by PTFE, were manufactured and used. The introduction of the stainless steel screws helps to provide a continuous exposure of fresh binder sample to the air; consequently, the test duration is reduced as the screws accelerate the ageing process and, in the case of testing polymer modified binders, the problems related to ‘skinning’ are minimised.

Plate 1: Glass bottle, PTFE bottle and mixing screw and “new” PTFE coated aluminium bottle (left to right)

6. THE MAIN TEST PROGRAMME

The recovery and accelerated ageing protocol currently specified in the SHW Clause 955 was chosen, subjected to the following modifications to suit the aim of this study:

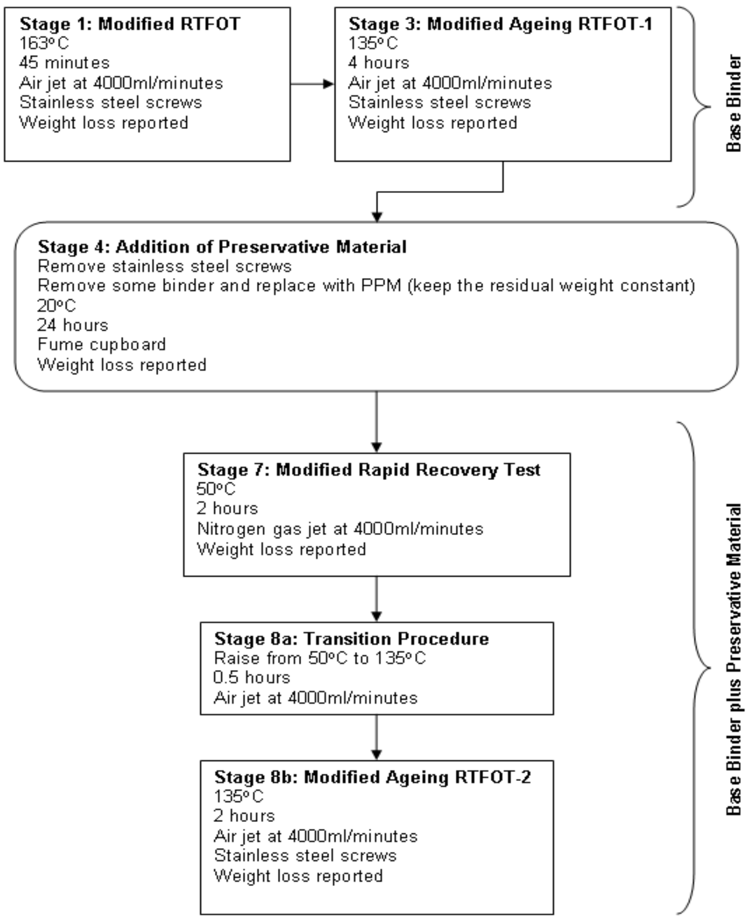
- A combination between the ageing protocol for cut-backs/emulsions and hot mix asphalt binders was adopted.
- The first half of the ageing process was carried out to rapidly age the control (base) B50 bitumen, thus the procedure in accordance with **Figure 1**, but with the Modified Ageing RTFOT; “Ageing Profile” protocol for up to 4 hours only.

- The second half of the protocol was to "recover" and further age a blend of control bitumen and PPM with recovery time at 50°C for 2 hours in nitrogen followed by accelerated ageing at 135°C for another 2 hours in air.
- The RTFO was placed under an active extraction unit in the laboratory mixing room and the test was closely monitored by using an electrical viewing device (i.e. webcam); this allowed remote monitoring and prompt action if it was required.

Considering the above modifications, the step-by-step protocol adopted for the Main Test Programme is summarised as follows:

a) The base binder B50 is initially subjected to short-term ageing i.e. conditioning at 163°C for 45 minutes in air jetted at 4000 ml/minute;
b) After completion of short-term ageing, the base binder is left to cool down and then subjected to accelerated ageing at 135°C for 4 hours in air jetted at 4000 ml/minute;
c) The bottles are then removed from the oven and placed in the fume cupboard and allowed to cool down to ambient;
d) PPM is then added to the above binder at an appropriate rate. This process involves removal of an amount of base binder which is then replaced by an equivalent amount of the PPM. In this manner, the weight of material within the test container remains constant. Note that the residual binder contents of the emulsion and solvent based PPMs were 60% and 40% by the total weight of PPM, respectively;
e) The bottles containing the PPM are left in the fume cupboard at ambient temperature for 24 hours. This process allows any very low flash point volatile oil to safely evaporate and consequently reduce the amount of hydrocarbon solvent within the bottle;
f) The bottles are transferred to the RTFO oven at 50°C for 2 hours in nitrogen jetted at 4000 ml/minute;
g) The nitrogen supply is then changed to air jetted at 4000 ml/minute;
h) The oven temperature is raised from 50°C to 135°C within 30 minutes;
i) The conditioning at 135°C is continued for another 2 hours in air jetted at 4000 ml/minute;
j) At each stage of assessment, samples are weighed and removed for further assessment.

For clarity, the above protocol is illustrated in **Figure 2**; the test schedule is shown in **Table 1.**



Note: Stages 2, 5 and 6 are interim conditioning involving either preheating or cooling of sample and/or oven.

Figure 2: Modified Rapid Recovery and Accelerated Ageing Procedures for Pavement Preservation Materials

Table 1: Test Schedule

Base Binder	Added PPM	Stage of Ageing Protocol*				
		1	**3**	**4**	**7**	**8b**
B50	None	T	T	-	T	T
B50	D	-	-	A	T	T
B50	E	-	-	A	T	T
B50	F	-	-	A	T	T
B50	G	-	-	A	T	T
B50	H	-	-	A	T	T
B50	I	-	-	A	T	T

*Note:

- Stage of Ageing Protocol refers to that presented in **Figure 2**.
- "T" denotes the point at which a sample (1 bottle) was taken and the binder tested for rheology.
- "A" denotes the point at which PPM additive was applied to the bottle containing the aged B50 sample.

Stage 1 was intended to simulate the short-term ageing of bituminous binder, to a similar level as that experienced during the manufacturing of an asphalt mixture in the mixing plant. This protocol is exactly the same as that specified in the SHW sub-Clause 955.6 for "Binders for Manufacturing Asphalt or other Hot Mixed Materials". This treatment was applied to the control base binder B50.

In a previous study completed by URS Scott Wilson for the Highways Agency [3], hot mixed, modified or non-modified binders, when subjected to the modified ageing RTFO for 8 hours would harden to the same level as binder after the High Pressure Ageing Test (HiPAT), PAV85 (BS EN 14769), which simulates ageing in service for 5 – 10 years. The present study required a partly aged binder, having similar residual properties as that exposed in service for 3 to 5 years. Consequently, the control binder B50 recovered from Stage 1 was subjected to a further 4 hours ageing in air (which is half of the 8 hours ageing) in Stage 3.

In Stage 4, the binder recovered from Stage 3 was treated by PPM at the respective application rate. Subsequently the treated binder was subjected to a further ageing test in Stages 7 and 8b.

Assessment of the materials recovered from Stages 1, 3, 7 and 8b, was carried out by using an Advanced Dynamic Shear Rheometer (DSR) at varying test temperatures and a frequency of 0.4Hz; enabling empirical values such as penetration to be calculated. In this test, complex shear (stiffness) modulus and viscoelastic response were specifically determined.

Figure 3 shows the reasoning behind the test protocol. The comparison with a control after addition of the PPM and after accelerated ageing and using an advanced DSR to study rheology (G* and phase angle) provides a robust product identification test.

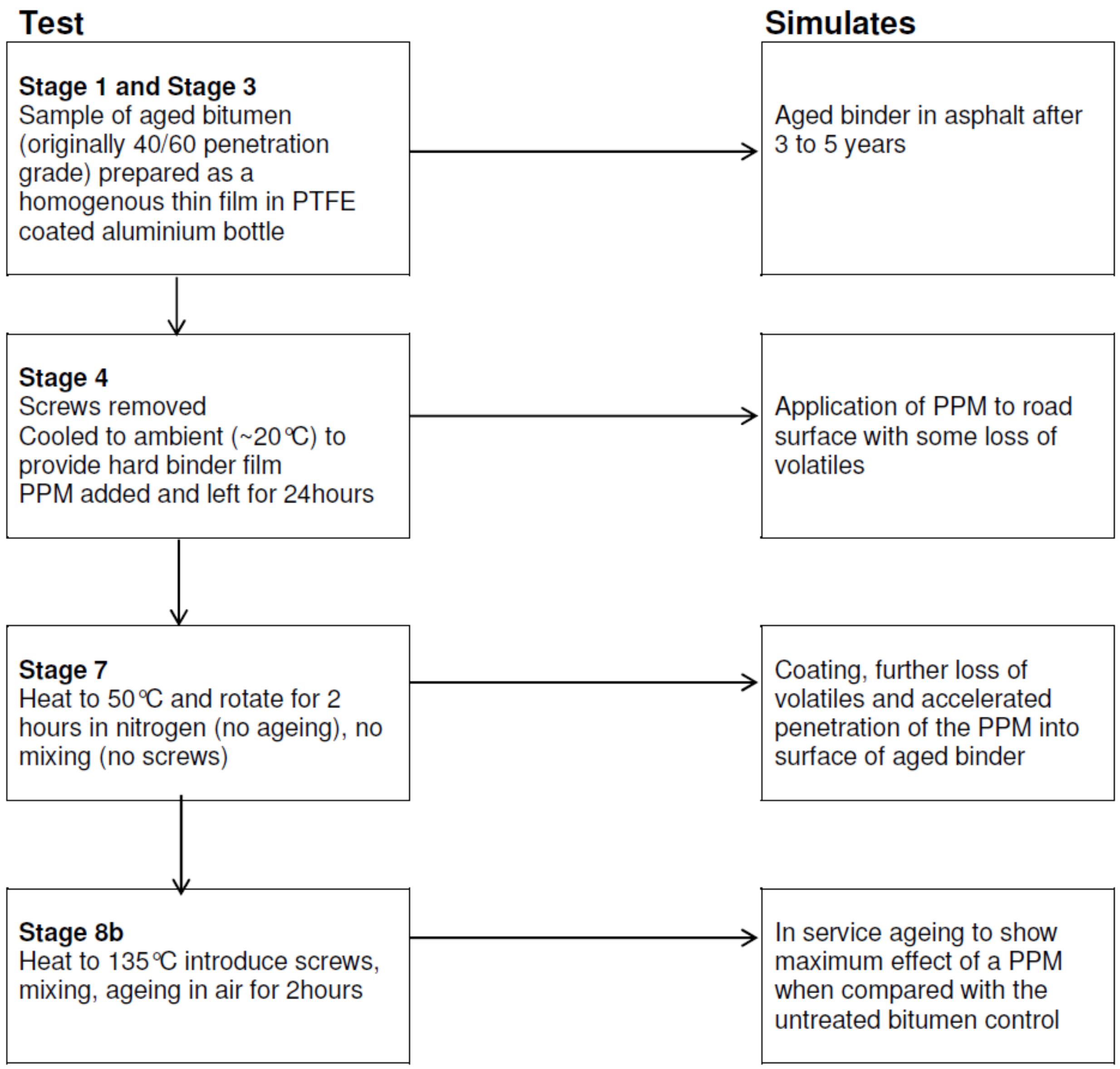


Figure 3: Pavement Preservative Material Identification Test

7. RESULTS AND DISCUSSION

7.1 Ageing Profile of the Base Bitumen (Sample B50)

In order to assess the effectiveness of PPMs, the ageing profile of the base bitumen, i.e. Sample B50, was initially established. Test results on this sample were subsequently used for benchmarking purposes.

The test results are presented in the following figures, together with results previously reported [3] for:

- The Ageing Profile test of a similar bitumen grade (i.e. 40/60 pen) and supplier, tested to SHW Clause 955 for hot mix asphalt binder (Stage 1 in **Figure 4**) (samples with prefix OM143 refer to results from [3]);.
- The RTFO (EN) and HiPAT (EN) tests of the same bitumen after being subjected to RTFO and HiPAT protocols to EN12607-1 and EN14769 respectively. These protocols are known to simulate Short Term Ageing (STA) and Long Term Ageing (LTA) of bituminous binders; for simplicity the stage of ageing which takes place between these protocols will be referred as Medium Term Ageing (MTA).

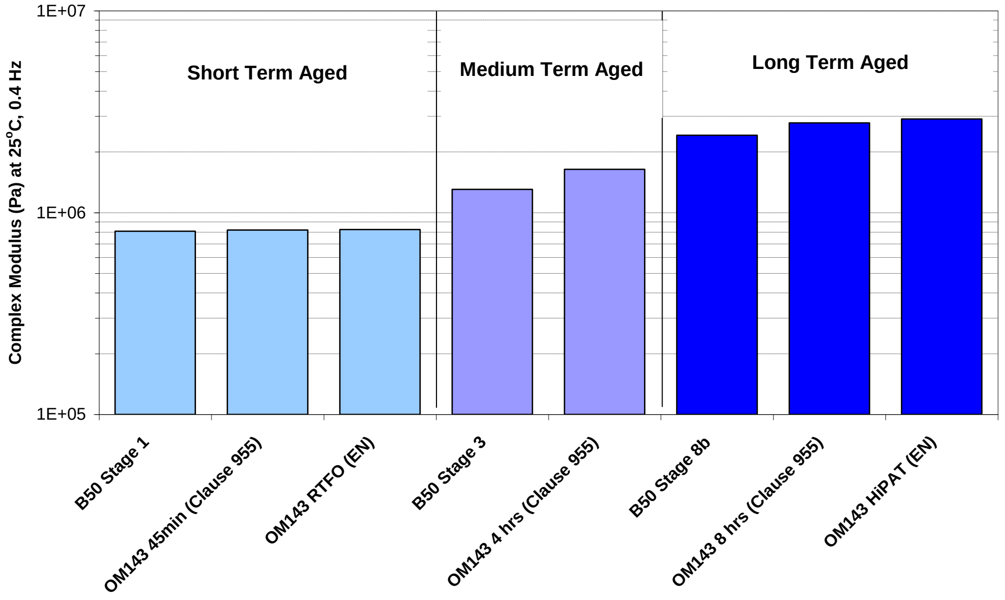
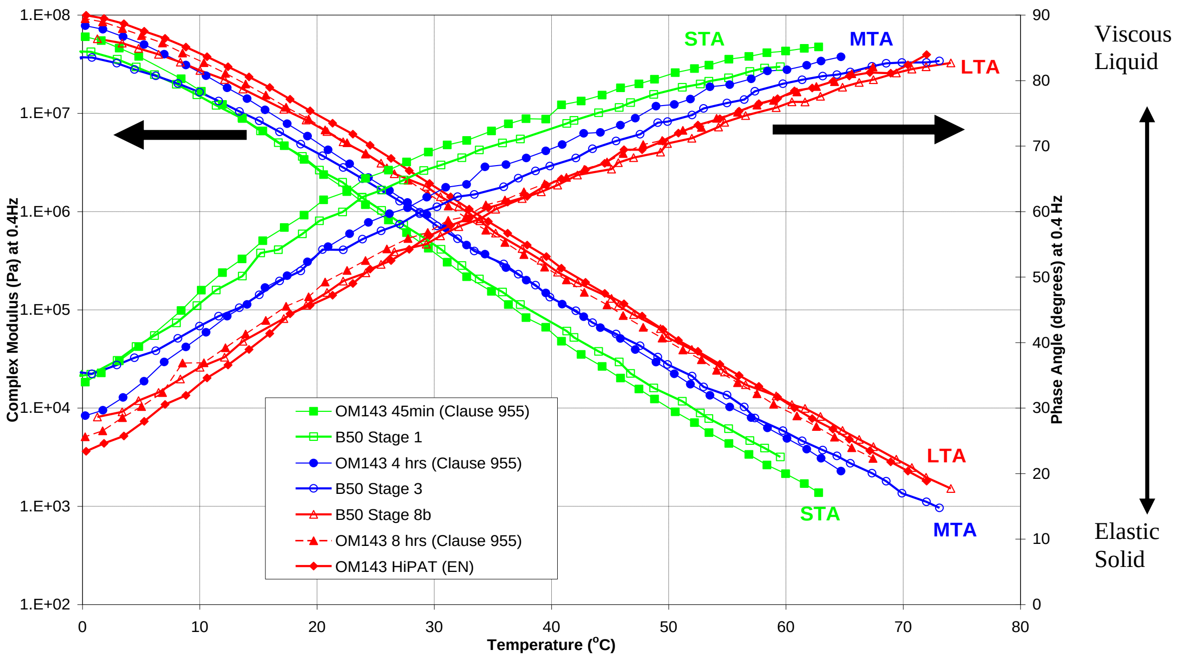


Figure 4: Complex Modulus vs Stage of Ageing of Bitumen Grade 40/60 at 25°C

Figure 4 shows that:

- As expected, the complex stiffness (shear) modulus of these samples increases in order of short, medium to long term ageing;
- For binders at a similar stage of ageing, the complex modulus values of B50 (current) sample were slightly lower than those subjected to the SHW Clause 955 ageing protocol. This is not unexpected since the SHW protocol would be expected to be slightly more severe than that of the current ageing protocol;
- The binders subjected to the current ageing protocol (Stages 1, 3 and 8b) can be considered as having comparable properties to those after short, medium and long term ageing respectively. Hereafter these stages will also be referred as STA, MTA and LTA.



Note: graphs in colour codes depending upon stage of ageing = green (STA), blue (MTA) and red (LTA).

Figure 5: Ageing Profile of Sample B50 (Rheology)

Figure 5 shows that the overall rheology (complex modulus and phase angle) over a range of temperatures of Sample B50 tested after Stages 1, 3 and 8b is comparable to that of the OM143 binders after STA, MTA and LTA protocols respectively. The results demonstrate that as the stage of ageing increases:

- Complex modulus values also increase over the test temperature range. This indicates stiffening or hardening of the binder;
- Phase Angle decreases over the test temperature range. This indicates higher elastic response. This may improve deformation resistance at high temperature, but this also means increased 'brittleness' at failure which may lead to reduced resistance to low temperature cracking;
- The above trends are expected for "as supplied" 40/60 paving grade bitumen.

From the literature review and contact with industry, it is understood that the best time to apply PPM is during the early life of the surfacing material particularly within the first 3 – 5 years after construction. The above findings suggest that application of the ageing protocol to the Base Binder B50 has successfully resulted in residual binder having similar properties as a binder having less than 5 years ageing in service, i.e. a level of hardening between that of STA and LTA. Consequently, the protocol was adopted and the residue of binder after Stage 3 was subjected to PPM application.

Using the same set of data, empirical properties such as penetration, softening point and penetration index were calculated from the rheological data. The results are summarised in **Table 2**.

Table 2: Empirical Properties Calculated from Rheology

Sample	Equivalent test	Calculated Penetration (d_{mm}) at 25°C	Calculated Softening Point (°C)	Penetration Indices (I_P)
B50 Stage 1	RTFOT = STA	33	61.0	0.3
B50 Stage 3	MTA	25	65.8	0.8
B50 Stage 8b	LTA = PAV85	18	70.2	0.8

The above test results demonstrate that as the level of ageing increases, the penetration value reduces, the softening point and PI values increase. These trends are as expected showing loss of volatile oils and oxidation.

7.2 Effectiveness of PPMs

Using the same principles as that adopted for the base bitumen Sample B50, comparisons have been made for the B50 samples after being treated by PPM. For clarity, summaries of the test results are presented in separate figures with overall comparison shown in **Figure 6** and details in **Figures 7 to 9**. Sample G was the bituminous base used to manufacture the emulsion PPM F so the recovery protocol for the emulsion does not appear to affect the assessment of the preservative.

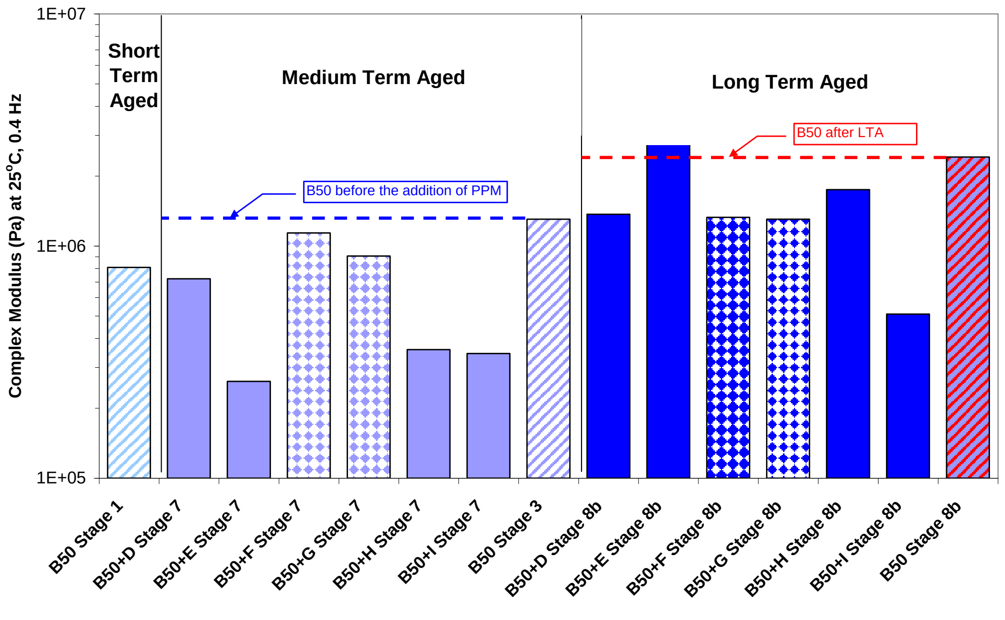
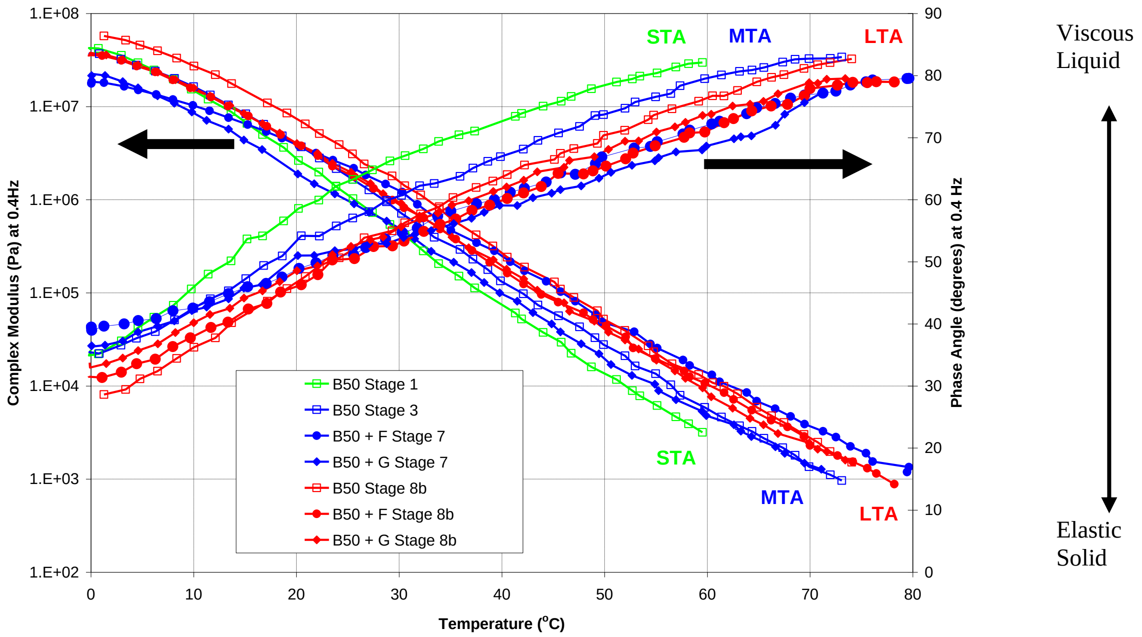


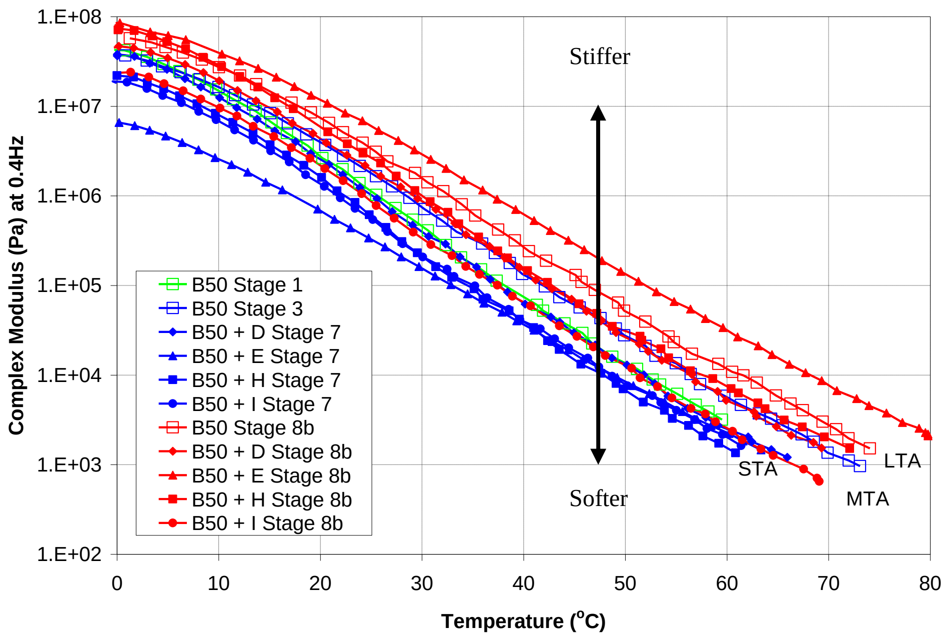
Figure 6: Complex Modulus vs Stage of Ageing of Samples at 25°C and 0.4Hz

Figure 6 shows that the addition of PPM reduced the complex modulus of the B50 binder after MTA, when tested at 25°C at 0.4 Hz. Apart from the binder treated by PPM E, the complex modulus values of the other treated binders, after being subjected to further ageing, remain less than that of the B50 binder after LTA. In addition to this, binders treated by PPM F and binder G show comparable properties after further ageing; this is not unexpected since sample G was the base binder of sample F and this condition was consistent throughout the test temperatures and stages of ageing, as illustrated in **Figure 7**. However, these conditions varied for different PPM materials, as seen from the illustrations given in **Figures 8 and 9.**



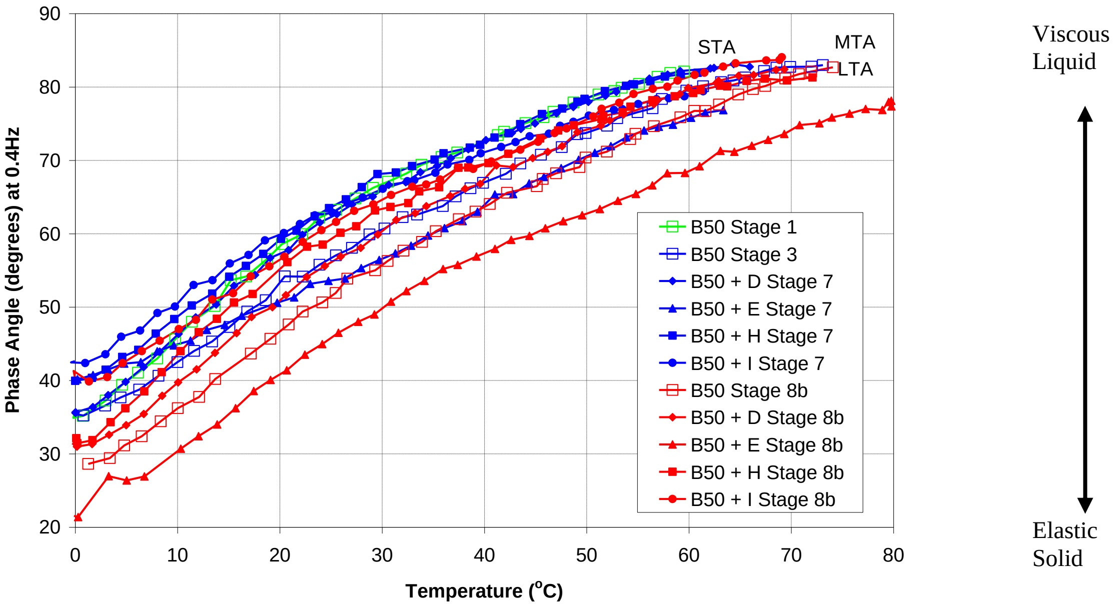
Note: graphs in colour codes depending upon stage of ageing = green (STA), blue (MTA+PPM) and red (LTA).

Figure 7: Ageing Profile of Samples with the Same Base Binder



Note: graphs in colour codes depending upon stage of ageing = green (STA), blue (MTA+PPM) and red (LTA).

Figure 8: Ageing Profile of Samples – Complex Moduli



Note: graphs in colour codes depending upon stage of ageing = green (STA), blue (MTA+PPM) and red (LTA).

Figure 9 : Ageing Profile of Samples – Phase Angle

The above Figures show the overall rheology (complex modulus and phase angle) over a range of temperatures of Sample B50 tested after being treated with emulsion based PPM. The results show that as the stage of ageing increases:

- Complex modulus values were initially reduced, but this was then followed by increases in complex modulus over the test temperature range. This indicates initial softening after the addition of the PPMs, followed by hardening of the binder, although the rate of hardening was generally less than that for the base bitumen. For example, after LTA, all binders treated with these PPMs, but apart from that treated by PPM E, have lower complex modulus values than that of B50 sample. Sample B50 + E after LTA has significantly higher complex modulus values than B50 sample after LTA;
- Phase Angle generally decreases over the test temperature range, although some samples show increased phase angle at lower test temperatures. This may indicate improvement in high temperature properties of the treated samples, i.e. improved deformation resistance at high temperature and improved resistance to low temperature cracking.

The above trends show different effectiveness of the treatment as the binder undergoes further ageing. Using the same set of data, empirical properties such as penetration, softening point and penetration index were calculated from the rheological data. The results are summarised in **Table 3**.

Table 3: Empirical Properties Calculated from Rheology for Samples with PPM

Sample	Calculated Penetration(d_{mm}) at 25°C	Calculated Softening Point (°C)	Penetration Indices (I_P)*
B50 + D Stage 7	35	59.4	0.3
B50 + D Stage 8b	24	64.8	0.6
B50 + E Stage 7	61	58.6	1.6
B50 + E Stage 8b	12	78.4	1.3
B50 + F Stage 7	27	72.8	2.0
B50 + F Stage 8b	25	69.6	1.4
B50 + G Stage 7	31	65.0	1.1
B50 + G Stage 8b	25	68.8	1.3
B50 + H Stage 7	51	56.4	0.7
B50 + H Stage 8b	21	67.2	0.7
B50 + I Stage 7	53	57.8	1.0
B50 + I Stage 8b	42	59.8	0.9

Note: *Ip is applicable for unmodified bitumen only; thus a comparison of Ip data between modified/unmodified bituminous materials will not be valid. For completeness however the Ip of PPM treated samples is shown in the above table.

The above test results demonstrate that as the level of ageing increases, the penetration value reduces. These trends are similar to those found for the base bitumen B50. However, there are also unfavourable trends i.e. initial increases in penetration followed by significant reduction of the penetration value after ageing.

The almost identical rheological data for Stage 8b results for PPM F and its base binder G demonstrates that the protocol to remove the water and volatile oil from the emulsion and age that "recovered" binder when compared to ageing the base is robust.

As a part of the test ageing test protocol, weight loss was measured at the each stage of testing. The test results suggest that the initial conditioning of 24 hours at ambient (Stage 4) and 2 hours at 50°C in Nitrogen (Stage 7) has driven off most of the water from PPM emulsions (assuming that the water content was around 40%). Further weight loss was recorded after further 2.5 hours ageing at 135°C in air (Stage 8a and 8b).

8. LESSONS LEARNT FROM THIS STUDY AND THE CURRENT PRACTICES

The findings from the current study have successfully demonstrated a suitable test protocol to measure the effectiveness of different PPM treatments. It was found that the effectiveness of PPMs to preserve the properties of the treated binder may be affected by several factors such as the type of PPM and the post-treatment ageing condition.

Recovered binder is often evaluated soon after the asphalt is treated with the PPM, however this study indicates that consideration should be given to properties of the recovered binder after a few years to properly measure performance.

- At 60°C:
  - all samples, apart from that treated by sample B50+F, show reduction in complex modulus by at least 50%.
  - only samples treated by samples B50+D and B50+H show an increase in phase angle by 3%;
- At 25°C:
  - all samples, apart from that treated by sample B50+F, show reduction in complex modulus by at least 30%;
  - samples treated by samples B50+D, B50+I and B50+H show an increase in phase angle by 8 to 11%.

The above analysis shows variations in the level of 'effectiveness' of different treatments, depending upon the test temperature.

In the UK the DSR test frequency is generally 0.4Hz as specified in SHW clause 956 which simulates slow moving traffic and has a comparable loading time to the penetration test and has been correlated for a number of different types of binder (used to calculate penetration value in **Table 3**).

Removing samples to recover binder from the upper 10mm of an aged surface course (or any agreed depth) before and after treatment may not necessarily represent the effective penetration of the PPM into the asphalt and as stated earlier, there is a possibility of interaction between the treated binder and the solvent used during the binder recovery process.

Based upon observations and test results from the current laboratory work, it is suggested that:

- Assessment of the effectiveness of PPMs should be based on measurements over a range of test temperatures since responses of the treated materials may vary between low and high temperatures;
- Accelerated ageing protocol should be a part of the assessment methods, since some results indicated an initial softening effect but subsequently hardened at a greater rate than bitumen without treatment. The ageing protocol adopted in this study could be used as the basis for assessment of the PPM against a control base binder.

The present study was limited to assessment of a control paving grade bitumen aged and treated by different types of PPM, whilst current practice has been mostly based on the properties of post-treatment recovered binder. Whilst the assessment method adopted in the current study may have successfully differentiated the effectiveness of different PPMs, there is still a gap between this work and procedures adopted in practice. It is therefore recommended that the findings from the current study should be verified and further work should be carried out. The proposal should include tests of asphalt cores and in situ treated roads to determine benefits including reduction of water permeability.

9. SUMMARY

The protocol developed during this study was considered as robust and suitable for use as product identification test of samples treated by PPM.

The laboratory work has demonstrated that different treatments resulted in different level of effectiveness to resist hardening of bituminous binder. For clarity, an overall comparison between the different treatments is reproduced on the same graph, as shown in the following figures.

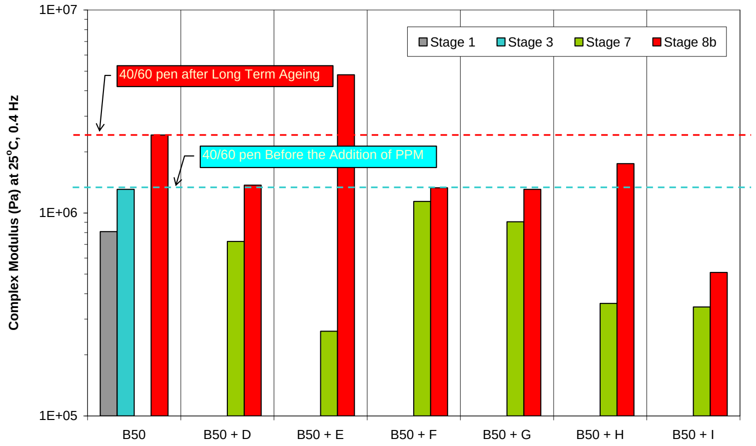


Figure 10: Comparison Between Different Treatments – Complex Modulus

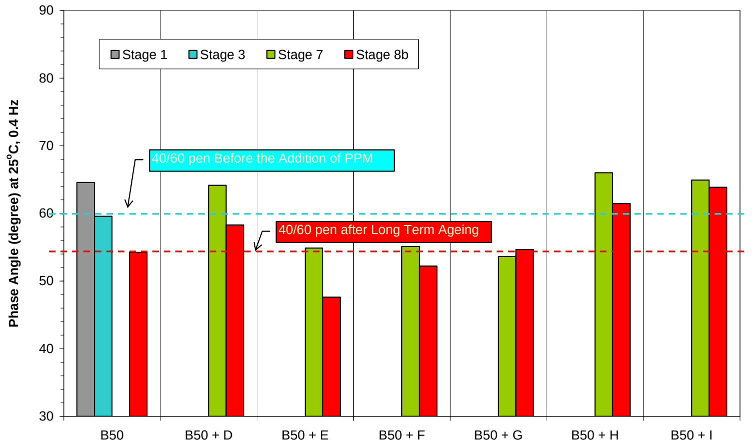


Figure 11: Comparison Between Different Treatments – Phase Angle

The above **Figures 10 and 11** demonstrate that the effectiveness of PPM in terms of preserving the binder stiffness and reducing the rate of hardening may vary considerably between products. This study suggests that assessment of PPMs should be based on measurement over a range of test temperatures and, more importantly, include an ageing protocol. Some samples treated PPMs were trending towards a much lower phase angle, which may imply increased brittleness.

Figure 12 shows the Viscous Elastic Transition Temperature (VET) of artificially aged B50 penetration grade with different PPM treatments associated with asphalt cracking phenomena as previously reported in [3 - 6]. This indicates that treatments E and F should be carried out after 3 to 5 years to maintain resistance to ageing and that some binders (mainly polymer modified emulsions) have a greater potential; although it is thought that they are not very effective in modifying the aged binder in asphalt.

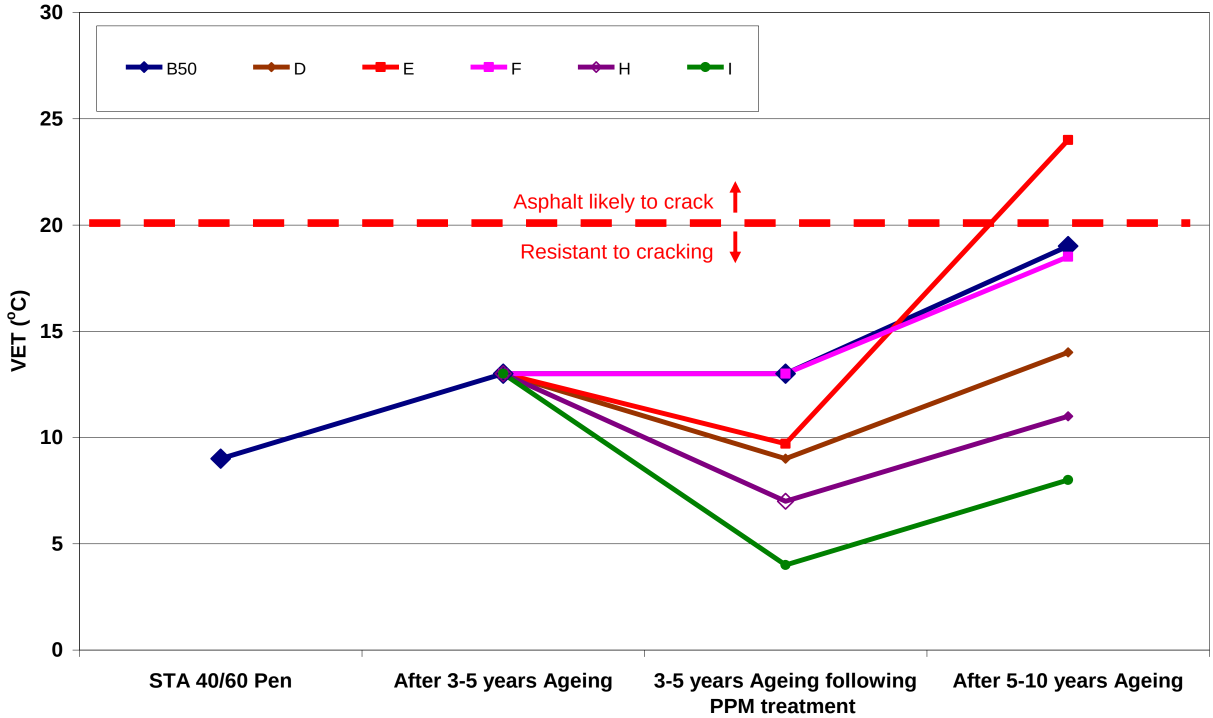


Figure 12: Viscous Elastic Transition temperature with ageing and PPM addition

10. ACKNOWLEDGEMENT

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