EVALUATION OF STABILIZED AGGREGATE SURFACE COURSE MATERIAL FROM U.S. ARMY FORT BLISS TRAINING AREA

Stabilization Products LLC

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Pavements/Materials Program

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Evaluation of Stabilized Aggregate Surface Course Material from U.S. Army Fort Bliss Training Area

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Introduction

This report summarizes the evaluation of stabilized aggregate materials that were sampled during construction of military heavy haul roads at the U.S. Army's Fort Bliss Training Area which extends into the states of New Mexico and Texas. These military heavy haul roads are also known as Tank Trails or Main Supply Routes (MSR's). They are trafficked by convoys of military battle tanks and other tracked military equipment as well as heavy haul trucks weighing over 120 tons when fully loaded. The overall project is divided into three contract phases (W9126G-09-R-0206, W126G-10-R-0183 and W9126G-10-R-0080) which extend approximately 117 miles in total length and encompass Routes 1, 2, 3, 4, 5, 5A, 6, and 8. Design and construction management are under the direction of the Fort Worth District Office of the U.S. Army Corps of Engineers (USACE). The EMC SQUARED Stabilizer product, manufactured by Soil Stabilization Products Company, Inc. (SSPCo), was specified by USACE for treatment of subgrade soils and for stabilization of aggregate surface course materials.

This report details the results of a laboratory testing series on the stabilized aggregate material conducted in the Pavements/Materials laboratory at the University of Nevada, Reno (UNR). The laboratory evaluation was conducted under the direction of Dr. Peter Sebaaly, Director of the Western Regional Superpave Center.

Laboratory Evaluation

The laboratory evaluation of the stabilized aggregate material measured the following two properties: Dynamic Modulus (E*) and resistance to permanent deformation in the Repeated Load Triaxial (RLT) test. Table 1 summarizes the experimental plan for the laboratory evaluation.

Table 1. Experimental Plan for the Stabilized Aggregate Material

Curing	E* Master Curve	RLT at 104°F
72 hrs at 104°F	3 replicates	2 replicates
24 hrs at 140°F	3 replicates	2 replicates

The stabilized aggregate material incorporated a crushed surface course aggregate material that was mined within the boundaries of the Fort Bliss Training Area and manufactured according to USACE specifications. The stabilized aggregate mixture was produced by pugmill mixing plants operated by the contractors. The stabilized aggregate mixtures for Routes 1 through 5 were placed in two lifts to a total depth of eight inches (8") by asphalt paving machine equipment. The sample of stabilized aggregate material for the laboratory testing series was collected from the windrow directly in front of the paving operation by consultant Kyle Kubik on March 17, 2011. The sample of stabilized aggregate was taken from the full cross section of the windrow according to ASTM and AASHTO guidelines.

Compaction and Curing of Samples

All samples were compacted in the Superpave Gyratory Compactor (SGC) into 4 inch diameter by 6 inch height. The SGC shown in Figure 1 is used to compact hot mix asphalt (HMA) mixtures for the Superpave volumetric mix design as outlined in AASHTO M323 and T312. The SGC applies a gyratory stress of 87 psi at an angle of gyration of 1.25 degrees onto the material being compacted inside a solid steel mold. The number of gyrations for HMA design is determined based on the expected design traffic for the pavement.

The number of SGC gyrations to be used in the compaction of the stabilized aggregate material was established by matching the density of the SGC compacted samples with the density achieved by the modified proctor compaction of γ_{dmax} = 135 pcf at an optimum moisture content (OMC) of 5.8%. The determined number of SGC gyrations was 50. The materials were delivered to the UNR laboratory in sealed buckets. No additional water was introduced prior to the compaction of the materials in the SGC. Figure 2 show a sample compacted in the SGC. The density of the compacted samples was determined by measuring the weight and dimensions of the samples immediately after compaction.

After compaction, the samples were cured as shown in Figure 3 in a forced draft oven at the two conditions listed in Table 1. The compacted samples were weighed before and after curing to determine the amount of moisture lost during the curing period as summarized in Table 2. The data in Table 2 show the percent moisture loss is consistent among the three replicates and the 72 hrs at 104^{o}F resulted in approximately one-percent additional moisture loss than the 24 hrs at 140^{o}F. Apparently, the sampled materials were delivered at a moisture content that is slightly higher than the OMC. Following the curing period the samples were tested for dynamic modulus and RLT.

Table 2. Moisture Loss due to Curing of the EMC SQUARED Stabilized Aggregate Material

Curing Period	**Replicate**	**Initial Weight (g)**	**Final Weight (g)**	**Moisture Loss (%)**
72 hrs at 104^{o}F	1	2650	2459	7.2
	2	2651	2459	7.2
	3	2653	2457	7.4
24 hrs at 140^{o}F	1	2651	2492	6.0
	2	2650	2493	5.9
	3	2651	2488	6.1

Figure 1. Superpave Gyratory Compactor.

Figure 2. Compacted Sample of the Stabilized Aggregate Extruded from the SGC Mold.

Figure 3. Compacted Sample of the Stabilized Aggregate Cured in Oven.

Modulus Property of Paving Materials

The fundamental definition of modulus is the relationship between the stress and strain of an engineering material. For linear elastic material such as concrete the modulus is referred to as “elastic modulus”. For other paving materials that are not completely linear elastic such as unbound granular and fine materials the modulus is referred to as “resilient modulus”. The resilient modulus test for unbound granular and fine materials is conducted in the axial loading mode under triaxial conditions following AASHTO T-307. In the case of HMA materials, the definition of modulus has changed through the years to reflect advances in the testing and analysis techniques. Up to the early 1990s, the diametral resilient modulus test was commonly used to evaluate the modulus of HMA mixtures. The diametral test applies a compressive pulse load along the diametral axis of the sample at a single loading rate. In the late 1990s the technology of testing HMA mixtures advanced to the measurement of the dynamic modulus to better represent the visco-elastic behavior of HMA mixtures. The details of the Dynamic modulus test are provided in the next section.

Dynamic Modulus Property

The AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) uses the dynamic modulus (E*) master curve to evaluate the structural response of the HMA pavement under various combinations of traffic loads, speed, and environmental conditions. The E* property of a HMA mix is evaluated under various combinations of loading frequency and temperature. AASHTO TP62-07: “Determining Dynamic Modulus of Hot Mix Asphalt” and PP62-09: “Developing Dynamic Modulus Master Curves for Hot Mix Asphalt” are followed. The test is conducted at frequencies of: 25, 10, 5, 0.5, 0.1 Hz and at temperatures of: 28.4, 40, 70, 100, and 130^{o}F. HMA mixtures are classified as visco-elastic materials where the magnitude of their modulus is a function of both temperature and loading rate. Typically, HMA mixtures exhibit lower modulus as the temperature increases and/or the loading rate decreases and higher modulus as the temperature decreases and/or the loading rate increases. At the other end of the spectrum are elastic materials which exhibit constant modulus as a function of temperature and loading rate. Using the visco-elastic behavior of the HMA mixture, the master curve can be used to identify the appropriate E* for any combination of pavement temperature and traffic speed. Figure 4 shows the components and testing conditions of the dynamic modulus test along with a typical master curve for HMA mixtures. The E* property provides an indication on the general quality of the HMA mixture.

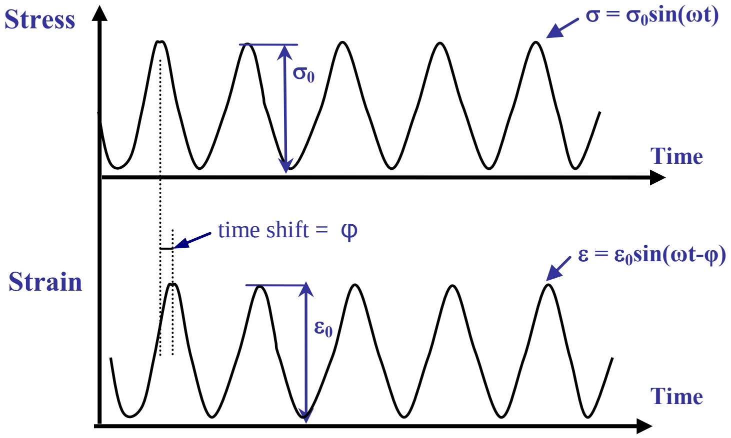
The same AASHTO procedures for determining the E* for HMA mixtures were used in this evaluation to measure the E* for the stabilized aggregate material from the Fort Bliss facility. Figure 5 shows the stabilized aggregate sample in the dynamic modulus testing set up. Figures 6 and 7 show the E* property of the stabilized aggregate material at the curing conditions of 72 hrs at 104^{o}F and 24 hrs at 140^{o}F, respectively. Figure 8 shows typical trends of E* data for a HMA mixture. It should be noted that the E* property of HMA mixtures varies significantly as a function of aggregate source, gradation and properties, volumetric properties of the mix, and the grade/modification of the asphalt binder. Therefore, the typical trends shown in Figure 8 are of interest but not the absolute magnitude of the E* property at the various levels of temperature and loading rate.

The most significant difference between the trends of E* of the stabilized aggregate and the typical trends of the HMA mixture is the impact of temperature and frequency of loading. In the case of the HMA mixture, the E* property decreases with increasing temperature and increases with increasing the frequency of loading which is an indication of a visco-elastic behavior. On the other hand, the impact of temperature and frequency of loading on the E* property of the stabilized aggregate is minimal. This indicates that the stabilized aggregate does not behave as visco-elastic material and its behavior is closer to elastic material. Therefore, the stiffness of the stabilized aggregate can be represented by a constant E* rather than an E* master curve.

Figures 9 and 10 compare the magnitude of the E* property at various temperatures of the stabilized aggregates at the two curing stages. The bars in Figures 9 and 10 represent the average E* values while the whiskers on top of the bars represent the limits of the 95% confidence interval (CI) of the measured E* property. An examination of the data in Figures 9 and 10 leads to the following two conclusions:

Dynamic Modulus Set-Up

Applied Stress & Measured Strain



$$\text{Dynamic Modulus}\quad |E^*| = \frac{\sigma_0}{\varepsilon_0}$$

Typical E* Master Curve

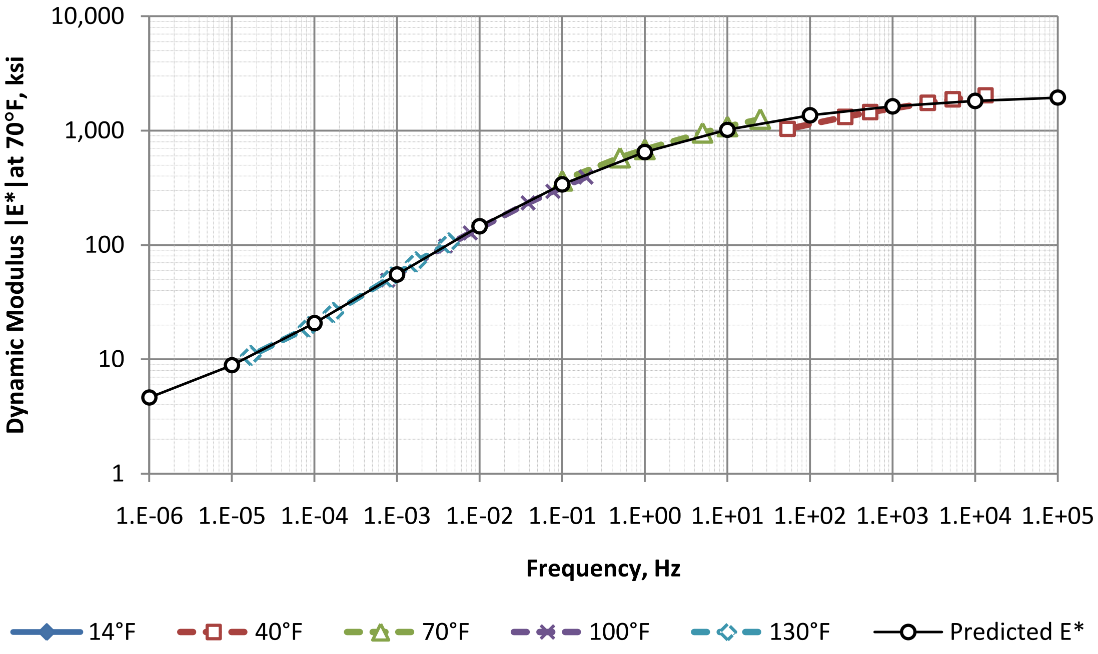


Figure 4. Components of the Dynamic Modulus Test and a Typical E* Master Curve for a HMA mix.

Figure 5. Stabilized Aggregate Sample in Dynamic Modulus testing Set-up.

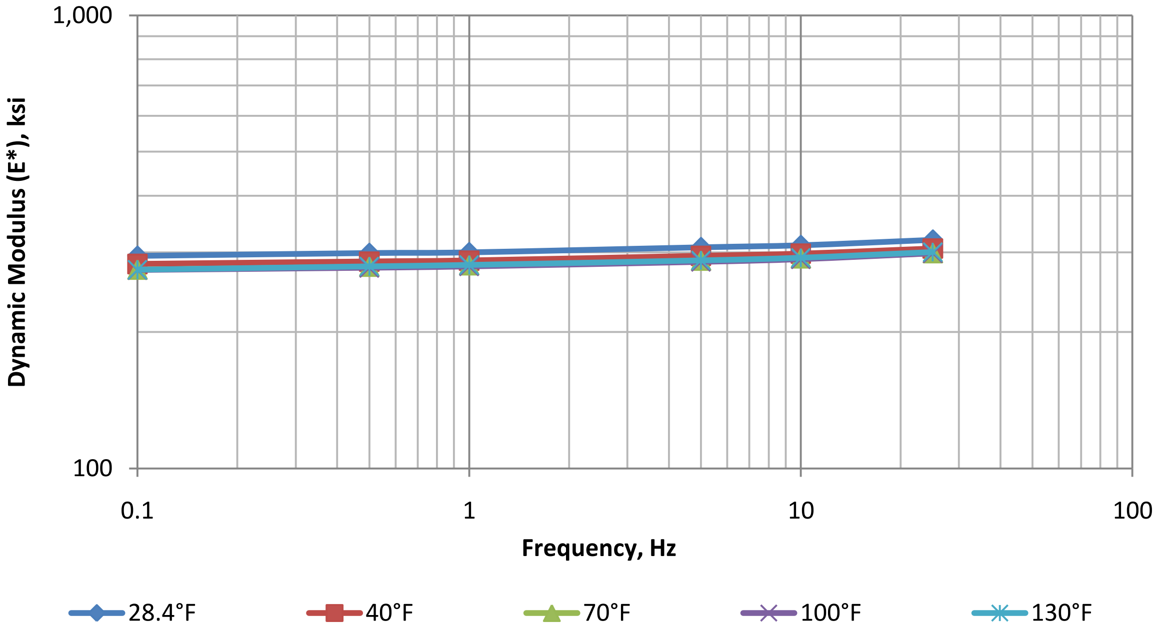


Figure 6. Dynamic Modulus of EMC SQUARED Stabilized Aggregate Cured for 72 hrs at 104°F.

**ksi = 1,000 psi*

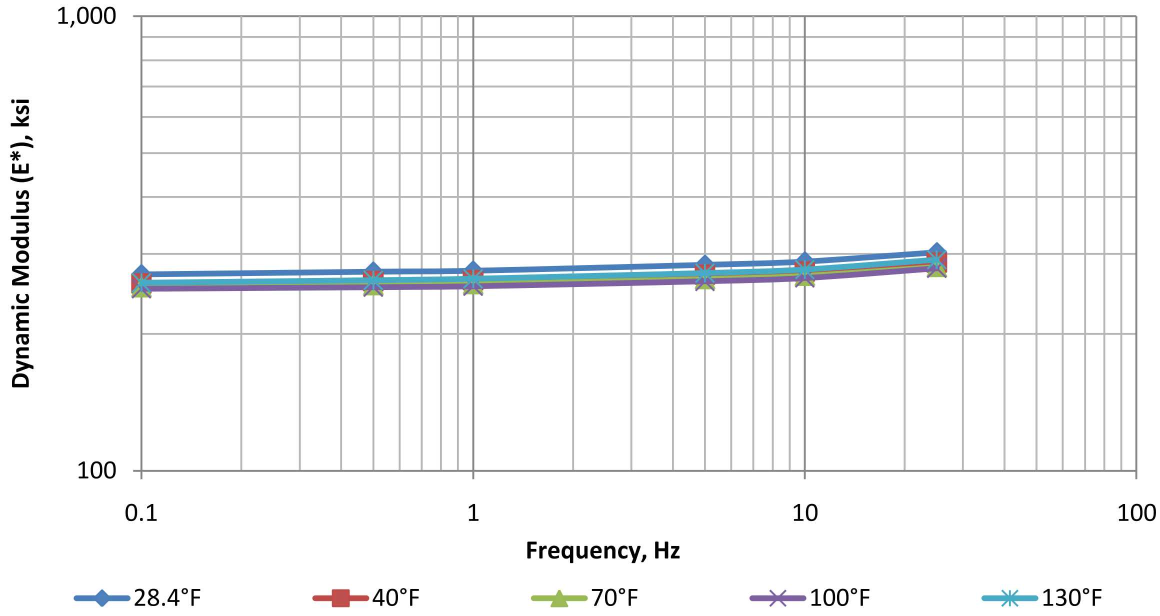


Figure 7. Dynamic Modulus of EMC SQUARED Stabilized Aggregate Cured for 24 hrs at 140^{o}F.

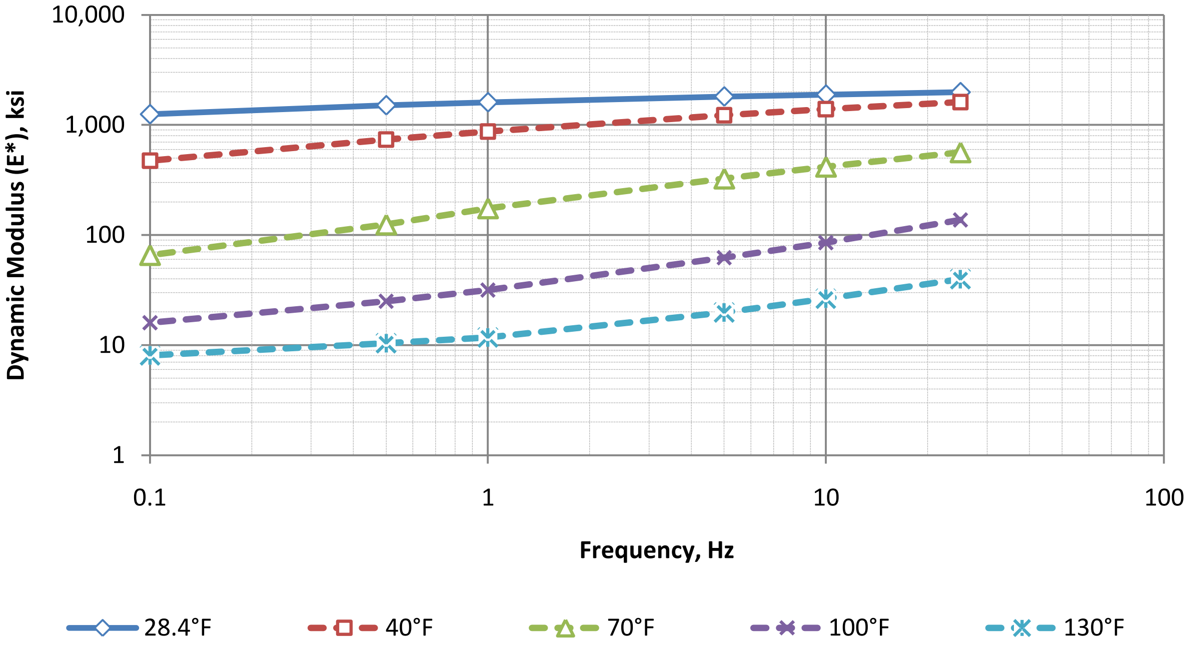


Figure 8. Typical Dynamic Modulus Data for HMA Mixture.

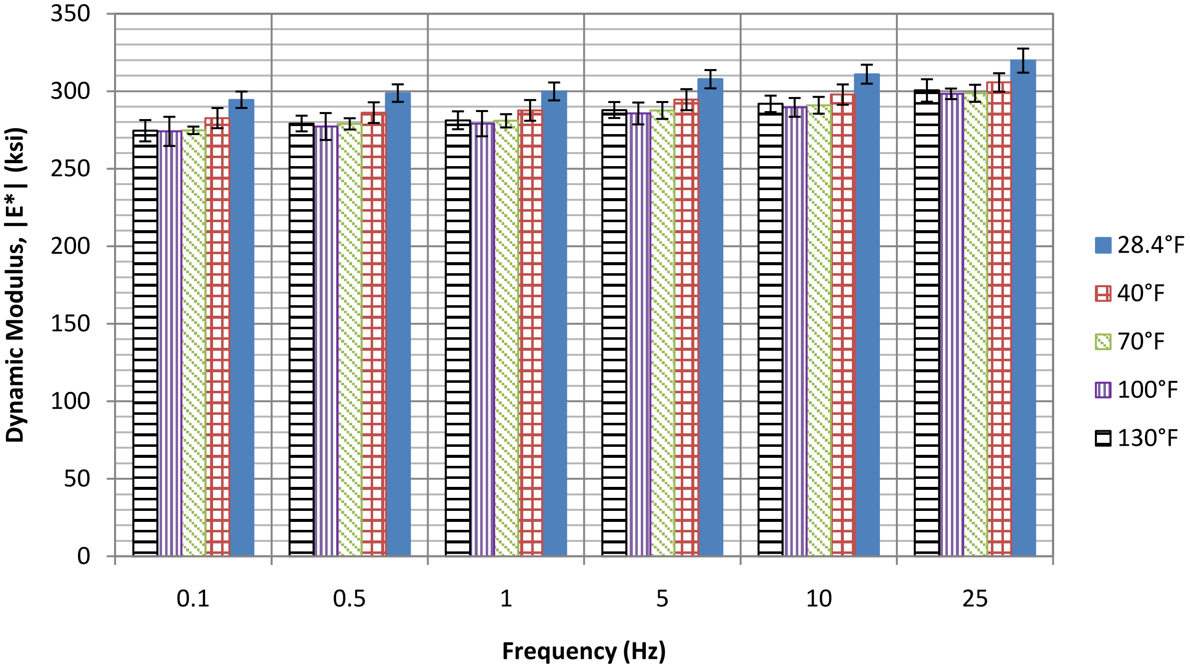


Figure 9. Dynamic Modulus Property of EMC SQUARED Stabilized Aggregate Cured for 72 hrs at 104^{o}F.

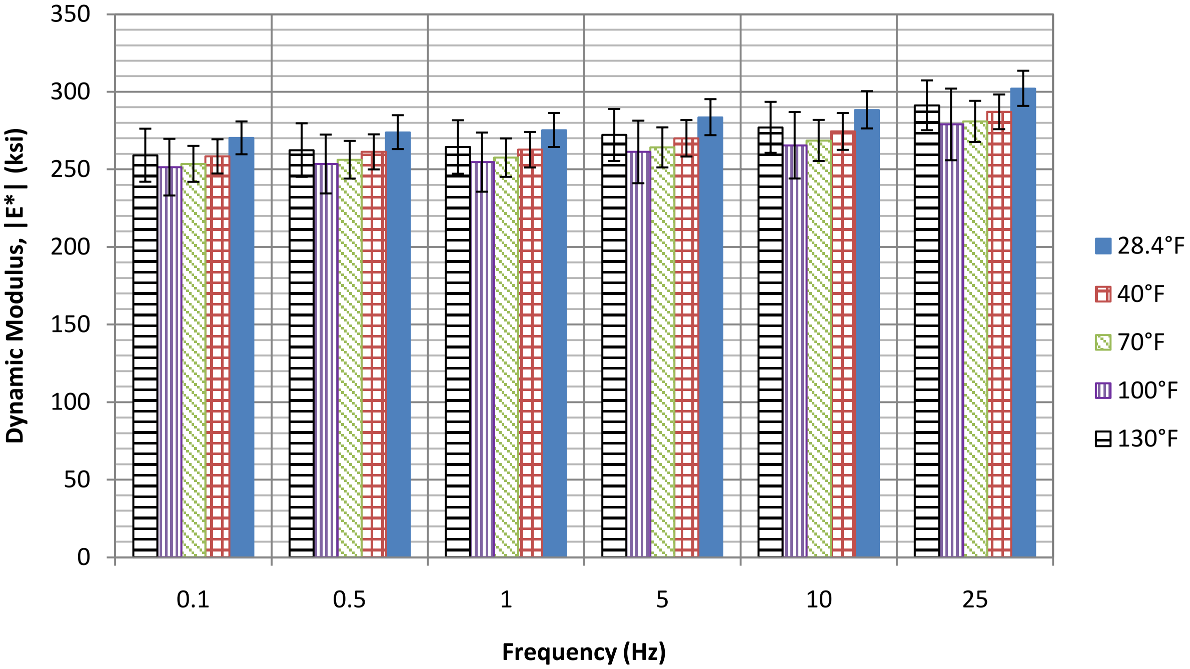


Figure 10. Dynamic Modulus Property of EMC SQUARED Stabilized Aggregate Cured for 24 hrs at 140^{o}F.

- There is a significant overlap among the 95% CI (i.e. whiskers) across all loading frequencies which indicates that the magnitudes of the E* are statistically similar at all temperatures and all loading frequencies.

- The 95% CI (i.e. whiskers) for the curing period of 24 hrs at 140^{o}F is almost double the 95% CI for the curing period of 72 hrs at 104^{o}F which indicates higher variations in the E* property for the curing period of 24 hrs at 140^{o}F. The data in Table 2 show that the moisture loss is higher for the curing period of 72 hrs at 104^{o}F. Combining these two observations leads to the conclusion that the curing period of 24 hrs at 140^{o}F results in more moisture remaining in the sample which creates higher variations in the measured E* property.

Table 3 summarizes the E* properties of the stabilized aggregate material at the two curing periods. The data in Table 3 show the following trends:

- The impact of temperature on the E* property of the stabilized aggregate is minimal, i.e. within the acceptable variability of the E* test.

- The stabilized aggregate cured for 72 hrs at 104^{o}F exhibit lower variability and higher E* property than the material cured for 24 hrs at 140^{o}F which is driven by the lower moisture content of the samples cured for 72 at 104^{o}F (i.e. Table 2).

- It is recommended that the curing period of 72 hrs at 104^{o}F be used for the standard characterization of stabilized aggregate material. However, the magnitude and variability of the E* property of the stabilized aggregate cured for 24 hrs at 140^{o}F were also acceptable, therefore, when the E* property is needed on a short time schedule, the curing period of 24 hrs at 140^{o}F can be used.

- The average E* property of the stabilized aggregates at both curing periods represent excellent stiffness level for a stabilized aggregate layer.

Table 3. Summary of E* for EMC SQUARED Stabilized Aggregate Material.

Curing	Average E* for all Loading Frequencies (psi)					Average E* for all Temp (psi)
	28.4^{o}F	40^{o}F	70^{o}F	100^{o}F	130^{o}F	
72 hrs at 104^{o}F	***305,000***	***293,000***	***285,000***	***284,000***	***286,000***	***291,000***
24 hrs at 140^{o}F	282,000	269,000	264,000	261,000	271,000	270,000

Impact of Long-term Curing on Dynamic Modulus

This part of the experiment evaluated the impact of long-term curing on the dynamic modulus of the EMC SQUARED stabilized aggregate material from the Fort Bliss facility. The long-term curing was simulated in the laboratory by placing the compacted samples in an oven for 168 hours at 104^{o}F. The objective of this evaluation was to assess the degree of stiffening the EMC SQUARED stabilized aggregate material will experience during its lifetime in the pavement. Figures 11 and 12 present the E* property of the EMC SQUARED stabilized aggregate material as a function of temperature and frequency of loading.

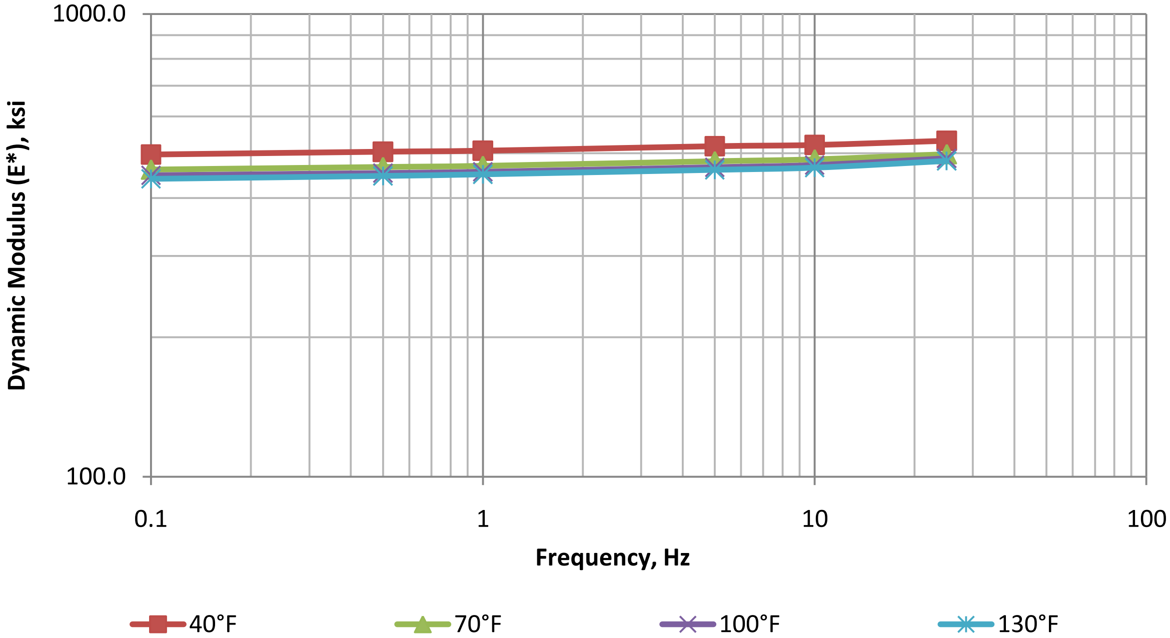


Figure 11. Dynamic Modulus of EMC SQUARED Stabilized Aggregate Cured for 168 hrs at 104°F.

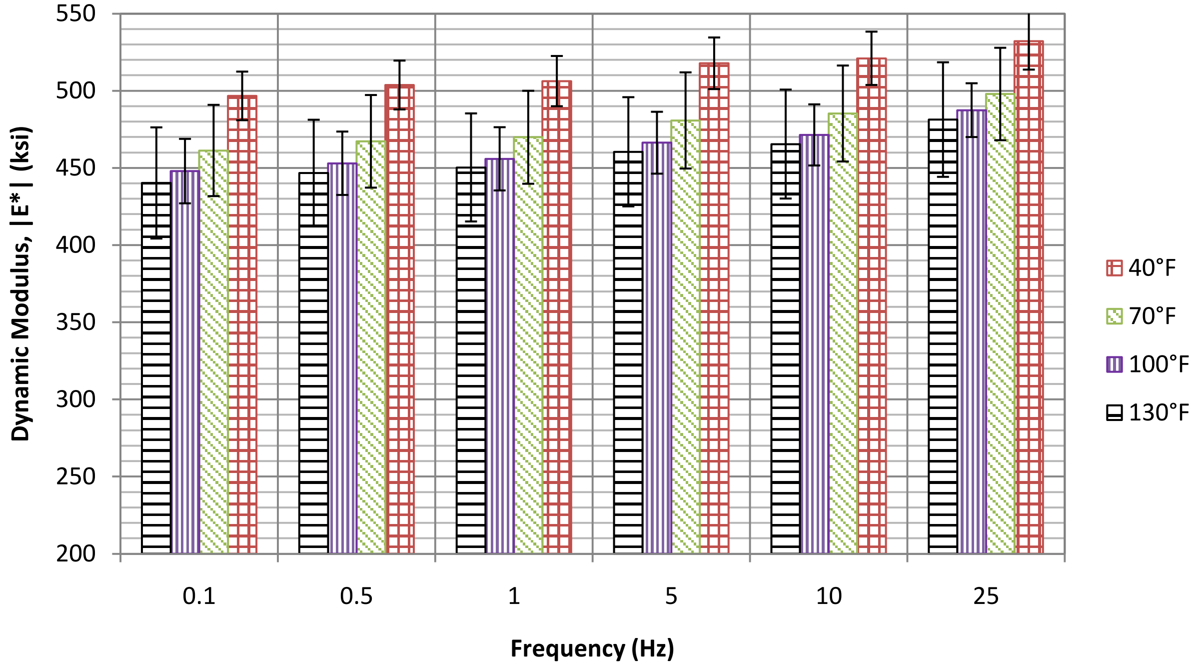


Figure 12. Dynamic Modulus Property of EMC SQUARED Stabilized Aggregate Cured for 168 hrs at 104°F.

A review of the data presented in Figures 11 and 12 leads to the same observations made on the 72 hours curing period: *the impact of temperature and frequency of loading on the dynamic modulus property of the long-term cured EMC SQUARED stabilized aggregate material is minimal indicating that the long-term cured material is showing elastic behavior*. Therefore, the long-term cured EMC SQUARED stabilized aggregate material from the Fort Bliss facility can be represented by an average constant value E* property of 475,000 psi.

The second part of this evaluation compared the dynamic modulus property of the EMC SQUARED stabilized aggregate material at the two curing periods of 72 and 168 hours as shown in Figure 13. The data in Figure 13 show a significant increase in the dynamic modulus property of the EMC SQUARED stabilized aggregate material as the curing period increases from 72 to 168 hours. It should be noted that an increase in the E* property with curing is a desirable characteristic of paving materials since it minimized the development of permanent deformation under repeated traffic loading. However, the increase in E* with time should not be excessive in order to avoid the development of shrinkage cracking. The values of the E* property after the 168 hours curing are in the range of 450,000 to 500,000 psi which do not indicate excessive stiffening of the material which may cause the development of shrinkage cracking while in the same time it represents a very stable material that is expected to resist permanent deformation very effectively. Again, the combination of the elastic behavior of the EMC SQUARED stabilized aggregate material with its good level of long-term modulus makes it an appropriate choice for pavements serving heavy loads at slower speeds as well as for pavements subjected to standard loading conditions.

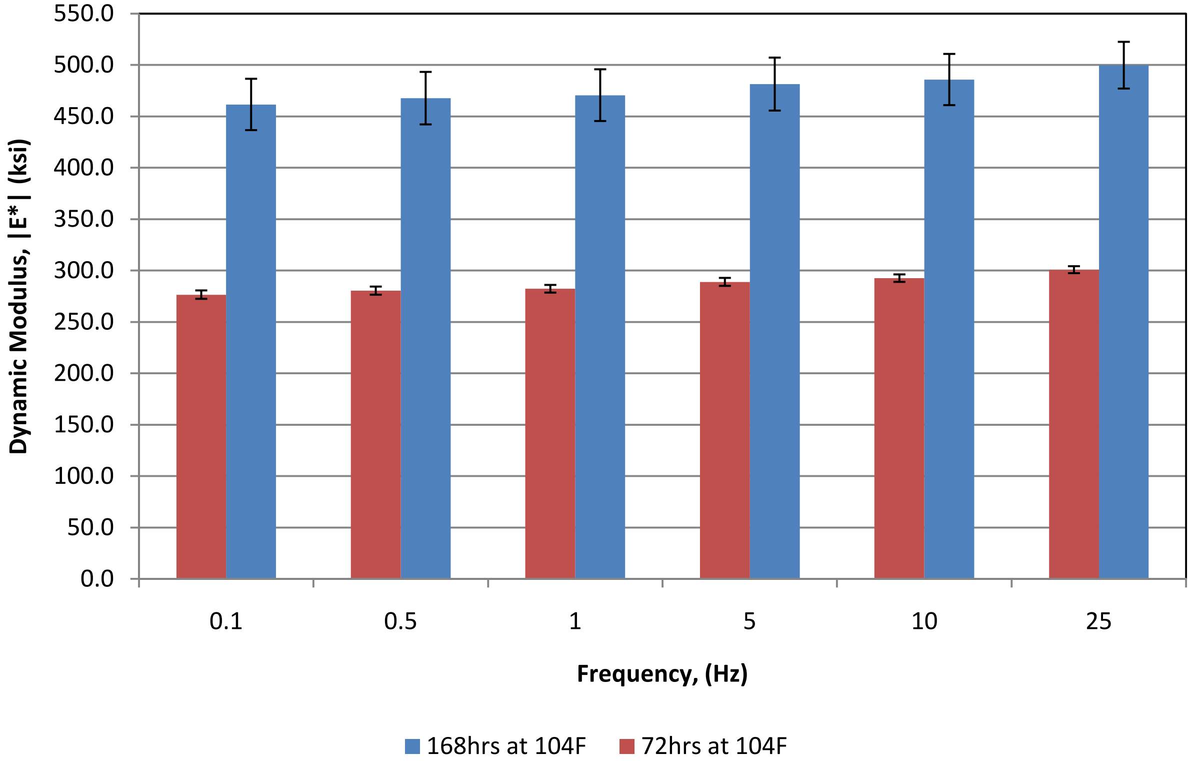


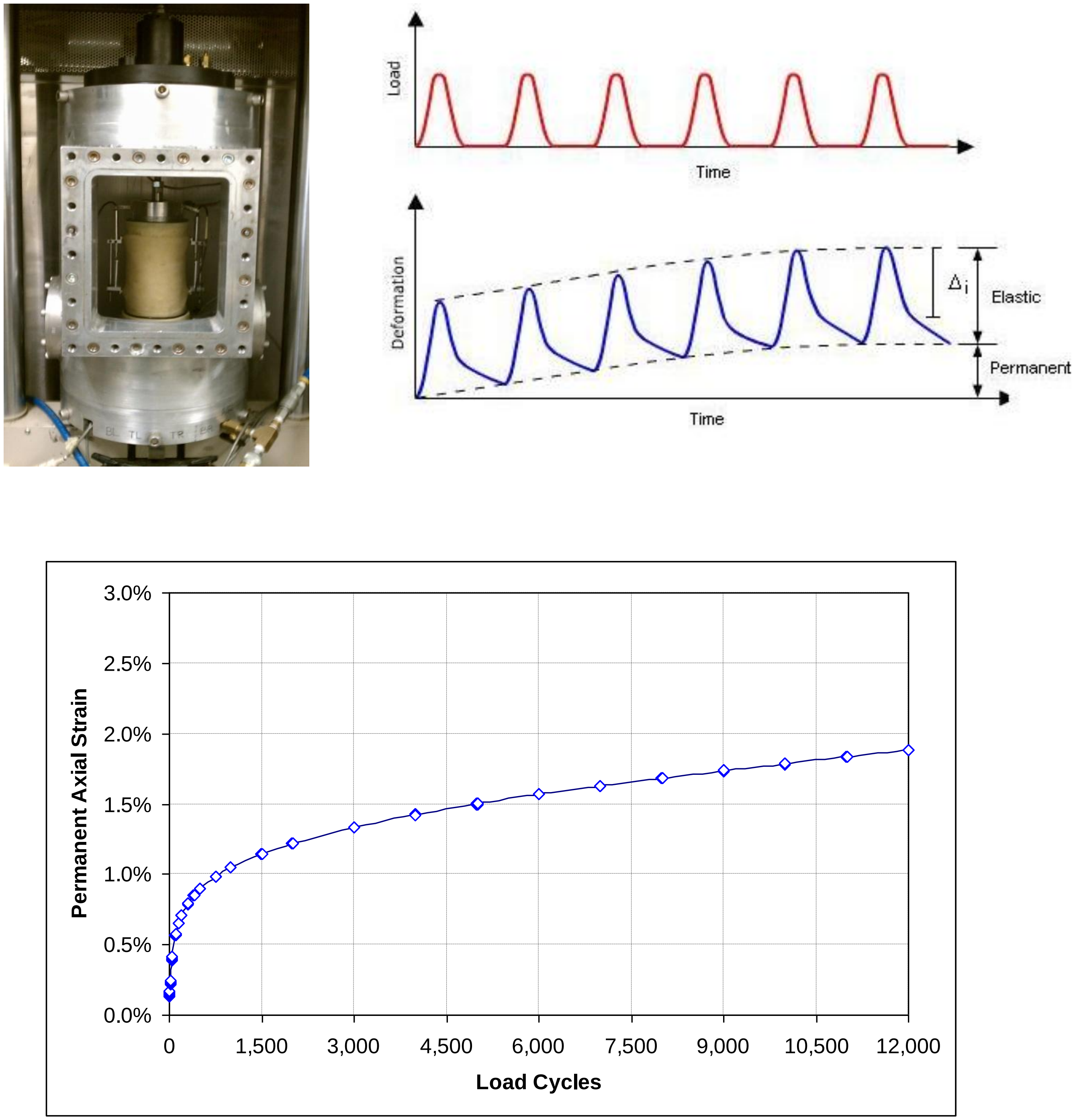
Figure 13. Comparison of E* of EMC SQUARED Stabilized Aggregate Cured for 168 hrs andf 72 at 104^{o}F.

Resistance to permanent Deformation

The resistance of the stabilized aggregate material to permanent deformation was evaluated in the RLT test. The RLT test consists of testing 4 inch x 6 inch cylindrical sample under triaxial state of stresses. Under a confining pressure of 30 psi, a repeated haversine deviator stress of 70 psi is applied for 0.1 second followed by a 0.6 second rest period while keeping the confining pressure constant. Figure 14 shows the components of the RLT test and a typical HMA response. The axial deformation of the sample is measured over the middle 4 inch of the sample by two linear variable differential transformers (LVDTs) placed 180 degrees apart. The LVDTs measure both the resilient and permanent deformations. The axial permanent strain is calculated as the ratio of the permanent deformation over the 4 inch gauge length times 100.

Figure 15 shows the sample of the stabilized aggregate mixture inside the triaxial chamber of the RLT device. Figures 16 and 17 show the permanent deformation responses of the stabilized aggregate material for the two curing conditions. In order to assess the behavior of the stabilized aggregate material, the shapes of the permanent axial strain curves in Figures 16 and 17 can be compared to the typical HMA curve shown at the bottom of Figure 14. It should be noted that only the shape of the curves should be compared and not the actual values. It can be clearly seen that the permanent strain behavior of the stabilized aggregate is significantly different than that of the typical HMA mix. The typical HMA curve shows a small initial jump followed by a steady increase in the magnitude of the axial permanent strain. On the other hand, the stabilized aggregate curves show a higher initial jump followed by a constant magnitude of the axial permanent strain. The difference in the shapes of the typical HMA curve and the curves of stabilized aggregate material clearly indicates the difference between the visco-elastic behavior of HMA mixtures and the elastic behavior of the stabilized aggregate material. This coincides well with the observations based on the E* property.

The magnitude of the axial permanent strains that were measured in the stabilized aggregate material from the Fort Bliss facility under both curing conditions as shown in Figure 16 and 17 are around 1,000 microns which converts to approximately 0.1% permanent axial strain in the 4 x 6 inch sample. This level of permanent axial strain is low and typically indicates low propensity of rutting in the stabilized aggregate layer at the Fort Bliss facility. In addition, the constant relationship between E* and temperature of the stabilized aggregate material presented earlier indicates that the permanent deformation characteristics of the stabilized aggregate material is expected to remain constant at other testing temperatures.



Repeated Load Triaxial Set-Up

Loading and Response

Figure 14. Components of the Repeated Load Triaxial Test and a Typical Permanent Deformation Curve for a HMA Mix.

Figure 15. Stabilized Aggregate Sample in Repeated Load Triaxial testing Set-up.

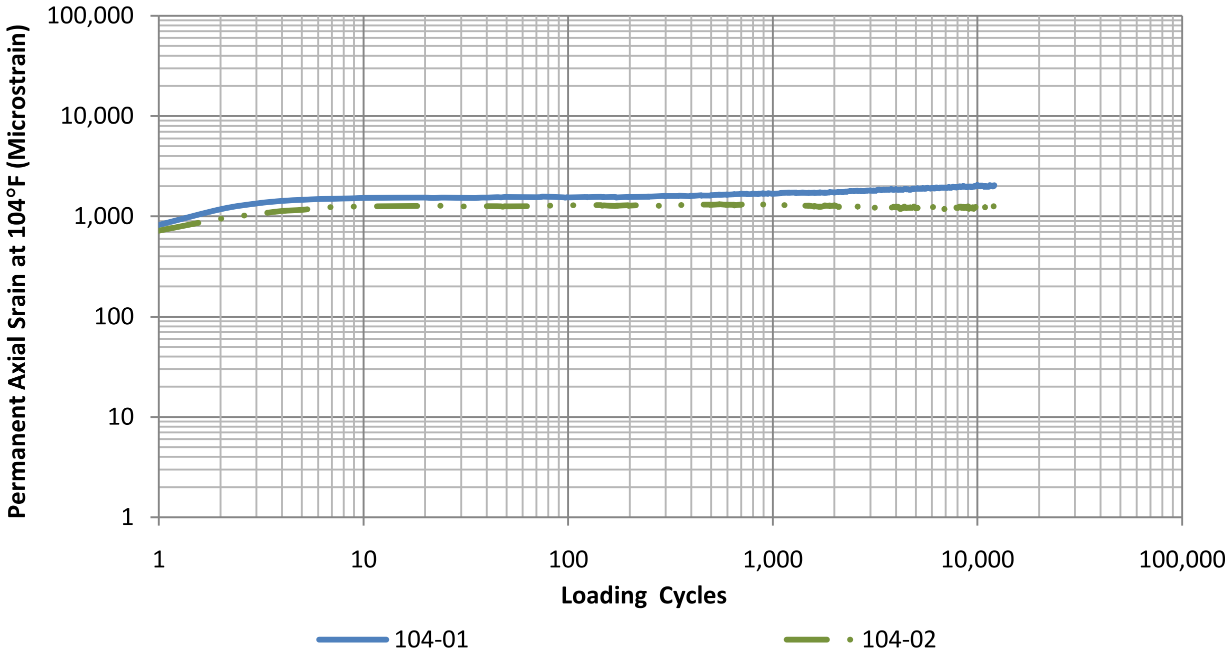


Figure 16. Permanent Deformation Characteristics of the EMC SQUARED Stabilized Aggregate Cured for 72 hrs at 104°F.

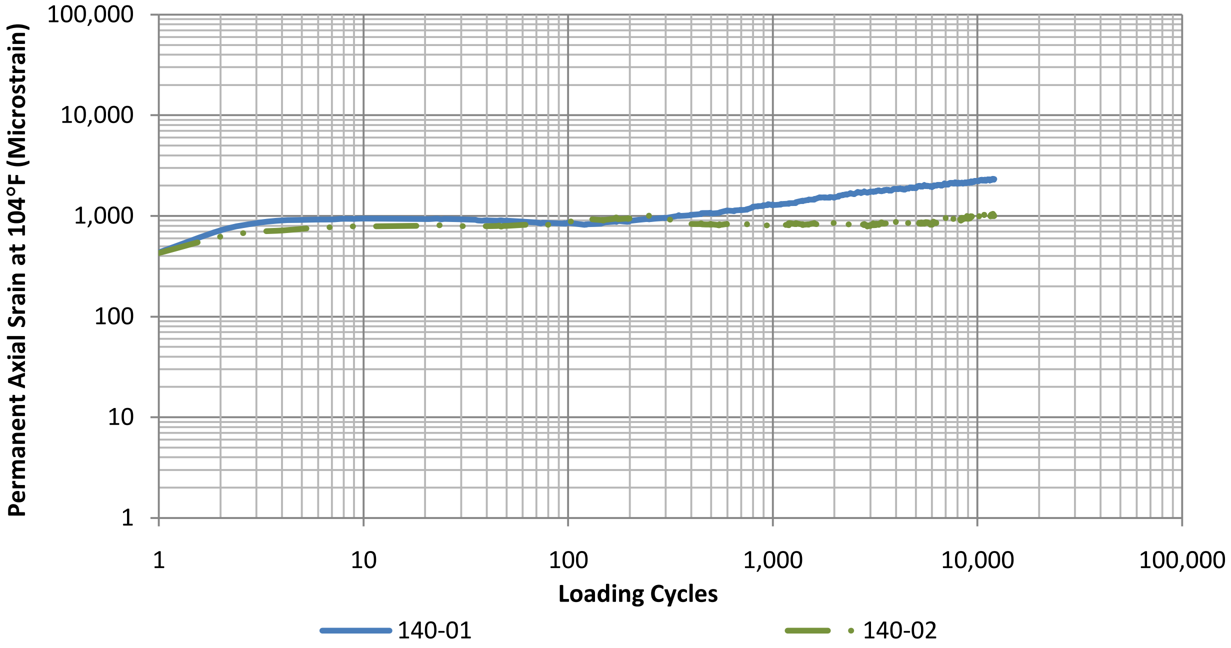


Figure 17. Permanent Deformation Characteristics of the EMC SQUARED Stabilized Aggregate Cured for 24 hrs at 140^{o}F.

Application of Measured Properties

This section of the report discusses the applications of the measured properties of the stabilized aggregate material in pavement engineering. The following presents a brief discussion on the various applications.

The dynamic modulus is typically used to conduct structural design of the flexible pavement using the MEPDG. The stabilized aggregate layer can be designed as a surface or base layer in a new pavement structure or as a surface layer over an existing pavement structure. Whether the stabilized aggregate is used as a surface or a base layer, it will be represented by a modulus. The data generated in this study indicated that the stabilized aggregate material behaves as elastic materials and therefore, will be represented by a constant modulus in the range presented in Table 3. The MEPDG will directly incorporate the magnitude of the modulus into the design of the stabilized aggregate layer. It should be noted that the worst loading condition on flexible pavements is slow moving loads in hot environment. The elastic behavior of the stabilized aggregate material from the Fort Bliss facility coupled with its relatively good level of E* makes it a good candidate for pavements loaded under such severe conditions. In addition, the stabilized aggregate material is expected to perform as well in pavements subjected to standard loading conditions. Furthermore, the long-term cured material showed significant increase in the dynamic modulus property but not to the level of becoming brittle and causing shrinkage cracking.

The resistance of the stabilized aggregate material to permanent deformation as measured in the RLT will be used to estimate the rutting generated in the stabilized aggregate material as a surface or base layer in a new pavement structure or as a surface layer over an existing pavement structure. The RLT data generated in this evaluation indicated that the stabilized aggregate material from the Fort Bliss facility is not anticipated to generate any permanent deformation under a wide range of loading conditions.