

FACTORS AFFECTING RESILIENT MODULUS

Saleh M & S J JI

University of Canterbury, Christchurch, New Zealand

ABSTRACT: Resilient modulus is an important property for asphalt concrete design and for mechanistic analysis of pavement response under traffic loading. This study investigates the different factors affecting the resilient modulus of hot mix asphalt. A fractional factorial design of experiment was carried out to investigate seven factors each factor was studied at two levels. These factors are: the maximum nominal aggregate size, specimen diameter and thickness, the load pulse form and duration, preset strain level and the compaction method. Two types of hot mix asphalts with different maximum aggregate sizes (10mm and 14mm) were studied. Gyratory and Marshall compaction methods were used to prepare the specimens. All mix specimens were compacted to the same air voids content ($5.0 \pm 0.5\%$). Sinusoidal and triangular load pulse forms were used in the measurement of the resilient modulus. This study attempts to examine how the different factors interrelate to affect the resilient modulus. It was found that the most significant factor affecting the resilient modulus value is the maximum nominal aggregate size followed by the load duration period, specimen thickness, specimen diameter, compaction method and strain level, and then the interaction between specimen diameter and thickness, the interaction between aggregate size and thickness, aggregate size and compaction method. The effect of wave pulse form whether triangular or sinusoidal was found that it has no significant difference of the resilient modulus value.

KEY WORDS: Resilient, strain, modulus, factors

1. BACKGROUND

The resilient modulus is an important parameter that is used in the mechanistic pavement design as it is being used as an input to the multilayer layer elastic theories or finite elements models to compute pavement response under traffic loading. These responses can be used through transfer functions to calculate the optimum thickness design for new pavement or to estimate the remaining life of an existing pavement. This makes the resilient modulus one of the most important parameters in pavement design and analysis.

Due to the simplicity and ease of application to test laboratory compacted specimens and field cores, the indirect tensile test is the most common repeated load test to measure the resilient modulus of bituminous mixture. This involves preparing a compacted cylindrical asphalt mixture subjected to diametrical repeated loading. This test is standardised as the Australian Standard AS 2891.13.1-1995.

There are two parts to the resilient modulus test. The first is the preconditioning and test setting determination to find the load required to reach certain level of strain of 50 micro-strain as required by the Australian standard. After that the resilient modulus is determined using equation 1.

$$E = \frac{P(\nu + 0.27)}{Hh_c} \quad \text{Equation 1}$$

Where

- E = resilient modulus (MPa)
- P = peak load (N)
- ν = Poisson ratio (assumed as 0.4)
- H = recovered horizontal deformation of specimen (mm)
- h_c = height of specimen (mm)

Although the resilient modulus test is used widely worldwide (Huang, 1993), there are a lot of factors affecting resilient modulus of asphalt subjected to indirect tensile test. These include the geometric factors of the test specimens (specimen thickness and diameter), maximum nominal aggregate size, the load waveforms and pulse durations applied to the test specimens, the preset strain level that is to be met during the test, and the type of compaction of the test specimen. This research is to study the effects of these factors, their interactions, and their significance on the resilient modulus through a fractional factorial design of experiment.

2. FACTORIAL ANALYSIS

There are a lot of factors that can be considered in the determination of resilient modulus. However, for the purpose of this research, seven factors were considered. These are classified in terms of geometric factors, experimental factors and compaction method. Table 1 shows the factors that have been considered in the half fractional factorial analysis and the high and low level of the numerical factors and the different levels for the categorical factors. The symbols used are shown in Table 1 for each factor in the factorial analysis.

Table 1: Factors and their level that considered in the factorial analysis.

Factors	Levels		Units	Symbol
Specimen Diameter	100	150	mm	A
Specimen Thickness	40	70	mm	B
Max. Agg. Size	10	14	mm	C
Compaction Method	Marshall	Gyratory	Categorical	D
Load Wave Form	Triangular	Sinusoidal	Categorical	E
Load Duration	100	200	ms	F
Strain Level	20	60	$\mu\epsilon$	G

For seven factors each at two level and with three replicates per test, the total number of tests/specimens required is $3 \times 2^7 = 384$ runs. Therefore, it was decided to use half fractional factorial which reduces the number of runs to $3 \times 2^{7-1} = 192$ runs.

3 RESULTS AND ANALYSIS

Figure 1 is a half probability chart of the effects generated by Design Expert Software (2004). Table 2 shows the analysis of variance for the different effects. The higher the F value or the lower the P value the higher the significance of the factor. Effects which lie on the straight line are the insignificant effects, whereas the significant effects are far from the line (Douglas, 2001). It is clear that the aggregate maximum nominal size is the most important factor affecting the resilient modulus, followed by the load duration, then the specimen geometry represented by the thickness and diameter then the interactions between the different factors.

Figure 2 shows the effect of the aggregate nominal maximum size on the resilient modulus. The coarser the aggregate gradation the higher the stiffness of the mix. This may be explained by the higher partial to partial contact in the coarser aggregate structure which results in a higher resilient modulus. The analysis of variance shown in Table 2 shows that this factor has the highest F value which reflects the importance of the aggregate gradation on the resilient modulus value. This results agrees with Figure 1. These results agreed with findings of Lim and Tan (1995) and those of Brown and Bassett (1990).

DESIGN-EXPERT Plot
Resilient Modulus

- A: Diameter
- B: Thickness
- C: Aggregate Size
- D: Compaction
- E: Load Form
- F: Duration
- G: Strain Level

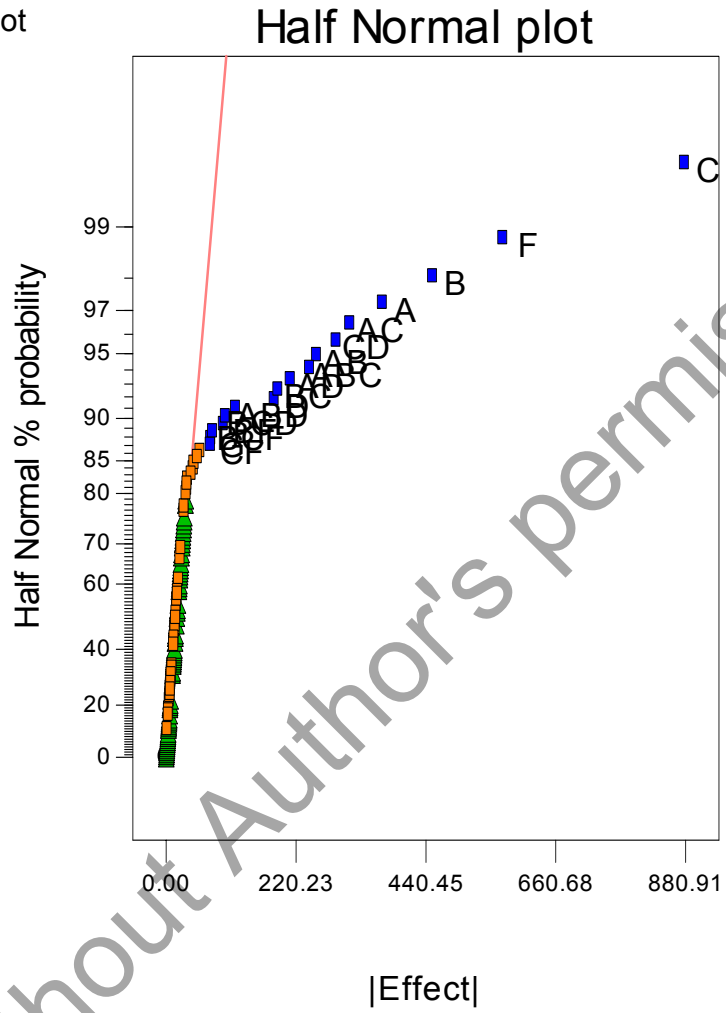


Figure 1: Half normal probability plot of the effects.

Table 2: Analysis of Variance of the significant factors.

Source	Sum of Squares	DF	Mean Square	F Value	P-Value Prob > F
Model	61571729	18	3420652	162.6082	< 0.0001
A	4345352	1	4345352	206.5659	< 0.0001
B	6589358	1	6589358	313.2397	< 0.0001
C	24831866	1	24831866	1180.438	< 0.0001
D	1095940	1	1095940	52.09794	< 0.0001
F	10507674	1	10507674	499.5055	< 0.0001
G	192355	1	192355	9.144022	0.0031
AB	2108945	1	2108945	100.2533	< 0.0001
AC	3140645	1	3140645	149.2975	< 0.0001
AD	1443301	1	1443301	68.61048	< 0.0001
BC	1171215	1	1171215	55.6763	< 0.0001
BF	311655.1	1	311655.1	14.81522	0.0002
CD	2690620	1	2690620	127.9046	< 0.0001
CF	188498	1	188498	8.96067	0.0034
ABC	1922761	1	1922761	91.40268	< 0.0001
ABD	456729	1	456729	21.71163	< 0.0001
BCD	334971.1	1	334971.1	15.92359	0.0001
BCF	206885.3	1	206885.3	9.83475	0.0022

The effect of the load duration on the resilient modulus is depicted in Figure 3. The shorter the time duration the higher the resilient modulus (Huang, 1993). This effect can be attributed to the viscoelastic nature of the bituminous materials which make the properties of these mixes load rate dependent. It is well known that slow traffic has the most damaging effect on the asphalt pavement causing severe rutting and distortions in the pavement structure. Therefore, in measuring the resilient modulus in the laboratory an appropriate load duration should be selected in order to measure a representative resilient modulus for the insitu conditions.

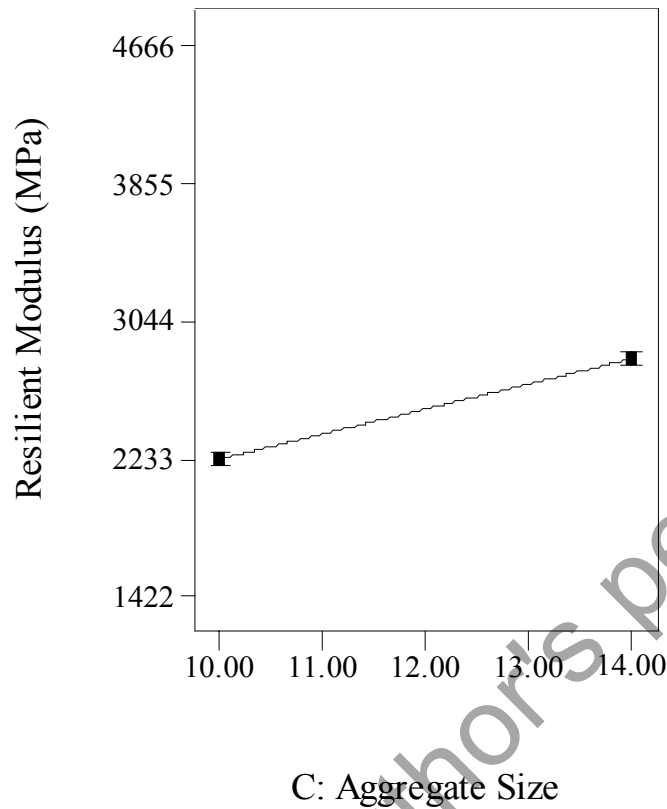


Figure 2: Effect of maximum nominal aggregate size on the resilient modulus

Figures 4 and 5 reveal the effect of the specimen geometry on the resilient modulus. It is clear that smaller diameter and thinner specimens yield higher resilient modulus than larger diameter and thicker specimens. This finding is in agreement with Kandhal and Brown (1990) as they found that the tensile strength of the 150mm diameter specimens were always lower than the 100mm diameter specimen. This effect may be explained by the higher confinement of the aggregate particles in the smaller diameter and thinner specimen. In addition for the larger diameter and thicker specimens the probability of having higher percentages of micro-cracks is higher than that in the smaller specimens, therefore, the rate of energy release in the larger specimens is higher than that in the smaller specimens. A similar effect of that is noticed in Portland cement specimens as the smaller cylinders always yield a higher strength than that of the larger specimens. Therefore, a representative geometry should be selected in order to have a resilient modulus that matches the actual field conditions.

The interaction between the aggregate size and the specimen diameter is shown in Figure 6. The effect of the coarse gradation is very pronounced in the small size diameter specimen while this effect is much less in the larger diameter specimen. This means using smaller molds, 100 mm diameter, in the laboratory is very sensitive to the aggregate gradation compared to the 150 mm diameter specimens. Again this is probably because of the degree of confinement in the smaller mold is much higher than that in the larger diameter mold.

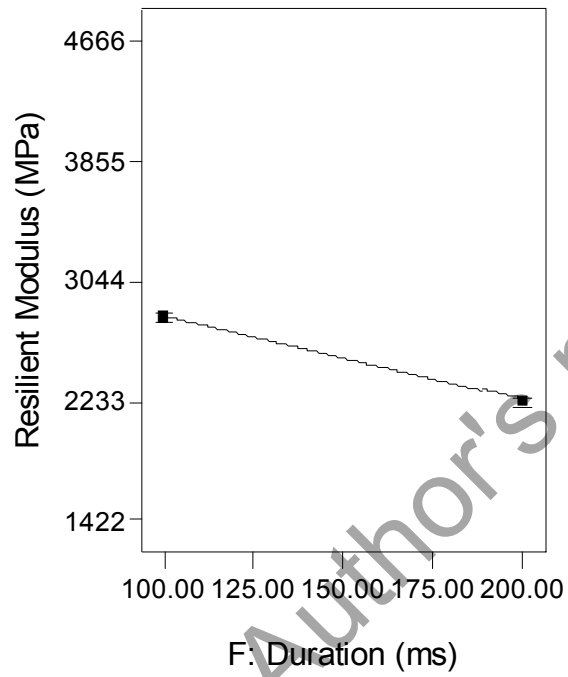


Figure 3: Effect of maximum load duration on the resilient modulus

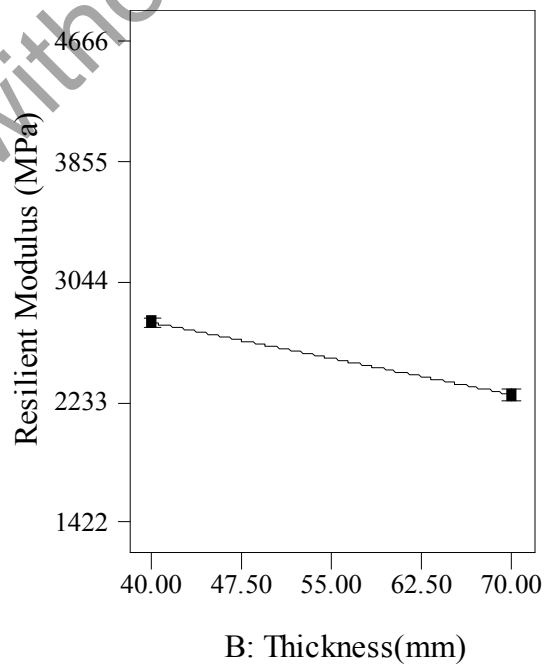


Figure 4: Effect of specimen thickness on the resilient modulus

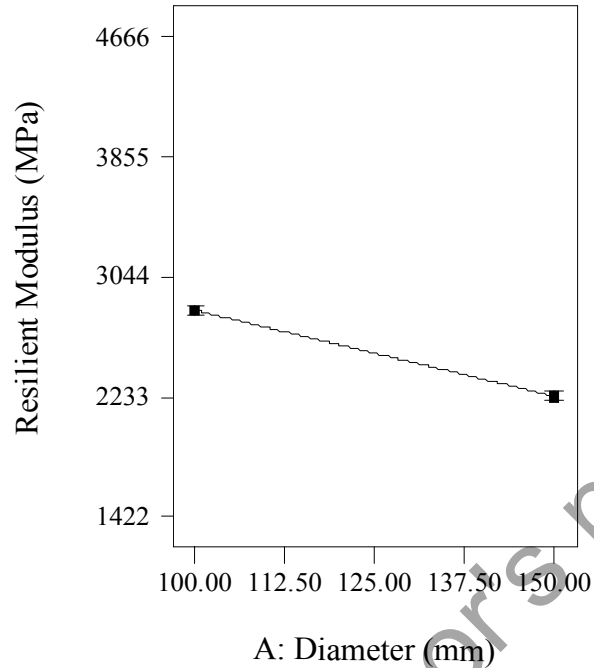


Figure 5: Effect of specimen diameter on the resilient modulus

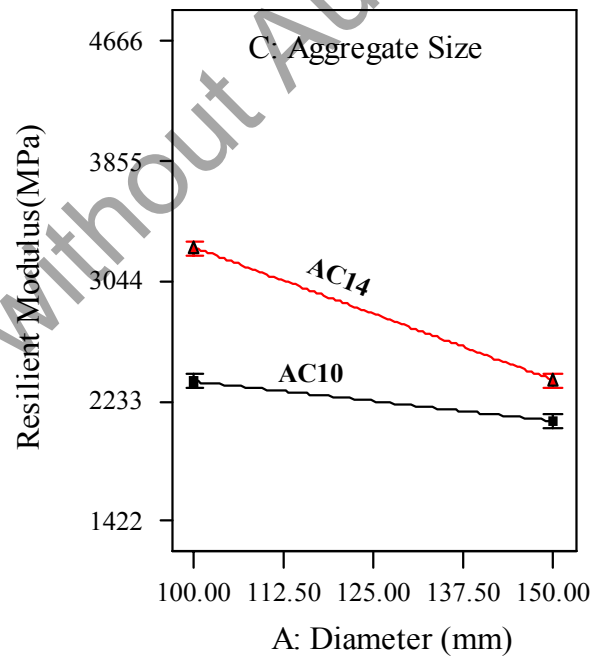


Figure 6: Effect of interaction between aggregate size and specimen diameter on the resilient modulus.

Figure 7 shows the interaction between the specimen thickness and diameter. It is obvious that the smaller diameter specimens are very sensitive to the specimen thickness as the effect of

thickness is quite pronounced, however, the large diameter specimens are not sensitive to the thickness of the specimen as both the 40 mm and 70mm thick specimens produced a relatively similar resilient modulus for the 150 mm diameter specimen. This will add another advantage for the 150 mm diameter specimen compared to the 100 mm diameter.

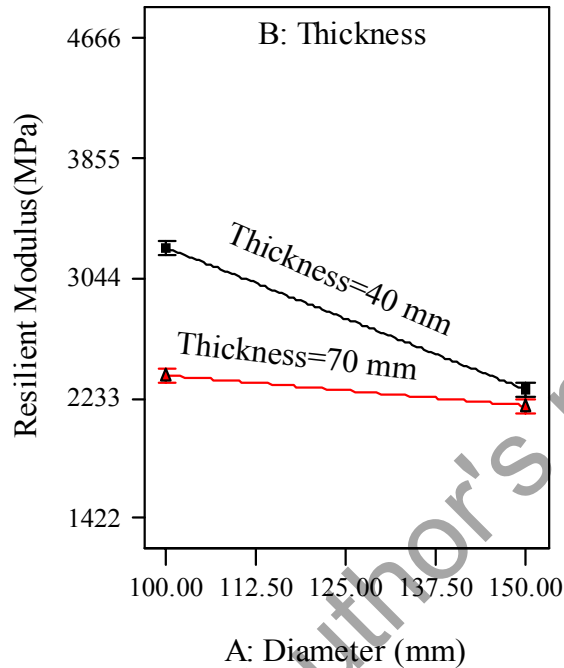


Figure 7: Effect of interaction between thickness and diameter of the specimen on the resilient modulus.

Figure 8 depicts the interaction between the compaction method and the specimen diameter. It is clear that Marshall compaction is providing higher resilient modulus than gyratory compaction for smaller diameter specimens however for the larger diameter there is no effect between the two compaction methods.

The interaction between the aggregate gradation and the thickness of the specimen is shown in Figure 9. The coarser gradation is providing slightly higher effect on the resilient modulus for the thin specimens (40 mm) and this effect is reduced for the thick specimens (70 mm).

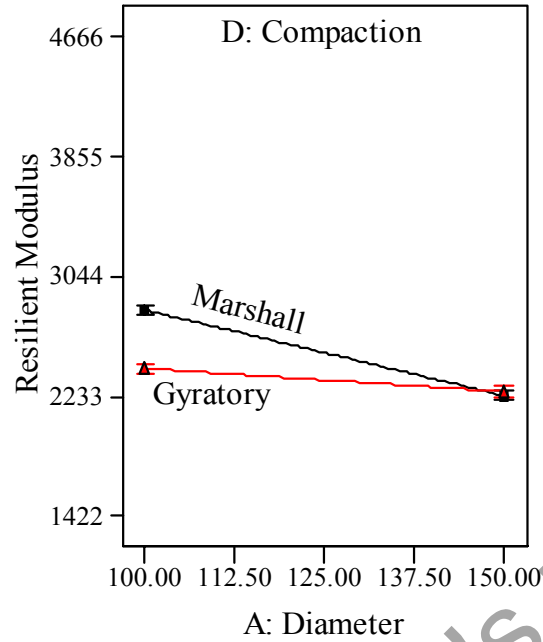


Figure 8: Effect of interaction between compaction method and diameter of the specimen on the resilient modulus

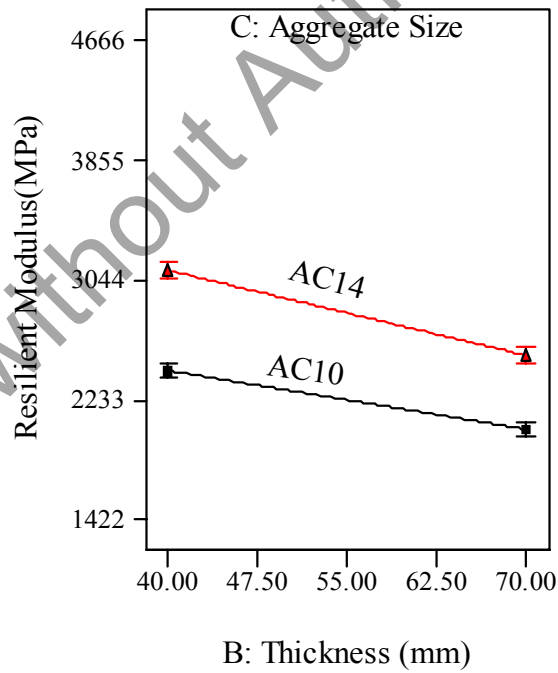


Figure 9: Effect of interaction between aggregate maximum nominal size and specimen thickness on the resilient modulus

4 CONCLUSION

Resilient modulus is affected by many factors. The aggregate gradation is the most significant factor as the coarser gradation provides significantly higher resilient modulus compared to the fine gradation. The time duration is the second most significant factor affecting the resilient modulus due to the visco-elastic nature of the bituminous materials. The shorter the loading time (the faster the speed) the higher the resilient modulus and vice versa. The specimen geometry (the thickness and diameter) are quite important factors affecting resilient modulus. The smaller size specimens tend to have a higher resilient modulus than the larger size specimens. The interactions between specimen geometry and aggregate size and the compaction method are also important factors. The large size specimens (150mm diameter and 70 mm thick) tend to be less sensitive to the compaction method and the aggregate gradation compared to the smaller size specimens.

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REFERENCES

- AS 2891.13.1-1995 Methods of sampling and testing asphalt. Method 13.1: Determination of the resilient modulus of asphalt – indirect tensile method
- Brown, E. R. and C. E. Bassett, 1990. *Effects of maximum aggregate size on rutting potential and other properties of asphalt-aggregate mixtures*. Transportation Research Record (1259): 107-119.
- Design Expert version 6, State-Ease Inc. 2021 East Hennpin Ave., Suite 480, Minneapolis, MN 55413
- Douglas C. M., *Design and Analysis of Experiments*, John Wiley & Sons, Inc, 2001
- Huang, Y.H. 1993. *Pavement Analysis and Design*, Prentice Hall Inc.
- Kandhal, P.S and E.R. Brown 1990. *Comparative evaluation of 4-inch and 6-inch diameter specimens for testing large stone asphalt mixes*. Serviceability and Durability of Construction Materials – Proceedings of the First Materials Engineering Congress Part 1, Aug 13-15 1990.
- Lim, C.T. and Tan, S.A 1995. *Specimen size effects on the diametrical mechanical testing of cylindrical asphalt mixes*. Journal of Testing and Evaluation, Volume 23: 436-441.