The effect of binder composition and properties on the water sensitivity of asphalt mixtures

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ABSTRACT

Resistance of asphalt to the effects of water is of fundamental importance to the long term durability of the pavement structure. This paper compares two standard methods frequently used in the UK to assess the water sensitivity with real-time, long-term field exposure. Five binders, including paving grade and polymer-modified binders of similar nominal penetration were used to produce AC10-type asphalt with two different aggregate sources. The Indirect Tensile Stiffness Modulus (ITSM) of the field-exposed asphalt samples was evaluated at regular intervals over a two year period and compared to those obtained under the standard methods.

It was found that there was little correlation in the results obtained using the standard methods to the those from the field aged samples.

Keywords: Adhesion, Asphalt, Modified Binders, Stiffness, Testing

1. INTRODUCTION

The water sensitivity of asphalt mixtures has long been recognized as being an important performance parameter and over the years many methods have been developed to assess its determination. As far back as the 1940's Hveem [1] acknowledged water sensitivity as being one of the four primary engineering characteristics required to produce long-lasting, high quality asphalt pavements, with it being generally agreed that the primary failure mechanism is loss of adhesion between the bitumen and the aggregate [2,3].
A range of laboratory tests have been developed to measure the effect of water on the bitumen to aggregate bond. Tests may be performed on coated aggregates using a static water immersion procedure such as EN 12697-11: Part B or dynamically, using a method such as the rolling bottle method EN 12697-11: Part A. Often these methods are used as a screening tool to assess whether there is requirement for an adhesion promoter to be added to a particular bitumen and aggregate system prior to asphalt design work
Once an asphalt mixture has been designed, a variety of tests are available to the pavement engineer to assess its water sensitivity. The majority of these tests involve testing a reference dry sample, and then exposing further samples to either water or moisture prior to testing. The choice of method to determine water sensitivity of asphalt is largely territorial. For example, the preferred method within Europe is EN 12697-12: Determination of the Water Sensitivity of Bituminous Specimens while in the USA ASTM standards D 4867-92 and D 1075-94 are preferred. There are also test methods which have been developed for specific mixtures, such as the Vandskak which determines the water sensitivity of fines (mastic) by abrasion, and the Duriez procedure, EN 12697-12 method B, which is used when assessing Enrobé à Module Élevé (EME). The Saturation Ageing Tensile Stiffness (SATS) test was also developed [4] to assess the effect of both heat and moisture on high modulus base asphalts.

In the United Kingdom the British Board of Agrément (BBA) is responsible for approving new construction products through the Highway Authorities Product Approval Scheme (HAPAS). Historically a part of the UK approval process is the determination of water sensitivity using a BBA specific procedure [5] developed under the DoT Link programme led by the University of Nottingham [6]. This has now been replaced with the European standard method [7], but many of the current approval certificates still use the older method.

Each of the tests mentioned above use different storage temperatures and exposure times. A consequence of this wide range of tests being available to the engineer is that it becomes difficult to compare results obtained from different methods. As many of the laboratory methods aim to determine water sensitivity in a reasonably practical time scale, they may involve the application of heat and/or pressure to accelerate moisture damage. Examples of these accelerated tests include the Saturation Ageing Test (SATS) and the BBA / HAPAS method.Furthermore, the relationship between the test result and field performance may not always be clear. A study was therefore undertaken to compare the real-time aging of asphalt to controlled laboratory conditions.

In our earlier paper [8] we described the performance of a number of asphalt mixtures under both accelerated and field aging conditions and concluded that there was little correlation between the methods. In this paper we have extended the scope of the assessment to include enhanced or upgraded binders containing polymers, adhesion agents and synthetic waxes. The performance enhancements obtained by polymer modification, incorporation of synthetic waxes and adhesion agents are well documented in several areas (permanent deformation, fatigue, stripping resistance etc.). One of the aims of this work was to determine if long-term sensitivity to water would be improved when these upgraded binders are used in combination with marginal aggregates to produce asphalt.

2. MATERIALS AND MIX DESIGN

The empirical properties of the five binders used in this study are shown in Table 1. In order to increase the level of control in the asphalt assessment, binders of a nominally similar penetration were used. Additionally all binders were produced using bitumen of the same origin.

Table 1: Empirical binder properties

Experimental code	Description	Penetration at 25°C (dmm)	Softening Point (°C)
50R	40/60	41	55.4
50RA	40/60 + adhesion promotor	40	52.5
PMB1	PmB 25/55-60	43	63.9
PMB2	PmB 25/55-75	34	84.6
WMB	Synthetic wax modified binder	58	53.2

Gritstone and granite aggregates from quarries typically used for asphalt surfacing in the UK were used in this study to produce a PD6691 [9] recipe-based AC10 close surf with grading curves as shown in Figure 1.
AC10 asphalt mixtures were prepared in the laboratory at optimal temperatures and compacted into 100mm Marshall specimens using 50 blows per side. A total of 24 specimens were produced for each binder / aggregate combination, giving a total of 240 specimens for the assessment.

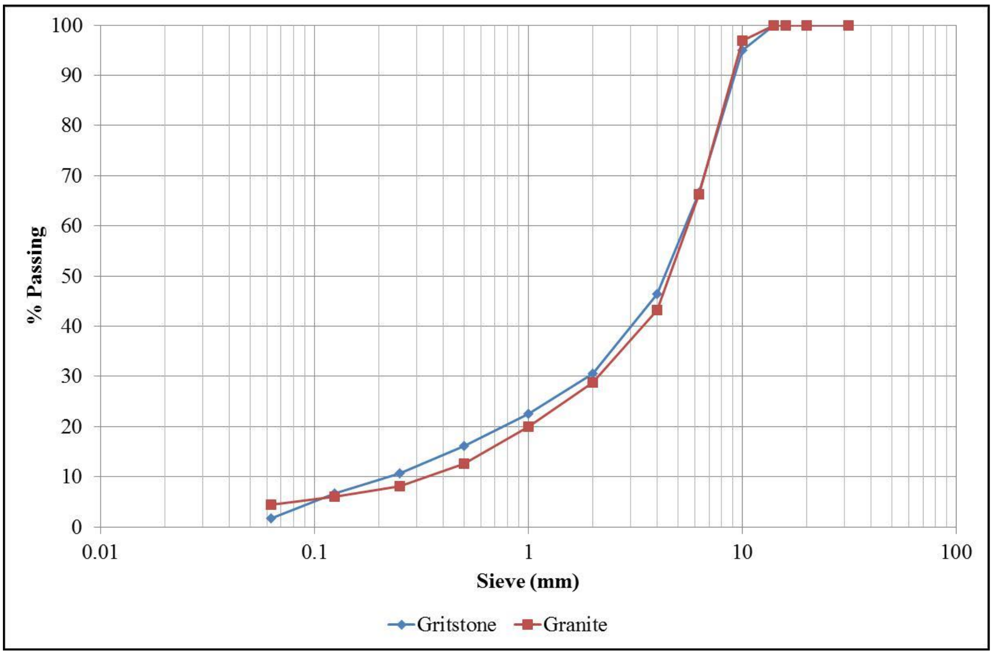

Figure 1. Aggregate grading curves

3. TESTING METHODOLOGY

Real time aging of the asphalt was assessed by storing the specimens outside the laboratory on a raised platform where they were subjected to the local weather conditions. Locating the specimens off the ground ensured that they were not resting in standing water. As these samples were effectively in an uncontrolled environment the meteorological conditions were recorded by a weather station located close to the samples. Maximum and minimum temperature and monthly rainfall were recorded as shown in Figure 2.

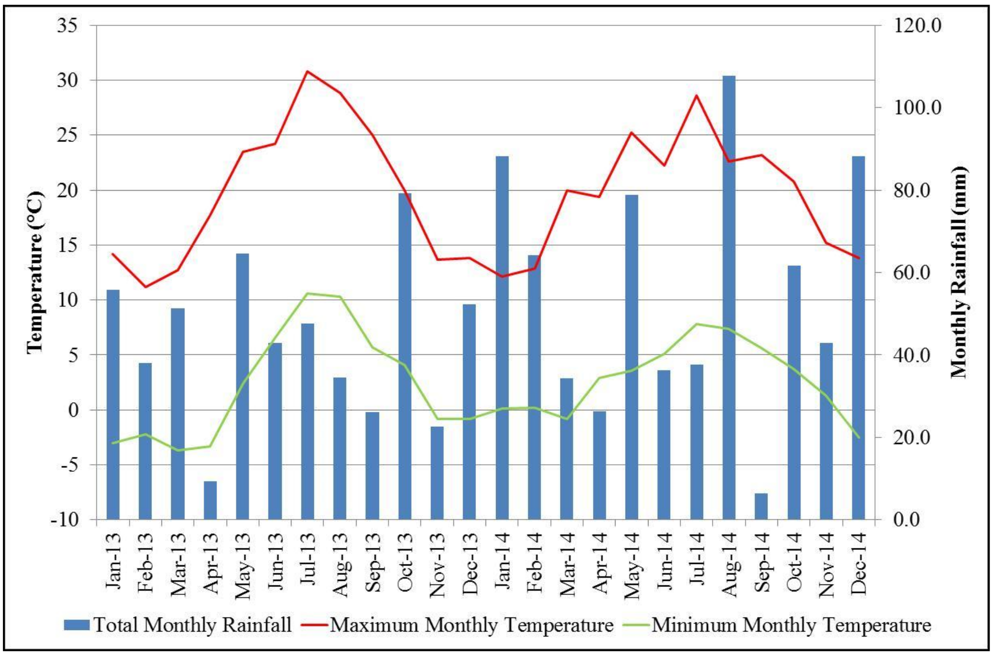

Figure 2: Monthly rainfall and maximum and minimum monthly air temperatures

The reference water sensitivity method used was the BBA/HAPAS procedure as this has the longest history of use in the UK. Results were also obtained using the new EN standard to allow direct comparison of the methods [7].

A controlled-exposure study was also undertaken in the laboratory environment in which the specimens were stored dry in a refrigerator at 4-6°C to produce an inert reference condition. The initial stiffness modulus of each specimen was measured at 20°C according to EN 12697-26 annex C [10]. Further measurements of stiffness modulus were then obtained at regular intervals over a two year period.

The initial Indirect Tensile Stiffness Modulus (ITSM) for each specimen was determined, with the average result shown in Figure 3. The initial stiffness was found to be broadly comparable despite the significant differences in binder composition. The granite specimens exhibited a slightly higher stiffness than their gritstone equivalents.

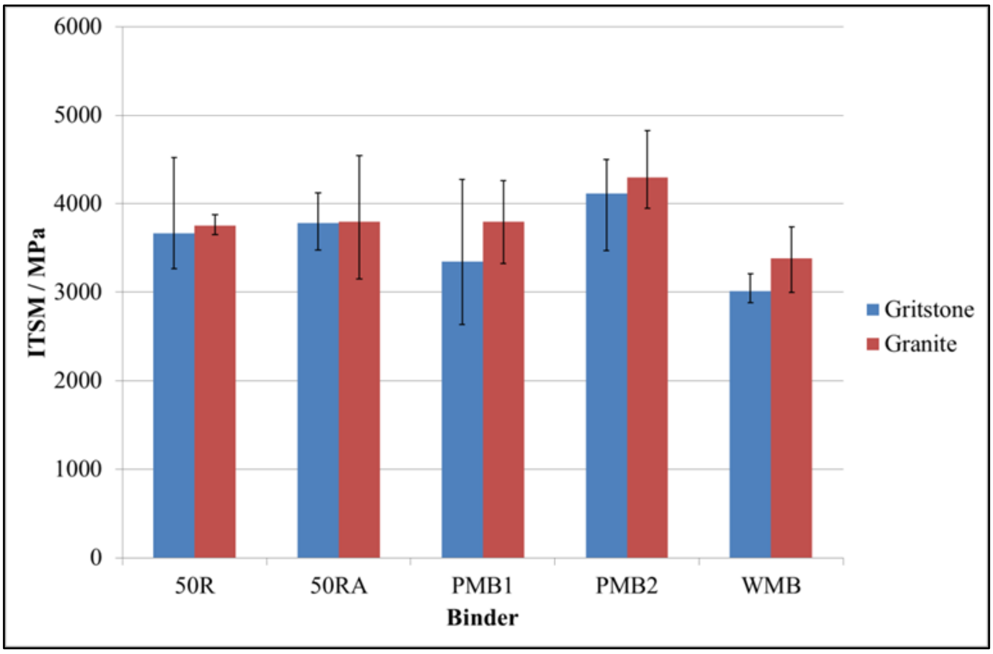

Figure 3.ITSM results (initial stiffness)

4. ANALYSIS OF RESULTS

4.1 BBA/HAPAS TEST

There was very little correlation or consistency in the performance of the binders using the BBA/HAPAS test (Figures 4 & 5). In the case of gritstone, the results are very difficult to interpret with the specimens exhibiting random changes in stiffness with each cycle. The results obtained using granite are a little easier to interpret as most of the specimens exhibited an increase in stiffness after the first cycle, followed by a gradual reduction over the two subsequent cycles. The exceptions to this were the synthetic wax modified binder (WMB), which decreased in stiffness after cycle 1 and thereafter remained nominally constant and PMB2 which gradually decreased in stiffness with each cycle.

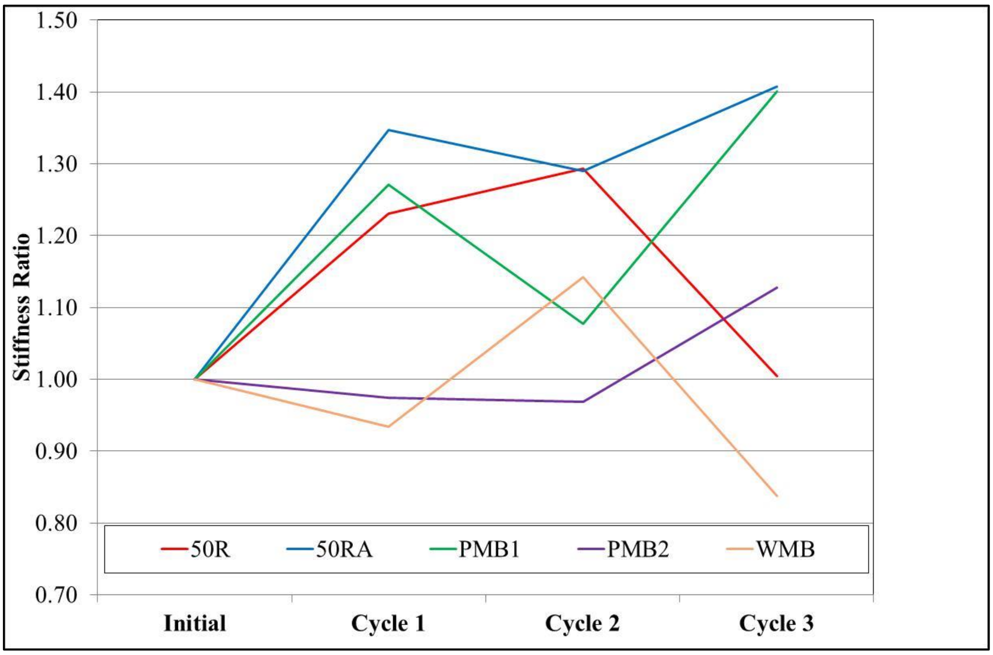

Figure 4. BBA/HAPAS results (Gritstone)

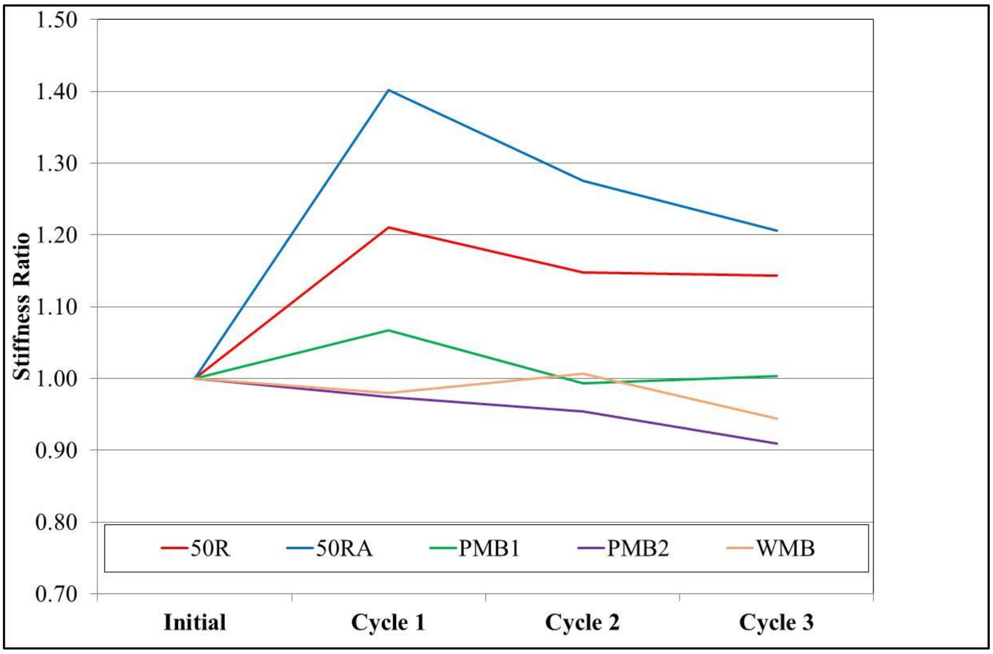

Figure 5. BBA/HAPAS results (Granite)

4.2 RETAINED INDIRECT TENSILE STRENGTH (EN 12697-12)

All of the binder/aggregate combinations performed well in this test, with retained stiffness values in excess of 80% being observed (Figure 6). Again, there is little indication of any trend in the results with the only significant observation being the difference in retained stiffness in the 50R bitumen in combination with gritstone and granite. The former specimens exhibited an increase in stiffness, while the latter reduced in stiffness. The performance of the PmB specimens was very constant regardless of the aggregate source. In the case of binder WMB, the gritstone specimens exhibited no change in stiffness while the granite specimens increased in stiffness.

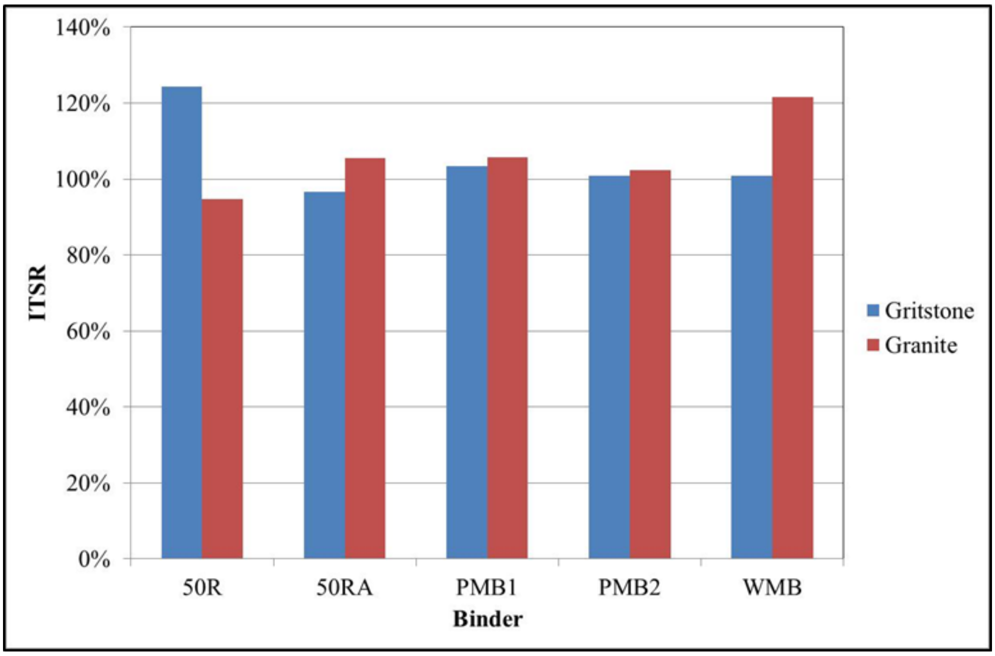

Figure 6. ITSR results

The retained stiffness values from the BBA/ HAPAS test were plotted against those obtained from the ITSR test and are shown in Figure 7. There appears to be no correlation between the two methods.

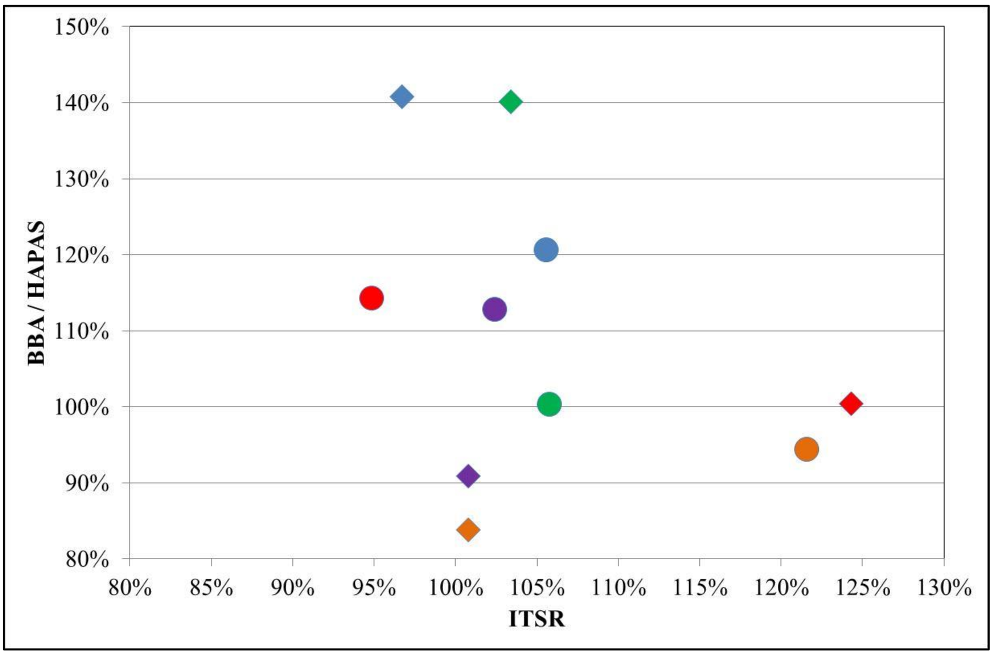

Figure 7. Correlation between BBA/HAPAS and ITSR

(Note that binders are identified using the same colour scheme as in figures 5 & 6. Gritstone samples are displayed as diamonds and granite samples as circles)

4.3 REFRIGERATED CONDITIONING

The change in stiffness of the refrigerated specimens over time is shown in Figures 8 & 9. In this series of tests there appears to be a difference in behaviour depending on the binder type and aggregate source. In the case of the gritstone samples, there is a marked increase in stiffness observed for the 50R and 50RA binders, which exhibited a significantly higher stiffness than the PmB and synthetic wax modified binders at the end of the conditioning period. It was also observed that there was a rapid increase in stiffness for the 50R and 50RA over the first three months of the test, which was followed by a moderate reduction and subsequent increase. This contrasts with the behaviour of PMB1, PMB2 and WMB, which all exhibited a gradual decrease in stiffness over the first 15 months of the test, which was followed by an increase and subsequent fall. The difference in stiffness between 50A and 50RA compared to PMB1, PMB2 and WMB at the end of the conditioning period was marked with the both of the former binders exhibiting significantly higher stiffnesses.

The granite specimens exhibited a similar pattern of behaviour, with the exception of binder WMB which followed the stiffness pattern of 50R and 50RA rather closely. The polymer modified specimens were practically unaffected by the conditioning regime for the majority of the conditioning period and only exhibited a significant increase in stiffness towards the end of the conditioning period. As was the case with gritstone, the final stiffness of the 50R and 50RA granite specimens was significantly higher than that of the polymer modified specimens. The final stiffness of the WMB granite specimen was intermediate to that of the 50R, 50RA and polymer modified specimens, which is in contrast to that of its gritstone equivalent.

The increases in stiffness in the case of the 50R and 50RA specimens is broadly in line with that reported in our previous work [8]. This work also further confirms that storing asphalt samples in refrigerated conditions does not guarantee that there will be no changes in stiffness.

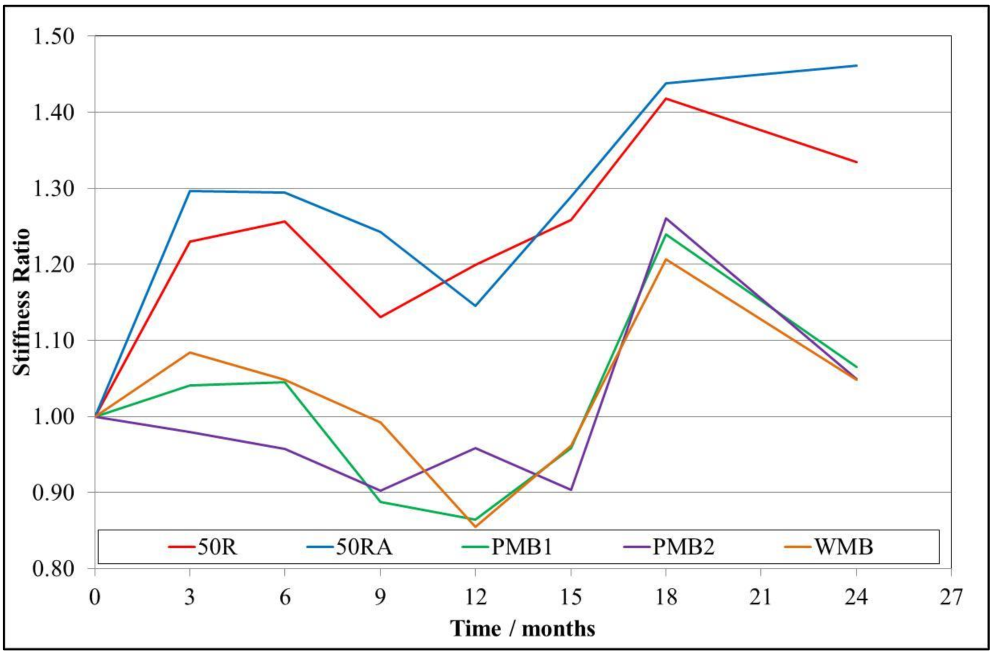

Figure 8 Refrigerated Conditioning (Gritstone)

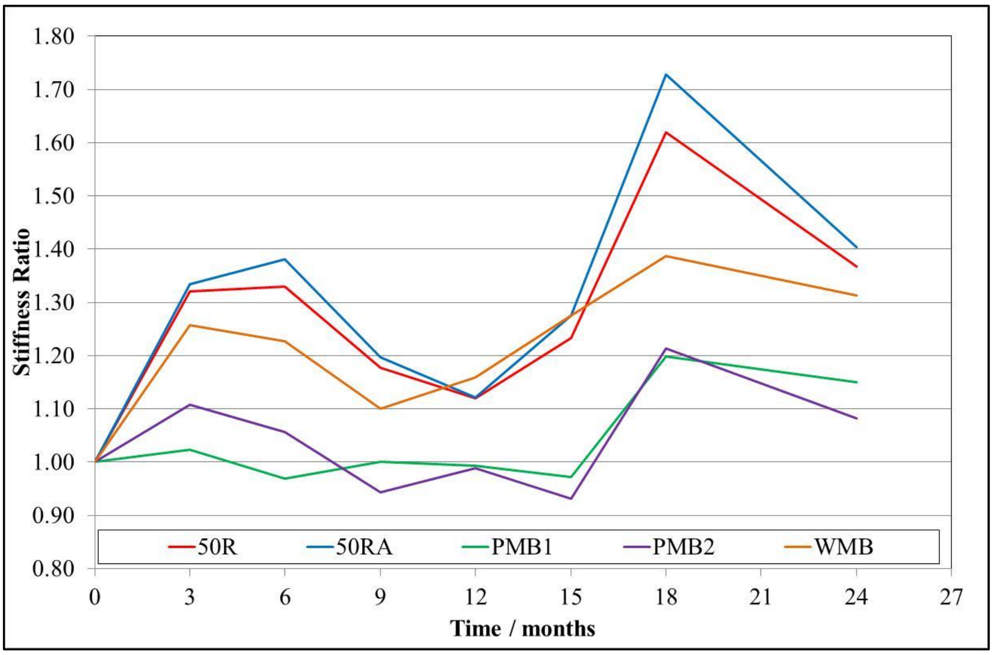

Figure 9. Refrigerated Conditioning (Granite)

4.4 ENVIRONMENTALLY EXPOSED

All of the specimens which were stored outside in uncontrolled conditions exhibited an increase in stiffness. As with the other conditioning regimes reported above, there was no consistency between the binder-aggregate combinations. A general pattern of initial increase in stiffness, followed by a moderate reduction and subsequent increase was observed. In very general terms, the gritstone specimens (Figure 10) exhibited the greatest change in stiffness with an increase of between 1.31-1.67 compared to 1.11-1.41 for the granite specimens (figure 11). For the gritstone specimens, 50R exhibited the greatest increase in stiffness, while for the granite, PMB1 had the greatest increase. In both sets of specimens, the wax modified binder (WMB) exhibited the lowest increase in stiffness. In all other cases, there was no consistent ranking of stiffness change.

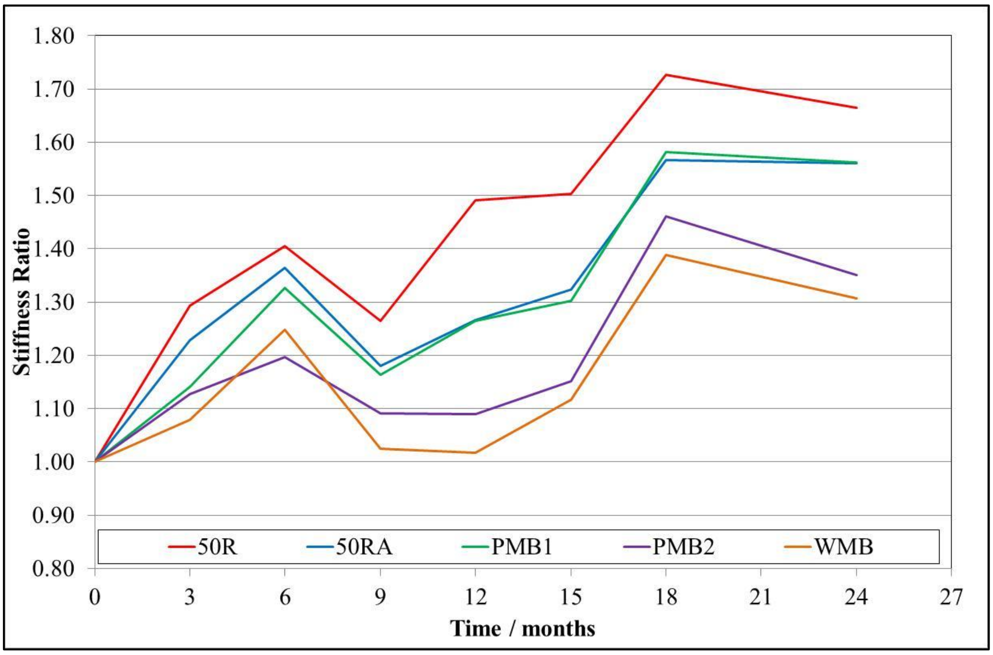

Figure 10. Environmental exposure results (Gritstone)

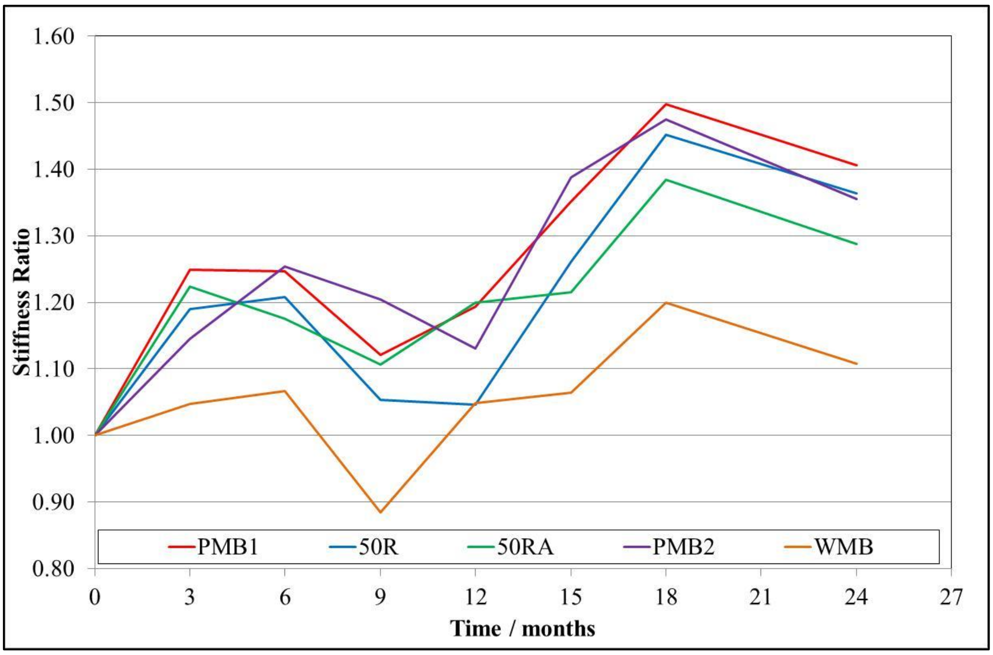

Figure 11. Environmental exposure results (Granite)

5. CONCLUSIONS

This work was carried out with the aim of determining the correlation between accelerated methods of assessment of water sensitivity and field exposure with a number of binder-aggregate combinations. To simplify the assessment process, binders were prepared which had nominally similar penetration values.

Under the BBA HAPAS method, which has been commonly used in the UK to assess water sensitivity, all of the specimens were found to increase in stiffness, which is in contrast to our previous work on hardstone aggregates. There was also no distinct pattern of stiffness development with each of the binder-aggregate combinations. There was no correlation between the results obtained using the BBA/HAPAS method to those obtained using other methods, which is in agreement with previous work.

All of the specimens behaved well under the ITSR test, with none exhibiting any significant reduction in stiffness. However, the ITSR results also showed no degree of consistency in behaviour for the specimens. Additionally, there was no correlation between the BBA/HAPAS results and ITSR.

By way of contrast to some of the other findings, the refrigerated specimens exhibited a similar trend in stiffness development to previous work. All of the specimens increased in stiffness, although the polymer-modified were slightly less affected. This latter result is positive as it indicates a higher level of performance in polymer-modified bitumens in terms of low-temperature susceptibility than for straight-run bitumens with a similar penetration range. The increase in stiffness exhibited by the 50R specimens was broadly in line with results reported in our previous work.

The general increase in stiffness exhibited by all of the refrigerated specimens again illustrates that the common assumption that there is no change in asphalt properties when stored at moderately low temperature for a prolonged period of time is not valid.

All of the environmentally exposed samples exhibited an increase in stiffness, which is consistent with our previous work. The increases in stiffness exhibited by the 50R specimens is also in line with that observed in our earlier work. However, as with the other assessment methods, there is no consistency of behaviour between binder-aggregate combinations.

In summary, this work has confirmed that accelerated methods of assessment of water sensitivity do not correlate well with real-time field exposure. This work has also identified an inherent variability in the assessment methods, which are sensitive to both aggregate and binder type.

REFERENCES

[1] .“Quality Tests for Asphalts—A Progress Report”, F.N. Hveem, Proceedings, Association of Asphalt Paving Technologists, Vol. 15. 1943.

[2] “Summary Report on Water Sensitivity”, R.L. Terrel and J.W. Shute, in SHRPA/ IR-89-003 Strategic Highway Research Program, 1989.

[3] “Moisture Sensitivity of Asphalt Pavements”, Transportation Research Board Seminar, February 4–6, 2003 San Diego

[4] “Development of the Saturation Ageing Tensile Stiffness (Sats) Test”, A.C. Collop, Y.K. Choi, G.D. Airey and R.C. Elliott, ICE Journal of Transport, Vol. 157, Issue TR3, 2004

[5] “Guideline document for the assessment and certification of thin surfacing systems for highways”, British Board of Agrément, Appendix A.2 pp 18-20, 2008

[6] “Development of laboratory protocols for the ageing of asphalt mixtures” S.F. Brown and T.V. Scholz, 2nd Eurasphalt and Eurobitume Congress Barcelona, pp. 83-90, 2000

[7] BS EN 12696-12 “Bituminous mixtures – Test Methods for hot mix asphalt – Part 12 : *Determination of the water sensitivity of bituminous specimens”,* British Standards Institution, 2008

[8] “The correlation between accelerated and field water sensitivity of asphalt mixtures” I.M. Lancaster, I.M Lancaster & S Armstrong, 5th Eurasphalt and Eurobitume Congress, P5EE-324, 13-15 June 2012

[9] PD 6691 Guidance on the use of BS EN 13108 Bituminous mixtures – Material specifications, British Standards Institution, 2007.

[10] BS EN 12697-26 “Bituminous mixtures – Test Methods for hot mix asphalt – Part 26: Stiffness”, British Standards Institution, 2012