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Establishing a resilient modulus test protocol for miniature cylindrical asphalt mix specimens

IOP Conf. Series: Materials Science and Engineering **512** (2019) 012058 doi:10.1088/1757-899X/512/1/012058

Establishing a resilient modulus test protocol for miniature cylindrical asphalt mix specimens

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Abstract. The resilient modulus is a very important parameter to be identified and used in pavement design. The indirect tensile test is the most common repeated load test to measure the resilient modulus of asphalt mixtures and the easiest method to test laboratory compacted specimens and field core specimens. The resilient moduli of asphalt mixtures are measured using the indirect tensile procedure (ASTM D4123). A metal loading strip with a concave surface with the radius of the test specimen is required to apply load to the specimen. Typically, specimens are either a nominal 100mm or 150mm in diameter with a minimum thickness over diameter ratio of 0.4. However, typical 100mm diameter core samples with 40mm to 50mm thickness taken from the site most often do not fulfil the minimum ratio of 0.4 after the samples are trimmed for testing. As such, a new procedure was developed to test specimens smaller than 100mm in diameter. This expected to be very useful and minimize the volume requirement from the field. This novel protocol for resilient modulus test using miniature specimens of 37.5mm and 56.3mm in diameter has great potential for practical relevance for the industry.

1. Introduction

The distresses of asphalt pavement, including fatigue, rutting, and low temperature cracking are related to the elastic modulus of the asphalt layer. In addition, the elastic modulus of asphalt concrete is a design variable for asphalt pavement structural design when elastic-layer system theory is employed. However, in the most commonly used asphalt concrete design methods (the Marshall, Hveem, and Superpave methods), the elastic modulus is not used as a control variable. Therefore, these design methods do not ensure that the desired elastic modulus of asphalt concrete will be obtained [1]. Falling Weight Deflectometer (FWD) testing has been used widely to measure the structural conditions and identification of the resilient modulus of flexible pavement layers. The results of resilient modulus values for flexible pavement layers acquired from the back calculation analysis may not be precise, despite the fact that the measured and calculated deflection may remain within acceptable parameters [3]. Wide interpretation is associated with getting the resilient modulus of these flexible pavement layers. FWD interpretation has turned out to be more demanding, since more of our flexible pavements have encountered various milling processes and overlays. The properties of a structure in terms of damaged layers, thickness variety and temperature differences can affect the deflection values, having a much more critical impact than those made by structural layer stiffness.

This paper discusses on the new thinking which was developed in this study to identify a new procedure to carry out resilient modulus testing on cored specimens from field overlay or asphalt concrete wearing course (ACWC) layers. These new findings could allow researchers and practitioners to perform resilient modulus test on specimens smaller than 100 mm in diameter while maintaining equivalence to the standard test procedure as per ASTM D4123.

2. Literature review

2.1. Diameter of specimen

The relative development of the resilient modulus and dynamic modulus of hot mix asphalt as material properties to be used in the flexible pavement design has been carried out [7]. It was found that the size of the sample mathematically influenced the obtained resilient modulus measurement. Resilient modulus measurements acquired for 100mm diameter samples were higher than those obtained for 150mm diameter samples in all variable temperatures used for carrying out the testing [13]. Figure 1 shows the effects of specimen diameter.

Kandhal did a similar assessment on 4-inch (100mm) and 6-inch (150mm) diameter samples and found that the rigidity (resilient modulus) of the 6-inch (150mm) diameter samples was dependably lower than the 4-inch (100mm) diameter samples. Under a similar loading, the strain rate for the 6-inch (150mm) diameter samples was dependably lower than that of the 4-inch (100mm) samples [4].

Likewise, Lim et al. investigated the sample size impacts on the aftereffects of diametrical mechanical testing approaches, in particular the resilient modulus and indirect tension tests. The diameter over height proportion of sample was consistent at 1.6 and it was found that the resilient modulus diminishes as the diameter of the sample increments [12].

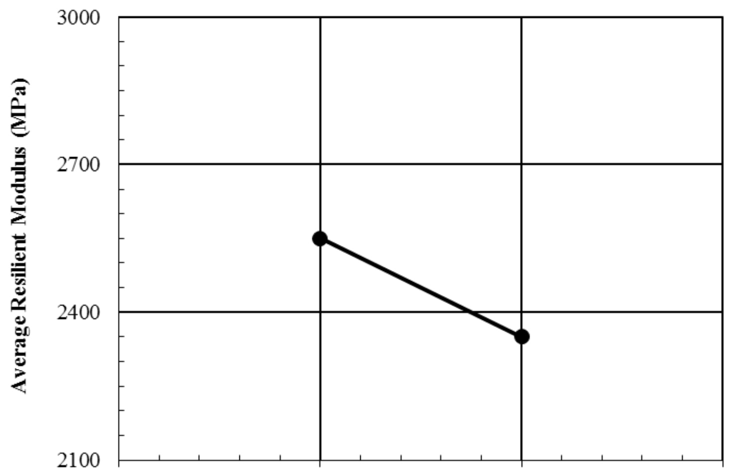

Figure 1. Effect of specimen diameter [2]

2.2. Thickness of specimen

As indicated in the Australian Standard AS 2891.13.1, the thickness of the test samples is to be in the vicinity of 70mm and 35mm thick for 100mm diameter samples and in the vicinity of 90mm and 60mm thick for the 150mm diameter samples [14]. Utilizing static Indirect Tensile Test, Hugo and Schreuder assessed the impact of the sample thickness on the tensile strength and related engineering practices. They found that the indirect tensile strength increments as the sample thickness increments [8]. The sample with thickness more than 20mm will be experiencing stress concentrations at the bottom and top of the contact surface. The stress along the rest of the vertical diameter would be diminished far beneath the average calculated stress level [5]. This could be the reason for the expansion in tensile strength, considering the way that the unequal pressure dissemination makes the sample quality pressure-reliant. This shows the centre part of the samples once the uppermost and the base contact points (very pressured points) outwardly begin to fail [11].

2.3. Maximum nominal aggregate size

In view of the Australian Standard AS 2891.13.1, the element size of up to 40mm can be utilized for the resilient modulus sample test. An examination by Lim et al. on the impact of diameter/utmost nominal aggregate size proportion demonstrated that the resilient modulus diminishes as the proportion upsurges [2].

Research coordinated by Brown and Bassett on the connection between asphalt blend properties and utmost stone size showed a strong relationship between the resilient modulus and the utmost stone size. Consequently, the resilient modulus upsurges as the stone size upsurges [10]. Figure 2 shows the effect of maximum nominal aggregate size on the resilient modulus.

Tongyan et al. carried out research intended to explore the impacts of the material properties of the significant segment on the resilient modulus of asphalt blends with the coarse stone texture considered as the main factor [9]. With modulus experiments carried out at a temperature of 25°C, utilizing coarse stone with more irregular morphologies significantly enhanced the resilient modulus of asphalt blends [6].

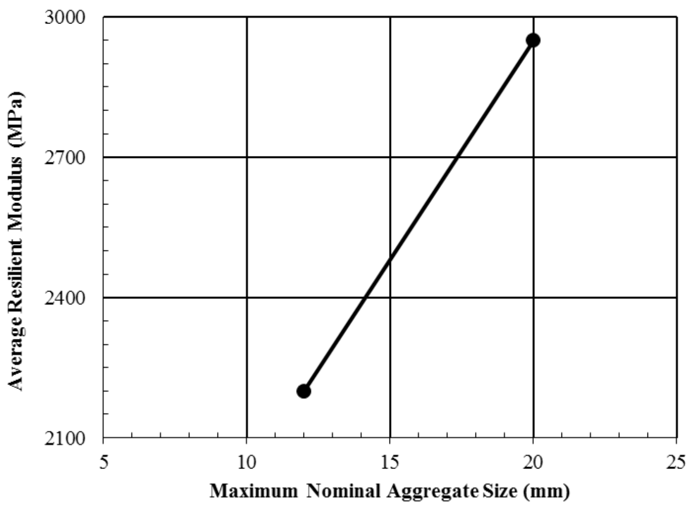

Figure 2. Effect of maximum nominal aggregate size on the resilient modulus [2]

2.4. Resilient modulus test

The five-pulse indirect tensile modulus test is a material stiffness test conforming to ASTM D4123. In the test, a pulsed diametral loading force is applied to a specimen. The resulting total recoverable diametral strain is then measured from the axes 90 degrees from the applied force. Strain in the same axis is not measured; thus, a value of 0.4 for Poisson's ratio is used as a constant. With a fixed level of applied peak force, the test sequence consists of the application of 150 conditioning pulses followed by 5 pulses where data acquisition takes place. The conditioning pulses ensure that the loading plates are seated onto the specimen for consistent results. For controlled temperature testing, the specimen's skin and core temperatures are estimated by transducers inserted in a dummy specimen and located near the specimen under test. The specimens are mounted in the indirect tensile test jigs and the results are recorded in a computer. Resilient modulus tests were performed on laboratory prepared samples.

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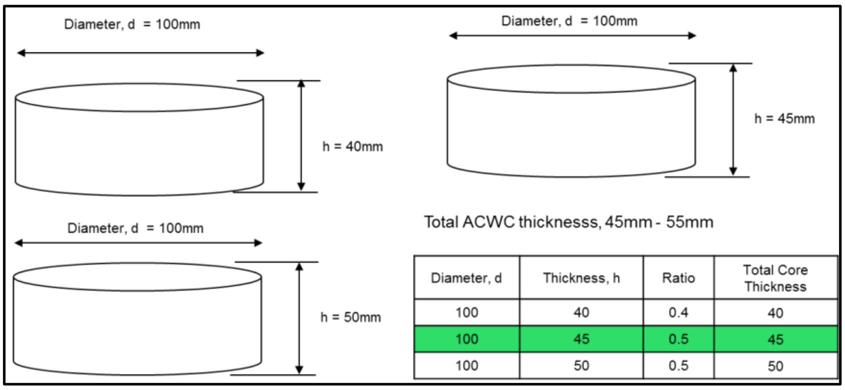
3. Design and fabrication of specimen and test assembly

3.1. Establishment of sample thickness and diameter

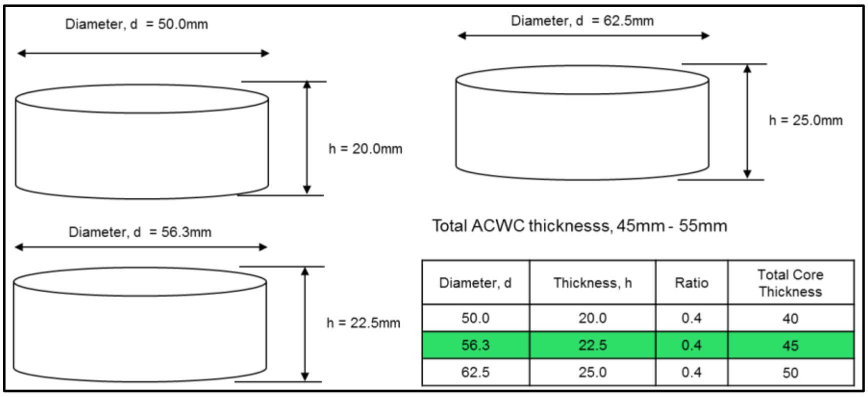
Performance tests were conducted on 225 samples, with 75 samples with 100mm diameter as control, 75 samples with 56.3mm diameter and 75 samples with 37.5mm diameter. The minimum thickness of samples was determined based on 0.4 ratio of height over diameter for each 100mm diameter sample. Figure 3 shows the calculated minimum thickness for 100mm diameter sample.



Diameter, d	Thickness, h	Ratio	Total Core Thickness
100	40	0.4	40
100	45	0.5	45
100	50	0.5	50

Figure 3. Calculated minimum thickness for 100mm diameter sample

The minimum thickness of samples was determined based on 0.4 ratio of height over diameter for 56.3mm diameter sample. Figure 4 shows the calculated minimum thickness for the 56.3mm diameter sample.



Diameter, d	Thickness, h	Ratio	Total Core Thickness
50.0	20.0	0.4	40
56.3	22.5	0.4	45
62.5	25.0	0.4	50

Figure 4. Calculated minimum thickness for 56.3mm diameter sample

The minimum thickness of samples was determined based on 0.4 ratio of height over diameter for 37.5mm diameter sample. Figure 5 shows the calculated minimum thickness for 37.5mm diameter sample.

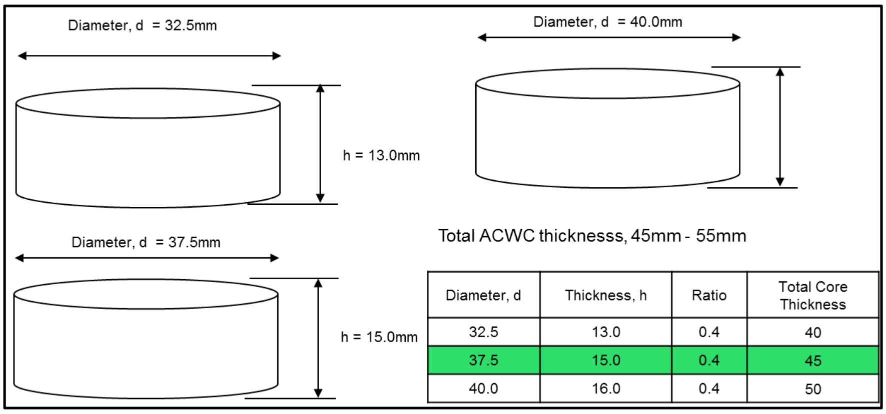
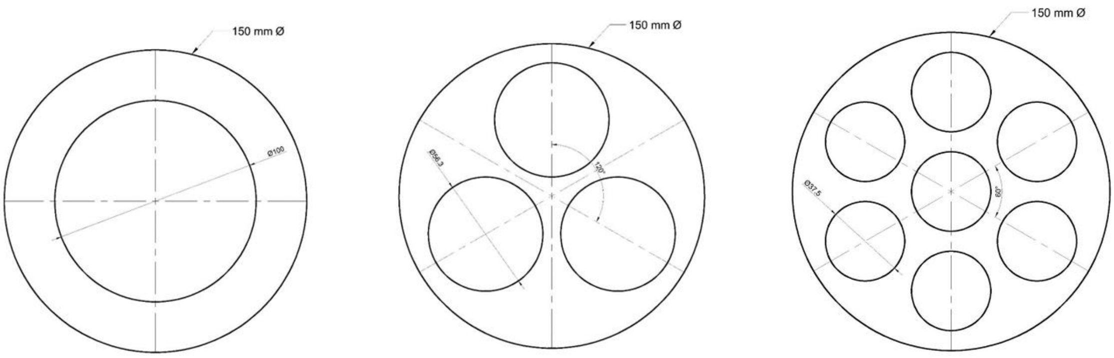


Figure 5. Calculated minimum thickness for 37.5mm diameter sample

3.2. Coring on cylindrical gyratory compacted sample

The samples extracted from the original 150mm diameter compacted samples are labelled accordingly on top of each extracted samples to ensure that the samples to avoid confusion. Later, the 100mm, 56.3mm and 37.5mm diameter samples are to be sliced to its required thickness. During slicing, the samples have to be again labelled from top to bottom and on the top surface of each sample using a planned labelling method using permanent markers to ensure that the samples are not confused and also to ensure the ability to trace back to the original samples to minimize any discrepancies during the performance test. Figures 6 (a), (b) and (c) below show how the markings have been made on the 150mm samples compacted using gyratory compactor.



(a) **(b)** **(c)**

Figure 6 (a), (b) and (c). Coring layout to extract 100mm and 56.0mm diameter samples from 150mm diameter

4. Results

4.1. Resilient modulus test on 100mm diameter control sample

Resilient Modulus test has been performed using the Material Testing and Analysis (MATTA) machine in the UPM laboratory in accordance with ASTM D4123 standard. The standard diameters of test samples are 100mm and 150mm. The control sample diameter used in this study is a 100mm diameter sample. The standard load and pulse are 1200N and 3000ms, respectively. The results of the resilient modulus test for various load and pulse for 100mm diameter control samples has been tabulated and shown in Table 1 below.

Table 1. Summary of resilient modulus (Mpa),lLoad (N) and pulse (ms) data for 100mm diameter sample

Load (N)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)
350	2000	2738	2500	2628	3000	2250	3500	2504	4000	2359
550	2000	2928	2500	2888	3000	2291	3500	2723	4000	2802
750	2000	3145	2500	2834	3000	2466	3500	2778	4000	2837
950	2000	3013	2500	2835	3000	2514	3500	2807	4000	3145
1200	2000	2950	2500	2555	3000	2400	3500	2801	4000	2974

The resilient modulus obtained from the test specimen has been plotted as shown in Figure 7 below.

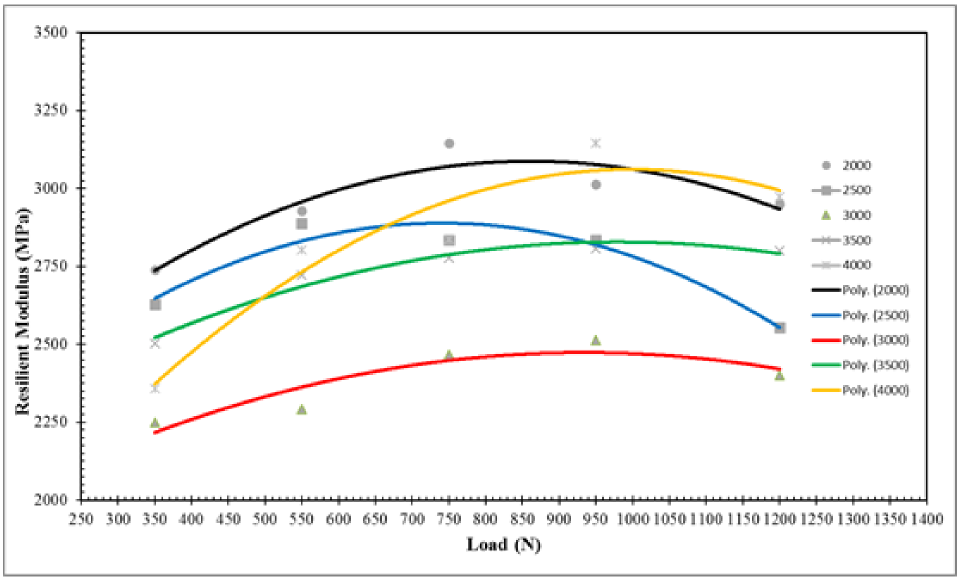


Figure 7. Resilient modulus for 100mm diameter specimens versus load @ a pulse width of 2000ms, 2500ms, 3000ms, 3500ms and 4000ms

4.2. Resilient modulus test on 56.3mm diameter miniature sample

Resilient Modulus test has been performed using the MATTA machine in the laboratory in accordance with the ASTM procedure. The results of the resilient modulus test for 56.3mm diameter samples are tabulated and shown in Table 2 below.

Table 2. Summary of resilient modulus (Mpa), load (N) and pulse (ms) data for 56.3mm diameter sample

Load (N)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)
350	2000	3303	2500	2857	3000	2588	3500	2881	4000	2872
550	2000	3367	2500	3069	3000	2821	3500	3388	4000	2535
750	2000	3543	2500	2927	3000	2930	3500	3753	4000	2953
950	2000	3032	2500	2902	3000	3060	3500	3423	4000	3190
1200	2000	2880	2500	2419	3000	2758	3500	3570	4000	2530

The resilient modulus obtained from the test specimen has been plotted as shown in Figure 8 below.

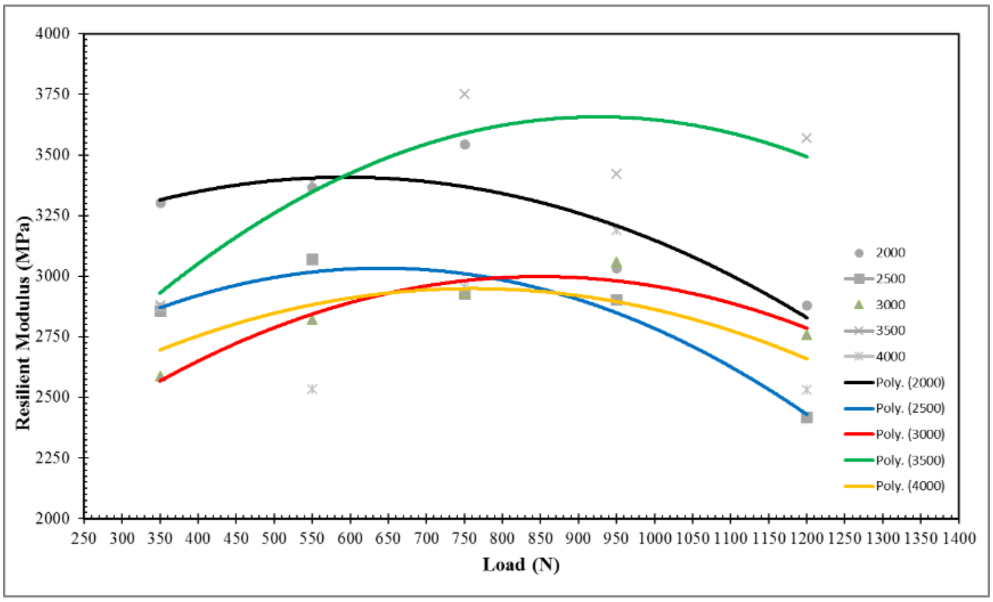


Figure 8. Resilient modulus for 56.3mm diameter specimens versus various load and pulse width

4.3. Resilient modulus test on 37.5mm diameter miniature sample

Resilient Modulus test has been performed using the MATTA machine in the laboratory in accordance with procedure. The results of the resilient modulus test for 37.5mm diameter samples are tabulated and shown in Table 3 below.

Table 3. Summary of resilient modulus (Mpa), load (N) and pulse (ms) data for 37.5mm diameter sample

Load (N)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)	Pulse (ms)	M_R (Mpa)
350	2000	2110	2500	2060	3000	3739	3500	2176	4000	2291
550	2000	3389	2500	3855	3000	4250	3500	2554	4000	3456
750	2000	4778	2500	3412	3000	4254	3500	3530	4000	3116
950	2000	3525	2500	5250	3000	5065	3500	4113	4000	3690
1200	2000	3753	2500	4892	3000	4520	3500	3806	4000	3024

The resilient modulus obtained from the test specimen has been plotted as shown in Figure 9.

From the plots as shown in Figures 4.1, 4.2 and 4.3, the optimum resilient modulus and optimum load values for sample diameter 100mm, 56.3mm and 37.5mm are tabulated as shown in Table 4 below. The optimum values are obtained using the quadratic equation.

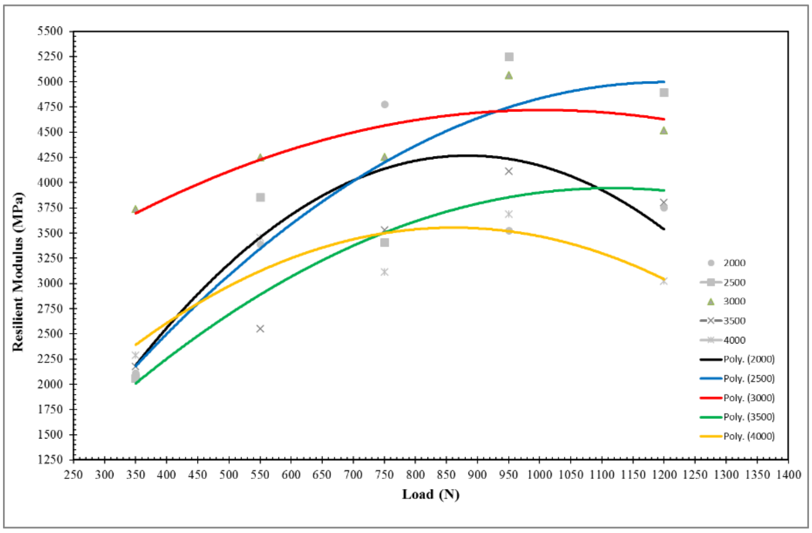


Figure 9. Resilient modulus for 37.5mm diameter specimens versus various load and pulse width

Table 4. Summary of optimum resilient modulus (Mpa), optimum load (N) and pulse (ms) results for the various diameter speciemens

100mm Ø			56.3mm Ø			37.5mm Ø		
Pulse (N)	Load (ms)	M_R (Mpa)	Pulse (N)	Load (ms)	M_R (Mpa)	Pulse (N)	Load (ms)	M_R (Mpa)
2000	888.92	3119	2000	583.75	3398	2000	883.49	4267
2500	733.75	2881	2500	667.11	3027	2500	1190.81	4932
3000	878.44	2434	3000	862.50	3017	3000	1000.71	4711
3500	923.56	2790	3500	920.57	3645	3500	1115.76	3945
4000	1023.53	3103	4000	760.20	2948	4000	869.92	3587

5. Conclusion

The linear equations as shown in Figure 10 below demonstrates a strong relationship between the three (3) type of specimen test results. The 100mm diameter specimen results were correlated with the 56.3mm diameter specimen and 37.5mm diameter specimen. The load values at each pulse width are analysed to identify the shift factor between 100mm diameter specimen against 56.3mm diameter specimen and also 100mm diameter specimen against 37.5mm diameter specimen. From the established linear equation (1), which represents the equation for 56.3mm diameter specimen, a shift factor is introduced for each pulse width as shown in equation 1.1 below. For example, if a sample with 56.3mm diameter is being tested at a pulse width of 3000ms, the equation 1.4 is adopted to identify the appropriate load value to be used to begin the test.

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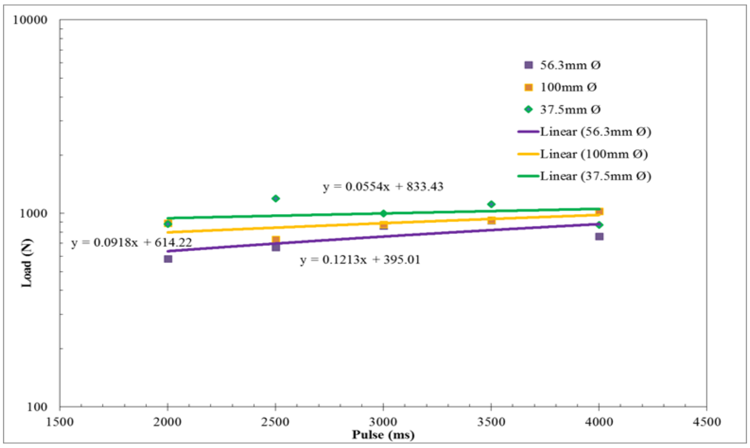

Figure 10. Correlations of load versus pulse for 100mm, 56.3mm & 37.5mm diameter specimens

Equation: $y = 0.1213x + 395.01$ (1)

$L_{56.3,Pulse} = [0.1213P + 395.01] * \text{Shift Factor}$ (1.1)

$L_{56.3,2000} = [0.1213P + 395.01] * 1.251$ (1.2)

$L_{56.3,2500} = [0.1213P + 395.01] * 1.208$ (1.3)

$L_{56.3,3000} = [0.1213P + 395.01] * 1.172$ (1.4)

$L_{56.3,3500} = [0.1213P + 395.01] * 1.141$ (1.5)

$L_{56.3,4000} = [0.1213P + 395.01] * 1.115$ (1.6)

where P is the desired Pulse to be applied and L is the recommended Load.

From linear equation (2) which represents the equation for 56.3mm diameter specimen, a shift factor is introduced for each pulse width as shown in equation 2.1 below. Again, if a sample with 37.5mm diameter being tested at a pulse width of 3000ms, equation 2.4 can be adopted to identify the appropriate load value to be used in the test.

Equation: $y = 0.0554x + 833.43$ (2)

$L_{37.5,Pulse} = [0.0554P + 833.43] * \text{Shift Factor}$ (2.1)

$L_{37.5,2000} = [0.0554P + 833.43] * 0.845$ (2.2)

$L_{37.5,2500} = [0.0554P + 833.43] * 0.868$ (2.3)

$L_{37.5,3000} = [0.0554P + 833.43] * 0.890$ (2.4)

$L_{37.5,3500} = [0.0554P + 833.43] * 0.911$ (2.5)

$L_{37.5,4000} = [0.0554P + 833.43] * 0.930$ (2.6)

where P is the desired Pulse to be applied and L is the recommended Load.

6. References

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Acknowledgement

The Authors wish to thank the Ministry of Higher Education for financing the above research through FRGS.