Resilient Modulus to Dynamic Modulus Relationship and Pavement Analysis with the Mechanistic-Empirical Pavement Design Guide

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Summary

Research work over the past decade has investigated the relationship between dynamic modulus and resilient modulus of AC pavements. A result of this work is an approximate relationship between dynamic modulus values at 5 Hz and resilient modulus values at the same test temperature. Such a relationship means that analysis and conclusions based on changes in dynamic modulus values can be extended to similar changes in resilient modulus values.

Several MEPDG design simulations were performed on a FORTA fiber reinforced pavement and a conventional pavement to determine relationships between AC layer thickness and percent improvement in total rutting and fatigue cracking resistance due to the addition of the FORTA fibers. These design simulations used laboratory data, specifically dynamic modulus and fatigue test data for both AC mixtures.

Based on these MEPDG design simulations, the maximum AC layer thickness reduction of the FORTA fiber reinforced pavement to provide equivalent predicted pavement performance of conventional pavements for both total rutting and fatigue cracking is 32%. Given the relationship between dynamic modulus and resilient modulus, it is expected that similar thickness reductions may be achievable for AC pavements designed using resilient modulus data.

Resilient Modulus in Pavement Analysis

Despite the widespread measurement and use of the resilient modulus, the most advanced pavement analysis tools rely on the dynamic modulus. Both of these material properties relate the magnitude of a strain response to some applied stress. In the case of the resilient modulus the loading pattern involves a haversine load pulse followed by a rest period (0.1 seconds of loading and 0.9 seconds of rest). It is often measured at three different temperatures (approximately 40, 70, and 100°F) although the test at the middle temperature (70°F) is most often used in analysis. The dynamic modulus represents the stress-strain response under continuous cyclic loading. Two protocols exist, but the one most often used in practice also covers the range from 40 to 100°F but includes multiple frequencies of loading between 10 and 0.1 Hz.

The relationship between these two quantities has been an issue of interest to researchers and practitioners, with the majority of work being produced in the years between 2003 and 2010 (1-4). Essentially this work proves that the two moduli values are related. It also shows that if one knows the dynamic modulus at the aforementioned frequencies and temperatures that they can readily calculate the resilient modulus through mathematical manipulation of linear viscoelastic stress-strain relationships. The same calculations also show that if one knows the resilient modulus they cannot directly calculate the dynamic modulus. This inability stems from the fact that dynamic modulus is a quantity with a stronger mathematical foundation, e.g., it is more *fundamental*. Although it is not possible to mathematically convert resilient modulus to dynamic modulus, the citations above do propose conversion methods.

Overall, the results of these works (supported with experimental data) shows that an approximately useful rule of thumb is that at a fixed temperature the resilient modulus is equivalent to the dynamic modulus at the same temperature and at a 5 Hz continuous loading frequency as shown in Figure 1. Such a relationship means that observations regarding improvements in dynamic modulus in mixtures containing FORTA fibers are equally applicable to expected improvements in resilient modulus. In light of this observation it is possible to draw conclusions on the effect of FORTA fibers on resilient modulus values. Table 1 shows the estimated values for the resilient modulus of the FORTA reinforced asphalt concrete mixtures based on this correlation.

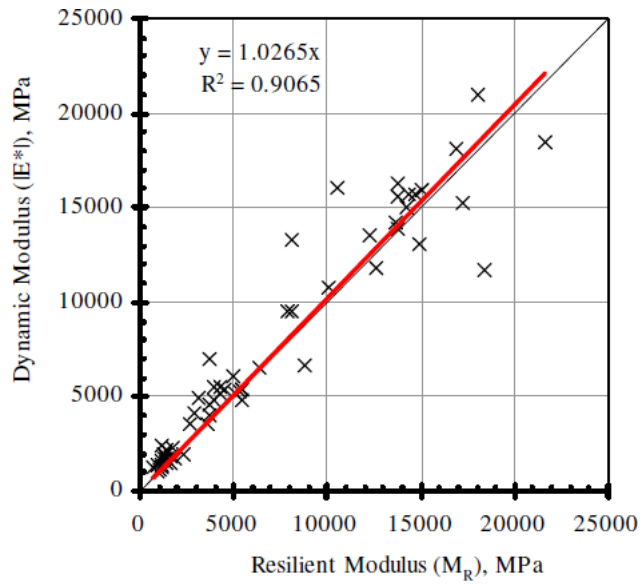

Figure 1. Relationship between resilient modulus and dynamic modulus at 5 Hz (Xiao 2009).

Table 1. Estimated Resilient Modulus for FORTA Fiber Asphalt Mixture.

Test Temperature (°F)	Mixture	
	Control	FORTA 1 lb/ton
	Equivalent Resilient Modulus (ksi)	Equivalent Resilient Modulus (ksi)
40	3,793	4,812
70	1,760	2,669
100	685	1,246

Method

In this analysis, laboratory test results from a non-fiber reinforced mixture (control) and a fiber reinforced mixture at 1 lb/ton dosage were used as inputs into the Mechanistic Empirical Pavement Design Guide (MEPDG) computer program (5). The control and fiber reinforced mixtures were sampled from an actual field project in Tempe, Arizona (6-7). The asphalt mixture type was 19-mm dense graded mixture with 7.0% air voids, 5.0% asphalt content, and PG 64-22

binder grade. This analysis was carried out to investigate the predicted field performance per the MEPDG, and to evaluate the impacts on varying pavement design thicknesses on the performance of control and fiber reinforced pavements. A total of 10 analysis simulations were performed for each of the control and fiber reinforced asphalt mixtures for the following conditions. It is important to note that this analysis used laboratory dynamic modulus data for control and fiber reinforced mixtures.

- Two traffic levels, 1500 and 7000 Annual Average Daily Traffic (AADT), representing an intermediate and high traffic levels.
- Five Asphalt Concrete (AC) layer thicknesses, 2 to 6 inches (50 to 150 mm) over a constant thickness base of 8 inches (200 mm).
- The base layer consists of unbounded A-3 material with modulus of 29,000 psi and the subgrade layer consists of A-6 soil with modulus of 14,500 psi.
- Climatic conditions: Phoenix, Arizona, USA
- Design life: 10 years

Results

The following observations were made based on the results from this analysis:

1. For a rutting criterion not to exceed 0.4 inches during the design period of 10 years, 5.5 inches of AC pavement thickness was needed for the control mixture; whereas the fiber reinforced mixture AC layer thickness required only 3.5 inches.
2. For high traffic level, (7000 AADT) a reduction of 2 inches in the total AC layer thickness was observed to achieve the same pavement performance against rutting. This savings was 1.5 inches for the lower traffic level of 1500 AADT.
3. For fatigue cracking predicted by the MEPDG, the results show similar trends, in that lower fatigue cracking is predicted for the fiber reinforced mixture. However, the results are also dependent on the AC layer thickness.

Based on the MEPDG results, the AC layer thickness reduction due to the use of fiber reinforcement compared to the conventional (control) was evaluated by calculating the pavement performance enhancement percent. The pavement performance enhancement percent is calculated for total rutting and fatigue cracking through equations 1 and 2.

$$\%\ \text{Total Rutting Enhancement} = \frac{\text{Total Rutting}_{\text{Control at actual AC thickness}} - \text{Total Rutting}_{\text{fiber at reduced AC thickness}}}{\text{Total Rutting}_{\text{Control at actual AC thickness}}} \times 100$$

(Equation 1)

$$\%\ \text{Fatigue Enhancement} = \frac{\text{Fatigue}_{\text{Control at actual AC thickness}} - \text{Fatigue}_{\text{fiber at reduced AC thickness}}}{\text{Fatigue}_{\text{Control at actual AC thickness}}} \times 100$$

(Equation 2)

Figure 2 shows the relationship between percent reduction in AC layer thickness and the improvement percentage in total rutting due to the use of FORTA fibers. Figure 3 shows the relationship between percent saving in AC layer thickness and the improvement percentage in fatigue cracking percent due to the use of FORTA fibers. Using these two figures, the percent

reduction in AC thickness was determined such that an AC pavement modified with FORTA fibers has equivalent predicted performance as the same AC mixture without FORTA fibers.

The following observations are made in relation to Figures 2 and 3:

1. The maximum reduction in the AC layer thickness of the FORTA fiber reinforced pavement to provide the same predicted pavement performance of conventional pavements against total rutting and fatigue cracking are 38% and 32%, respectively.
2. The maximum reduction in the AC layer thickness of the FORTA fiber reinforced pavement to provide the same predicted pavement performance of conventional pavements for both total rutting and fatigue cracking is 32%.

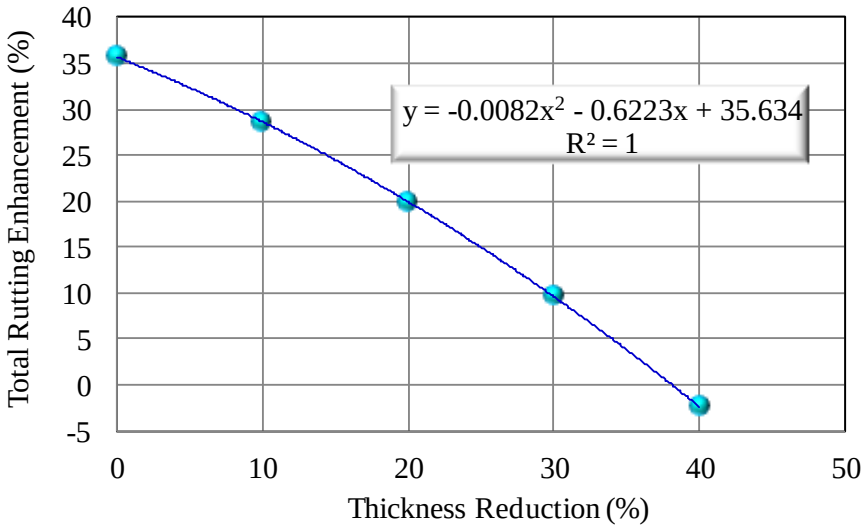

Figure 2 Effect of thickness reduction of fiber reinforced pavement on total rutting enhancement percent.

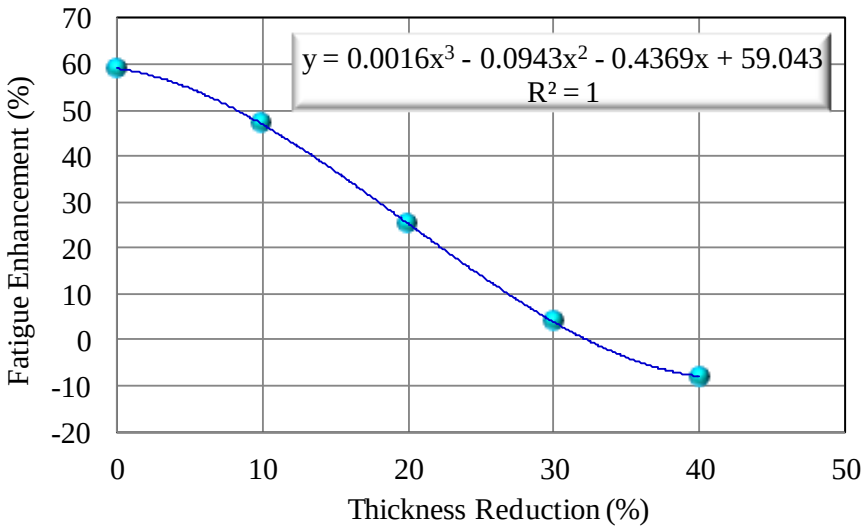

Figure 3 Effect of thickness reduction of fiber reinforced pavement on fatigue cracking enhancement percent.

Conclusion

Work by several researchers (1-4) has investigated the relationship between dynamic modulus and resilient modulus of AC pavements. Based on this work, a useful rule of thumb is that the resilient modulus is equivalent to the dynamic modulus at the same temperature and at a 5 Hz continuous loading frequency. Such a relationship means that observations regarding improvements in dynamic modulus in mixtures containing FORTA fibers are equally applicable to expected improvements in resilient modulus.

Based on MEPDG design simulations which used laboratory dynamic modulus and fatigue cracking data, the maximum AC layer thickness reduction of the FORTA fiber reinforced pavement to provide the same predicted pavement performance of conventional pavements for both total rutting and fatigue cracking is 32%. Given the relationship between dynamic modulus and resilient modulus, it is expected that similar thickness reductions may be achievable for AC pavements designed using resilient modulus data.

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