Non-Destructive Assessment of The Quality of Asphalt Laboratory Samples

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Abstract. In addition to instrumentation accuracy and test repeatability, the correlation of asphalt test data is very dependent on targeted “known” properties of asphalt samples or cores, such as air voids. In the case of air voids, sample preparation targets the desired sample attribute, however an assessment of the true air voids and their distribution within asphalt samples remains a challenge. Current assessment is usually via visual inspection and measuring the total air voids within the sample. However, such an approach fails to evaluate important factors such as air voids distribution and aggregate structure. In the case of testing regimes that are localised on test samples, the true air voids at the test location is essential for proper data correlation. In this study, an Ultrasonic Wave Transmission (UWT) technique was developed and applied as a non-destructive test to better assess the true localised air void properties of asphalt samples. The data correlation outcomes significantly changed the performance rankings of asphalt mixes and indicated that the UWT technique has excellent potential as a supplementary tool for evaluating asphalt laboratory samples.

1. Introduction

1.1. Non-destructive laboratory assessment of air voids of asphalt samples

An asphalt mixture (asphalt) is a complex distributed system of coarse aggregates, bitumen mastics (bitumen binder, fine aggregates and mineral powder) and air voids. The complex distribution of internal air voids and aggregate structures of asphalt samples as seen in figure 1 have been investigated in the laboratory using various non-destructive techniques.

Dubois et al. [1] successfully used a gamma-densitometer in 2010 to assess the influence of the compaction process on the air voids homogeneity of asphalt samples. Other non-destructive techniques such as X-ray Computed Tomography (CT) and image analysis methods [2-5] have been applied by researchers. The research outcomes have shown that air voids within compacted asphalt are not uniformly distributed [2, 4].

While X-ray methodologies have historically been used by researchers to investigate the complex distribution of air voids in asphalt mixtures, both cost and complexity of application do not support their widespread use. The research reported here describes a simple technique using ultrasonic assessment for laboratory use to predict the air voids content and their distribution in manufactured asphalt samples. This technique will be useful for better evaluating some tests such as fatigue and creep where the applied load (dynamic or static) is localised at a specific part of the asphalt sample.
1.2. Research plan
This research was planned in two phases. In phase one, which was presented in 2017 [6], the UWT technique was developed to measure the localised air voids in asphalt samples. In phase two, the Creep slope of the same asphalt samples was evaluated, and the results analysed using both the air voids of the whole sample (Using AS/NZS 289) and the air voids in the centre of the sample under the applied load (using the UWT technique developed in phase one).

The research reported here summaries the outcome of phase one and moves on to illustrate the benefits of measuring and application of localised air voids using UWT technique for analysing asphalt tests such as creep.

![Figure 1. Asphalt structure [7]](image)

2. Experimental Details
This research focuses on the importance of knowledge of localised air voids on the laboratory assessment of permanent deformation of manufactured asphalt samples using a confined creep approach.

2.1. Materials and sample preparation
Three commonly used hot mix asphalt (HMA) types used in Queensland Australia, were selected for use in the study. The aggregate gradation as seen in figure 2 was maintained constant. The aggregate and filler characteristics are shown in tables 1 and 2. Three different types of bitumen binders were used at 5%. They were Conventional (C320), Multigrade (M1000), and an SBS Polymer Modified (PMB-A5S) and their physiochemical properties are provided in table 3.

An asphalt shear box compactor using a range of compaction efforts was used to produce asphalt slabs with targeted air voids from 1% to 10%. Samples with a 150mm diameter were cored from the compacted asphalt slabs and then cut and trimmed to 50 mm height. Specimens were washed, dried and preconditioned at the test temperature of 25°C for 48 hours before being subjected to the air voids measurement test and the UWT test.
Table 1. Aggregate characteristics

| Test Method | Description                  | Limits       | 7mm Test result | 9mm Test result | 14mm Test result |
|-------------|------------------------------|--------------|-----------------|-----------------|------------------|
| AS 1141.11  | Grading                      | Conforming   | 11.6            | 12.4            | 7.8              |
| AS 1141.15  | Flakiness                    | <30%         | 11.6            | 12.4            | 7.8              |
| Q 214 B     | Water Absorption             | Max 2%       | 0.68            | 0.39            | 0.5              |
| Q 214 B     | Particle density (Dry) t/m³  | 2.666        | 2.668           | 2.672           |                  |
| Q 215       | Crushed Particles            | Min 80%      | 100             | 100             | 100              |
| Q 217       | Weak Particles               | Max 1%       | 0.7             | 0               | 0                |
| Q 205 B     | 10% Fines                    | Min 150 kN   | 296             | 272             | 239              |

Table 2. Filler characteristics

| Test Method | Description                  | Limits       | Baghouse Test result | Rockflour Test result | Combined BH/RF Test result |
|-------------|------------------------------|--------------|----------------------|-----------------------|----------------------------|
| AS 1141.11  | 600 µm Grading (AS 2357 Limits) | 100          | 100                  | 100                   | 100                        |
| AS 1141.11  | 300 µm Grading (AS 2357 Limits) | 95-100       | 100                  | 100                   | 100                        |
| AS 1141.11  | 0.075 µm Grading (AS 2357 Limits) | 75-100       | 92.8                | 97.1                  | 97.1                       |
| AS 1141.17  | Voids in Compacted Filler    | Min 38%      | 48                  | 49                    | 46                         |
| AS 1141.7   | Apparent Particle Density Products Conforms (Yes/ No) | TBR          | 2.706               | 2.756                 | 2.729                      |
Table 3. Properties of bitumen binder class C320, M1000 and PMB-A5S

| Property                        | Test Method | Limits       | Test result |
|---------------------------------|-------------|--------------|-------------|
| Viscosity at 60°C (Pa.s)        | AS 2341.2   | 260-380      | 328         |
| Penetration at 25°C, 100g, 5s   | AS 2341.12  | Min 40       | 49          |
| Softening point (°C)            | AS 2341.18  | Report       | 51.2        |
| Viscosity at 135°C (Pa.s)       | AS 2341.2   | 0.4-0.65     | 0.53        |

C320

| Property                        | Test Method | Limits       | Test result |
|---------------------------------|-------------|--------------|-------------|
| Viscosity at 60°C (Pa.s)        | AS 2341.2   | reported     | 910         |
| Viscosity at 135°C (Pa.s)       | AS 2341.4   | 1.5 max      | 0.78        |
| Softening Point, °C             | AS 2341.18  | Report       | 58.5        |
| Flash Point, °C                 | AS 2341.14  | 250 min      | 348         |

Multigrade

| Property                        | Test Method | Limits       | Test result |
|---------------------------------|-------------|--------------|-------------|
| Consistency at 60°C (Pa)        | AG: PT/T121 | 5000 min     | 11254       |
| Stiffness at 25°C (kPa)         | AG: PT/T121 | 30 max       | 19          |
| Viscosity at 165°C (Pa.s)       | AG: PT/T111 | 0.9 max      | 0.64        |
| Softening Point (°C)            | AG: PT/T131 | 82-105       | 103         |

2.2 Experimental procedure

2.2.1 UWT technique to measure air voids distribution

The UWT technique used to measure the air voids in the centre of the sample is briefly described below and the reader is referred to the paper by Zargar [8] for more details.

1. A Pundit 7 apparatus was applied according to BS EN 12504-4 standard to generate an ultrasonic wave and to determine the ultrasonic pulse velocity of the asphalt sample. Two 54-kHz piezoelectric crystal transducers (transmitter and receiver) were placed in parallel at each side of the specimen to measure the ultrasonic wave transit time at 17 different locations at 25°C as shown in figure 3. The transit time for the compression wave (P-wave) to pass the length of the asphalt sample was recorded to calculate the ultrasonic pulse velocity using the below formula:

\[ V = \frac{l}{t} \]  

(1)

Where, \( V \) = ultrasonic pulse velocity (km/s)  
\( l \) = length of specimen (mm)  
\( t \) = transit time (ms)

2. The air void content of whole samples was measured using the specimen’s bulk specific gravity (Saturated Method) and the asphalt’s theoretical maximum specific gravity (Rice Method) according to Australian Standard (AS/NZS 2891).

3. The linear correlation between average ultrasonic velocities at 17 points and air voids of the whole sample were used to generate the regression equation.

4. Air voids at the centre of samples were calculated using ‘ultrasonic velocity in the centre’ applied in the regression equation (obtained in stage 3). It is this value that has been used in the current research.
2.2.2 Confined Dynamic Creep Test

The Confined Dynamic Creep Test (CDCT) is a development of the current Australian creep test (AS 2891.12.1995) based on research conducted by Ahmadinia [9]. The CDCT test used to measure Creep slope of sample is briefly described below and the reader is referred to the Thesis entitled “Redesigning the Austroads creep procedure for the evaluation of permanent deformation of asphalt pavements in Australia” by Ahmadinia [9] for more details.

1. The CDCT test (figure 4) used a Universal Testing System (UTS) manufactured by Industrial Process Controls (IPC) Global Limited Company to measure the creep deformation for confined samples. In this test stress responsive confinement for samples is provided by an asphalt annulus, PVC ring (2.5mm) and resin infill.

2. The test conditions used were:
   - Total stage number: 1 stage
   - Compressive stress: 750kPa
   - Seating stress: 20 kPa
   - Loading period: 100 milliseconds (ms)
   - Pulse repetition period: 1000 milliseconds (ms)
   - Test temperature: 50°C
   - Termination pulse count: 40,000 cycles
   - Platen size: 50mm diameter
   - Sample size: 150mm diameter * 50mm thickness

3. Creep slope measured from the steady state of creep (figure 5) for all samples
3. Experimental Results and Discussion

3.1. Findings from phase one of the project
In phase one of this study reported in 2017 [6], asphalt samples with 14mm nominal aggregate size were manufactured with three types of bitumen: Class 320 (C320), Multigrade (M1000), and an SBS Polymer Modified Bitumen (PMB-A5S), and with different air voids were analysed using the UWT technique. The results for ultrasonic velocity (the overall average of the 17 locations) and air voids content (1% to 10%) for all asphalt mixes (C320, M1000 and PMB-A5S), calculated at the reference temperature of 25°C, are summarised in figure 6.

It was concluded from the results that the higher the air void content in the sample, the lower the expected ultrasonic velocity. The trend lines indicated that there is a close correlation between air voids and average ultrasonic velocity. The data demonstrated the potential use of the non-destructive UWT tests to estimate localised air voids contents in laboratory compacted asphalt using the relationship between air voids and ultrasonic velocity.
The air voids at the centre of all three types of laboratory compacted asphalts were estimated as described earlier in section 2.2 and compared with the air voids of the whole sample. The difference between the air voids of the whole sample and localised air voids in the centre can be seen in figure 7. The data indicates that the air voids at the centre of the sample vary from those of the whole sample for all three types of asphalt.

**Figure 6.** Ultrasonic velocity versus air voids (entire sample) content for mixtures with M1000, C320 and PMB in average 17 points [6]

**Figure 7.** Air Voids difference (air void of whole sample minus localised air voids in centre)
3.2 Findings from phase two of the Project

In phase two, the Creep slope of asphalt samples was measured (figure 5), and the results correlated with the air voids of the whole sample (Using AS/NZS 289) and the air voids in the centre of the sample directly under the 50mm diameter load platen (figure 4), determined using the UWT technique.

![Figure 8. Creep slope VS air voids content of the whole sample (%)](image)

![Figure 9. Creep slope VS estimated air voids content in the centre of the sample (%)](image)
Correlation between creep slope and overall air voids content
In figure 8, the creep slope is plotted versus the air voids content of the entire sample for the three types of asphalt. The data shows a good correlation between increasing air voids contents, and creep slope for each mix type. The data could be interpreted as ranking the PMB mix as the most rut (creep) resistant, followed by C320 and then closely by Multigrade M1000.

Correlation between creep slope and air voids in centre of the sample
The creep slope versus air voids at the centre of the sample for the three types of asphalt is plotted in figure 9. Again, close correlation is observed between increasing air voids, and increasing creep slope for each type of mixture. The data could be interpreted as ranking the mix types, and PMB is again ranked as the most rut resistant. However, the data now suggests that the Multigrade M1000 is the next best performer with C320 being ranked last. Such a change in mix ranking is significant and is a cause for further investigation.

4. Conclusion
The research has shown that the UWT technique can be applied as a fast and effective non-destructive tool to estimate the air voids content and distribution in asphalt mixes. It was found that the air voids are non-uniformly distributed in laboratory compacted asphalt samples. The UWT technique can be applied to assist researchers in the analysis and application of asphalt test data involving air voids as an experimental variable.

The usefulness of the ultrasonic technique to measure air voids and their distribution has been illustrated using the newly developed Confined Dynamic Creep Tests (CDCT) that were performed in conjunction with this research. A change in the ranking of mix types occurred when asphalt sample creep was based on localised air voids under the applied loads, instead of whole of sample air voids. It is believed that the use of UWT techniques allows for more accurate ranking of mixes by enabling the use of local air voids content at the point of stress application as a test variable.

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