Building Better Roads White Paper

Extended Asphalt Pavement Life Through Use of Aramid (polymer) Fibers

Mission – Through the establishment of a working group of industry associations and public agencies, with a localized emphasis on the regions resources and the County's needs, identify means, measures, and methods to improve the quality of regional roads.

Abstract

Using fibers to reinforce asphalt mixes has been practiced since the early 1980's [1]. While much use of fiber (i.e. cellulose or paper) in the United States (U.S.) is focused on reducing drain down in asphalt mixtures, the fibers discussed here within refer to engineered fibers that are used to improve the mechanical properties of the mixture as they relate to rutting, cracking, and structural modulus. Typically, synthetic polymer fibers are used for this purpose, and the resulting asphalt mix is referred to as fiber-reinforced asphalt concrete (FRAC). Numerous experimental studies have shown that adding synthetic polymer fibers to dense-graded mixes can improve their mechanical performance, particularly with regard to rutting and fatigue resistance. Laboratory and field results have shown that synthetic fibers can improve mixture cracking performance alone from 30-50% [2-8]. This paper is focused on the performance of aramid fiber that is superior in the family of reinforcing fibers because of its high strength-to-low-strain ratio, resistance to heat, and polymer-like performance.

Problem Statement

According to American Society of Civil Engineers (ASCE) 2017 report card, the U.S. highway system has been underfunded, resulting in $836 billion backlog of capital needs of which $420 billion is to repair our highways [1]. This lack of funding has forced the use of more recycled asphalt pavement (RAP) to overcome higher asphalt binder prices that have been experienced in the past 10 years. The result is asphalt pavements that are more brittle because of the improper use of RAP; where, higher RAP mixtures have not been compensated for with the use of softer binders, additional modifier, or sometimes added asphalt content. The brittleness that is created leads to early cracking, thus reducing the life of the pavement.

A typical solution to the above is to soften the asphalt binder (roofing flux, soft asphalt, rejuvenators, aromatic oils, paraffinic oils, extender oils, etc.) to incorporate the use of RAP but with fear that too much softening can result in rutting. Ideally, we need the best of both so that one can soften the mix to reduce cracking while also not sacrificing the rutting resistance. Solutions to this dilemma are usually solved through polymer modification and coordination with asphalt binder terminals to supply alternate asphalt grades as needed in the market. Knowing that every performance grade (PG) asphalt binder usually requires an additional tank at the contractor's hot mix asphalt (HMA) plant, we usually limit ourselves to just a few grades and more typically around two tanks or two PG types. These are usually a standard or workhorse grade (such as PG 70-10 in the desert southwest) and a higher grade to resist rutting for higher traffic pavements. We should not limit solutions to aggregate and asphalt binder-only combinations when many more options are available to improve our HMA directly at the plant.

Solution

What if we could modify this HMA on site at the contractors' plant to directly improve the high and low temperature PG of the asphalt mixture? This performance could then be directly measured through standardized tests that show the improvement of the added aramid.

One of the earliest uses of a fiber-reinforced asphalt concrete occurred in 1980 on a composite pavement (continuously reinforced concrete with. 4" of HMA on top) [2,3] on I-65 in Indiana. The existing HMA overlay was severely deteriorated after six (6) years of service. The Indiana Department of Highways placed a test section consisting of an overlay of fiber reinforced asphalt to determine the benefit. The new overlay was 2-in without any milling. Approximately 1,550 feet of polypropylene fiber reinforced mixture (0.3% fiber by total mix weight or about 6 pounds per ton of mix) was placed while the remaining portion of the project served as the control section. After 2.5 years of service, the control section was exhibiting twice the amount of cracking observed in the fiber section. In addition, the severity of the cracks in the control section were more severe (moderate and high, ¼" to. 3/8-in wide) compared to the fiber section (1/32-in wide). In terms of rutting resistance, the control section had severe rutting (as deep as 2.25") while the fiber section was all less than 3/8-in deep.

In the 1980's Pennsylvania started to see excessive rutting in their heavy-duty pavements [4]. A task force was assembled to discuss options (gradation changes, volumetric changes, construction changes, aggregate quality changes). One of these options was several types of binder modification techniques. A test project was conducted on I-80 in Clearfield County from mile marker 120 to 128 in 1989. This was an overlay (75-mm base mix, 63.5-mm binder course, and 38-mm surface mix) on an existing conventional jointed Portland Cement concrete pavement. The base asphalt was an AC-20 with six experimental sections with various modifiers (polyethylene, ethylene vinyl acetate, polyester fibers, SB-reacted, Gilsonite, and SBS 4141). After ten years of service, the fiber modified and elastomer modified mixtures are in excellent condition with little to no secondary cracking at the sawn joints with little raveling and minimal rutting [4].

Around 1990, the Strategic Highway Research Program (SHRP) was implementing binder specifications. Indiana Department of Transportation conducted a field trial to look at various asphalt modification techniques, one of them being synthetic fibers. The field trial was conducted in September of 1990 on I-465 (ring road) around Indianapolis [5]. This particular stretch of road would see 150,000 vehicles per day with 30% trucks. Paving was completed in September of 1990. The existing pavement was Portland cement concrete (PCC). Three (3) lifts of HMA was placed on top of the PCC. The base asphalt used was an AC-20 (similar to a PG 64-22 today). For additional details on the project and test sections, see McDaniel *et al.* [5]

Over the course of eleven (11) years, pavement surveys were conducted on the above test pavement. The following information collected was rut depth, transverse cracking, and longitudinal cracking. In terms of rutting resistance, the fiber and polymer modified mixture were comparable to the control. However, a great increased in performance was noted in cracking resistance of the fiber and polymer modified mixtures; particularly in later years (1996 and 2001). By 2001 the control mixture was overlaid, whereas the polymer and fiber modified mixtures were still performing satisfactorily.

Another study during the Superpave evaluation years looked at various asphalt modification techniques. This work was conducted by the Federal Highway Administration from 2002 and finished in 2008 [6]. This research occurred at the Federal Highway Administration (FHWA) accelerated loading facility (ALF). The section below will only show the abbreviated data set comparing a control, polymer, and fiber modified mixture. The fiber was added at 0.3% by total mix weight using a 10-mm polyester fiber. For the full report, please refer to Gibson *et al.* [6].

Multiple full-scale test sections were designed and constructed to look at permanent deformation and fatigue cracking [6]. The permanent deformation test sections were tested at 64°C with a 44-kN wheel load and 689-kPa tire pressure. The fatigue test sections were tested at 19°C with a 71-kN wheel load and 827-kPa tire pressure. Both the permanent deformation and fatigue test sections included wheel wander as part of the experiment. The SBS-LG and fiber modified mixture behave similar in terms of resistance to permanent deformation initially, up to approximately 30,000 cycles. At 64°C, the fiber section went to just beyond 120,000 cycles until failure whereas the control and SBS-LG (linear grafted) section were terminated at approximately 50,000 cycles (12-mm rut depth). At 74°C, both the SBS-LG and fiber section went to 100,000 cycles until the test was terminated (12-mm rut depth). The fiber modified mixture not only outperformed the control mixture by 8-times, but it outperformed the SBS-LG test section by 1.5-times. This FHWA report shows the benefit of the fiber in mitigating and bridging cracks, thus providing a mixture that can extend the life of a pavement.

More recently, companies have innovated and developed better delivery systems and products (i.e. aramid fibers) to enhance the longevity of HMA pavements. These materials should have similar field performance to those that were mentioned above 1980's, 1990's, and 2000. One method of quantifying benefits of these new innovative materials is through the use of performance testing. Mateos *et al.* have used the four-point beam fatigue (AASHTO T 321) to evaluate the cracking resistance of aramid fiber mixtures and the asphalt mixture performance tester (AMPT) dynamic modulus test (AASHTO T 378) to observe the stiffness of the mixture [7].

Mateos *et al.* observed that at low strain levels, aramid fibers did not impact the fatigue life, however, at high strain levels (900 me), there was a 200% increase in fatigue life of the fiber-reinforced asphalt mixture[6]. This indicates that the addition of aramid fibers to the asphalt mixture should provide improved resistance to cracking when subjected to high strains in the field (i.e. reflective cracking or bridge deck applications).

Noorand *et al.* considered a performance engineered approach to analyzing the benefits of aramid fibers [8] using the newest tools. Dynamic modulus (AASHTO T 342), Uniaxial Fatigue (AASHTO TP 107), and Repeated Load Permanent Deformation (AASHTO TP 79) data was used to generate inputs that were used in FlexPave. Noorand *et al.* formulated the following conclusions; dynamic modulus values showed no statistical difference between the mixtures, the uniaxial fatigue data and FlexPave simulations (damage characteristic curve and predicted fatigue life relationship) showed that the two fiber mixtures improved the fatigue life by 2-times, and one of the fiber mixtures showed a 139% improvement in flow number (rutting resistance) while the other fiber mixture had a similar flow number to the control. It should be noted that the dynamic modulus test is a compression test and cannot properly test the tension or bending benefit of engineered fibers.

Conclusion

Using fibers to reinforce asphalt mixes has been practiced since the early 1980's. Fibers in this paper refer to engineered fibers that are used to improve the mechanical properties of the mixture as they relate to rutting, cracking, and structural modulus. Typically, synthetic polymer fibers are used for this purpose, and the resulting asphalt mix is referred to as fiber-reinforced asphalt concrete (FRAC). Numerous experimental studies [2-8] have shown that adding synthetic polymer fibers to dense-graded mixes can improve the field performance and their mechanical performance, particularly with regard to rutting and fatigue resistance. Laboratory and field results have shown that synthetic fibers can improve mixture cracking performance immensely [2-8].

This paper focuses on the field performance of fiber mixtures that were constructed early in the development of reinforcing fibers. More recent laboratory performance and pavement simulation of aramid fiber show that they are superior in the family of fibers because of its high strength-to-low-strain ratio, resistance to heat, and polymer-like performance.

References

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Appendix

Table 1. Pavement Condition Survey - Rutting Summary [4]

Section	Rut Depth in 1/16th of an inch			
	Left 1993	Right 1993	Left 1996	Right 1996
A – Control	1.0	0.8	0.3	0.9
B – PAC20	1.0	0.4	0.4	0.5
C – Fiber	0.8	0.2	0.2	0.8

Table 2. Pavement Condition Survey - Cracking Summary [4]

Section	Transverse Cracking (sum (1 ft)			Longitudinal Cracking, Sum (1 ft)		
	1993	1996	2001	1993	1996	2001
A –Control	174	416	NA[3]	142	507	NA
C – Fiber[1]	144	150	178	30	70	370
B – PAC20[2]	24	87	186	15	198	665

[1]Polyester fiber supplied by BoniFibers.
[2]PAC20 Sulfur cross-linked SBS (Styrelf) supplied by Koch Materials.
[3]NA = not available, section overlaid.

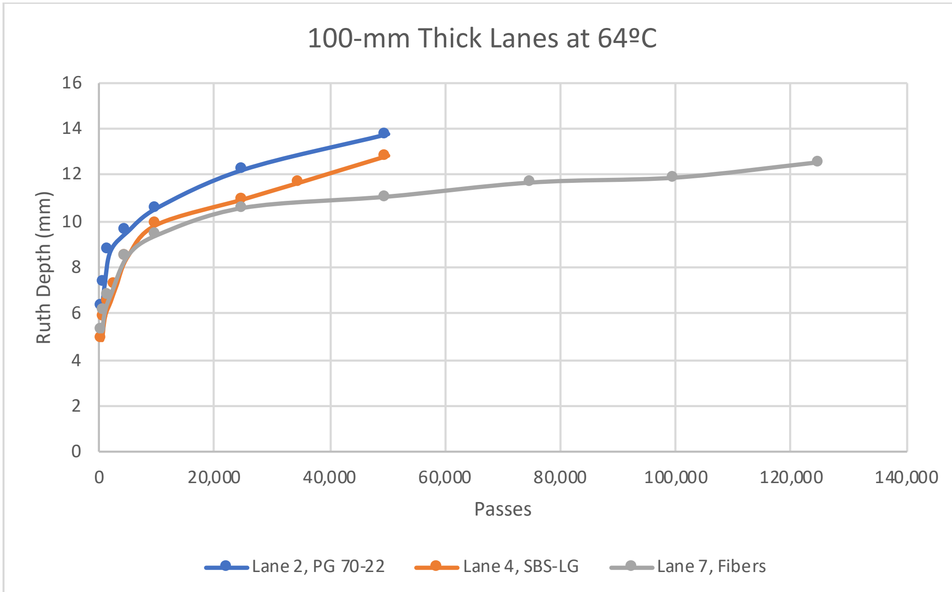

Figure 1. Rutting Data of 100-mm Lift Thickness at 64°C [5]

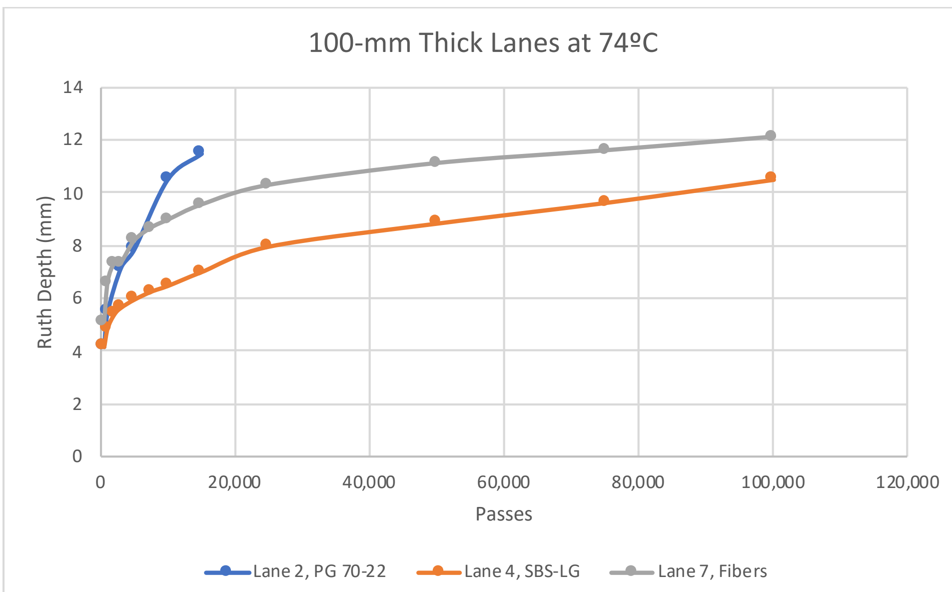

Figure 2. Rutting Data of 100-mm Lift Thickness at 74°C [5]

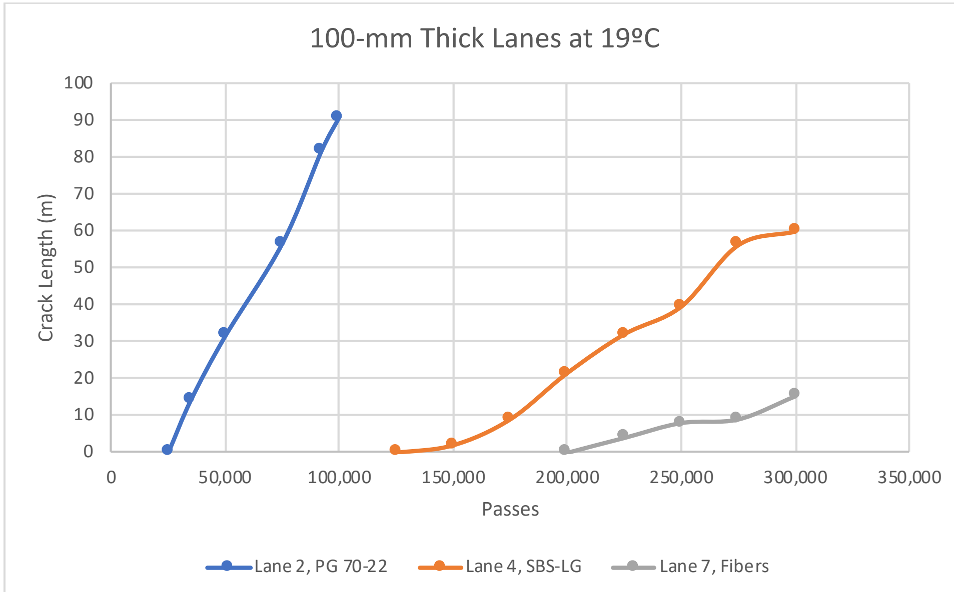

Figure 3. Cracking Length of 100-mm Lift Thickness at 19°C. [5]

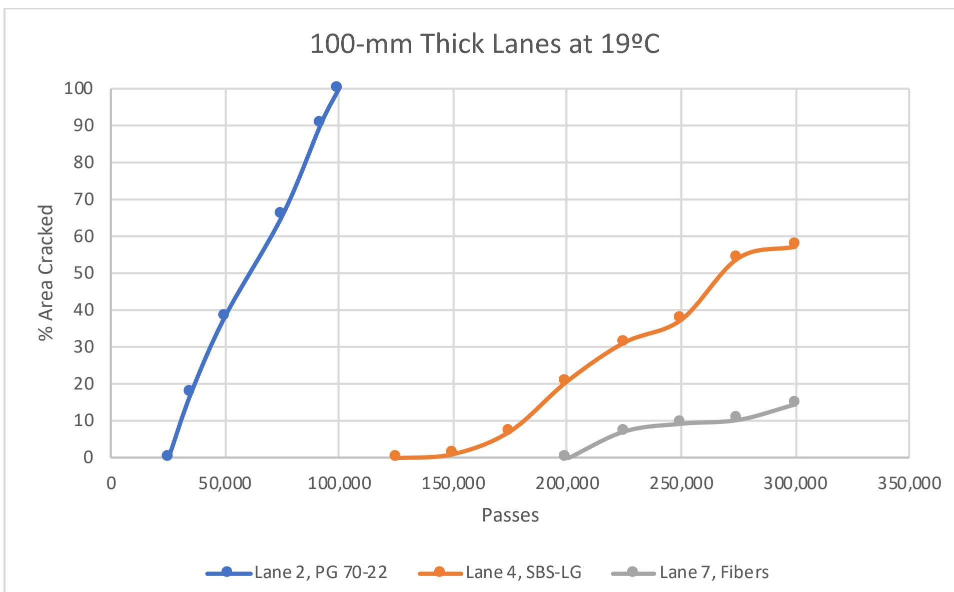

Figure 4. Percent Area Cracked of 100-mm Lift Thickness at 19°C [5]

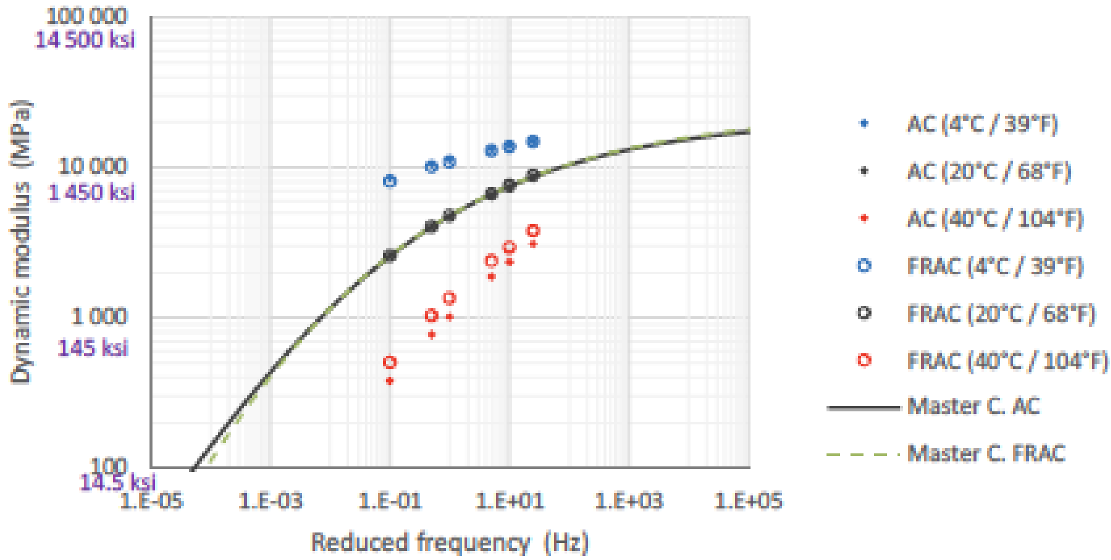

Figure 5. Dynamic Modulus from AMPT [6]

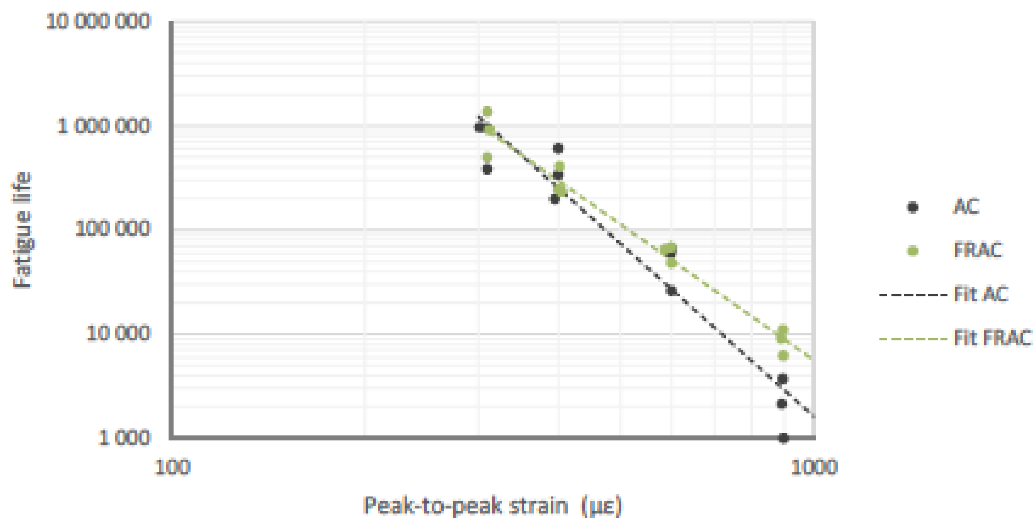

Figure 6. Four Point Beam Fatigue Performance [6]

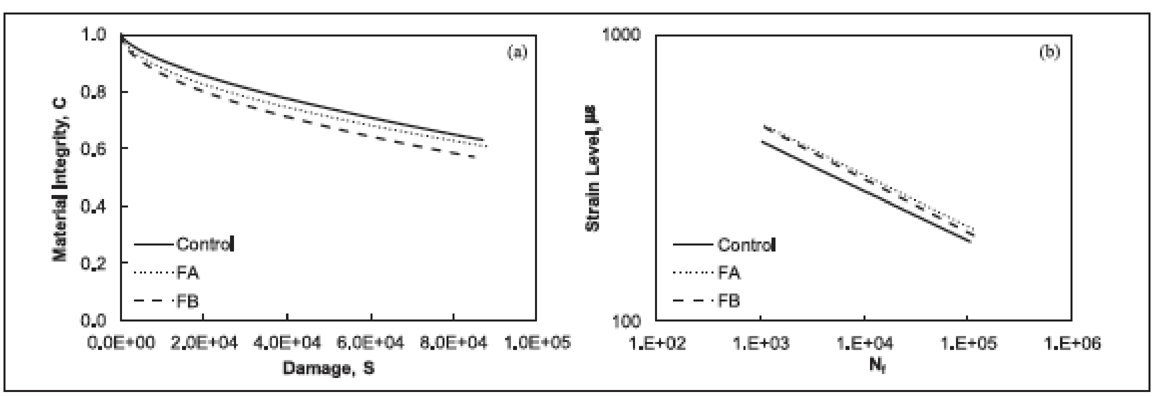

Figure 7. Uniaxial Fatigue Evaluation [7]

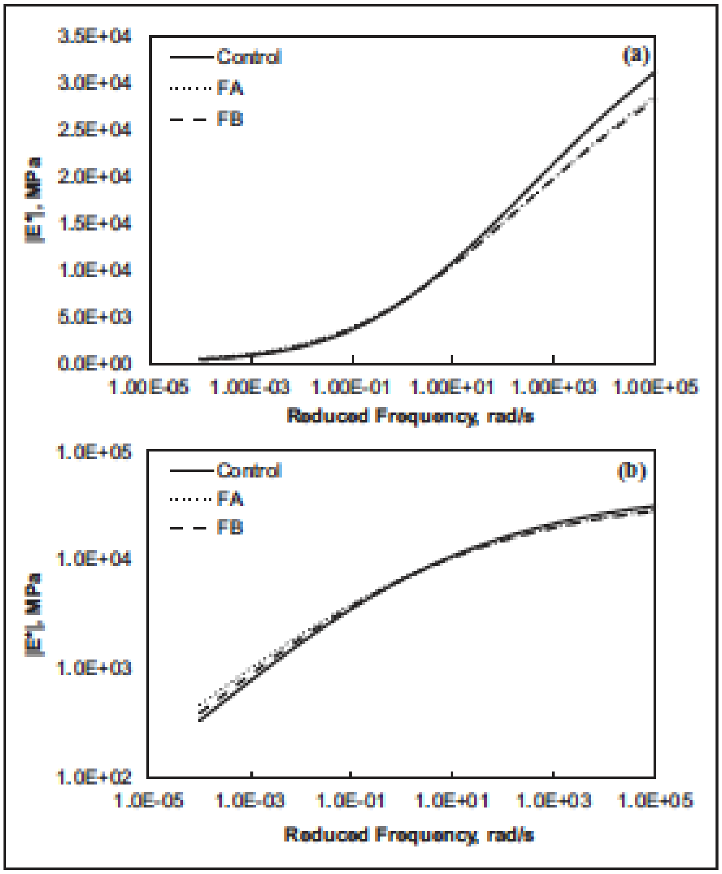

Figure 8. Dynamic Modulus Data [7]

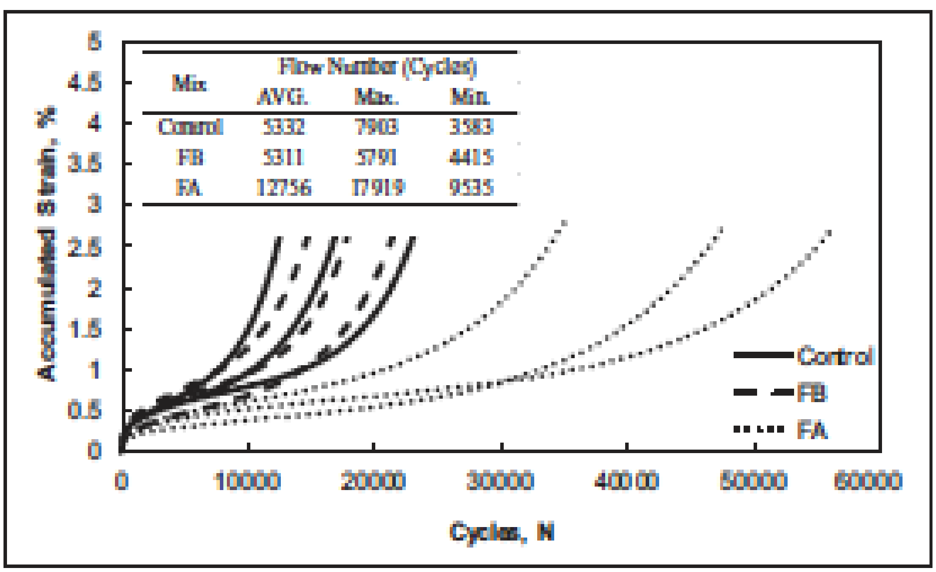

Figure 9. Repeated Load Permanent. Deformation Data [7]