BULK DENSITY INVESTIGATIONS IN SOUTH AUSTRALIA

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ABSTRACT

This paper presents the findings of investigations in South Australia of the various laboratory methods to evaluate the air voids of an asphalt sample for a range of asphalt mix types.

The methods of evaluating bulk density include presaturation (saturated surface dry), mensuration (by dimensions) and automatic vacuum sealing (vacuum sealed machine & plastic bag) method. Conclusions are provided to improve the presaturation test method and also the appropriate bulk density test for the differing mix types.

INTRODUCTION

It has been evident over time that the standard presaturation bulk density test (AS2891.9.2, 1993) used for Dense Graded Asphalt (DG) is inaccurate where the air voids are suspected to be high but the test does not indicate that this is the case. The other standard bulk density test is the mensuration method (AS2891.9.3, 1993) used for Open-graded Asphalt (OG). It is noted that Main Roads Western Australia uses the vacuum sealing method for Open-graded Asphalt (Halligan, 2006).

For Stone Mastic Asphalt (SMA), the presaturation test has proved inaccurate and another test method was sought. It is also noted that Queensland State Road Authority have adopted the silicon sealing method, but this has not been investigated in this paper.

A range of asphalt samples have been prepared for all three mix types (DG, OG14 & SMA10) using one mix size except for Dense Graded Asphalt, which contained two different nominal mix sizes.

BACKGROUND

In 1981, the Highway Department of South Australia internal correspondence suggested for “high void cores or segregated cores, all test methods discussed above (pre-saturation and wax method) are limited and consideration should be given to dimension measured core densities” (mensuration) (Keywood, 14/09/1981).

In early 2009, the authors suspected that the reported SMA10 in-situ voids of around 8% mark using the presaturation method did not reflect the visual field inspection where some parts of SMA10 held and then released water after rain. Therefore, it was decided to purchase a vacuum sealing machine to determine the “true” air voids of the mix using the vacuum sealing method.

At first, the department trialled the machine using the vacuum sealing test procedure from WA 733.2 (WAMR, 2006) on AC20 samples (known as AC28 interstate) compacted at a range of gyratory cycles, being specifically compacted to achieve high air voids. Results from internal investigation (DTEI, 2010) are shown in Figure 1.

This is confirmed in a WSDOT Technical Note where in Figures 6 & 7, a deviation of the vacuum sealing method from the presaturation method is evident (WSDOT, 2004). Both the Technical Note and Figure 1 suggest that 8% is possibly the limiting value for the presaturation test for Dense Graded Asphalt (Fine and Coarse) mixes.

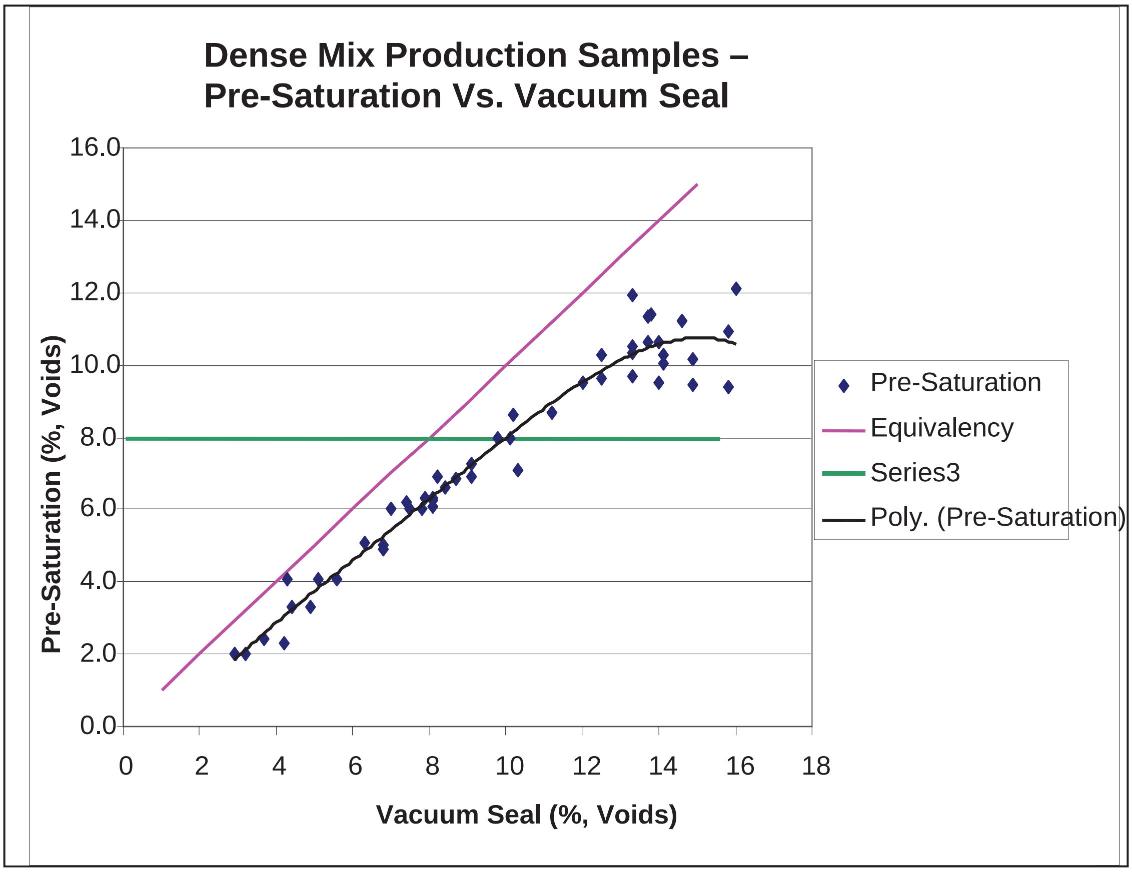

Figure 1. Presaturation verses Vacuum Sealing Methods for AC20 samples

LITERATURE REVIEW

The American standard for bulk density testing (ASTM D 2726-04 "Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures") contains a check of the pre-saturation test by checking the "absorption" of water within the sample, and specifies a limit of 2%.

The formula for bulk density (Equation 1) from AS2891.9.2 utilises three mass determinations, the mass in air (m_1), mass in water (m_2) and the mass of sample in saturated surface dry (SSD) state (m_3). The absorption check from ASTM D 2726-04 is given as Equation 2.

$$Bulk\_Density = \frac{m_1 * Density\_Water}{(m_3 - m_2)}$$ (Equation 1)

$$Water\_Absorbed\_by\_Sample = \frac{(m_3 - m_1)}{(m_3 - m_2)} * 100$$ (Equation 2)

The absorption check within the presaturation method has recommendations as to what level of absorption is acceptable, and the ASTM D 2726-04 recommends a limit of 2% absorption, and also that it should not be used for samples with open or interconnecting voids, therefore the assumption of applicability only for DG Asphalt.

Washington State Tech-notes (WSDOT, 2004) suggests that for SMA & Coarse DG Asphalt, the limit for absorption should be set at 0.4%.
University of Arkansas (F. Griffith, 2009) investigated the absorption of DG asphalt samples by dividing the absorption data into three levels of below 0.4%, between 0.4 and 2% and greater than 2%. It suggests that the differences between presaturation & vacuum sealing method are fairly consistent and low when samples have low air voids. The vacuum sealing method also gives consistently lower standard deviations for various operators than the presaturation method. Therefore, the bulk density differences for the two methods diverged apart as the samples increase in air voids. It also recommended that 1% higher air voids target should be used for DG mixes if the vacuum sealing method is used.

The European Standard (EN 12697-6, 2003) suggests within the one standard a range of bulk density test options, and provides recommendations as to the appropriateness of the use of each method.

Western Australia Main Roads (WAMR) also conducted an investigation into the use of vacuum sealing method to determine bulk density on three types of mixes (DG, SMA & OG) in 2006. It proposed to use this method to determine the in-situ voids for OG within their specification and further investigation of its use for SMA. A testing procedure (WA 733.2, 2006) was developed due to the difficulties of complying with ASTM D 2726 (S. Halligan, 2006).

METHODOLOGY OF THE VACUUM SEALING METHOD

The vacuum sealing method was applied to approximately 390 samples; some compacted from auditing work within the department, some production samples from contractors and included in-situ cores from a few large scale projects. Samples were also tested by presaturation and mensuration method.

The department utilised its own test procedures (DTEI, 2010) together with WA 733.2 & ASTM D2726-04, and calibration of equipment bags carried out to WA calibration procedures (WA715.1, 2009). Figure 2 provides photos of equipment & material used in the vacuum sealing method, with the testing process taking approximately 4 minutes per test.

Figure 2. Vacuum Sealed Machine & Sealed Sample (Polymer Bag)

AIR VOID TEST RESULTS & ABSORPTION VALUES OF PATS & CORES

An extensive grouping of asphalt samples have been tested for air voids using presaturation (SSD), mensuration (by dimension) and automatic vacuum sealing method (vacuum machine & plastic bag).

The dense mix groupings analysed were AC10M & AC14M pats, followed by OG14 & SMA10 pats and cores. Absorption values have been determined from presaturation testing using three masses (Equation 2) and applied to the other two tests (vacuum sealing & mensuration). Finally all the data supplied has been brought together to get a feel for absorption values over a wide air voids range for three methods.

1. AC10M – ASPHALT PATS

A review of 25 auditing pats for AC10M (known as AC14 interstate) using all three different methods were conducted. As the presaturation method is required by the specification, it was chosen as the reference method. The polynomial best fit in Figure 3 gives a R^2 value of 0.95, indicating a good data fit. Figure 3 indicates that the lowest offset is 0.8% at air voids of 3.5% & the highest offset is 1.5% at air voids of 8.5% where as Figure 4 shows an average bias of 1.24% air void content over the range of 3 to 8%.

Figure 3 illustrates the divergence of pre-saturation & vacuum sealing data, with increasing divergence with increasing air voids. There is, however, little data above 8.5% air voids, being the limit of the departmental specification for medium duty dense mixes with design/production voids of 3.5 - 6% and in-situ voids of 4 - 8.5%.

ASTM D 2726-04 recommends a limit of 2% absorption, suggesting possible limit of 7.5% pre-saturated air voids (Figure 5). Although there is lack of high voids data, the plot demonstrates a similar increase in air voids with higher absorption for both vacuum sealing and presaturation methods, and divergence seems to be restrained. Therefore, the presaturation method is still considered relevant to determine bulk density for AC10 dense mixes if the absorption is less than 2%.

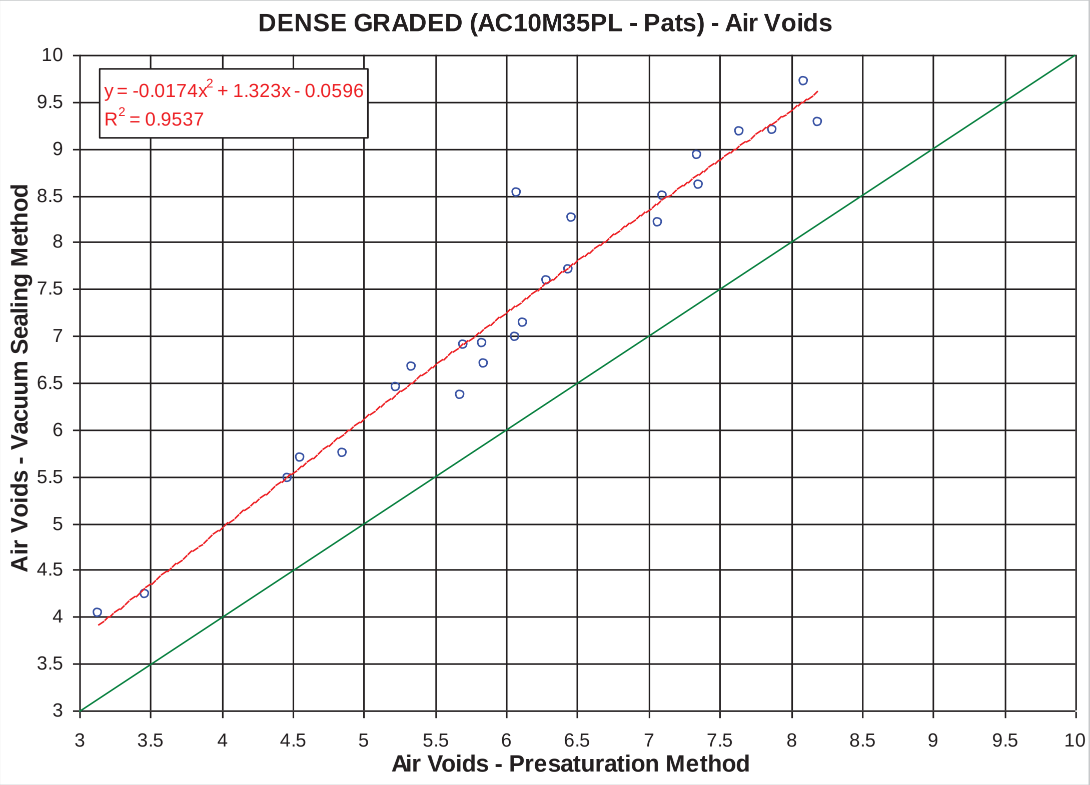

Figure 3. AC10M Pats: Air voids: Pre-saturation vs. Vacuum Sealing Method

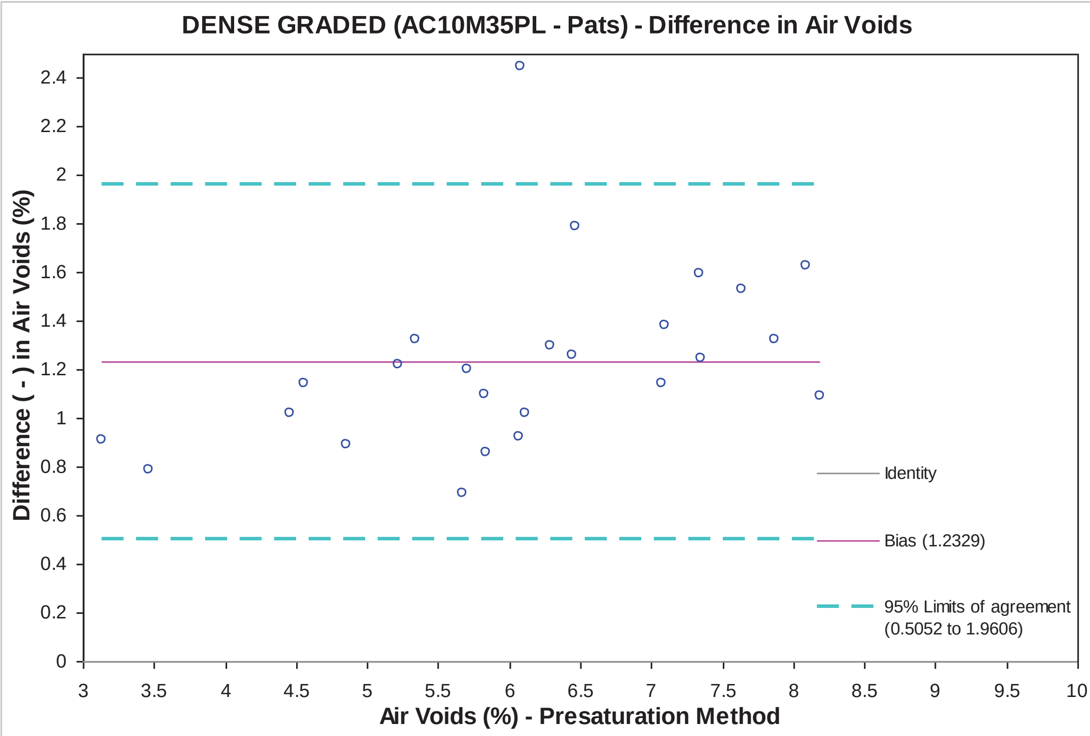

Figure 4. AC10M Pats: Air Voids Difference: Pre-saturation vs. Vacuum Sealing

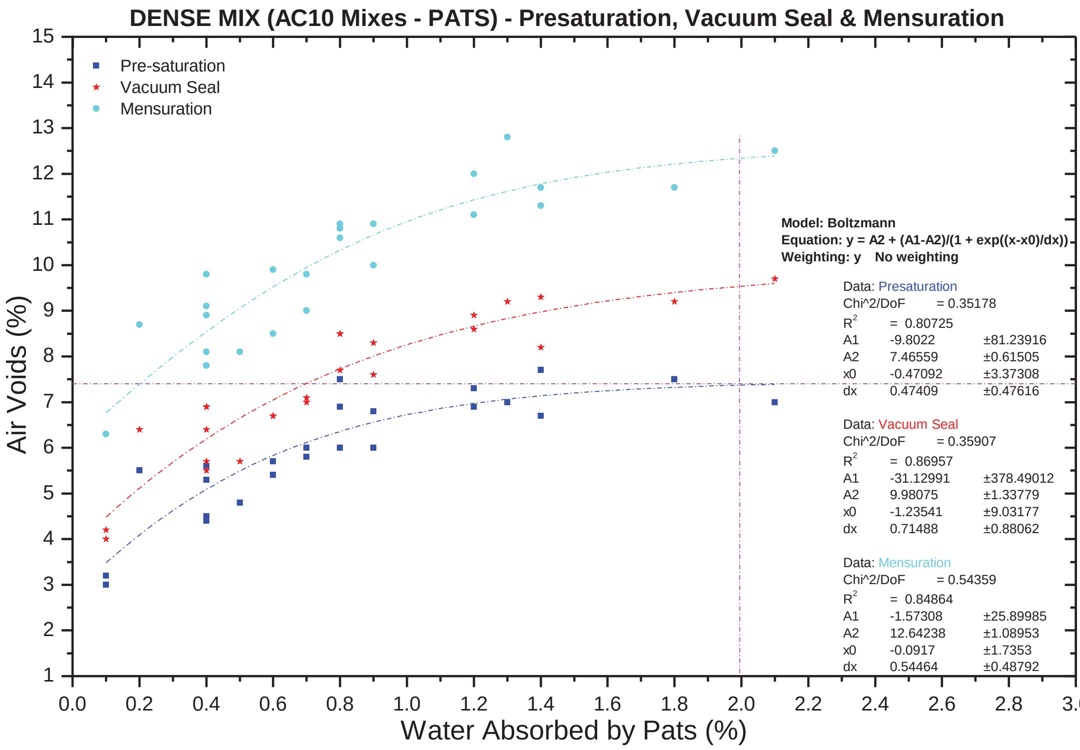

Figure 5. AC10M Pats: 3 Methods vs. Presaturation Absorption

2. AC14M – ASPHALT PATS

For the AC14M mix (known as AC20 interstate), 33 pats were tested. The polynomial best fit of Figure 6 better indicates the divergence expected of presaturation & vacuum sealing data as the pats increase in air voids to that of Figure 3. The R^2 value of 0.94 again presents a good fit to the data.

Figure 6 indicates that the lowest offset is 1.3% at air voids of 3.5% & the highest offset is 3.0% at air voids of 7.5% where as Figure 7 shows an average bias of 1.7% air void content, similar to that found for AC10M. The offset air voids are slightly higher than those of AC10M at the same limits, probably due to the increased surface texture of the larger stone mix.

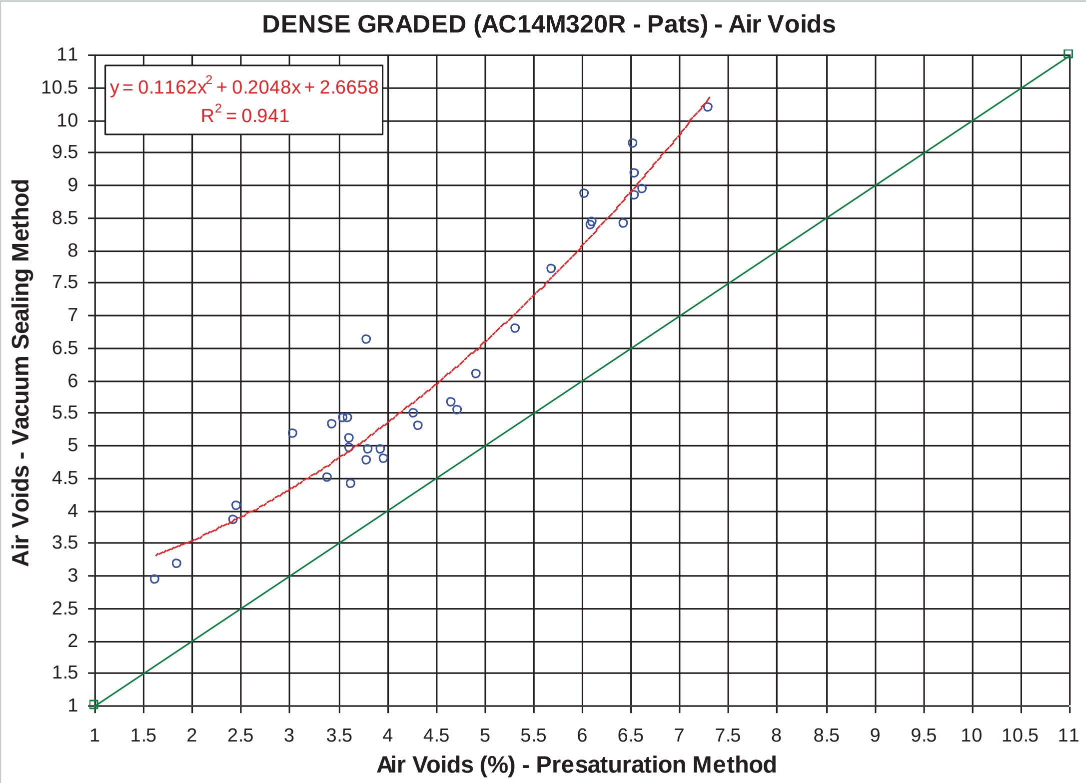

Figure 6. AC14M Pats: Air voids: Pre-saturation vs. Vacuum Sealing Method

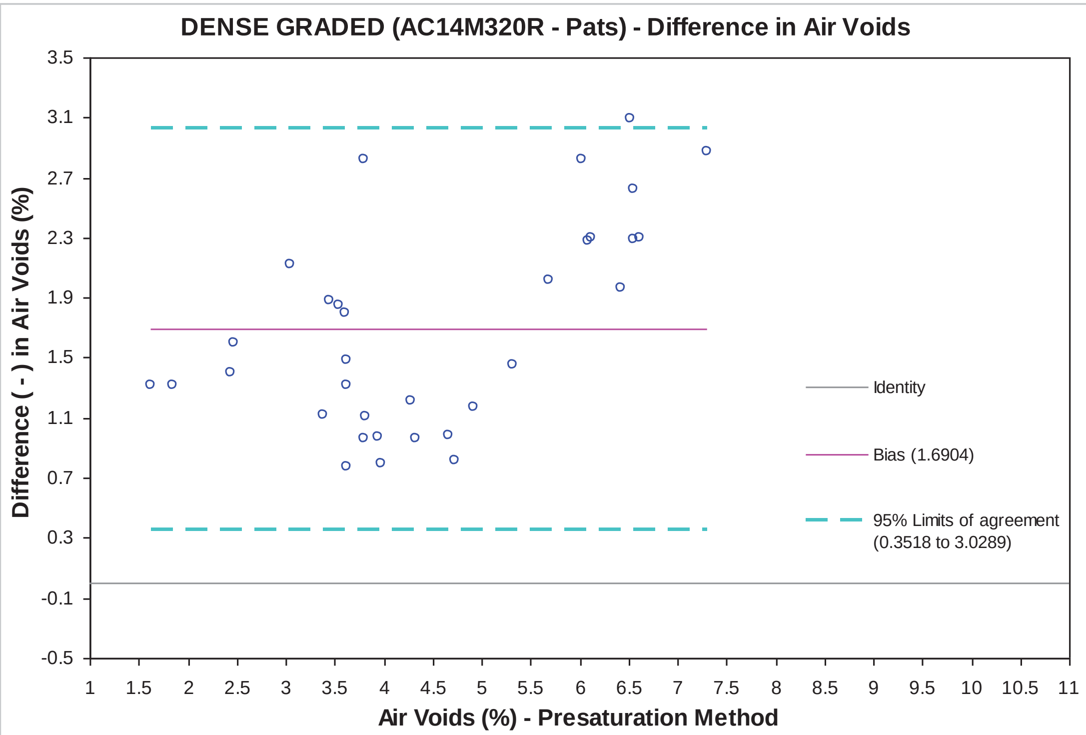

Figure 7. AC14M Pats: Air Voids Difference: Pre-saturation vs. Vacuum Sealing

Figure 8 illustrates as expected, similar to Figure 5, that the offset between presaturation and vacuum sealing diverge apart as the absorption increases. The limit of 2% absorption is also equivalent with 7.5% pre-saturated air voids. As for the AC14M mix, the presaturation method is still considered relevant to determine bulk density for this dense mix if the absorption is less than 2.0%.

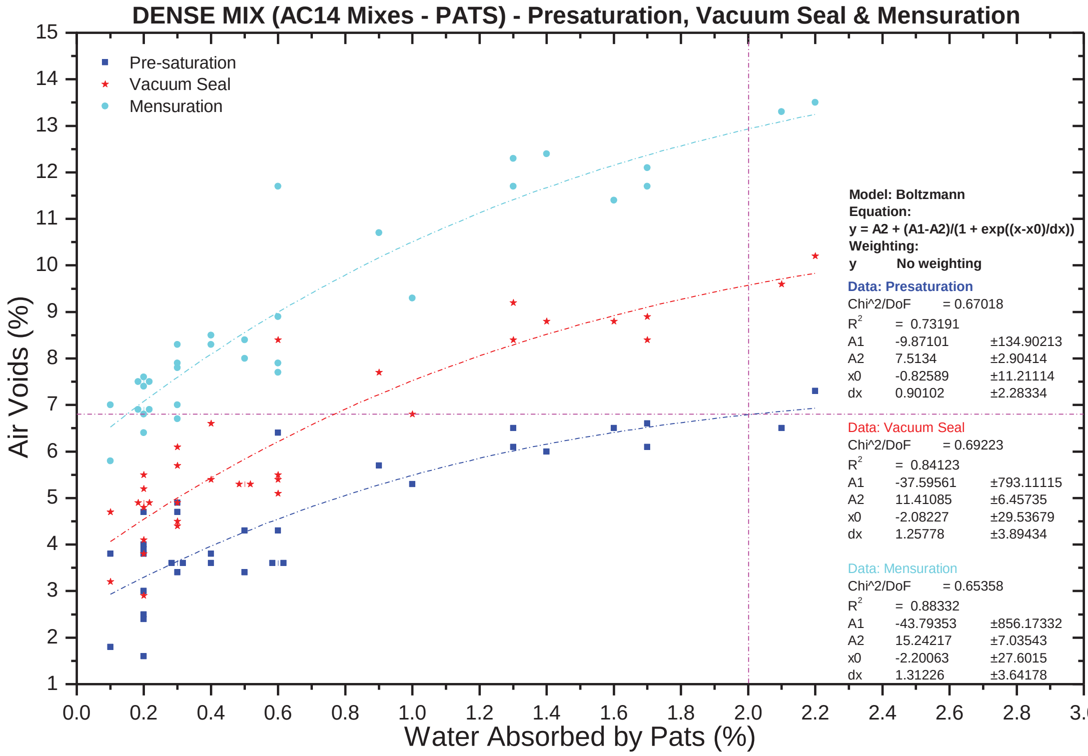

Figure 8. AC14M Pats: 3 Methods vs. Presaturation Absorption

3. OPEN GRADED (OG14) – ASPHALT PATS & CORES

Open-graded asphalt is a porous surfacing mix that allows water to penetrate into the surfacing layer. The mensuration method is adopted as the standard test to determine air voids for both production and field instead of pre-saturation. Figure 9 provides a comparison between the methods of mensuration and vacuum sealing, with polynomial providing a reasonable fit at R^2 of 0.8. Figure 10 indicates the average lowest offset is 3.5% at air voids of 17% & the average highest offset is 8% at air voids of 25%.

Figure 11 shows the poor performance of the presaturation test and a high scatter for the mensuration test. It is significant that the average bias between the mensuration and vacuum sealing methods is as high as 5.5% air voids (Figure 10), suggesting that if the vacuum sealing method is to be used in the specification, design and in-situ air void levels would need to be lowered by approximately 5% to maintain equivalency.

Open-graded asphalt mix has high air voids, with the departmental specification & Austroads document limiting in-situ voids to 18 - 23% and mix design air voids at 20% (AUSTROADS 4B, 2007). Therefore, the mensuration method is still considered relevant to determine bulk density for OG Asphalt.

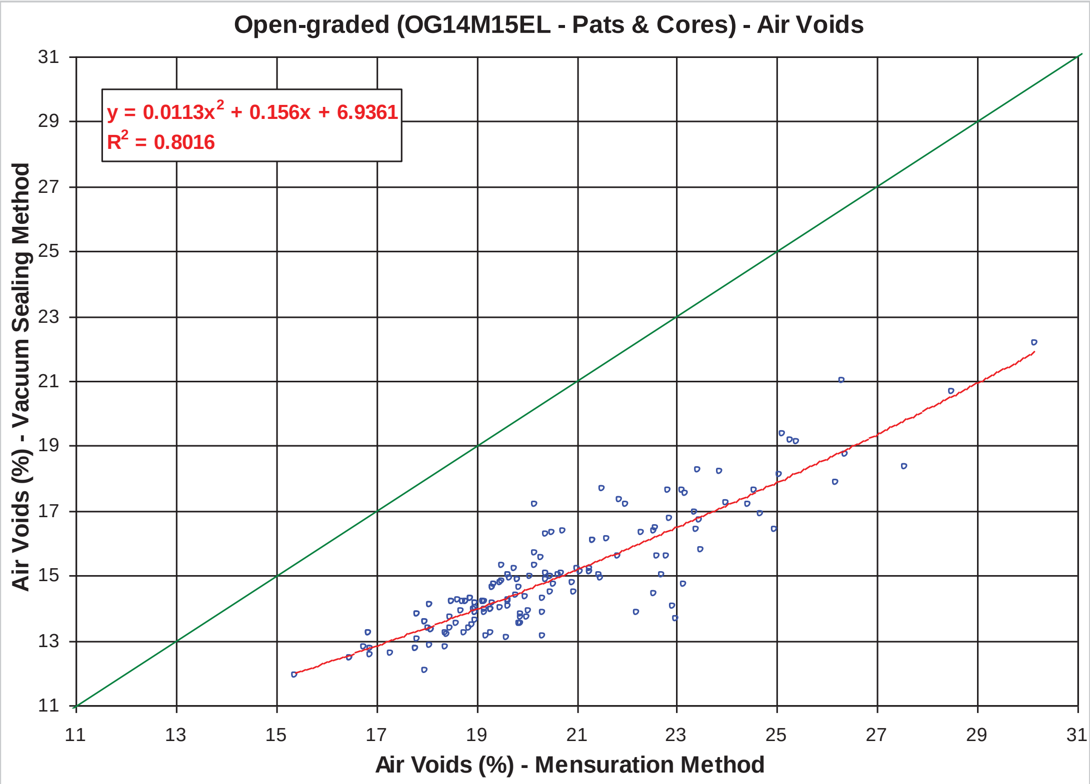

Figure 9. OG14 Pats & Cores: Air voids: Mensuration vs. Vacuum Sealing

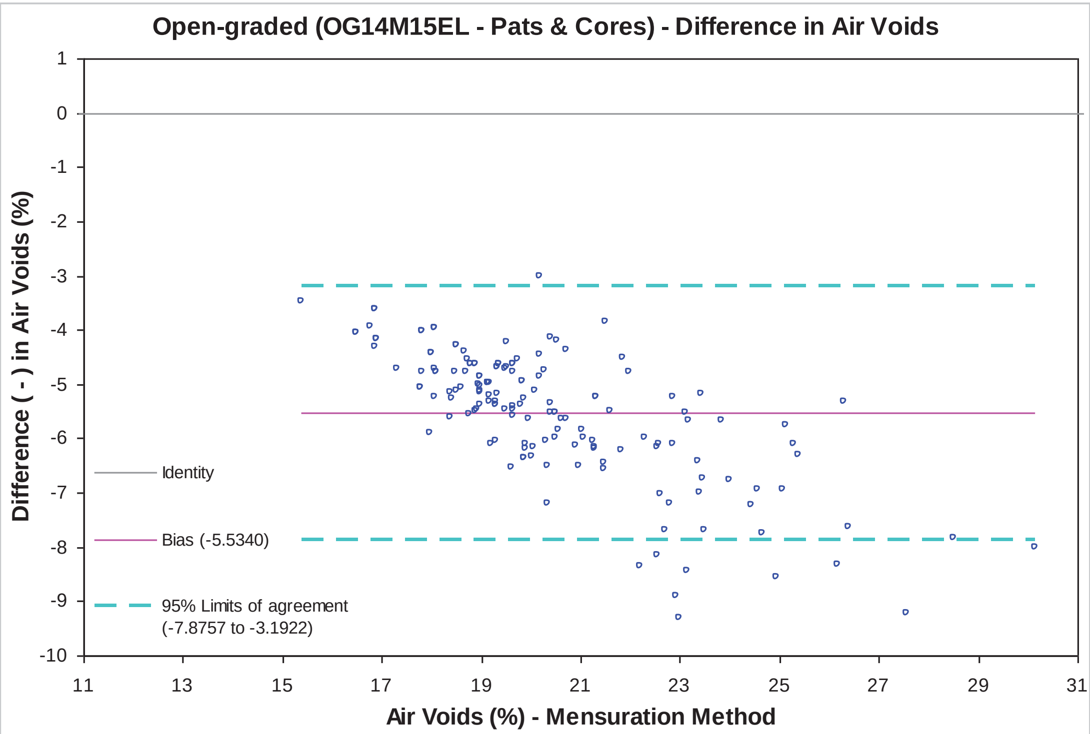

Figure 10. OG14 Pats & Cores: Air Voids Difference: Mensuration vs. Vacuum Sealing

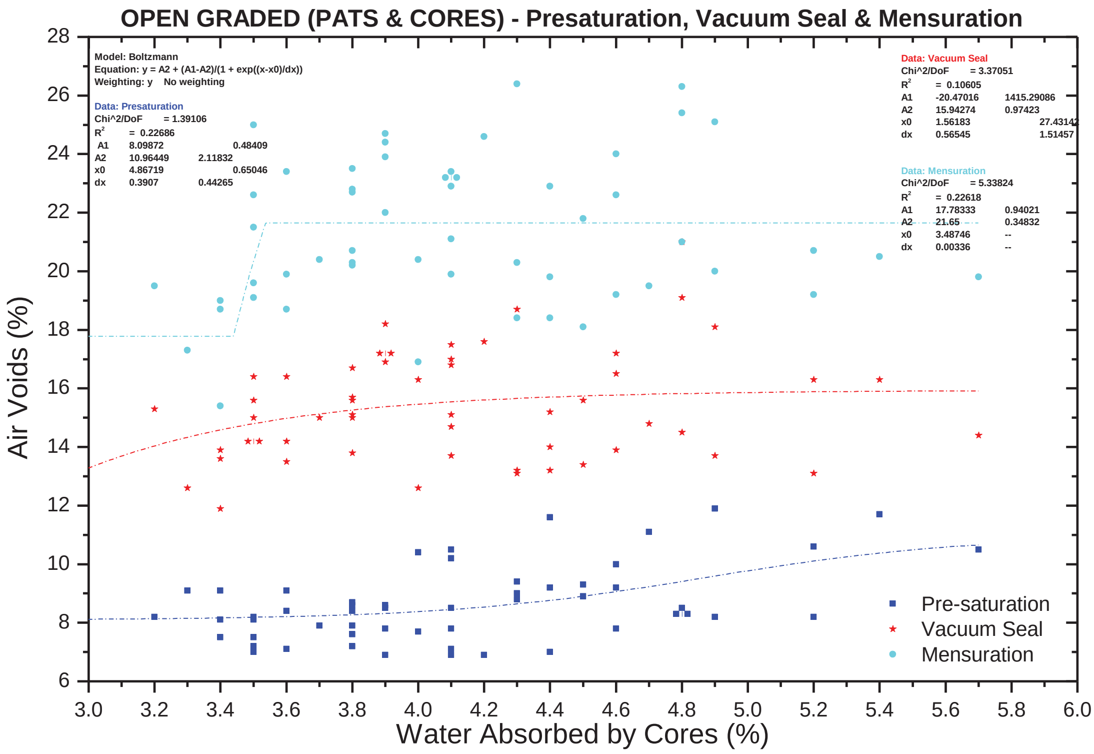

Figure 11 – OG14 Pats & Cores (3 Methods vs. Presaturation Absorption)

4. STONE MASTIC ASPHALT (SMA10) – ASPHALT PATS & CORES

Similar to the OG Asphalt, 79 pats and cores were tested for bulk density using the presaturation, vacuum sealing and mensuration tests. The presaturation method is currently used as the standard test to determine air voids for both production and field. Stone Mastic Asphalt is a rich binder and coarse gap graded mix, and has higher textures than the Dense Graded Asphalt but less than Open-Graded.

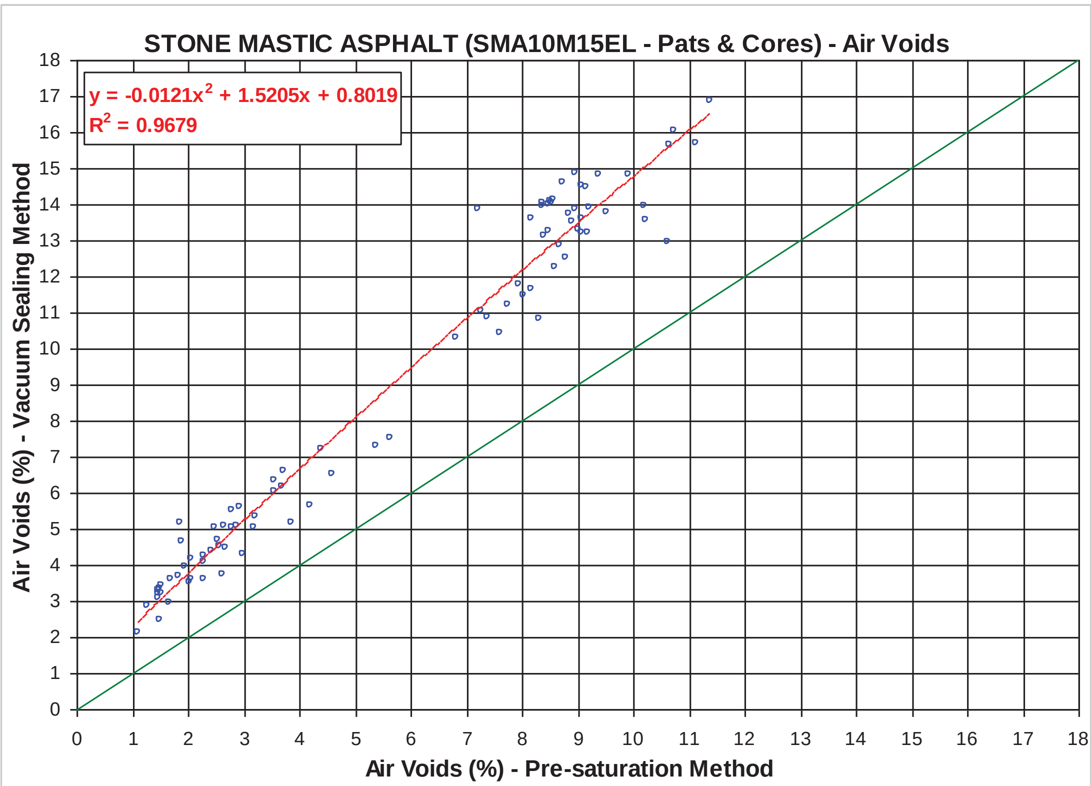

Figure 12. SMA10 Pats & Cores: Air voids: Pre-saturation vs. Vacuum Sealing

It is believed that the shallow holes on the surface should be counted as air voids and this may not be able to be achieved by the presaturation method. The limits of the departmental specification for Stone Mastic Asphalt (SMA10) are for design/production voids of 3.5 - 5% and in-situ voids of 2.5 - 7.0%. Figure 12 shows that all SMA10 data from the actual projects indicates the air voids range is between 7 to 11% for both production asphalt cores (80 Gyropac cycles) and in-situ cores.

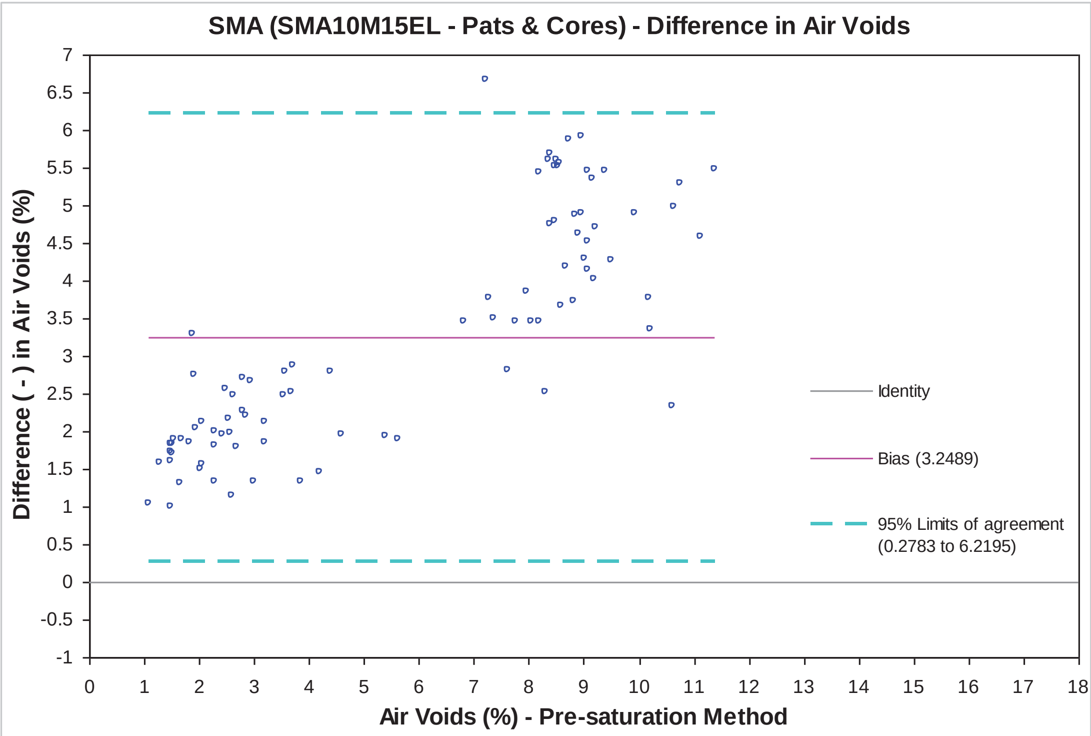

Figure 13. SMA10 Pats & Cores: Air Voids Difference: Pre-saturation vs. Vacuum Sealing

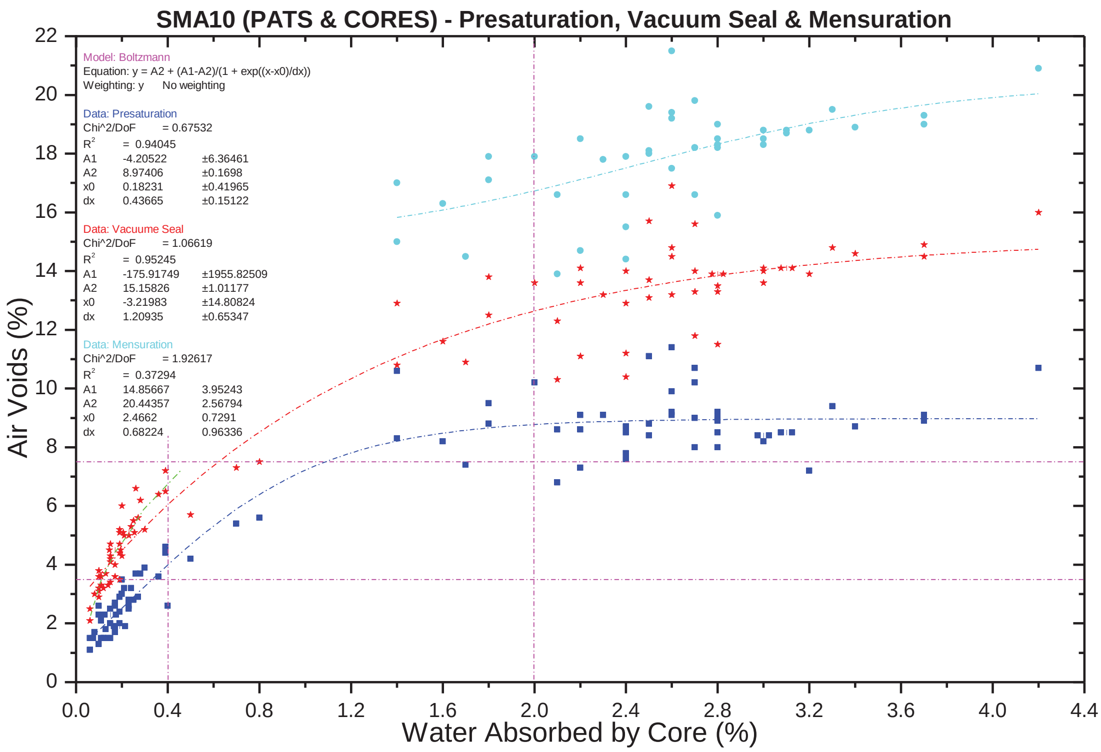

Figure 14 – SMA10 Vacuum Sealing Results against Pre-saturation

Figure 14 shows the presaturation tests have levelled off after 7.5% air voids while water absorption increases. This suggests that the presaturation test is not applicable for SMA mixes. Both the vacuum sealing and mensuration tests show increasing voids as expected.

The authors decided to make an extra 40 SMA10 pats with various compaction rates of 150, 200, 250 & 350 Gyropac cycles to achieve voids at levels required by the specification. The polynomial best fit of total data of Figure 12 indicates the divergence expected of vacuum sealing from presaturation as the pats increase in air voids. A 4% voids limit equivalent with 0.4% absorption (Figure 14) aligns with absorption limit for SMA in Washington Sate Tech-notes (WSDOT, 2004). The R^2 value of 0.97 in Figure 12 presents a good fit to the data. The lowest offset is 2% at air voids of 3.5% & the highest offset is 3.5% at air voids of 7.5%. There is a gap of air voids between 0.4 and 1.4% absorption. Figure 15 shows pictures of laboratory compacted SMA10 Samples.

Figure 15 – Surface of SMA10 Pats: Gyropac @ 80 (Left) & 350 (Right) Cycles

From Figure 14, it is suggested that the vacuum sealing method is more appropriate for SMA mixes for both production & in-situ samples due to the greater the 0.4% limit of absorption. Should the vacuum sealing method be used for SMA mixes, then it would seem reasonable it also to be used for OG mixes, so that the 5% step change between Stone Mastic Asphalt and Open-graded Asphalt is eliminated.

5. ALL ASPHALT MIXES – ASPHALT PATS & CORES

A plot of all bulk density data in air voids terms for all three mix types (DG, OG & SMA) and for all three test types is provided in Figure 16. Note the levelling off of the presaturation test data above 2.8% absorption, so a 2% limit seems reasonable. This excludes Open-graded Mixes, and possibly also Stone Mastic Mixes.

The SMA data suggests that 0.4% absorption may be an appropriate limit, as suggested (WSDOT, 2006). From this, it would appear that presaturation is not applicable for Stone Mastic Asphalt, so either vacuum sealing or mensuration appears applicable with vacuum sealing suggested as preferred method.

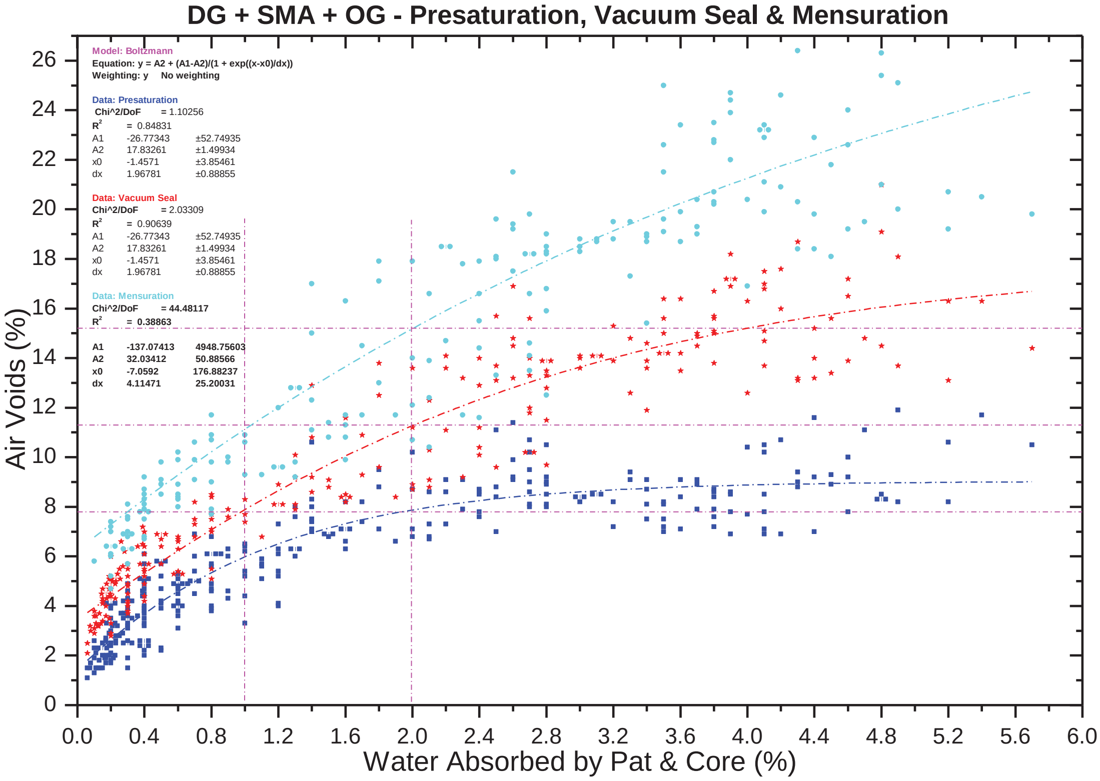

Figure 16 – Air voids verses Presaturation Absorption for all three mix types

CONCLUSIONS

This paper provides a comprehensive analysis of three bulk density tests carried out on the same samples. The samples included Dense Mix Asphalt, Stone Mastic Asphalt and Open-graded Asphalt.

All plots show data as expected, with pre-saturation the lowest, vacuum seal next and mensuration with the highest air voids. Figure 16 with all the data provided in a single plot demonstrates this clearly, and also demonstrates divergence increase from pre-saturation increases for both vacuum sealing & mensuration as absorption increases.

The differing textures of these mix types and the different treatment of the air voids emanating from the texture is a partial reason for the difference in air voids levels between the tests. The rest of the air voids difference is deemed to be due to the inter-connectivity of air voids with the asphalt samples.

The following conclusions are made from this analysis:

1. Presaturation, Vacuum Seal and Mensuration bulk density tests provide different voids for the same samples from low to high respectively as expected.
2. The presaturation test has serious limitations for asphalt samples with high void levels, and is considered to lose accuracy at around the 7% air void mark.

3. The “Absorption” check on the presaturation test values provides a useful check on the test’s suitability, and should be incorporated into the appropriate Australian Standard.
4. When the presaturation test is outside its range of suitability, the vacuum sealing method could be used, but a step change exists between the two methods making this option a little impractical. The absorption limits for each mix type need to be calibrated to Australian practice and asphalt mixes.
5. Vacuum sealing is a bulk density test that could be used on all asphalt mix types to create a seamless voids comparison but is considered not to be economical for regular Dense Grade production use.
6. The vacuum seal method is considered to be suitable for Stone Mastic mixes, especially for in-situ cores, but also mix design and production samples.
7. It is interesting to note that at the air voids levels of Open-graded mixes, the mensuration test is approximately equal to the vacuum seal test plus 5%. In other words, the Open-graded air voids of 20% is equivalent to Stone Mastic air voids of 15%.
8. Continued investigation of the vacuum sealing method for SMA, and for this to be introduced into Australian Standard as an alternative bulk density testing method.
9. Continued testing investigation of the vacuum sealing method to determine step change value at 2% absorption for each asphalt company DG mix e.g. AC20 mixes.
10. The vacuum sealing method has the potential to be used as the dispute resolution method but offset from standard test (presaturation) needs to be pre-determined (agreed) for each asphalt mix type (and possibly material type).

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