Resilient modulus values of Western Australia asphalt pavement

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Abstract. Resilient modulus (MR) is a property to measure the material’s stiffness in designing asphalt pavement thickness. The value is usually calculated from an Indirect Tensile Test (ITT) for decades since it is considered efficient and more practical in most applications, and it only uses a single loading time and temperature. The Austroads 2008 still included the resilient modulus values from ITT as an input value at the initial pavement design stage due to its practicality in the application, although this conventional approach has no longer been used in a mechanistic-empirical design guide by NCHRP. In this research, three asphalt mixtures with variables of aggregates diameter and type of asphalt using Western Australia materials were investigated. The mixes, i.e. AC10-320, AC14-320, and AC20-320, were cast in cylinders with a dimension of 75x100mm at a reference temperature of 25°C. The indirect tensile strength used triplicate samples. Research shows the resilient modulus values increase with an increase of nominal maximum aggregate size and a decrease of air voids percentage. The highest MR values were given by mix AC-320 with 3% air voids compared to other mixtures variation. The reasons are an improvement in particle-to-particle contact between the aggregates and density with low air voids in the mixes. From this study, the resilient modulus values of Western Australian asphalt mixtures still meet the lower part of the Austroads presumptive values and recommend as indicative values for design input in pavement thickness calculation.

1. Introduction

Western Australia is located on the West side of the Australia continent and has its specific climate compared to other states in Australia. This part of the state has particular materials and environmental characteristics that could affect pavement integrity in the long term. With a temperature and moisture changes that are similar to the Mediterranean climate, the most critical failure of pavement in this state is fatigue cracking. Mechanical and thermal loadings from repetitive traffic and temperature changes are causing fatigue cracking [1]. The typical environmental conditions and materials available in Western Australia have caused Main Roads Western Australia (MRWA) to use its design guide in designing flexible pavement to provide adequate stiffness.

Stiffness is an elastic modulus property of solids used in pavement design [2]. Material performance could be predicted based on the stiffness. Adequate stiffness will improve the ability of load spreading, the strength of a structure, and anticipated design life of the pavement in the long term. Stiffness can be characterized based on some modulus values, i.e. complex, resilient, flexural and
dynamic [3]. According to Lytton [4], the laboratory stiffness is characterized through some tests such as uniaxial or triaxial tensile and compressive test, shear test, bending or torsion test, and indirect tensile strength test.

Austroads is still using resilient modulus value in the pavement mix design. Huang [5] stated the elastic modulus value is determined from the recoverable strain under repetitive loads. The strains are recoverable property because deformation under repeated load is smaller than asphalt’s strength owed to visco-elastic property. Some factors affecting the resilient modulus under cyclic loading are volumetric material properties, test temperature, loading cycle frequency, load magnitude, load duration, aggregate gradation, and specimen dimensions [6-8]. An increase in air voids could decrease the resilient modulus of the mix. In the testing process, a shorter load duration increases resilient modulus due to less time for a viscous response. The coarser aggregate gradation, the higher the resilient modulus values because of better contacts between the particles. Thin and small specimens usually perform high resilient modulus values than larger and thicker samples due to a better confinement effect of the aggregate particles.

Indirect tensile strength and flexural tests are commonly used to obtain the resilient modulus values. According to the mechanistic-empirical design guide by NCHRP [9], the dynamic modulus is considered more suitable to represent actual conditions on the road than the resilient modulus. However, the Austroads 2008 still uses the resilient modulus from the laboratory as a design input in designing the flexible pavement because of its practical, rapid, low-cost and relatively precise method. Austroads [10] highlighted laboratory resilient modulus values for wearing course/fatigue course and the intermediate layer or base course based on asphalt classes. The typical values for Class 170 and Class 320 for the wearing course are 2200 and 3000 MPa, respectively. While the intermediate layer or base course for Class 170 and Class 320 are 3000 and 4000 MPa, respectively. Table 1 presents the values for typical Australian dense graded asphalt mixes with 5% air voids from the indirect tensile strength test using laboratory-manufactured samples.

| Binder     | Mix size (maximum particle size) (mm) | 10       | 14       | 20       |
|------------|--------------------------------------|----------|----------|----------|
|            | Range Typical                        | Range Typical | Range Typical | Range Typical |
| Class 170  | 2000–6000 3500 2500–4000 3700        | 2000–4500 4000 |
| Class 320  | 3000–6000 4500 2000–7000 5000        | 3000–7500 5500 |
| Class 600  | 3000–6000 6000 4000–9000 6500        | 4000–9500 7000 |
| Multigrade | 3300–5000 4500 3000–7000 5000        | 4000–7000 5500 |
| A10E       | 1500–4000 2200 2000–4500 2500        | 3000–7000 3000 |

Standard test conditions are 40 ms rise time and 25°C test temperature [12].

In this research, the resilient modulus of Western Australian asphalt mixes was investigated to determine the range of the values according to Austroads 2008. Resilient Modulus (E) value is used in Level 2 pavement thickness calculation of APRG Report No 18 [13]. Based on this study, the MR values could be used as a local material performance database. This study also highlighted the variety of typical aggregates diameter used in Western Australia and its calculated resilient modulus.

2. Materials and methods
Asphalt mixtures in this study comprise of coarse aggregates, fine aggregates, hydrated lime, baghouse dust, and bitumen. Class 320 BP residual bitumen was the primary binder for the asphalt mixtures. The coarse aggregates from Gosnells Quarry, Western Australia, with a maximum aggregate size of 10mm, 14mm, and 20mm were designed using Main Road Western Australia (MRWA) Specifications
The physical properties of the coarse aggregates need to meet requirements in Main Roads Western Australia (MRWA) [14]. The dense aggregate compositions were calculated based on Specification 504 and 510 of Main Roads Western Australia [15]. The grading envelopes of MRWA specifications could be seen in figure 1. The target aggregate grading was placed near the grading envelope midpoint. The grading was adjusted in the calculation to obtain the volumetric properties. Trial and error method were used to proportion the aggregate fraction quantities and filler according to sieve analysis [16].

![Figure 1. Grading envelopes of MRWA specifications.](image)

Table 2 presents the volumetric properties of Western Australian mixes. Mineral filler is a hydrated lime or calcium hydroxide. The filler has a lime approximately 80-90% and in compliance with AS 1672.1-1997 [17]. Baghouse dust is used as another mineral filler collected from plant and must pass a 0.075 mm Australian Standard sieve. Mixes AC10-320, AC14-320 and AC20-320 were investigated.

| Property       | AC10-320 | AC14-320 | AC20-320 |
|----------------|----------|----------|----------|
| Blows          | 75       | 75       | 75       |
| Bit. Content (%) Class | 5.4 ± 0.3 | 4.7 ± 0.3 | 4.5 ± 0.3 |
| Air voids (%)  | 4–6      | 4–7      | 3.5–5.5  |
| VMA (%)        | Min. 15  | Min. 14  | Min. 14  |
| Stability (kN) | Min. 8   |          |          |
| Flow           | 2-4      |          |          |
| Hydrated Lime (%) | 1.5 ± 0.5 |          |          |

The samples were prepared initially by conditioning the bitumen at a temperature of 155 to 160°C in the oven for an hour. The mixes were heated in the oven trays up to a temperature of 150±3°C for Class 320 bitumen. A portion of samples (quarter) was taken after conditioning for one-hour and compacted for 50 or 75 blows with a blow rate of 60-70 blows per minute using the Marshall method. The method is used to examine the asphalt mixture’s stability and flow. The indirect tensile test uses
specimens with 100±2 mm (dia) and 75±15 mm (height). A cylinder-type sample is more suitable than a cube for stability and flows, per AS 2891.5-2004 [18] or test method WA731 [19].

Samples were tested according to AS 2891.13.1-1995 [20]. A UTM 14P testing machine is provided with A Control Data Acquisition System (CDAS) and IPC UTS software. The test set up is shown in figure 2. The samples were tested based on the reference conditions at 25±0.5°C temperature, 0.04±0.005 s rise time (10 to 90%), 3.0±0.005 s of pulse repetition period (10% to 10%), and 50±20 με recovered the horizontal strain.

The resilient modulus (E) was calculated based on the average of three specimens with a variability of less than ±15%. The experimental values could be related to table 1 [21] to classify the associated values. The following equation is used to calculate E [22]:

\[ E = P \left( \frac{\nu + 0.27}{H \times h} \right) \]  

where \( E \) = resilient modulus (MPa), \( P \) = peak load (Newtons), \( \nu \) = Poisson ratio (assumed to be 0.4), \( H \) = recovered horizontal deformation of specimen after application of load (mm), \( h \) = height of specimen (mm).

3. Results and discussion

Figure 3 shows the asphalt mixtures resilient modulus values with a variety of aggregate nominal maximum and air voids percentage. In general, the resilient modulus values were increased along with the aggregate size. Mix AC20-320 had higher values than other mixes, i.e. AC10-320 and AC14-320. The size of aggregate significantly affects the aggregate gradation, since the higher aggregate nominal size, the coarser the aggregate gradation. The aggregate gradation influences contact between the particles and the mix stiffness of asphalt mixtures. A similar result was reported by Saleh [7] and Lim and Tan [23].

Air voids influence the modulus values in the asphalt mixtures. Figure 3 shows the effect of air voids on the resilient modulus of mixes AC10-320, AC14-320, and AC20-320, respectively. In general, the more air voids in the mixture, the lower resilient modulus values. Mix AC20-320 with 3%
air voids performed the highest resilient modulus value, followed by those for mixes AC14-320 and AC10-320. The results indicate the air voids have an essential role in the mixture because the smaller air voids content will produce a higher resilient modulus. The behaviour can be attributed to low porosity or high density due to little air voids in the mixtures. The previous study has highlighted that the indirect tensile strength or resilient modulus is strongly dependent on the porosity of the asphalt mixture [24].

Figure 3. Resilient modulus values with the various aggregate maximum size and air voids.

Triplicate samples were used in resilient modulus calculation. Based on Standard Deviation statistical analysis, the variability was observed mainly for mixtures with 3-4% air voids content. Mix AC20-320 with 3% air voids performed the highest variability. From the previous study, the indirect tensile strength test produced resilient modulus values with high variability with reproducibility around 40% of gross mean value [25]. Several factors were considered to cause high discrepancies in the results, for example, differences between MATTA software and hardware devices and interpretation of the test procedures.

Resilient modulus (E) values from laboratory test with a reference testing temperature of 25°C are presented in table 3. Mix AC10-320 modulus was in the range of 3483-3768 MPa with the average value was 3768 MPa with 3% air voids. There was an increase of resilient modulus by 28.98% of mix AC20-320 with 3% air voids than mix AC10-320 with the same air voids content. Similarly, an increase of air voids content also increases the resilient modulus of the mixtures. In general, the bigger the maximum aggregate size, then the lowest deformation of the mixes or the higher the modulus of the mixtures. Mix AC20-320 has the highest modulus values compared with other mixes, and those values were varied between 4087-4860 MPa. However, from the table, it is evident that mix AC14-320 had relatively similar resilient modulus values with mix AC20-320. The values indicated the differences between the aggregate nominal size of 14 and 20 were not too significant to improve the stiffness of Western Australia asphalt mixtures.

In this study, the resilient modulus values from the current investigation cannot be compared directly with the typical probable values in table 1. The differences in the values obtained were between 5.8%-34.5% for mixtures with 5% air voids. Based on the experimental results, the Western Australian asphalt mixtures in the lower part of the Austroads presumptive values [22]. A study by Julaihi [26] using a similar type of mix AC10 followed the same trend. The typical values were in the range of 2596 to 3585 MPa. However, the resilient modulus values from this study could be used in designing the full depth dense-graded flexible pavement, particularly in the Western Australia
region. The MRWA implied that the E values should not exceed the Austroads recommended typical dense-graded asphalt in mechanistic-empirical design procedure [27]. This suggestion possibly to accommodate the practical realities in using local bitumen and aggregates for asphalt manufacture. It can be concluded that the values from this research could be used as indicative resilient modulus values for pavement design inputs in Western Australia.

Table 3. Resilient modulus values from laboratory tests.

| Mix       | Air voids (%) | Peak Load (N) | Total recovered strain (me) | VMA (%) | VFA (%) | MR (MPa) | Austroads presumptive values (5% air voids, in MPa)a | Typical values (5% air voids, in MPa)a |
|-----------|---------------|---------------|-----------------------------|---------|---------|----------|-------------------------------------------------|-------------------------------------|
| AC10-320  | 3             | 1891          | 52.60                       | 15.40   | 82.50   | 3768     | 3000-6000                                      | 4500                                |
|           | 4             | 1915          | 55                          | 16.40   | 75.60   | 3554     |                                                 |                                    |
|           | 5             | 1836          | 53.60                       | 16.90   | 71.50   | 3483     |                                                 |                                    |
| AC14-320  | 4             | 2296          | 53.35                       | 15.31   | 71.60   | 4426     | 2000-7000                                      | 5000                                |
|           | 5             | 2150          | 54                          | 16.00   | 69      | 4048     |                                                 |                                    |
|           | 3             | 2593          | 53.55                       | 15.15   | 78.75   | 4042     |                                                 |                                    |
| AC20-320  | 4             | 2401          | 54                          | 16.00   | 74      | 4542     | 3000-7500                                      | 5500                                |
|           | 5             | 2190          | 54                          | 16.60   | 70.8    | 4089     |                                                 |                                    |

aAustroads [22].

4. Conclusions
Resilient modulus from the ITT test is usually used as an input design Level 2 for pavement thickness calculation by Austroads. In this research, the resilient modulus of Western Australia asphalt mixes with different nominal maximum aggregate size and air voids were investigated. Results show the resilient modulus values were influenced by the maximum aggregate size and the air voids percentage. As the nominal aggregate maximum size increases, so do the resilient modulus values. The higher the air voids percentage in the mixture was also significantly reduced the resilient modulus values. Mix AC20-320 had the highest E values compared to other mixes, i.e. AC10-320 and AC14-320 mixes with 3% air voids. The stiffness improved with high contact between particles and increased density due to low air voids in the mixes. Furthermore, the resilient modulus of the WA asphalt mixes was still within the Austroads presumptive values. The values from this research are recommended as input values in Western Australian pavement design.

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