

Fatigue Characteristics of Rich Bottom Bases (RBB) for Structural Design of Perpetual Pavements

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ABSTRACT

The accepted concept of a perpetual pavement is the bottom layer will contain an extra 0.5 percent of asphalt binder, and be compacted to 3 percent air voids. This mixture philosophy was thought to provide an increased modulus because of the lower air voids, and an extra fatigue resistance because of the extra binder. This paper presents the results of tests conducted on 10 Illinois DOT mixtures sampled from the construction site, and subjected to flexural fatigue testing at optimum, normal density, and at the increased asphalt content, lower density. The flexural testing was also carried out at low strain levels to examine the fatigue endurance limit of these mixtures. Consistently different behavior was noted for the standard and RBB mixtures. Stiffness is shown to increase with the RBB mixtures. Fatigue behavior was also shown to change in the RBB mixtures as the coefficients in the fatigue algorithm showed some differences. The fatigue endurance limit (FEL) behavior was present in all mixtures, and was not altered by the extra asphalt binder.

KEY WORDS: Perpetual pavement, fatigue, fatigue endurance limit.

INTRODUCTION

The design philosophy for a Perpetual Pavement (PP) introduces a distinct multi-layered approach as shown in Figure 1 (1). This pavement structure consists of a rut resistant surface layer, which is typically an SMA, over an intermediate layer with good rut resistance, over a standard layer. These mixtures are placed on a Rich Bottom Base (RBB) mixture. The structural design philosophy is that the combined thicknesses of these mixtures will be sufficient to eliminate fatigue failure in the section. This limits future rehabilitation to the surface mixture only. This surface deterioration may be durability related, or even top-down cracking, but traditional fatigue cracking (bottom-up) is eliminated.

The RBB mixture is the standard mixture used in the pavement section with an additional 0.5% asphalt binder added. This mixture is then compacted in the field to 3-4% air voids. This compaction requirement is different from standard mixtures which are typically only compacted to an air void level of 6-7%. This extra compaction, aided by the additional asphalt content, is expected to produce an increased modulus in the mixture that will improve the structural response of the section. The added asphalt content may also provide a more fatigue resistant mixture.

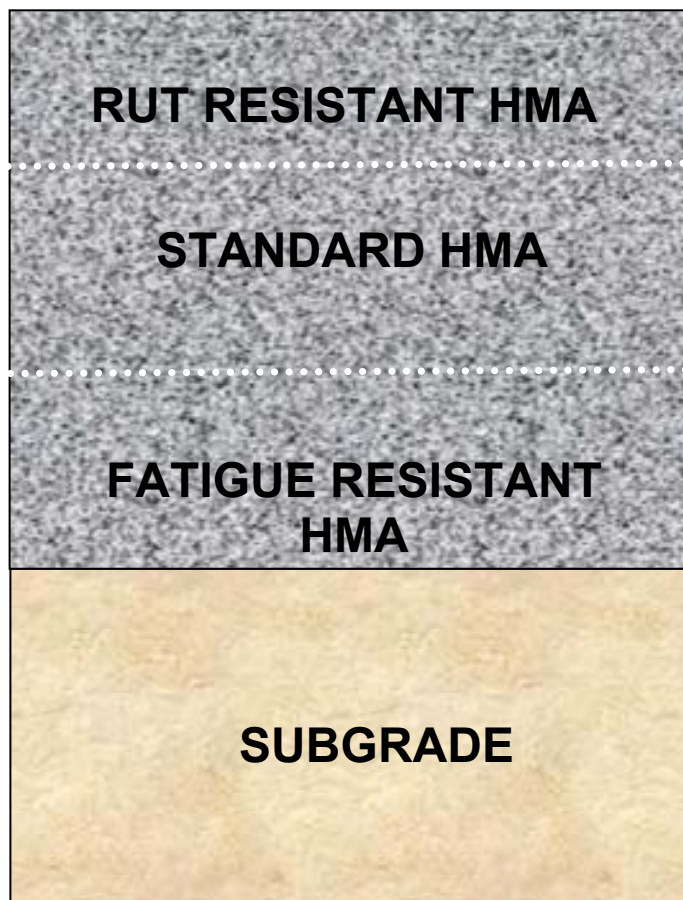


FIGURE 1 Perpetual pavement typical cross-section.

PERPETUAL PAVEMENT STRUCTURAL DESIGN

The primary consideration of the PP design philosophy hinges on the existence of a thickness producing no fatigue damage in the HMA. The structural adequacy of the design then relies on the ability of the RBB to satisfy these performance criteria with acceptable fatigue behavior. This design relies on the existence of what has been called the Fatigue Endurance Limit (FEL) for HMA, a strain/stress level below which the HMA will not develop fatigue damage under the imposed loadings. The secondary consideration is that the RBB does not invalidate the FEL concept.

Fatigue Endurance Limit (FEL)

The structural design philosophy of no fatigue damage was postulated long ago by Monismith et al. (2) and incorporated into the APA recommendations. The existence of a thickness that produced a strain/stress level that produces no fatigue damage had not been tested for in the laboratory until 1999 (3). This initial testing and subsequent work (4) have clearly established the existence of a "Fatigue Endurance Limit" (FEL, in micro-strain units). The FEL is a strain level below which the mixture has an extraordinarily long fatigue life, and for practical purposes can be assumed to be infinite in terms of the pavement's life.

Figure 2 illustrates the testing conducted to date that establishes the FEL (4). There is clearly a strain limit below which the fatigue life becomes extraordinarily long. The actual strain level varies by mixture (most likely binder type (5)). The point at which the FEL occurs is actually a consistent damage quantity regardless of binder and mixture properties(5).

OBJECTIVE

The objective of this study is to test typical Illinois DOT (IDOT) binder mixtures that could be used for PP construction. The first step is to establish the fatigue characteristics of the plant produced mixtures. The second step is to establish the fatigue characteristics of the plant mix modified to produce the RBB mixture. The third step is to determine whether the RBB mixtures exhibit the same FEL as the standard HMA mixtures. These performance characteristics will be compared to establish if there is a difference between the mixtures and the extent of that difference on the PP design philosophy.

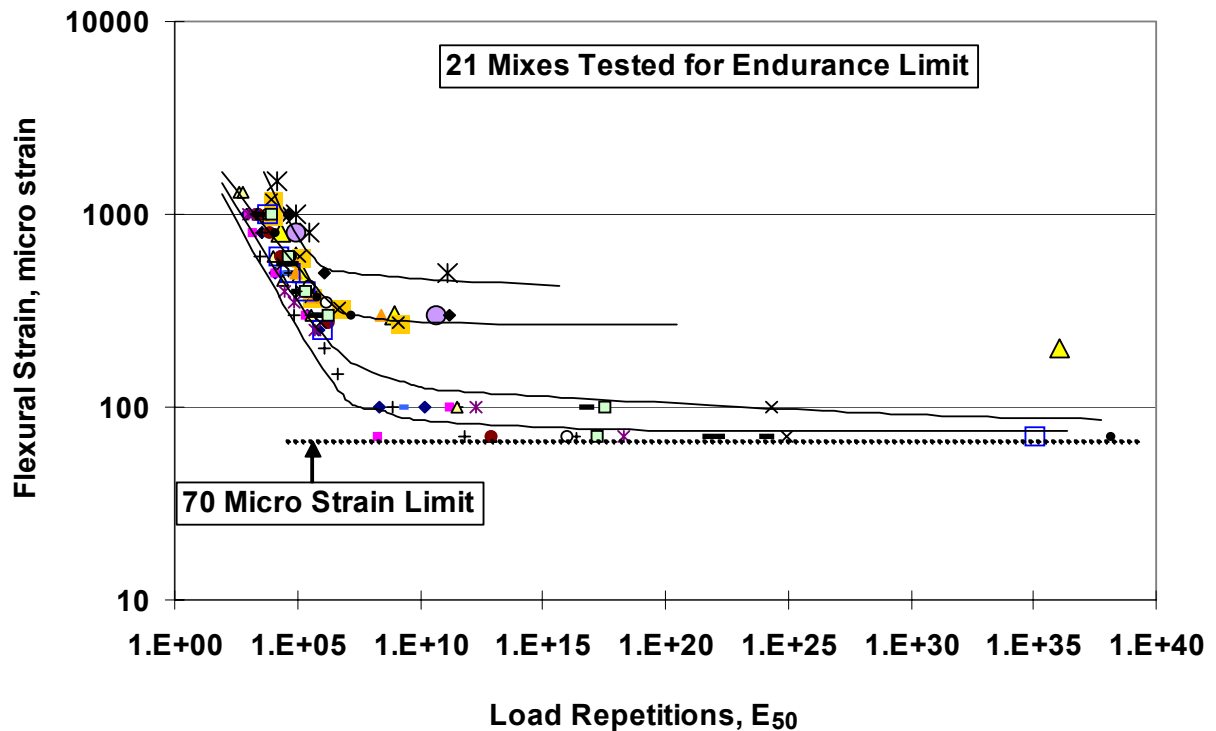


FIGURE 2 Fatigue curves at normal and low strain level tests.

MATERIALS

The materials used in this study were sampled from the trucks as they left the HMA plant during the 2003 construction season in Illinois. They were binder mixtures which would be considered the standard mixture in the PP design section. At the time the HMA samples were taken, samples of the asphalt binder used were also taken from the tanks at the HMA plant. Relevant mix data are given in Table 1. These mixtures represent a cross section of mix designs used in Illinois, different binders, different aggregate types, and different mix design gyration levels.

The mixtures were compacted in a rolling wheel compactor, which produces bricks that are sawn into two beams of the proper size for flexural fatigue testing. The standard mixtures were compacted to 7 percent air voids, and the RBB mixtures were compacted to 3 percent air voids, each at ± 0.5 percent air voids. The mixtures were all heated to the mixing temperature prior to compaction. The standard mixtures were cooled slightly to compaction temperature, and then compacted. The RBB mixtures were heated, mixed with the extra binder, combined through a sample splitter with a second sample to reduce variability, and then compacted. This procedure for the RBB mixtures involved slightly more time at elevated temperatures, but not an excessive amount, and any aging due to this could be offset by the addition of new binder, but this was not measured.

TABLE 1 Mixture Information for the IDOT Mixtures

Mix ID	Material information
5N105	SBS PG76-28, 0.1% lime anti strip, limestone, 4.70%AC
1N80DP	SMA, SBS PG76-28, 8.54%AC (rich)
3N90	SBS PG76-22, 0.5% anti strip, dolomite, 5.06%AC
1N80D	SMA, SBS PG76-28, 8.04%AC
3N90P	SBS PG76-22, 0.5% anti strip, dolomite, 5.45% AC (rich)
2N90P	SBS PG70-22 dolomite, 6.77%AC (rich)
3N70P	PG64-22 limestone, 5.62% AC (rich)
1N105P	SBS PG70-22 dolomite, 6.94%AC (rich)
3N90TP	PG64-22 limestone, 4.72%AC (rich)
5N90	PG64-22, 0.5% anti strip, dolomite, 4.90%AC
6N50P	PG64-22, 0.7% anti strip limestone, 5.55% AC (rich)
5N90P	PG64-22, 0.5% anti strip, dolomite, 5.53% AC (rich)
2N90	SBS PG70-22 Dolomite, 5.90%AC
1N105	SBS PG70-22 dolomite, 6.5%AC
3N70	PG64-22 limestone, 5.17%AC
6N50	PG64-22, 0.7% anti strip, limestone, 5.05%AC
8N70P	PG64-22 limestone, 5.23% AC (rich)
3N90T	PG64-22 limestone, 4.06%AC
8N70	PG64-22 limestone, 4.93%AC

Testing

Fatigue testing followed the standard AASHTO specification (6). This protocol uses a constant strain 10 Hz haversine load applied at 20 C. The equipment used is the Industrial Process Control (IPC) equipment. This equipment is completely computer controlled providing a consistent testing sequence for all samples. The strain levels varied from approximately 1000 micro-strain down to 70 micro-strain.

RESULTS

The results of fatigue testing for this study first allow examination of the traditional fatigue curve of the form:

$$N_f = K (1/\varepsilon)^n \quad (1)$$

Where:

N_f is the number of loads to failure

ε is the tensile strain

K and n are the regression coefficients

The second element of study is to examine the presence of the FEL breakpoint. Both mixture types will be compared to note any differences.

Traditional Fatigue

The traditional fatigue curves are shown in Figure 3 for the standard mixtures tested and in Figure 4 for the RBB mixtures. In these figures, the bold legend indicates a polymer modified binder. All mixtures exhibited the expected distinctive curves for each mixture. There does not appear to be a distinctive shift in fatigue behavior between standard and RBB mixtures. Graphical examination indicates that there may be a shift in fatigue behavior in the RBB mixtures.

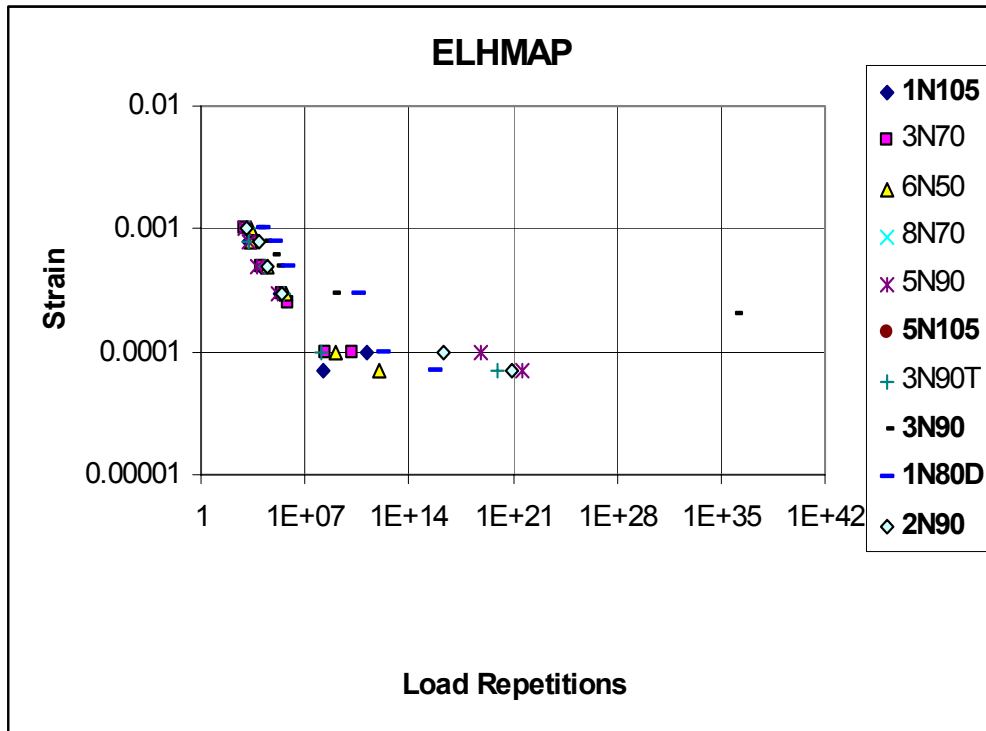


FIGURE 3 Conventional fatigue curves for standard mixtures.

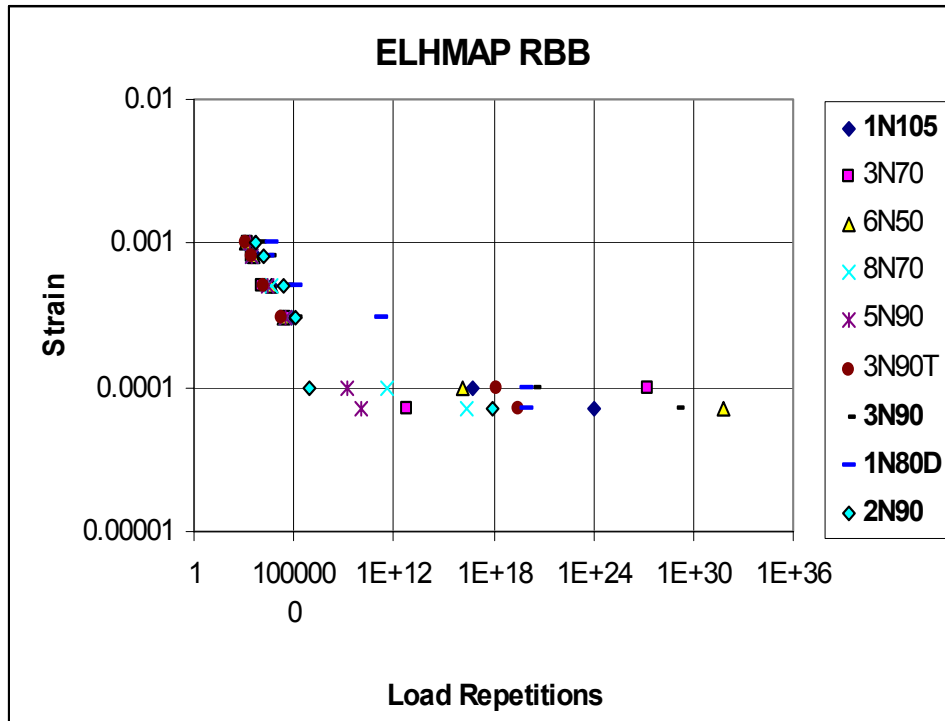


FIGURE 4 Conventional fatigue curves for RBB mixtures

The K and n values followed the expected trend indicating that the RBB procedure did not invalidate fatigue behavior or alter it in a manner that would produce unexpected poor behavior, as can be interpreted from the traditional fatigue curves shown previously. Figure 5 compares the K values for the standard and RBB mixtures. The curves clearly indicate that there is a general shift with the K value in the RBB mixtures being lowered. A similar trend is seen in Figure 6 which shows the n values for the two mixtures. There is a general shift in the n value with the RBB mixtures exhibiting an increased n value. Taken together these indicate that there could be an improved level of fatigue behavior in the RBB mixtures.

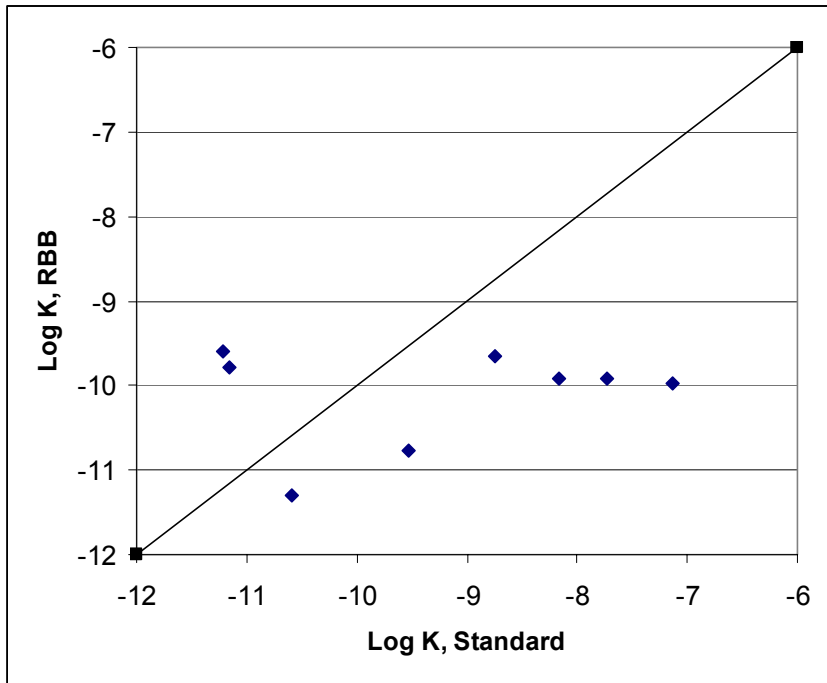


FIGURE 5. Comparison of K coefficients for standard and RBB mixtures.

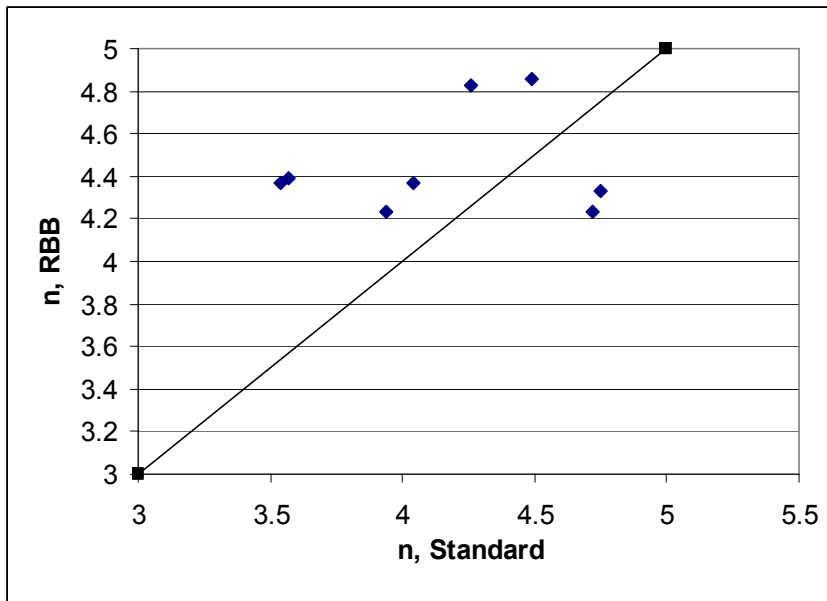


FIGURE 6 Comparison of n exponents for standard and RBB mixtures.

Modulus

There is a distinctive increase in the flexural stiffness of the RBB mixtures, as shown in Figure 7. This increase in flexural modulus corresponds to an increase in dynamic modulus, E^* as shown in the dynamic modulus testing of the standard mixtures.

Figure 8 compares the E^* value of the standard mixtures at 20 C, 10 Hz to the flexural modulus from the fatigue test which is conducted at 20C with a 10 Hz haversine load pulse. An increase in modulus is achieved with the RBB approach of compacting to a reduced air voids level.

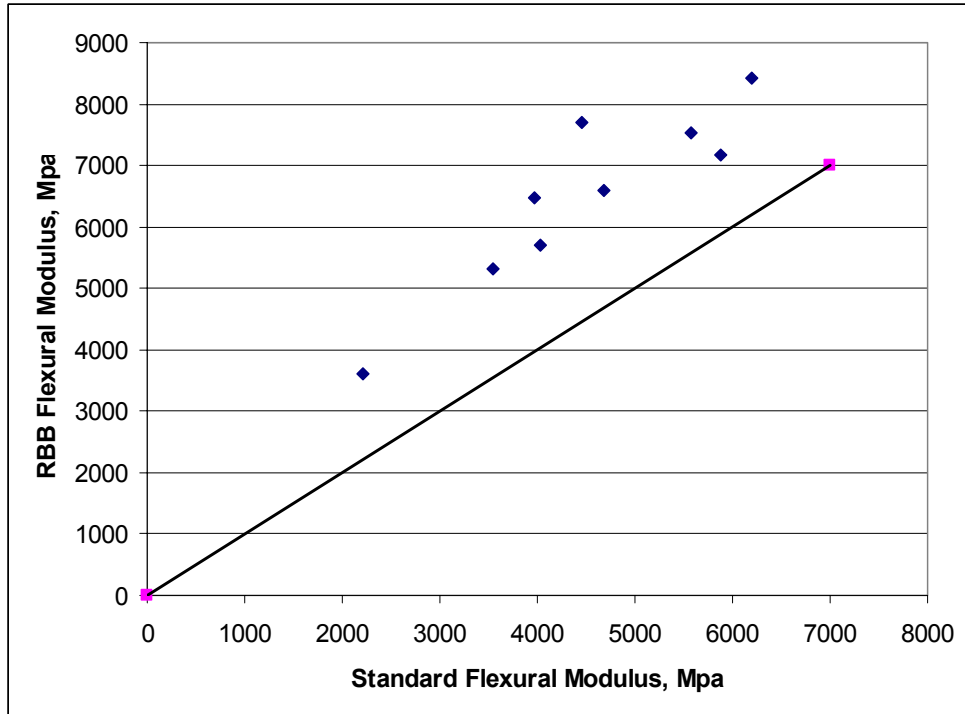


FIGURE 7 Comparison of flexural modulus values for standard and RBB mixtures.

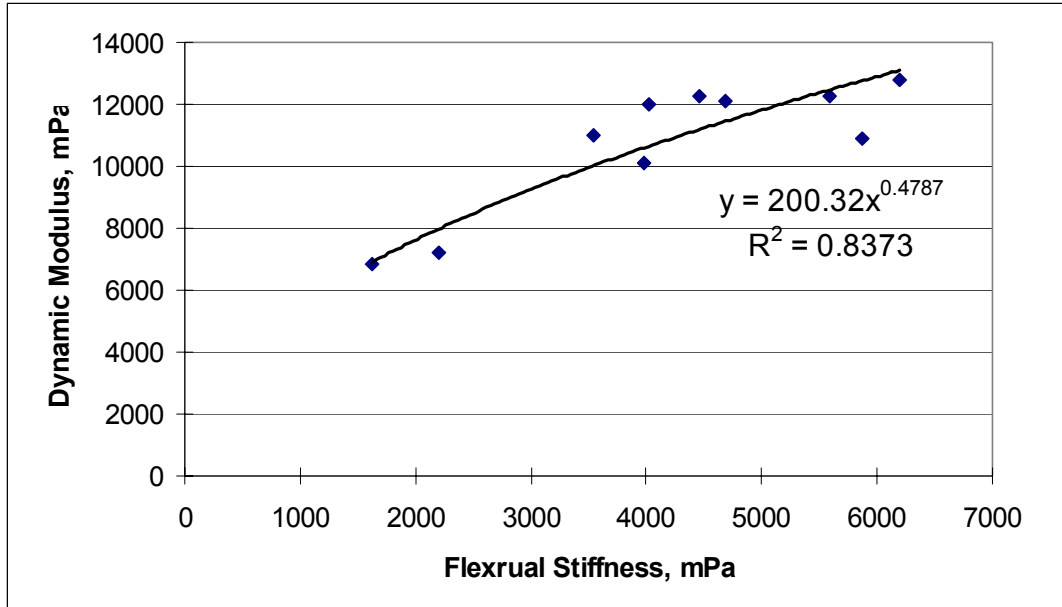


FIGURE 8 Relation between flexural and dynamic modulus, E^* for standard mixtures.

Fatigue Endurance Limit

Fatigue testing at strain levels below approximately 200 micro-strain was conducted to generate data to examine and determine whether the extended fatigue life was present, and the strain level at which the extended fatigue life begins. As previously shown, the traditional fatigue relationship with low strain testing clearly supports the FEL breakpoint for the regular mixtures and for the RBB mixtures. The FEL is not invalidated by the preparation of a RBB mixture. The question of interpreting the data to state whether the FEL value is changed by the RBB mixture procedure is not quite so straightforward, and requires utilization of the dissipated energy work previously completed by the authors, primarily the Plateau Value (PV).

Plateau Value The dissipated energy approach to examine fatigue damage has produced a unique relationship between damage, indicated by Plateau Value (PV) and the loads to failure. While not being discussed in this paper, the reader is referred to previous references for an understanding of how the PV is developed (3, 4, 5). The relation between PV and loads to failure is shown in Figure 9. This unique relationship between the PV damage level and the number of loads to failure is the unifying element of the dissipated energy approach. Statistical comparison of the traditional fatigue curve and the extended life portion show that there is one unique PV value where the breakpoint for FEL behavior develops, termed PV_L , shown in the figure. Using this value of PV_L a prediction of the strain level at which the FEL begins to control fatigue behavior, producing extended fatigue life when strains are below this value, is obtained.

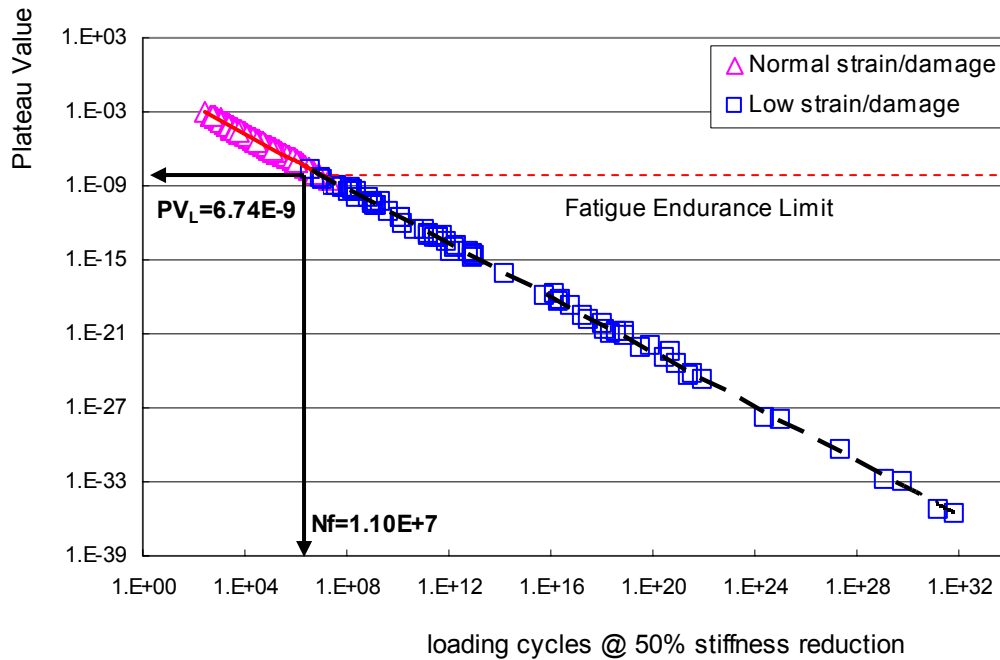


FIGURE 9 PV – Nf relationship with FEL indicated.

Table 2 presents the FEL values determined from the standard fatigue curves shown earlier, and the FEL determined from the plateau value relationship, PV_L . These values are comparable, and the main differences result from the limited testing for any one mixture as only one or two samples were tested at the low strain level to establish the tested FEL value. Figure 10 compares the PV_L calculated FEL for the standard mixtures and the PV_L calculated FEL for the RBB mixtures. This figure clearly shows that there is not a discernible trend in the FEL induced by the RBB procedure, and the FEL from a standard mixture is an extremely good indicator of the FEL for the RBB mixture. The RBB procedure does not significantly alter the FEL.

Table 2 Tested and PVL Calculated FEL Values For the IDOT Mixtures

Mix ID	Tested FEL strain ($\mu\epsilon$)	PV_L FEL strain ($\mu\epsilon$)
5N105	500	387
1N80DP	300	301
3N90	300	229
1N80D	300	273
3N90P	200	218
2N90P	150	196
3N70P	100	157
1N105P	100	181
3N90TP	100	171
5N90	100	162
6N50P	100	166
5N90P	100	150
2N90	100	170
1N105	100	139
3N70	100	134
6N50	100	168
8N70P	100	177
3N90T	100	136
8N70	100	167

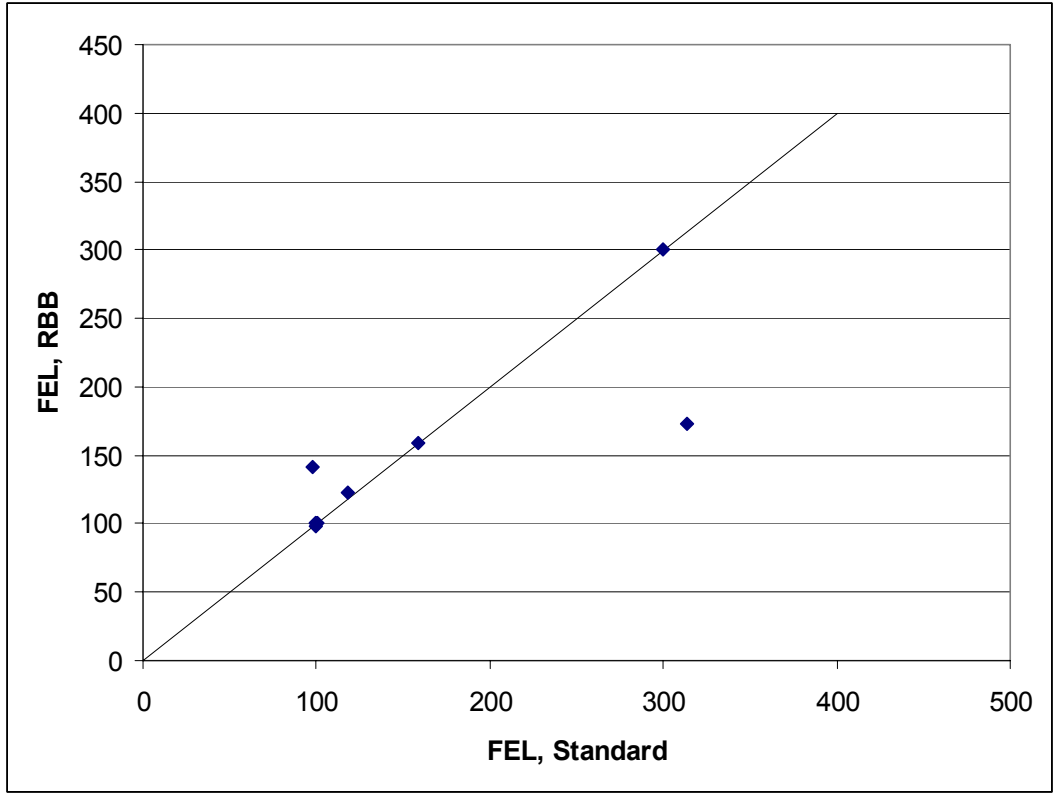


FIGURE 10 Comparison of the FEL values for standard and RBB mixtures.

Modulus Effect Figure 11 shows the relationship established between the FEL and the flexural modulus for the standard and the RBB mixtures. This curve indicates that there is an effect of modulus on FEL, but the increased modulus in the RBB mixtures does not alter the FEL. This comparison is interesting as FEL relates to modulus, but there is no change in FEL when the RBB procedure produces a higher modulus.

This contradiction actually provides support for the thought that it is not really modulus itself, but the change in modulus produced by using different binders which alter the characteristics of similar mixtures. Because the FEL is primarily a result of healing potential (a chemical/molecular kinetic that is constantly active) of the asphalt binder (5), changing modulus using the same binder should not alter the FEL significantly. Any mixture differences produced while using the same binder should not be expected to alter the FEL, as the healing potential of a binder is constant regardless of the amount of binder present. It must be explained that normal variability in asphalt values are discussed here, and the production of intentionally dry or wet mixtures could have a serious impact on the fatigue performance, including the FEL.

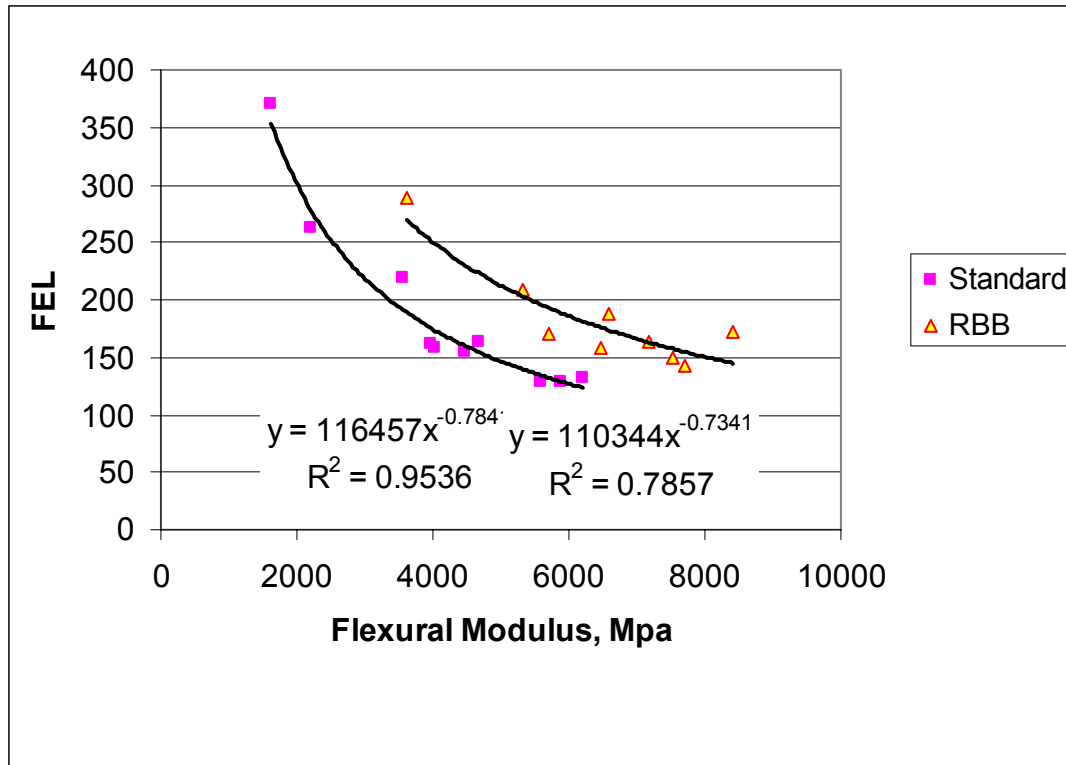


FIGURE 11 Relation of the FEL and flexural modulus for standard and RBB mixtures.

CONCLUSIONS

This investigation into the fatigue characteristics of 10 typical IDOT binder mixtures that could be used in the fatigue resistant layer of a Perpetual Pavement provides some clear indications of what can be achieved with a Rich Bottom Binder layer, and some preliminary indications of where behavioral differences may exist.

- The RBB procedure of adding 0.5 percent asphalt binder and compacting to 3 percent air voids does increase the modulus of the RBB mixture over that of the standard mixture.
- The traditional fatigue resistance commonly used for structural design of HMA pavements does change when the standard HMA mixture was altered to produce a RBB mixture with an apparent increase in fatigue resistance in the RBB mixtures.
- A fatigue Endurance Limit (FEL) was illustrated for both the standard mixture and the RBB mixture. There was no discernible difference produced in the FEL when the standard mixture is altered to produce a RBB mixture.
- For similar mixtures as shown here, increased modulus resulting from the use of different binders, produced lower FEL values.

- RBB mixtures with higher modulus values, compared to the standard mixtures, did not demonstrate a lower FEL. This supports the contention that healing potential is uniform for a binder type, and therefore the FEL should not change significantly for different mixture composition when the same binder is used.

RECOMMENDATIONS

The structural impact of the RBB procedure in altering the modulus and fatigue resistance must be investigated to determine the thickness reduction in a Perpetual Pavement produced by this bottom fatigue resistant layer having a slightly higher modulus.

The potential differences induced by using a polymer modified binder should be investigated to verify that the FEL does not change even though the traditional fatigue curve changes positions. There is not sufficient data in the testing for this paper to justify a statement at present.

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DISCLAIMER

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