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Title: **The Influence of Air-blowing on the Performance Related Properties of Paving Asphalt**

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The Influence of Air-blowing on the Performance Related Properties of Paving Asphalt

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ABSTRACT

A comprehensive experiment was designed to compare the performance related properties of a wide range of air-blown asphalt binders to those of straight run asphalt binders of similar viscosity grades. The binders were evaluated using the concepts of the Superpave Binder Specfications. In contrast to the prevailing perception in the industry, all of the performance related properties of the air-blown binders were found to be as good or better than conventional straight run asphalt binders.

Key Words: asphalt, air-blowing, Superpave, binder, performance

INTRODUCTION

The main objective of this investigation was to determine the influence of air-blowing on the performance related properties of paving grade asphalt as measured by the Superpave binder tests AASHTO MP 1.[1] In particular, this investigation sought to identify potential advantages and disadvantages of using air-blown asphalt binders for paving and to evaluate the impact of various air-blowing processing conditions on binder performance. A comprehensive experiment was designed to test a wide range of air-blown asphalt binders and to compare their properties with straight run asphalt binders of similar viscosity grades.

The general approach in this investigation was to fix the high temperature PG-grade of air-blown binders to be equal to straight run binders made from the same crude. Since the air-blown and straight run binders have equivalent high temperature PG-grades, they are expected to perform equally well with respect to rutting resistance. By fixing the high temperature grade, it is then possible to make direct comparisons of the fatigue and thermal cracking resistance of the binders. Fixing the high temperature PG-grade is appropriate since the binder generally has a smaller impact on rutting resistance than it does on fatigue crack and thermal crack resistance.[2] The high temperature performance grade was set by targeting a specific asphalt viscosity at 60°C.

There is a perception in the paving community that air-blown asphalt binders may perform poorly in paving applications. The main areas of concern are fatigue related properties, aging stress relaxation rate, physical hardening, and failure properties. These concerns were all carefully evaluated in this investigation using the concepts of the PG-grading specification.

and B), and the level of air-blowing involved in the process. The level of blowing included light air-blowing each of the AC-2.5 and AC-5 to an AC-30 and AC-10 grade and heavy blowing with back blending to the same grades. Two replicate samples were tested for each of the air-blown asphalt samples. The replicate samples were made from asphalt that was obtained from the refiner as two separate batches a few months apart. This was done to minimize the chance that an asphalt sample on any one given day was not a “typical” material. Each asphalt was then processed separately to match the design points of the experimental design and tested according to the Superpave test procedures. Three replicate samples of each of the straight run materials (with the exception of the one design point (straight run AC-30 from crude B) for which only one sample could be obtained) were also obtained several months apart and tested independently.

All of the air-blowing was performed in laboratory scale converters by bubbling air through the molten asphalt at 232°F for a time sufficient to reach the desired viscosity or softening point. The lab converters were made of a steel cylinder with an air disperser at the bottom and were operated at atmospheric pressure. Comparison testing has revealed that the Superpave performance of air-blown asphalt obtained from the lab converters was identical to air-blown asphalt from conventional, full scale air-blowing converters. The “lightly blown” samples were made by air-blowing the entire sample batch. The “back blended” samples were made by blowing an AC-2.5 and then blending the air-blown material with the original unblown AC-2.5. The testing was performed according to the Superpave asphalt binder test methods set forth in the AASHTO MPl-93).[4] The testing included the dynamic shear rheometer for samples of unaged and RTFO aged binders at high pavement temperatures. The PAV aged samples were tested using the dynamic shear rheometer at intermediate pavement temperatures. The bending beam rheometer and the direct tension test were used to measure properties at low pavement temperatures.

For each MPl test the limiting temperature was calculated by measuring the binder properties at three or four temperatures over a range that included the specification limit. The data was then curve fit and the limiting temperature was calculated; the limiting temperature is the temperature at which the binder exhibits the value of the specification limit. The average limiting temperature values from the replicate samples were used in the analysis of data and the confidence intervals were obtained from the variability observed in these replicate samples.

RESULTS AND DISCUSSION

The data collected were analyzed using the response parameters selected for the Superpave binder specification. These parameters are related to the three main pavement distress mechanisms rutting, fatigue cracking, and low temperature thermal cracking.

Contribution of Binder to Rutting Resistance

The Superpave test designed to measure the contribution of binder to rutting resistance is the dynamic shear rheometer (DSR) The test allows for measuring the performance of the asphalt binder at high service temperatures where rutting would be most likely. This test is run on both unaged (Tank) and rolling thin film oven (RTFO) aged binders. The RTFO aging is designed to simulate the oxidation and volatile loss that will occur in the asphalt binder during the mixing operation and the construction of the pavement. Both DSR tests are designed to insure that the asphalt will be stiff enough to contribute to rutting resistance. The key parameter that is used to relate to rutting resistance is G*/sin 6.

In the design of this experiment, the air-blown (both lightly air-blown and back blended) asphalt binders were tailored to have DSR-Tank limiting temperature similar to the controls (straight run asphalt binders). Table 1 lists the DSR limiting temperatures for the asphalt binders. The temperatures, which correspond to G*/sin 6 values of 1.O KPa, range between a low of 61.4°C and a high of 63. l°C for the AC-10 grade. For the AC-30 grade the range is between a low of 66.5°C and a high of 70.6°C. The pooled standard deviation is 1.1°C. For all 20 set point in this investigation, the DSR-Tank test defined the high temperature PG-grade. Therefore, the air-blown and straight run asphalt binders in this investigation are expected to perform equally well with respect to rutting resistance.

The limiting temperature from the DSR-RTFO test also revealed no significant difference between the air-blown and straight run asphalts. Table 2 lists the DSR limiting temperatures after RTFO aging. The results indicate that all RTFO limiting temperatures are higher than those from the corresponding tank specimens. The increase ranges between a low of 0.3°C and a high of 3.3°C. On the average, the back blending showed an increase of 2.l°C, which is very similar to the average of the light air-blowing which also showed an average increase of 2.0°C. The RTFO aging of the asphalts resulted in mass loss that was found to be the same in the air-blown binders as in the straight run materials and all of the samples were well below the 1% limit set in the binder specifications.

The use of air-blowing allows for the tailoring of asphalt to meet any high temperature PG-grade. For lightly blown products the high temperature PG-grade can be increased by longer blowing times. With back blending the high temperature PG-grade can be improved by blending with a higher concentration of air-blown asphalt or by using an air-blown asphalt with a higher softening point. In general, blowing or back blending an asphalt binder to an AC-30 viscosity grade resulted in a DSR-Tank limiting temperature that was 5°C to 9°C higher than for a binder with a viscosity grade of AC-10.

Fatigue Crack Resistance

Fatigue cracking has been found to occur most often at moderate pavement temperatures, and it becomes more of a problem as the pavement ages. The test for fatigue crack resistance involves testing the binder with the DSR at intermediate pavement temperatures after the binder has been aged in the RTFO and pressure aging vessel (PAV). PAV aging is designed to simulate the aging that will occur in the road over several service years. The limiting temperature from the DSR-PAV test along with the limiting temperatures from the bending beam rheometer testing will set the low temperature of the PG-grade.

An asphalt binders that has a lower limiting temperature in this test is expected to contribute more to resistance to fatigue cracking (strain-controlled) than a binder with a higher limiting temperature. The key parameter for fatigue resistance is G* sin δ which is directly proportional to the total dissipated energy under cyclic loading (stain controlled).[5]

Table 3 Summarizes the results from this investigation with respect to the DSR-PAV testing. Based on the DSR results, it is clear that the limiting temperatures for all air-blown and back blended binders are lower than the straight run asphalts. The pooled standard deviation for this type of measurement is 2.2°C which is relatively high. This high level of variability is expected because of the confounding variability inherent in the air-blowing, testing, and aging in the RTFO and PAV.

The best performance is observed by the binders produced by air-blowing of an AC-2.5 grade. These binders show an average limiting temperature of 17.0°C which is 4.2°C lower than the average of 21.2°C calculated for the straight run asphalt. Air-blowing of the AC-5 grades show an average limiting temperature that is only 1.7°C lower than the straight run binders. Back blending results indicate that using a heavily blown (softening point of 93°C) or moderately blown (softening point of 60°C) asphalt does not have any influence on the limiting temperatures. Binders made from back blending with air-blown asphalt of both levels resulted in average limiting temperatures of 18.3°C and 18.4°C that are 2.8°C to 2.9°C lower than the straight run asphalts. The DSR-PAV results indicate that air-blowing or back blending of heavily blown asphalts will result in binders that have more favorable fatigue related properties compared to straight run asphalts.

When comparing the DSR-PAV limiting temperature of all of the light air-blown and all of the back blended asphalt binders tested in this study, no difference was observed. This suggests that binders with equal fatigue related properties can be made by either light air-blowing or back blending and indicates that there is a great deal of flexibility with regard to preparing paving grade binders with air-blowing. For example, highly blown asphalt with a softening point of 93°C can be used as a blend stock to meet any desired high temperature PG-grade and still get the same improved fatigue performance as would be expected from blowing the entire batch to the same high temperature PG-grade.

In the case of lightly air-blown asphalt binders, as blowing time increased, the fatigue limiting temperature of the binder was found to increase. In the case of back blended asphalt binders, as the concentration of air-blown asphalt increased, the fatigue limiting temperature of the binder was found to increase. This will limit the amount of blowing or amount of blown asphalt that can be tolerated and still meet some desired low temperature PG-grade. However, this increase in fatigue limiting temperature with increasing light air-blowing time or higher concentrations of air-blown asphalt was also accompanied by improved high temperature performance. As the high temperature performance of the straight run materials increases (AC-30 compared to AC-10) the expected fatigue limiting temperature also increases. When comparing materials with equivalent high temperature performance (i.e. “apples to apples”) the air-blown asphalt materials show lower fatigue limiting temperatures (more favorable) compared to straight run asphalts in the DSR-PAV testing.

Thermal Crack Resistance

Thermal cracking is a consequence of pavement shrinkage at low temperatures resulting in tensile stresses that exceed the tensile strength of the pavement. Two tests, the bending beam rheometer (BBR) and direct tension (DT), have been designed to predict the relative performance of asphalt binders with respect to thermal cracking. The resistance to cracking of the binders is expected to decrease with age; therefore, both of these tests are performed on RTFO and PAV aged asphalt which is meant to represent the worst case scenario. The general principle behind both test is that if the binder can relax internal stresses and flow during the shrinkage of the pavement then the internal stresses will not exceed the tensile strength and cracking can be prevented. The bending beam test is a nondestructive test that is used to determine the lowest temperature where the binder has a reasonably low stiffness (S) and high stress relaxation rate (m). The DT is used to determine the lowest temperature where a reasonable amount of elongation can occur before fracture.

Result from the Bending Beam Rheometer (stiffness)

Table 4 summarizes the results from this investigation with respect to the BBR-S testing. The stiffness results indicate that, on average, both the light air blowing and back blendiig binders result in stiffness limiting temperatures that are lower then the straight run asphalts. The reduction in limiting temperature ranges between a minimum of 2.3°C for the AC-5 with light air-blowing to a maximum of 4.7°C for the AC-2.5 with light air-blowing. The pooled standard deviation for the stiffness measurements is estimated at 1.3°C This indicates that the binders produced by air-blowing are expected to show better performance at low temperatures as compared to straight run binders at the same high temperature PG-grade. The results also indicate that when preparing an asphalt binder by lightly air-blowing, blowing an asphalt with a lower AC-grade (within the same crude type) will result in a binder with better performance in this test.

For the case of back blending, no statistical difference was observed in the BBR-S test when comparing binders made form air-blown asphalt with a 60°C or 93°C softening point. This suggests that equal performing binders can be made by making appropriate blends with air-blown asphalt of any softening point and indicates that there is a great deal of flexibiity with regard to preparing binders with back blendiig. Since there is no difference in binders made from back blending air-blown asphalt with either a 60°C or 93°C softening point, all of the back blended binders were considered together and were found to have limiting temperatures that were on average 4.6°C lower than those of the straight run binders.

When comparing the BBR-S limiting temperature of all of the light air-blown and all of the back blended asphalt binders tested in this study, no difference was observed. This suggests that equal performing binders can be made by either light air-blowing or back blending and indicates that there is a great deal of flexibility with regard to preparing paving grade binders with air-blowing. As in the DSR-PAV testing, highly blown asphalt with a softening point of 93°C can be used as a blend stock to meet any desired high temperature PG-grade and still get the same improved

BBR-S limiting temperature as would be expected from blowing the entire batch to the same high temperature PG-grade.

Finally, it is noted that the increase in blowing time and the increase in the concentration of air-blown asphalt to convert the AC-10 binders to AC-30 binders showed no significant difference in the BBR-S performance. Therefore, it can be concluded that neither blowing time nor concentration of air-blown asphalt strongly influence the BBR-S limiting temperature.

Results of the Relaxation Rate "m"

The m value obtained from the BBR test is the rate at which the logarithm of the stiffness changes as a function of time at a specific temperature and loading time. The m value by definition is the stress relaxation rate at the particular time and temperature where it is measured. The m value is in the specification because it is believed that when the pavement temperature decreases, a binder that relaxes internal stress more slowly will build up internal stress faster than a binder with a higher stress relaxation rate and, therefore, crack (internal stresses exceed the tensile strength of the material) sooner (i.e. at a higher temperature).

The limiting temperature for “m” was calculated in the same manner as for the other Superpave binder tests; the m value was measured at three different temperatures (two specimens at each temperature). Using linear interpolation between m values and the test temperature, the limiting temperatures for the m values were calculated. The results for the “m” value are shown in Table 5. These results indicate that air-blowing and back blending result in a slight reduction of the limiting temperatures for m. The reduction ranges between a low of 0.2°C for the AC-5 lightly blown to a high of 2.5°C for the AC-2.5 lightly blown. For back blending the reductions in limiting temperature are 1.2°C and 1.3°C for binders made from the intermediate and more highly blown asphalt. However, since the pooled standard deviation is relatively high (2.5°C), these measured differences are not outside of the observed variability. Nevertheless, these results indicate that air-blown asphalts are expected to have m values that are similar, if not more favorable than straight run asphalts.

In the case of lightly air-blown asphalt binders, as blow time increased (AC-30 compared to AC-l0) the limiting temperature for the m value of the binder increased. Likewise, in the case of back blended asphalt binders as the concentration of air-blown asphalt increased, the limiting temperature increased. This increase in m with blow time or air-blown asphalt concentration will limit how much air-blowing can be done on a given asphalt and still meet some desired low temperature PG-grade. However, this increase in the m value is accompanied by improved high temperature performance. As the high temperature performance of the straight run materials increased (AC-30 compared to AC-l0), the limiting temperature for m was also found to increase. When comparing materials with equivalent high temperature performance in the BBR-m binder test (i.e. “apples to apples”) the air-blown and straight run binders performed equivalently.

Physical Hardening

It has been well documented that asphalt tends to stiffen with time at temperatures in the low end of the pavement temperature range; this is called physical hardening.[6] Since the stiffness changes with conditioning time, a standard conditioning time of one hour was arbitrarily chosen for the Superpave binder specifications to facilitate rapid testing. However, some asphalt binders get much stiffer than others when held at low temperatures for extended periods of time that are more representative of the actual pavement conditions. As a result, the Superpave specifications can be tricked with certain modifiers to give low stiffness measurements at short times which may not be representative of actual performance in the pavement. Although it is not used in Superpave PG-grading at this time, the Super-pave testing protocol does recommend that physical hardening tests be run by making the BBR measurements at -18°C after conditioning times of 1 hour and 24 hours. In this investigation physical hardening tests have been conducted on all of the samples. The average increase in stiffness for the straight run asphalt was 36% relative to the 1 hour value. The average for the lightly air-blown binders averaged 22% for the AC-2.5 initial grade and 31% for the AC-5 initial grade. For the back blending the average was approximately 32% for both levels of air-blowing. The pooled standard deviation was approximately 9% which leads to the conclusion that the air-blown asphalts have similar physical hardening behavior to the straight run binders.

Failure Properties

One of the assumptions built into the Superpave binder specifications is that the stiffness of an asphalt binder at low temperatures is directly related to resistance to thermal cracking. Although this assumption is generally true for conventional straight run asphalts, it is not always true for modified asphalts.[7] Thermal cracking is a fracture mechanism which is related to much more than the stiffness of the material. This was recognized by the team that established the Superpave binder specification and they included an optional direct tension (DT) test into the specifications that primarily should benefit the higher strength polymer modified materials. At the present time the DT test is still optional (mostly because the equipment required for this testing has not yet been perfected), but the DT test is likely to be adopted as a requirement for modified asphalts sometime in the future.

Concern has been expressed that asphalt is embrittled during the air-blowing process (the assumption is that the asphalt is chemically degraded through oxidation) so that even if it has an acceptable stiffness to meet a desirable PG-grade, a lower strength or elongation to break would make it more susceptible to cracking than a straight run asphalt. As in the BBR testing, the DT testing is conducted on PAV aged samples which are meant to represent asphalt that has been on the road for several years. Thermal crack resistance is expected to decrease as a result of aging so this test like the BBR test evaluates the worst case scenario.

An asphalt binder showing a higher strain to failure at low temperatures in this test is expected to be more resistant to thermal cracking than an asphalt binder with a lower strain to failure at the same temperature. For the DT experiments, the limiting temperature was calculated where the percent failure strain equals 1% at a extension rate of 0.5 mm/min as measured by a laser extensometer. Four dog-bone specimens were run for each sample at each measurement temperature. Results from the direct tension test are shown in Table 6.

The direct tension results clearly indicate that air-blown asphalts are not inferior in their failure behavior compared to the straight run controls. The average limiting temperature for lightly air-blown AC-2.5 asphalt is 5.2°C lower than straight run asphalts. Similar improvements of 5.2°C and 4.1°C were observed for the back blended asphalts made from the 60°C and 93°C softening point asphalts, respectively. These results are statistically significant at the 95% confidence level considering the fact that the pooled standard deviation is 2.0°C for this type of measurement. The smallest reduction of the limiting temperature was observed for the asphalts produced from the AC-5 grade. The average limiting temperature for these asphalts was only 1.4°C lower than the straight run asphalts. This indicates that the binders produced by air-blowing are expected to show better performance at low temperatures as compared to straight run binders at the same high temperature PG-grade. These results also indicate that when preparing an asphalt binder by lightly air-blowing, blowing an asphalt with a lower AC-grade (within the same crude type) will result in a binder with better performance as measured by DT. As blow time increased (time to blow AC-10 to AC-30) the limiting temperature of the binder was not found to change significantly.

For the case of back blending, the limiting temperatures estimated from the direct tension were found to be independent of the softening point of the air-blown asphalt. As the concentration of air-blown asphalt increased (to make the binder viscosity increase from an AC-10 to AC-30), the thermal crack resistance of the binder did decrease slightly as evidenced by a 0.3°C to 4.4°C decrease in limiting temperature; however, this was also accompanied by an 7-10°C improvement in the high temperature performance. Finally, as in all of the other binder tests, no difference was found between lightly air-blown and back blended binders that have the same high temperature PG-grade.

In addition to failure strain, the failure stress was also evaluated. The failure stress represents the strength of the binder. A binder with a higher failure stress will need to be stressed more before it will crack than a binder with a lower failure stress. Unlike the failure strain, the failure stress was not found to systematically increase or decrease with temperature. Therefore, to evaluate this response in the experimental design the average failure stress at -6°C, -12°C, and -18°C was used to represent the low temperature performance of each binder.

The air-blown asphalt binders (both light air-blown and back blended) were found to have strength equal to straight run asphalt binders. The air-blown asphalt binders, therefore, have higher failure strain and equivalent failure stress compared to straight run binders. Since failure energy is determined from the area under the stress vs. strain curve, air-blown asphalt binders will have a greater failure energy than straight run asphalt binders. In contrast to the results from the BBR-m test, these results suggest that air-blown binders should outperform straight run binders in resistance to thermal cracking.

The tensile modulus was also measured from the DT testing. The tensile modulus was taken to be equal to the tangent modulus at 0.25% strain except for when the samples failed prior to 0.25%

strain in which case the tensile modulus was taken to be equal to the secant modulus of the entire stress vs. strain curve. The tensile modulus from DT testing was found to correlates well with S from BBR testing with a correlation coefficient, R^2, equal to 0.93. Therefore, an analysis of tensile modulus in this experimental design results in conclusions very similar to those for BBR-S. For binders with the same high temperature PG-grade, the air-blown asphalt binders have lower tensile moduli at low pavement temperatures after PAV aging than straight run binders.

DT/BBR Correlation

The bending beam test was adopted as a Superpave binder test because it was believed that measuring the stiffness (S) and stress relaxation rate (m) of a binder at low temperatures would correlate with fracture that is observed in the highways. When the stiffness from the BBR is plotted vs. the DT failure strain for each sample and test temperature evaluated in this investigation, a reasonably good correlation is found (see Figure 2). However, when the m value was plotted versus the failure strain, a poor correlation was observed (see Figure 3). This finding indicates that the m value as an independent parameter does not relate very well to the failure properties of the binder. This lack of correlation between the DT-strain and m values raises the question as to how important the m value is to "performance". **It would seem to be desirable to combine S and m into a single variable that weights each parameter according to its influence on the failure performance of asphalt binders. The** bending relaxation modulus was proposed as an alternative to combine these two parameters.[8] This parameter is a fundamental engineering property that can be estimated from S and m values as follows.[9]

$$\text{relaxation modulus} = E = S * \sin(\pi m)/(\pi m)$$

From the data set used in this investigation a good correlation ($R^2 = 0.80$) was found between E from BBR and failure strain from DT. Based on the BBR-E results, the air-blown asphalt binders (both light air-blown and back blended) are expected to be more favorable than straight run asphalt binders in the resistance of thermal cracking.

PG-Grades

The PG-grade is a measure of the temperature range in which the asphalt binder will be expected to perform satisfactorily.[1] The "PG" stands for performance grade. Because it grades the samples, the PG-grade will be used to compare the "quality" of different binder materials and will ultimately determine the financial value of the asphalt binder.

For all of the binders tested in this investigation, the high temperature PG-grade was limited by the DSR-Tank test and the low temperature PG-grade was limited by the BBR-m test. Since the limiting temperatures for the air-blown and straight run binders were found to be equivalent in both the DSR-Tank and BBR-m tests, the PG-grades will also be the same. Because the low temperature PG-grade is limited by the BBR-m results, the air-blown asphalt binders are not recognized for their higher performance in the BBR-S, DSR-PAV, DT-strain testing.

Aging

Oxidative aging tends to stiffen the binder in the road with time. The PAV (pressure aging vessel) portion of the binder specifications has been developed to simulate long term oxidative aging.[10] The value of G*/sin δ was measured on the Tank asphalt and RTFO/PAV aged asphalt for each binder at a temperature of 70°C, and it was found that the increase in stiffness at this temperature due to the RTFO/PAV aging was very high for all binders. The increase in G*/sin δ was found to be greater for the air-blown binders than the straight run binders; G*/sin δ for the straight run binders increased an average of 11 times their original G*/sin δ value with aging and the air-blown materials increased an average of 14 times. Therefore, at these high pavement temperatures, the faster aging of the air-blown binders will result in better resistance to rutting with time compared to the straight run binders. However, stiffening at intermediate and low pavement temperatures may result in fatigue and thermal cracking, respectively. Since the Superpave binder specifications require that the intermediate and low temperature tests be performed on RTFO/PAV aged binders, any differences in the aging of air-blown and straight run asphalts should have been accounted for by the Superpave testing. The fact that air-blown binders were found to perform equivalently to straight run binders in the BBR-m and better than straight run binders in DSR-PAV, BBR-S, and DT-strain tests suggest that air-blown asphalts are no more likely to crack due to aging than straight run asphalt. In fact, the BBR-S limiting temperature was also determined for a number of binders that were not aged (Tank) which revealed that the limiting temperature of the air-blown binders actually decreased less with RTFO/PAV aging than those of the straight run binders. Further, the rheological glass transition temperature (peak in loss modulus at 1 Hz) was measured from master curve data for select binders. The master curves were generated from an Oberst bar test which is a test commonly used to measure the rheology of viscoelastic materials." The results indicate that the glass transition temperature of the air-blown binders increases less than straight run binders when aged in the RTFO and PAV. As a result, the air-blown binders after RTFO/PAV aging were found to have glass transition temperatures about 15°C lower than straight run binders with the same high temperature PG-grade. Asphalt binders with lower glass transitions temperatures are expected to perform better at low pavement temperature than asphalt binders with higher glass transition temperatures.

SUMMARY OF FINDINGS

In this study the performance related properties of air-blown asphalts were compared to straight run asphalts of the same viscosity grade. The air-blown asphalts were produced from two crude sources by either blowing softer grades or by back blending of heavily blown stocks. Based on the analysis of the data collected at high, intermediate, and low temperatures using the Superpave binder testing procedures the following findings can be stated:

1. Air blown asphalts are found to be softer than straight run asphalts at intermediate temperatures. This indicates that air-blown asphalts are expected to perform better with regard to strain controlled fatigue as indicated in the Superpave specification.

2. Air-blown asphalts are found to have, on average, lower stiffness values and equal or higher m values than straight run asphalts. The stiffness limiting temperatures were lower for the air-blown

asphalts by 2.3°C to as much as 4.7°C as compared to the straight run binders. Although lower on average, the limiting temperatures based on the m value for the air-blown binder was not found to be statistically different from those of the straight run controls.

3. The direct tension test results indicate that air-blown asphalts can have significantly higher strains at failure with the same stress at failure. This indicates that air-blown asphalts can be more ductile than straight run asphalts. Limiting failure strain temperatures for AC-2.5 lightly blown asphalts are more than 5.0°C lower than straight run asphalts of similar viscosity grades.

4. The rheological glass transition temperature of air-blown asphalts are found to be lower than those of straight run asphalts after RTFO and PAV aging.

5. The results of this investigation indicate that air-blown asphalts are not deficient in any way compared to conventional straight run asphalts. In fact, air-blown asphalts are generally more favorable than conventional asphalts in terms of the PG-grading system. Therefore, there is no foreseeable technical reasons why air-blown asphalts should be excluded from use in paving applications where they meet the desired PG-grade.

6. Within a given crude, air-blowing of a softer grade (AC-2.5 in this study) can be more beneficial than air-blowing of a harder grade (AC-5 in this study). Improvements were observed in the limiting temperatures from the DSR-PAV, BBR-S, and DT tests when starting with the softer grade.

7. Similar binder performance was found from light air-blowing and back blending. Similar binder performance was also observed in back blended binders made from air-blown asphalt with softening points of 60°C and 93°C. This indicates that air-blowing can offer flexibility of production without compromising critical properties.

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REFERENCES

1. Anderson, D. A, and Kennedy, T. W., "Development of SHRP Binder Specification," Journal of the Association of Asphalt Paving Technologists, Vol. 62,1993, p. 481.

2. Hicks, R G., Finn F. N., Monismith, C. L., and Leahy, R B., "Validation of SHRP Binder Specification Through Mix Testing," Journal of the Association of Asphalt Paving Technologists, Vol. 62, 1993, p. 565.

3. Box, G., Hunter, W. and Hunter, J., Statistics for Experimenters, John Whiley & Sons, New York 1978.

4. AASHTO Provisional Standards for Asphalt Binders: MP 1, PPl, PP5, PP6, TP1, TP3, and TP5, September 1993, In Appendix A, "Superpave Asphalt Binder Test Methods; An Illustrated Overview," FHWA-SA-94-068.

5. Bahia, H.U. and Anderson, D. A, "The New Proposed Rheological Properties: Why are They Required and How They Compare to Conventional Properties," Physical Properties of Asphalt Cement Binders: ASTM STP 1241, John C. Harden, Ed. American Society for Testing and Materials, 1994, (in print).

6. Bahia, H. U. and Anderson, D. A, "Glass Transition Behavior and Physical Hardening of Asphalt Binders," Journal of the Association of Asphalt Paving Technologists, Vol. 62,1993, pp. 93-130.

7. Anderson, D. A and Dongre, R, "The SHRP Direct Tension Specification Test - Its Development and Use," Presented at the ASTM Symposium on Physical Properties of Asphalt Cements held in Dallas/Ft. Worth, Texas, December 7, 1993.

8. Bahia, H. U., Personal communication regarding proposal presented to the FHWA Expert Task Group on Asphalt Binders, meeting in October 1994.

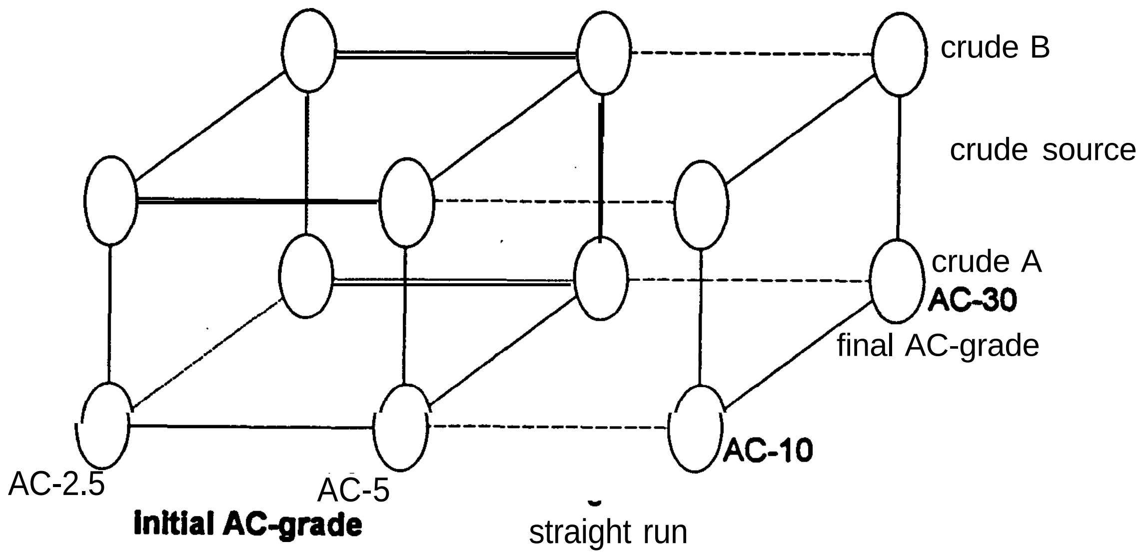
9. Ferry, J. D., Viscoelastic Properties of Polymers, John Wiley & Sons, New York,1980.

10. Bahia, H. U. and Anderson, D. A, "The Pressure Aging Vessel (PAV): A Test to Simulate Rheological Changes Due to Field Aging," Physical Properties of Asphalt Cement Binders: ASTM STP 1241, John C. Harden, Ed., American Society for Testing and Materials, 1994, (in print).

11. Nashif A D., Jones, D. I. G., and Henderson, J. P., Vibration Damping, John Wiley and Sons, New York, 1985.

Figure 1: Experimental Design

Lightly Air-blown Binders and Straight Run *Controls*



Back Blended Binders
(Highly Air-blown Asphalt Blended with Straight Run AC-2.5)
and Straight Run Controls

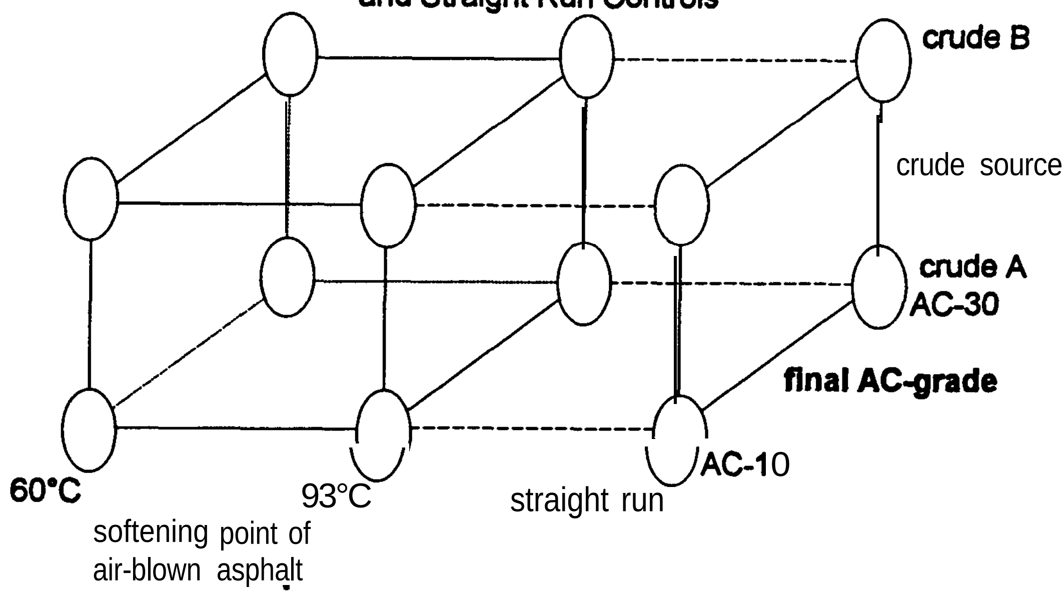


Figure 2: The relationship between the BBR stiffness and the DT failure strain.

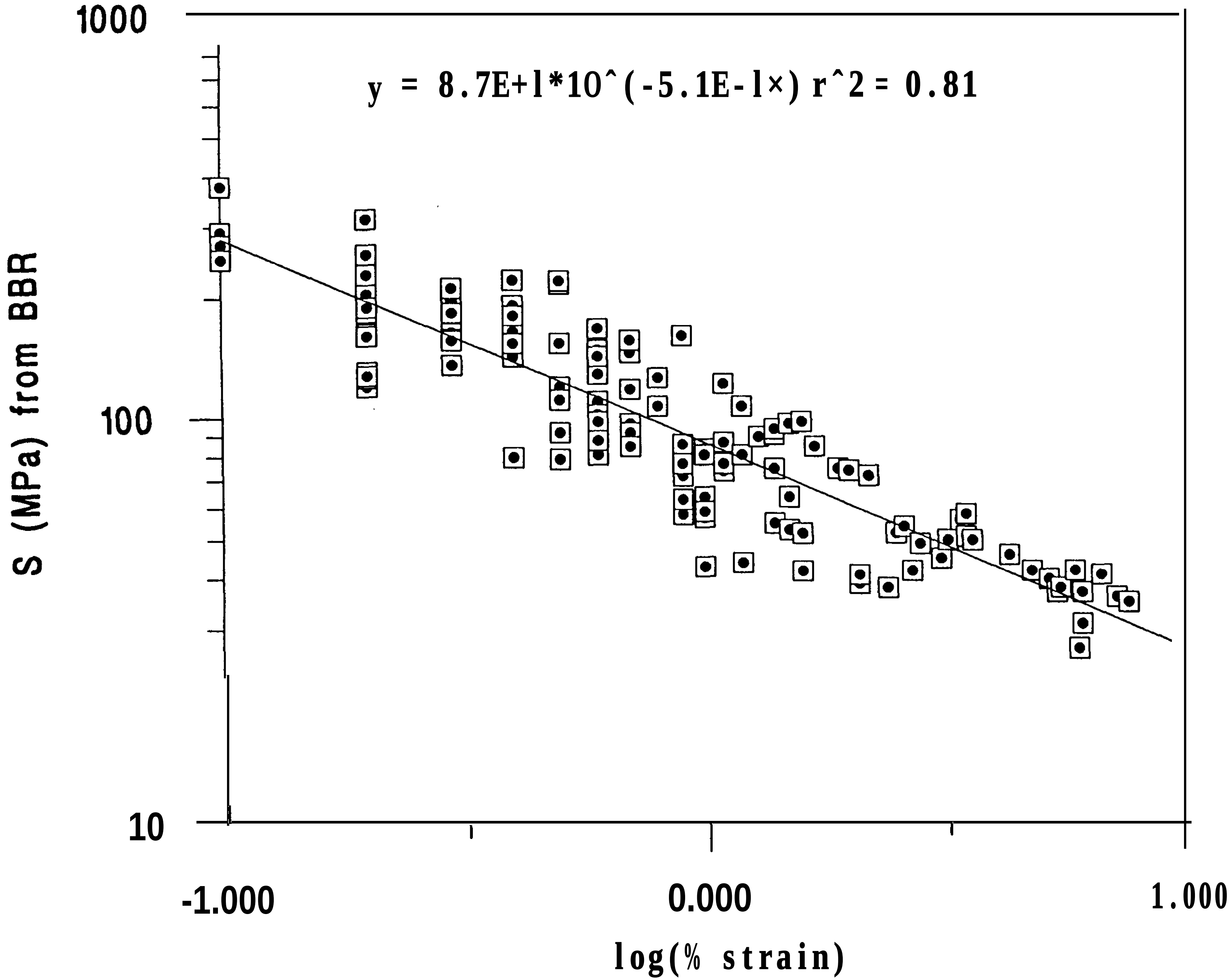


Figure 3: The relationship between the BBR "m" value and the DT failure strain.

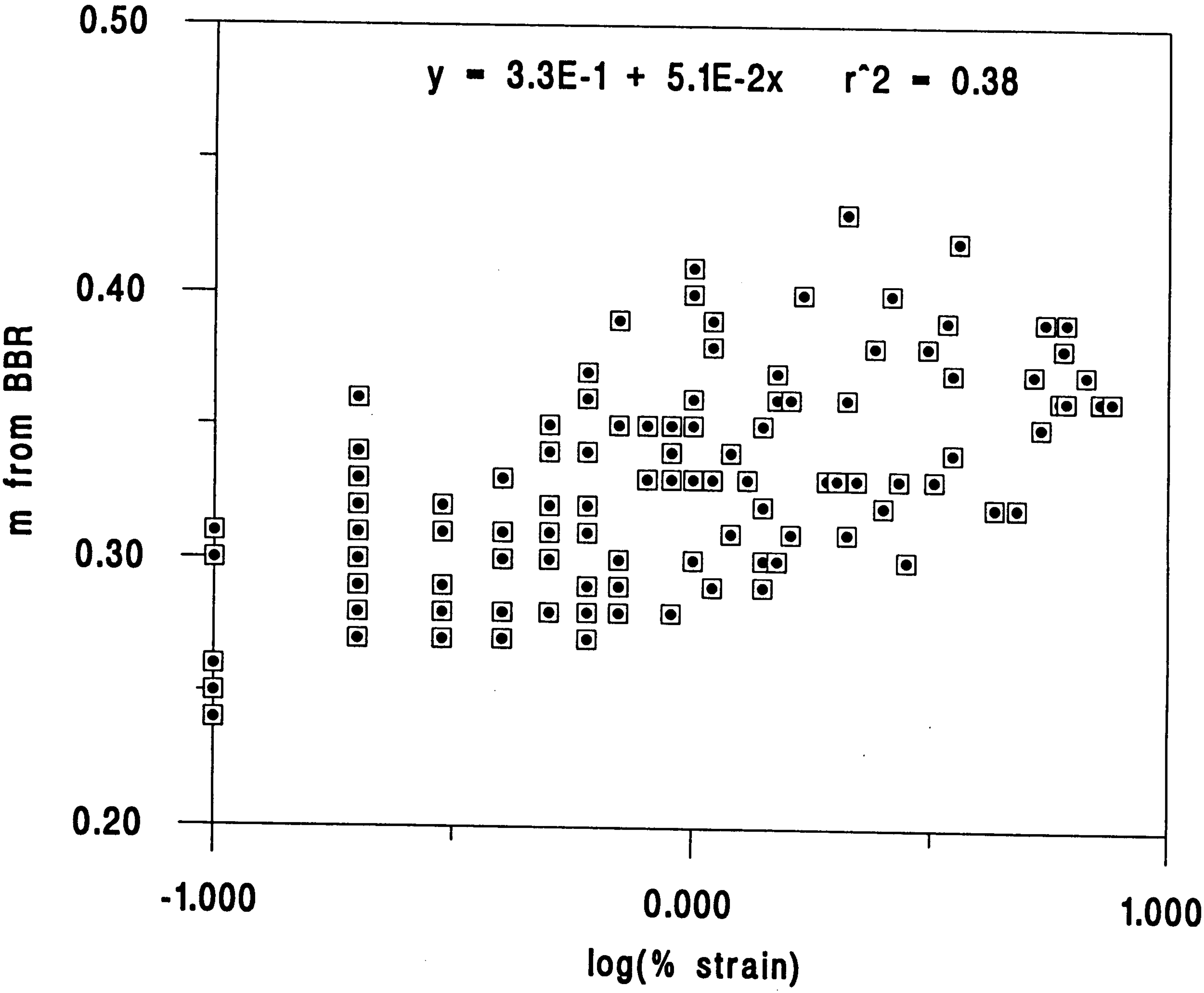


Table 1: Limiting temperature data from DSR-Tank testing

Design Point	Limiting Temperature replicate 1 (°C)	replicate 2 (°C)	replicate 3 (°C)	replicate average (°C)	group average (°C)
Lightly air-blown AC-2.5					64.8
AC-10; crude A	60.8	62.1		61.5	
AC-10; crude B	62.8	62.5		62.7	
AC-30; crude A	69.2	68.1		68.7	
AC-30: crude B	67.4	65.6		66.5	
Lightly air-blown AC-5					65.5
AC-10; crude A	63.3	61.6		62.5	
AC-10; crude B	63.4	61.0		62.2	
AC-30; crude A	69.7	68.5		69.1	
AC-30; crude B	69.2	67.4		68.3	
Back blended (air-blown asphalt with 60°C s.p. blended with AC-2.5)					66.3
AC-10; crude A	63.4	62.7		63.1	
AC-10; crude B	62.0	61.0		61.5	
AC-30; crude A	69.9	71.2		70.6	
AC-30; crude B	69.3	71.1		70.2	
Back blended (air-blown asphalt with 93°C s.p. blended with AC-2.5)					65.8
AC-10; crude A	62.7	60.0		61.4	
AC-10; crude B	63.1	60.2		61.7	
AC-30; crude A	71.1	69.5		70.3	
AC-30; crude B	71.2	68.5		69.9	
straight run					65.7
AC-10; crude A	62.7	62.2	62.1	62.3	
AC-10; crude B	63.0	61.8	61.5	62.1	
AG30; crude A	69.6	70.1	70.3	70.0	
AG30: crude B	68.4			68.4	
pooled standard deviation = 1 .1°C					

Table 2: Limiting temperature data from DSR-RTFPO testing

Design Point	Limiting Temperature replicate 1 (°C)	replicate 2 (°C)	replicate 3 (°C)	replicate average (°C)	group average (°C)
Lightly air-blown AC-2.5					66.8
AC-10; crude A	60.1	63.5		61.8	
AC-10; crude B	64.1	65.0		64.6	
AC-30; crude A	71.2	71.3		71.3	
AC-30; crude B	69.9	69.6		69.8	
Lightly air-blown AC-5					67.6
AC-10; crude A	62.8	63.3		63.1	
AC-10; crude B	67.1	63.6		65.4	
AC-30; crude A	72.2	70.5		71.4	
AC-30; crude B	70.8	70.4		70.6	
Back blended (air-blown asphalt with 60°C s.p. blended with AC-2.5)					68.0
AC-10; crude A	64.7	64.9		64.8	
AC-10; crude B	63.2	62.5		62.9	
AC-30; crude A	70.1	72.7		71.4	
AC-30; crude B	72.6	73.4		73.0	
Back blended (air-blown asphalt with 93°C s.p. blended with AC-2.5)					68.3
AC-10; crude A	65.2	62.7		64.0	
AC-10; crude B	65.4	62.6		64.0	
AC-30; crude A	72.3	72.8		72.6	
AC-30; crude B	73.2	71.8		72.5	
straight run					67.5
AC-10; crude A	64.2	64.0	62.7	63.6	
AC-10; crude B	63.5	62.4	63.9	63.3	
AC-30; crude A	71.0	71.0	72.6	71.5	
AC-30; crude B	71.4			71.4	
pooled standard deviation =	1.2°C				

Table 3: Limiting temperature data from DSR-PAV testing

Design Point	Limiting Temperature replicate 1 (°C)	replicate 2 (°C)	replicate 3 (°C)	replicate average (°C)	group average (°C)
Lightly air-blown AC-2.5					17.0
AC-10; crude A	16.6	16.7		16.7	
AC-10; crude B	10.3	17.4		13.9	
AC-30; crude A	18.6	18.9		18.8	
AC-30; crude B	16.1	21.1		18.6	
Lightly air-blown AC-5					19.5
AC-10; crude A	16.8	19.8		18.3	
AC-10; crude B	19.6	18.9		19.3	
AC-30; crude A	20.0	23.0		21.8	
AC-30; crude B	17.8	19.8		18.8	
Back blended (air-blown asphalt with 60° C s.p. blended with AC-2.5)					18.4
AC-10; crude A	17.2	17.4		17.3	
AC-10; crude B	15.6	17.6		16.6	
AC-30; crude A	18.9	20.1		19.5	
AC-30; crude B	17.2	23.3		20.3	
Back blended (air-blown asphalt with 93° C s.p. blended with AC-2.5)					18.3
AC-10; crude A	16.1	17.3		16.7	
AC-10; crude B	15.3	17.1		16.2	
AC-30; crude A	21.6	20.3		21.0	
AC-30; crude B	17.5	20.8		19.2	
straight run					21.2
AC-10; crude A	19.5	21.1	17.8	19.5	
AC-10; crude B	16.6	20.2	19.5	18.8	
AC-30; crude A	23.0	24.0	23.7	23.6	
AC-30; crude B	22.8			22.8	
pooled standard deviation =	2.1°C				

Table 4: Limiting temperature data from BBR-S testing

Design Point	Limiting Temperature replicate 1 (°C)	replicate 2 (°C)	replicate 3 (°C)	replicate average (°C)	group average (°C)
Lightly air-blown AC-2.5					-23.9
AC-10; crude A	-23.0	-25.4		-24.2	
AC-10; crude B	-23.5	-24.3		-23.9	
AC-30; crude A	-21.8	-24.9		-23.4	
AC-30; crude B	-23.7	-24.3		-24.0	
Lightly air-blown AC-5					-21.5
AC-10; crude A	-21.5	-21.1		-21.3	
AC-10; crude B	-20.8	-23.4		-22.1	
AC-30; crude A	-20.9	-20.9		-20.9	
AC-30; crude B	-21.7	-21.9		-21.8	
Back blended (air-blown asphalt with 60°C s.p. blended with AC-2.5)					-23.9
AC-10; crude A	-22.2	-25.5		-23.9	
AC-10; crude B	-24.1	-25.1		-24.8	
AC-30; crude A	-22.0	-23.8		-22.9	
AC-30: crude B	-24.1	-24.0		-24.1	
Back blended (air-blown asphalt with 93°C s.p. blended with AG2.5)					-23.7
AC-10; crude A	-23.0	-24.6		-23.8	
AC-10; crude B	-23.6	-25.2		-24.4	
AC-30; crude A	-21.3	-24.1		-22.7	
AC-30; crude B	-23.2	-24.5		-23.9	
straight run					-19.2
AC-10; crude A	-19.3	-19.7	-19.7	-19.6	
AC-10; crude B	-21.3	-21.6	-22.1	-21.7	
AC-30; crude A	-17.4	-15.4	-19.5	-17.4	
AC-30; crude B	-18.3			-18.3	
pooled standard deviation =	1.3°C				

Table 5: Limiting temperature data from BBR-m testing

Design Point	Limiting Temperature replicate 1 (°C)	replicate 2 (°C)	replicate 3 (°C)	replicate average (°C)	group average (°C)
Lightly air-blown AC-2.5					-16.9
AC-10; crude A	-20.4	-22.1		-21.3	
AC-10; crude B	-18.2	-18.3		-18.3	
AC-30; crude A	-16.3	-17.1		-16.7	
AC-30; crude B	-10.5	-12.0		-11.3	
Lightly air-blown AC-5					-14.6
AC-10; crude A	-18.8	-18.7		-18.8	
AC-10; crude B	-14.3	-19.7		-17.0	
AC-30; crude A	-15.1	-16.9		-16.0	
AC-30; crude B	-4.7	-8.5		-6.6	
Back blended (air-blown asphalt with 60°C s.p. blended with AC-2.5)					-15.7
AC-10; crude A	-19.2	-20.2		-19.7	
AC-10; crude B	-18.5	-19.3		-18.9	
AC-30; crude A	-8.7	-16.8		-12.8	
AC-30; crude B	-12.5	-10.4		-11.5	
Back blended (air-blown asphalt with 93°C s.p. blended with AC-2.5)					-15.6
AC-10; crude A	-17.1	-24.0		-20.6	
AC-10; crude B	-16.0	-16.6		-16.3	
AC-30; crude A	-14.8	-16.7		-15.8	
AC-30; crude B	-5.7	-14.1		-9.9	
straight run					-14.4
AC-10; crude A	-18.7	-16.7	-18.0	-17.8	
AC-10; crude B	-13.2	-17.5	-17.7	-16.1	
AC-30; crude A	-15.0	-12.9	-13.0	-13.6	
AC-30; crude B	-9.9			-9.9	
pooled standard deviation =	2.5°C				

Table 6: Limiting temperature data from DT testing

Design Point	Umiting Temperature replicate 1 (°C)	 replicate 2 (°C)	 replicate 3 (°C)	replicate average (°C)	group average (°C)
Lightly air-blown AC-2.5					-12.5
AC-10; crude A	-9.9	-12.1		-11.0	
AC-10; crude B	-14.9	-14.2		-14.6	
AC-30; crude A	-9.0	-15.0		-12.0	
AC-30; crude B	-13.1	-12.0		-12.6	
Lightly air-blown AC-5					-8.7
AC-10; crude A	-6.3	-11.1		-8.7	
AC-10; crude B	-8.6	-12.0		-10.3	
AC-30; crude A	-5.0	-4.8		-4.9	
AC-30; crude B	-10.8	-10.9		-10.9	
Back blended (air-blown asphalt with 60°C s.p. blended with AC-2.5)					-12.5
AC-10; crude A	-10.8	-12.6		-11.7	
AC-10; crude B	-16.1	-13.5		-14.8	
AC-30; crude A	-9.0	-11.2		-10.1	
AC-30; crude B	-13.1	-14.0		-13.6	
Back blended (air-blown asphalt with 93°C s.p. blended with AC-2.5)					-11.4
AC-10; crude A	-9.7	-12.6		-11.2	
AC-10; crude B	-15.3	-14.6		-15.0	
AC-30; crude A	-5.6	-9.9		-7.8	
AC-30; crude B	-9.4	-13.8		-11.6	
straight run					-7.3
AC-10; crude A	-5.2	-8.9	-8.9	-7.7	
AC-10; crude B	-11.5	-11.6	-11.9	-11.7	
AC-30; crude A	-2.8	-4.5	-6.6	-4.6	
AC-30; crude B	-5.4			-5.4	
pooled standard deviation =	2.0°C				