THE CORRELATION BETWEEN ACCELERATED AND FIELD WATER SENSITIVITY OF ASPHALT MIXTURES

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ABSTRACT

A commonly utilised method for determining accelerated water sensitivity in the United Kingdom was applied to eight asphalt mixtures manufactured with two different aggregate sources, two gradings, and two bitumens. These results were then compared to real-time ageing of the same asphalt materials under three different conditioning regimes. It was found that the stiffness development of the asphalt was dependant on both the storage conditions and the aggregate type, but with little effect from grading or bitumen type.

Keywords: asphalt, water sensitivity, stiffness

1. INTRODUCTION

The importance of water sensitivity in asphalt mixture design has been accepted since the early part of the twentieth century. 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].

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 [3] 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). As part of the approval process the determination of water sensitivity is required using a BBA specific procedure [4] developed under the DoT Link programme led by the University of Nottingham [5].

Each of the tests mentioned above use different storage temperatures and times, and one consequence of the wide range of tests available to the engineer is that it becomes difficult to compare results from different methods. 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 storage conditions.

2. MATERIALS AND MIX DESIGN

Two different aggregate types, limestone and hardstone dolerite, were used in the study in two different asphaltic concrete mixtures. These were AC10 open and AC10 close as described in PD6691 [6] and shown graphically in figure 1. For each combination an asphalt mixture was made using a hard (40/60) and a soft (160/220) bitumen, both of Venezuelan origin, giving a total of 8 different combinations of aggregate, bitumen, and grading. The binder contents and richness factors for each mixture are given in Table 1.

Table 1 : Asphalt binder contents and binder richness factors

	Hard stone AC10 close	**Hard stone AC10 open**	**Limestone AC10 close**	**Limestone AC10 open**
Binder content (PPC)	5.49	5.26	5.49	5.26
Binder richness (K)	3.44	3.47	3.33	3.36

For each mixture and exposure condition six 100mm Marshall specimens were prepared giving a total of 192 specimens for the study.

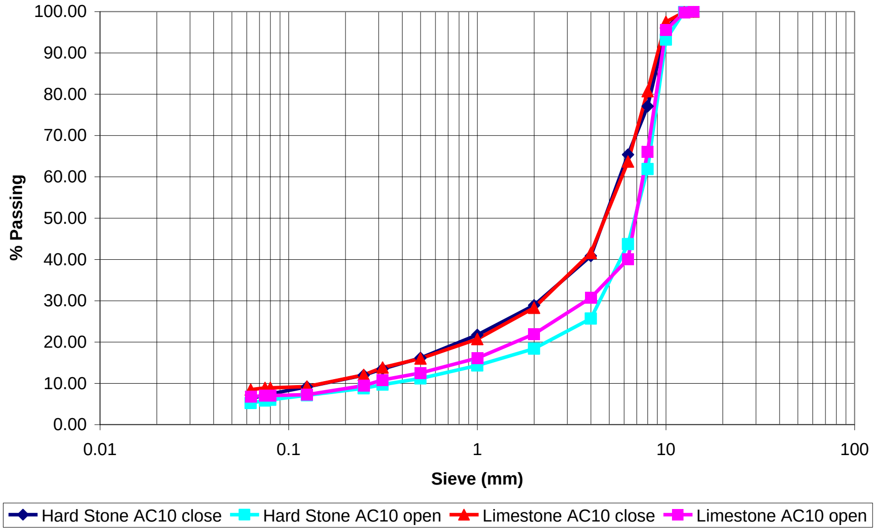

Figure 1: Asphalt grading curves

3. TESTING METHODOLOGY

To assess the real time aging of the asphalt, specimens were stored outside the laboratory on a raised platform where they were subjected to the local weather conditions. By locating the specimens off the ground this also 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 (max / min daily temperature, max/min daily humidity, weekly rainfall) as shown in figure 2

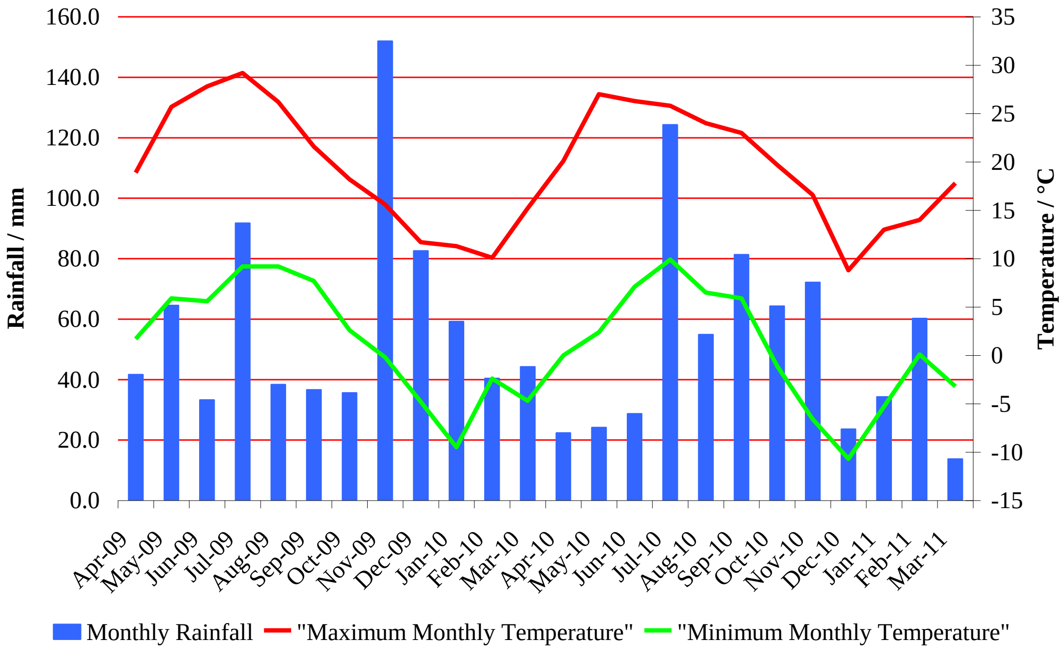

Figure 2: Monthly rainfall and maximum and minimum monthly air temperatures

The reference water sensitivity method used was the BBA/HAPAS procedure as this is still the most frequently requested technique in the UK.

Two controlled-exposure studies were also undertaken in the laboratory environment. In the first, the samples were stored dry in a refrigerator at 4-6°C to produce an inert reference condition. A second set were stored completely immersed in potable mains water at laboratory ambient temperature, which was typically 15 – 25°C. An ambient temperature was chosen to remove the potential for unrepresentative results, which may occur if the specimen is exposed to elevated temperatures, particularly above the softening point of the binder. This latter scenario is a feature of many “accelerated” water sensitivity test protocols.

The stiffness modulus of each specimen was measured at 20°C according to EN 12697-26 annex C. This was performed initially and then at regular intervals over a two year period. After two years of monitoring half of the specimens which had been stored wet, refrigerated, and outside had their indirect tensile strength measured at 5°C according to EN 12697-23. Finally the bitumen from these specimens was recovered following EN 12697-3 with dichloromethane as the solvent, and the physical properties of the recovered binder determined.

4. ANALYSIS OF RESULTS

4.1 Accelerated water sensitivity testing

As the BBA/HAPAS procedure was an accelerated ageing protocol these results are considered first.

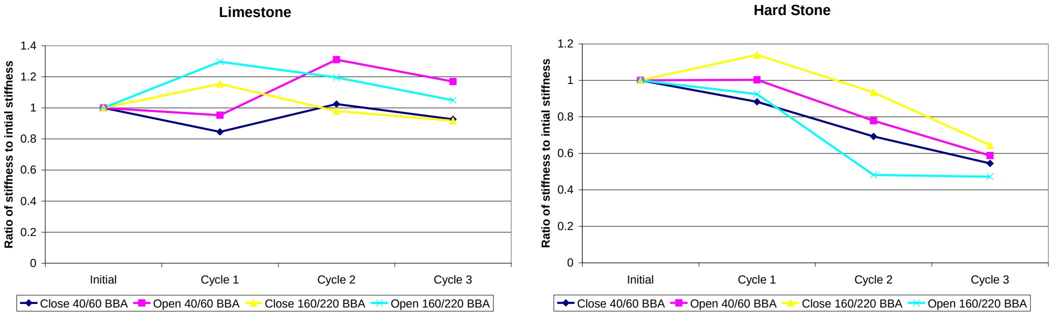

Figure 3: Stiffness ratio change over three cycles of the BBA/HAPAS procedure

As shown in figure 3 significant differences in performance of the aggregate types were found. The limestone based asphalts all showed effectively unchanged stiffness over the course of the test. However, the hard stone asphalts all displayed a reduction in stiffness to between 0.47 and 0.65 of their original values. Under the standard interpretation of the BBA/HAPAS test procedure, a result of less than 0.8 would indicate a material that was sensitive to water and would not be acceptable for use.

4.2 Long term stiffness monitoring

For the specimens stored outside and in the controlled laboratory conditions the stiffness modulus was measured at regular intervals, and the ratio to the initial stiffness calculated (figures 4, 5 and 6).

4.2.1 Submerged conditioning

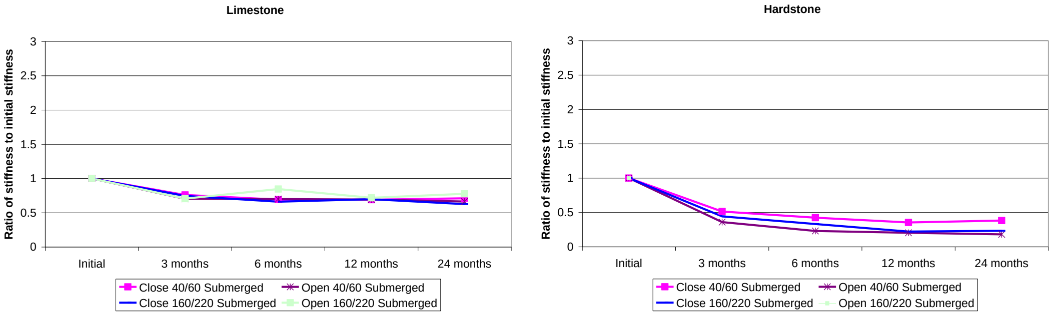

Figure 4: Stiffness ratio change over time for submerged samples

An initial reduction in stiffness was observed after 3 months for both limestone and hardstone-based asphalts that had been stored under water. The reduction was, however, less for the limestone than the hardstone. For the remainder of the two year conditioning period the limestone based specimens remained effectively constant in stiffness, whereas the hardstone asphalts continued to lose stiffness, albeit at a very low rate.

As was observed in the BBA/HAPAS protocol, the hardstone-based asphalt performs less well in the presence of water, but it is interesting to note that even after 2 years of total immersion in water, the asphalt still maintains structural integrity.

4.2.2 Refrigerated conditioning

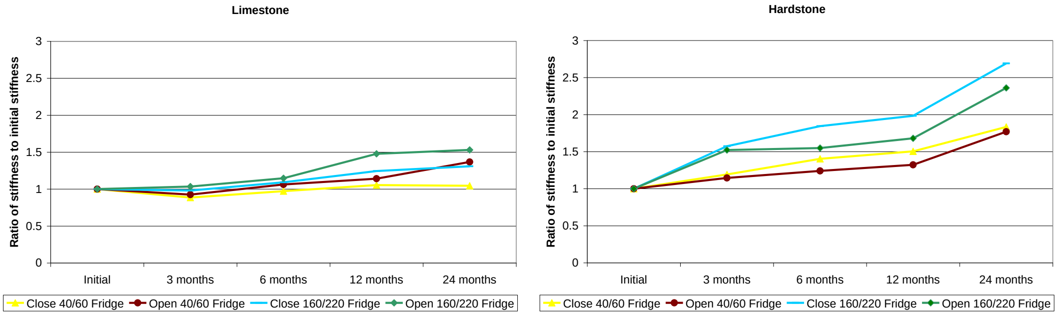

Figure 5: Stiffness ratio change over time for samples stored in a fridge

The rationale behind storing the specimens in refrigerator was that they would remain as reference materials throughout the test, with constant stiffness. However, it was found that this was not the case and all specimens increased in stiffness over the two years. This observation was particularly dramatic in the case of the hardstone with 160/220 bitumen which more than doubled in stiffness for both gradings. The general trends were, however, apparent with both hard and soft bitumens, and also with both the open and close gradings.

It is common laboratory practice that specimens may be stored in a fridge almost indefinitely prior to testing, e.g. EN 12697-26, B3.2.3 recommends that should specimens be stored for longer than two months then the storage temperature should be maintained between 5°C and 10°C prior to testing. However, this work has shown that storage of asphalt samples at these temperatures may lead to significant increases in stiffness.

4.2.3 Outside conditioning

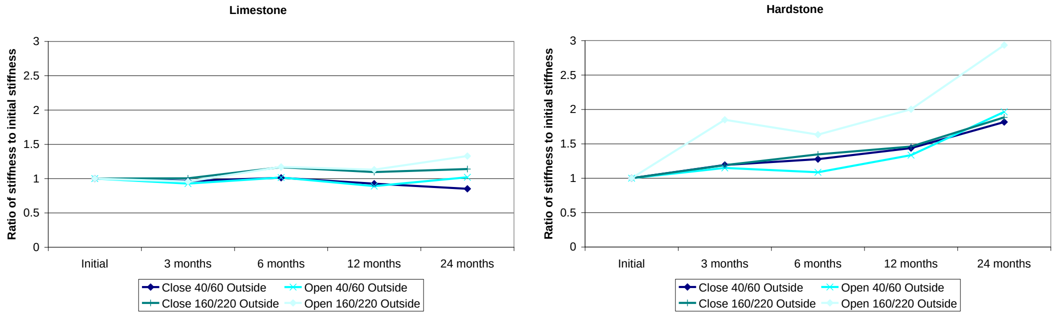

Figure 6: Stiffness ratio change over time for samples stored outside

During the two year test period the specimens produced using limestone aggregate showed little variation in stiffness, which is consistent with the other testing regimes. Despite the hardstone materials showing large stiffness decreases in both the BBA test and during total immersion, the impact of environmental rain does not, after two years, appear to have had a similar detrimental effect. Unexpectedly, the hardstone-based asphalt's stiffness increased significantly, with strong similarities to the trends observed with the refrigerated specimens.

4.3 ITS testing

Before the binder was recovered from the specimens, their tensile strength at 5°C was measured. For both aggregate types the destructive tensile strength results showed a high degree of correlation to the nondestructive indirect tensile stiffness modulus results as shown in figure 7.

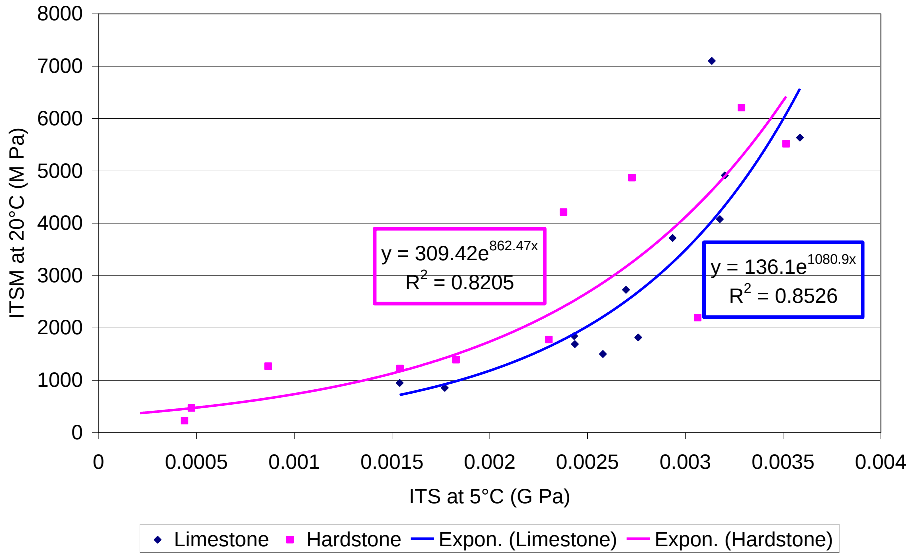

Figure 7: Correlation between ITSM and ITS testing after 2 years conditioning

4.4 Recovered binder testing

The binders were recovered and tested to determine if the changes is asphalt stiffness over the two years was due to changes within the bitumen. Figure 8 shows the penetration of the recovered binder, and it is clear that there are no significant differences in the results from any of the storage conditions. The results are also consistent with the drop in penetration encountered during standard asphalt mixing, and as measured during rolling thin film oven testing, indicating that little further change occurred within the bulk of the binder after the initial mixing and compacting was completed.

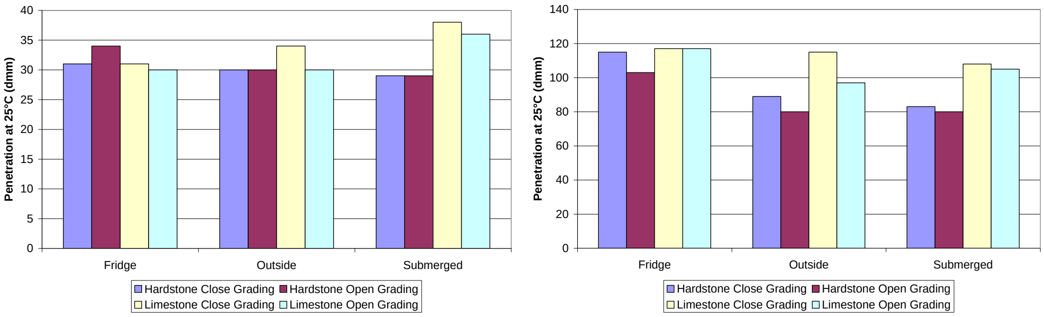

Figure 8: Recovered binder penetrations at 25°C

Figure 9 shows the relationship between the recovered binder penetration and the stiffness modulus of the asphalt prior to recovery. It is apparent that there is no correlation between the two, indicating that the bulk bitumen properties do not define the asphalt's stiffness in this case. It is therefore speculated that the increase in stiffness observed with the refrigerated and outside stored samples, particularly with the hardstone aggregate, is due to changes at the bitumen/aggregate interface with time.

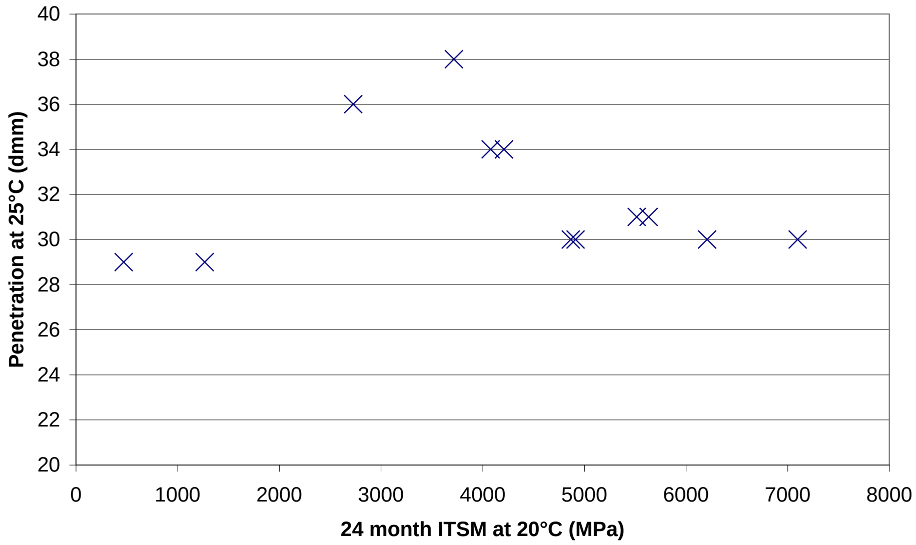

Figure 9: Recovered 40/60 binder penetration versus ITSM after 24 months

5. CONCLUSIONS

The ability of accelerated water sensitivity testing to discriminate between aggregate types was demonstrated with the BBA/HAPAS methodology, and the requirement for a laboratory test method to guide pavement engineers in the selection of the most appropriate aggregate source is not contested. However, the relationship between accelerated test results and those from real-time testing has been shown in this study not to be straightforward to interpret.

This study has demonstrated that while a hardstone-based asphalt may exhibit a relatively large reduction in stiffness under accelerated testing conditions and under total immersion, its stiffness may increase during exposure to normal climatic conditions. It should be noted that the hardstone aggregate used in this study is commonly used to produce asphalt in the UK without any documented performance issues.

In the case of limestone-based asphalt, the behaviour is somewhat more complicated. During accelerated testing, the limestone-based asphalts either increase in stiffness or remain essentially unaffected, which contradicts the observations with hardstone-based asphalts. During total immersion, the stiffness of these samples reduced, in a similar fashion to the hardstone-based materials. It is therefore apparent that the different test protocols may produce significantly different results with similar bitumen-aggregate combinations.

This study has also revealed that different aggregate-bitumen combinations may produce different results when subjected to the same test conditions. This is best demonstrated by the performance of the samples during exposure to normal climatic conditions in which the stiffness of the limestone-based samples remained relatively constant, while the hardstone-based samples exhibited a significant increase in stiffness.

It is apparent that the changes in stiffness are not the result of any significant change in the penetration of the bulk bitumen and are probably therefore be associated with changes at the bitumen/aggregate interface. Any interfacial effects, though, are likely to be masked during the recovery process as the whole of the bitumen becomes homogenised first in the dissolution stage and furthermore during centrifugation and removal of solvent, Determination of the nature of these proposed interfacial effects is an attractive area for further research.

Additionally this study has shown that even at low temperatures that the asphalt’s properties continue to evolve which has important implications for routine laboratory work.

6. ACKNOWLEDGEMENTS

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