Understanding Creep in Asphalt Concrete

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ABSTRACT

This report explains the necessity of creep tests in the pavement design process for asphalt concrete pavement. The creep properties in asphalt concrete are the cause of rutting in existing pavement structures. If this is placed as a higher priority in the pavement design process, the road may achieve a much higher life span, which would be a significant improvement to the infrastructure of the city/ state that the road exists in. This would save money in the long run as the road would not have to be reconstructed as often allowing for a long-term monetary surplus that could be used elsewhere in the public infrastructure.

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1.0 INTRODUCTION

Asphalt concrete is elastic, viscous, and plastic in nature, also known as viscoelasticplastic material (Zhu et al. 2013). Asphalt concrete pavement is flexible as it is not as stiff as a Portland Cement Concrete (PCC) pavement. Asphalt concrete is typically cheaper that PCC concrete and is a strong economic candidate for most reconstruction of roads.

Asphalt concrete has mechanical deformation concerning loading time, loading rate, and temperature, meaning it is subjected to viscous and elastic deformations (Mallick, El-Korchi, 2013). Deformation in asphalt concrete is also known as rutting. Figure 1 shows rutting in asphalt concrete pavement. The value of this property is referred to as the creep compliance of the asphalt (Zhang et al. 2012). Creep is defined as deformation in a material to the point of sudden fracture or its loss of usefulness due to the need to support a load for an extended period (Hibbeler 2017).

Figure 1: Pavement Rutting (Pavement Interactive n.d.)

This report is intended to examine creep in asphalt concrete. This report will cover creep testing according to standard, preparation of asphalt concrete laboratory samples and finally creep testing on the samples.

2.0 CREEP TEST METHODS

The purpose behind the creep test is to test for creep compliance, using a static compressive load of a fixed magnitude along the diametric axis of a specimen (Protocol P07 2001). This test would be repeated with different magnitudes of loads as described in the following Section.

The methods for testing for creep compliance have to follow the standard procedure that is set by the Federal Highway Administration (FHWA). This particular standard is Protocol P07 which is the test method for determining the creep compliance, resilient modulus (relaxation modulus), and strength of asphalt materials (Protocol P07 2001). The tests should be performed at the varying temperatures as described below:

1. Creep Compliance -10 °C (14 °F)
2. Resilient Modulus 5 °C (41 °F)
3. Creep Compliance 5 °C (41 °F)
4. Resilient Modulus 25 °C (77 °F)
5. Creep Compliance 25 °C (77 °F)
6. Resilient Modulus 40 °C (104 °F)

2.1 SAMPLE PREPARATION ACCORDING TO PROTOCOL P07 2001

The specimen will either need to be cored or cast at 102 mm diameter and that are 25-51 mm thick. These specimens also should be kept in an environment in which the temperature is controlled to 5 and 24 degrees Celsius. When Sawing the specimen to the right size, the cuts must be cut to parallel to obtain a smooth and plane top and bottom faces of the cylindrical specimen using a water-cooled saw. Gauge points will also have to be placed on the specimen to be able to measure the deflection during the test. An example of a prepped specimen is shown in Figure 2.

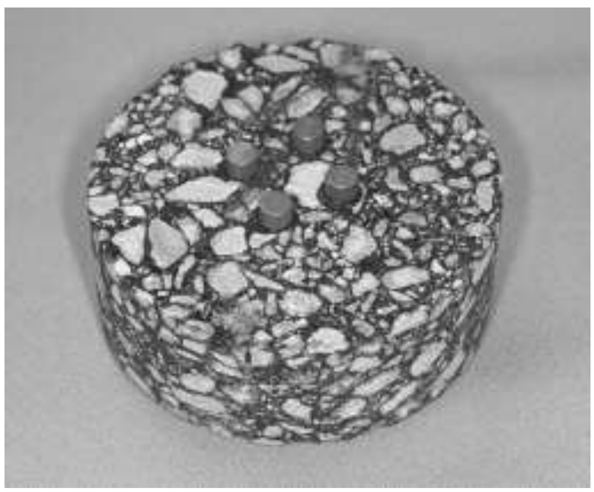

Figure 2: Prepared Sample with Gauge Points (Protocol P07 2001)

2.2 TEST APPARATUS

As per Protocol P07, the testing apparatus that is to be used in this test is to be a closed-loop, hydraulic, and top loading testing machine that is capable of providing a fixed load within 1 lbf. The maximum capacity of the machine shall also be at least 5,000 lbf. The use of diametric loading heads is required for the test. These heads are to be equipped with loading strips that have a curved surface equal to that of the specimen and 13 mm wide. To measure the deformation of the specimen 8-gauge points are required for each specimen to allow for the measurement in both the horizontal and vertical directions. During the test procedure, extensometers will be needed to allow for the simultaneous measurement of the deformation during the test. An example of an acceptable apparatus is shown in Figure 3.

Figure 3: Testing Apparatus (Protocol P07 2001)

2.3 TEST PROCEDURE OF CREEP

For each of the test, the specimen should be aligned to the test strips of the test apparatus and extensometer stability should be achieved before the start of the test. After stability is achieved a constant load is applied to the specimen for a predetermined amount of time while a measurement of deformation, strain, load, and stress is recorded at a specified time interval (INSTRON, (n.d)). This test complies with ASTM E-139, ASTM D-2990, and D-2991.

3.0 RESULTS/ DISCUSSION

The results of these test are going to be in the form of graphed data. Creep testing will be in the form of a loading (Strain) vs. time (Figure 4) which will show the deformation and recovery of the materials.

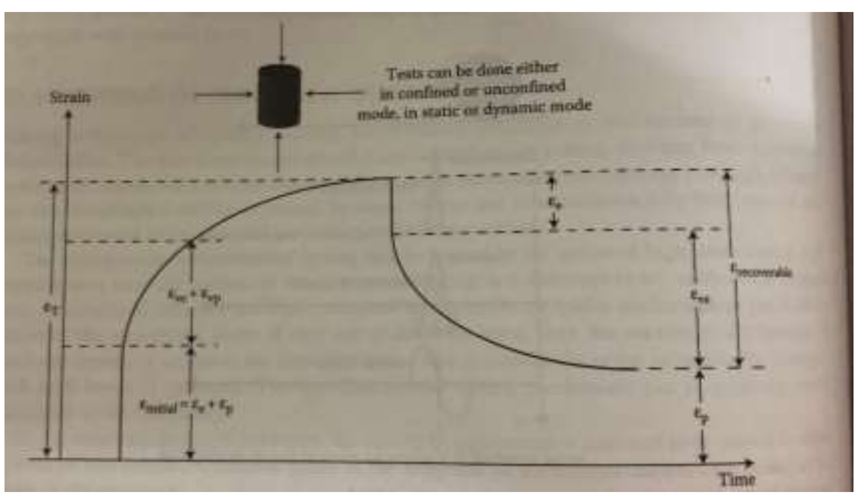

Figure 4: Schematic of Creep Testing (Mallic El-Korchi 2013)

From here an engineer can use the data from the test along with data that would be acquired during the early stages of the design process on the traffic volumes, can decide based on the frequency of the traffic and size and a number of vehicles on the road will cause the road to rut. It is necessary that the mix to be able to withstand a load that both is continuously applied and removed in terms of a car driving over any point as the relaxation test, and also to be able to withstand a load for some time without deformation occurring as in the creep test. If the mix is not compliant with the traffic volumes than the mix will have to be redesigned to provide a better product to the public.

It shown through these tests the effects of temporary loading of asphalt pavement causes deformations which result in rutting or cracking. These tests are to simulate the effects of vehicles driving over any singular point on a road which would cause a load to be applied to the asphalt then removing the load as the vehicle continues to drive down the road. If the asphalt does not recover from this load promptly then the road structure will be permanently damaged as more vehicles of varying weight travel down the road. To counteract this, engineers need to be able to design asphalt mixtures to be able to withstand the constant abuse from vehicles.

4.0 LAB TESTING

In the process of this project, the creep test was performed in the lab setting. This was performed to show how asphalt mix designs for the Central Illinois area perform to creep conditions. The test mixes that were used in this laboratory analysis were performed in the Bradley University Asphalt lab according to the proper ASTM and AASHTO standards.

4.1 MATERIALS

For the materials that were used for this test were directly from Tazewell County Asphalt who provided the mix design and samples of all the materials that were used in recreating the mixes. There were three aggregates, a mineral filler, and an asphalt binder that was used in this mix. The aggregates consisted of a CM 16, manufactured sand which consisted of a crushed version of the CM 16, and natural sand. The mineral filler was the fines that were separated in the process of generating the manufactured sand aggregate. The asphalt binder that was used for this experiment was also determined by the mix design that was provided, which had been specified at a PG 64-22. All materials for this experiment were generously provided by Tazewell County Asphalt in East Peoria, IL.

4.2 MIX DESIGN

To obtain an idea of how creep affects the pavements in Illinois, a mix design had to be acquired that is currently in use in Illinois. With there being many mix designs in use across the state a mix design was acquired from one of the local asphalt plants about Bradley University. Tazewell County Asphalt Provided the mix design that was currently in use at their asphalt plant for this test. The mix report provided what aggregates and binder that is being used along with the proper proportioning by mass that was required. An optimum binder content was also provided with the calculation on other contents that were used in the mix design process.

With this information, a mix designed was proportioned for the testing purposes. The mix proportion was generated with the optimum binder content. In the case of the mix that was provided for the project, the optimum binder content was 6.0%. The Mix design that was used in this test was proportioned to create a sample that was approximately 150 mm in diameter and 110 mm thick for the testing purposes with an approximate weight of the mix to be 5000 gm. The following is the mix proportion that was used in the test.

TABLE 1: Plant Mix Design

Gyrations	Asphalt Binder Content	Mass Binder	Mass Solids	Couse Aggregate	Natural Sand	Manufactured sand	Mineral Filler	Asphalt Binder
#	%	gm	gm	gm	gm	gm	gm	gm
50	6	279.92	4385.34	2587.35	1140.19	613.95	43.85	279.92

4.3 AGGREGATE TESTING

To ensure consistency with the original lab testing that was performed when the mix was initially created, lab tests were also performed on the samples of aggregate to ensure that the aggregate was similar in the conditions that were used in the original lab for the mix. The test that was run on the sample aggregate was a gradation test, an uncompacted void test for the fine aggregates, and a specific gravity test for each of the aggregates. These tests were performed according to the required ASTM and AASHTO standards for testing. The results were then compared to the information that was provided in the mix design report to ensure that the sample that would be used in the test would resemble the mix that is being used in the local road construction.

For the gradations of the aggregates, a test was performed on each of the three samples of aggregate. A sample size of 1500 gm was used for each of the samples, and the resultant gradations were graph along with the original gradation that was provided in the mix design. It was found that the gradations were similar to the original lab gradations and was determined acceptable to continue with the project. The following figures show the comparison for each of the aggregates in relation to the provided lab gradations.

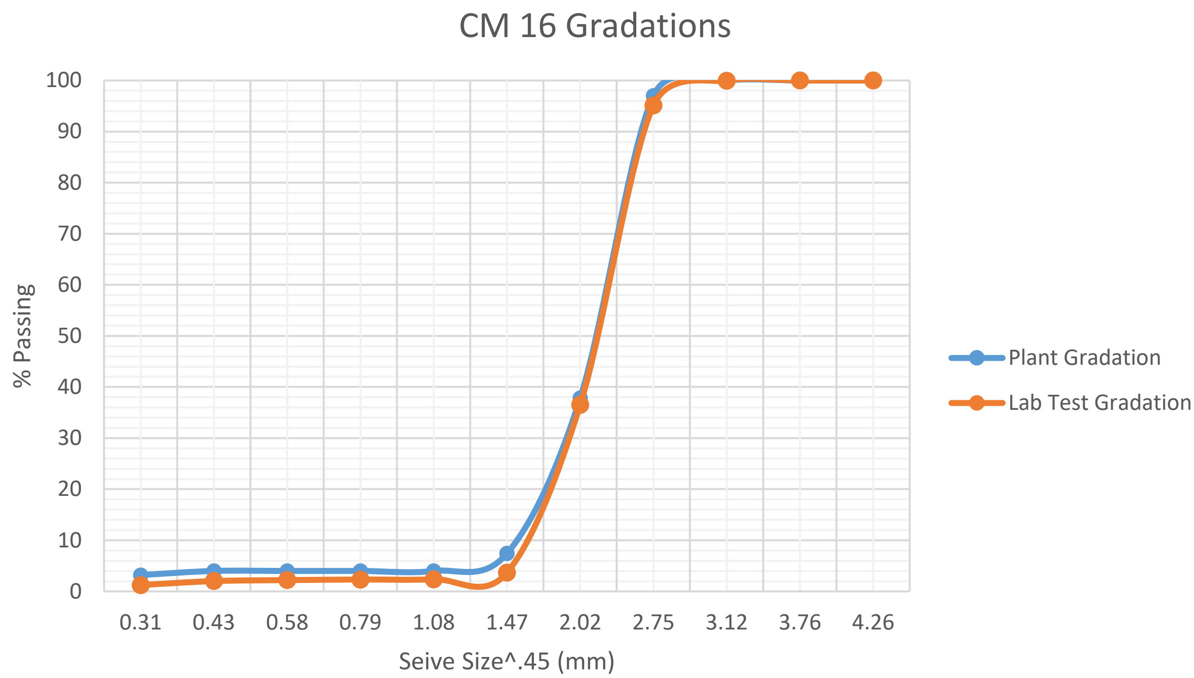

FIGURE 5: CM16 Gradations (Course Aggregate)

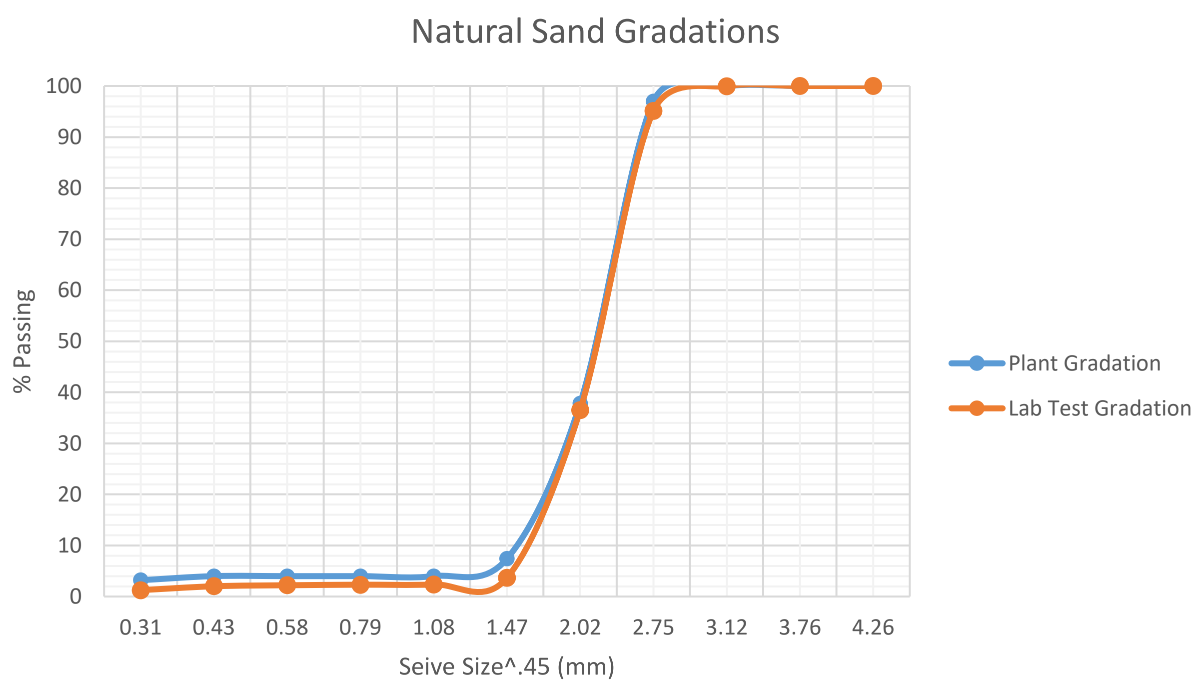

FIGURE 6: Natural Sand Gradations (Fine Aggregate)

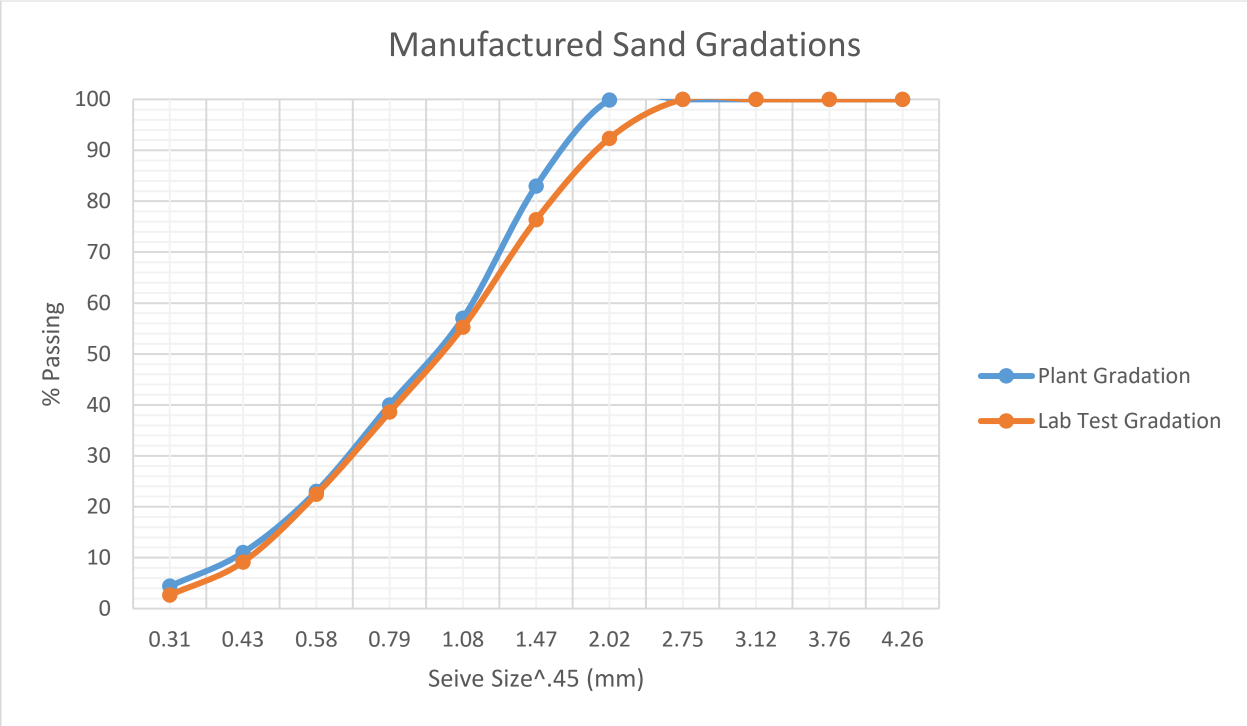

Figure 7: Manufactured Sand Gradations (Fine Aggregate)

The uncompacted void content test was performed on the two fine aggregates. This was done to obtain the percentage of voids that was in an uncompacted sample of the aggregates. As shown in Figure 8, the proper apparatus was used to generate the cylinder of the sample aggregate, and Table 2 shows the calculations and results of the test for each of the aggregates.

Figure 8: Uncompacted Voids Apparatus

TABLE 2: Uncompacted Voids Test results

Volume of Cylinder (ml) V	100			
Weight of Empty Cylinder (gm) A	180.7			
Bulk Dry SG of Aggregate	NS	1.242	MS	1.128
Natural Sand (NS) Tests	1	2	3	AVG
Wt. of Cylinder with Sample (gm) B	343.9	343.9	343.9	343.9
Net Wt. of sample in cylinder (F=B-A) (gm)	163.2	163.2	163.2	163.2
Uncompacted Voids in Percent [((V-(F/G))/V*100] (%)	31.41	31.41	31.41	31.41
Manufactured Sand (MS) Tests				
Wt. of Cylinder with Sample (gm) B	342.2	349.9	349.4	347.17
Net Wt. of sample in cylinder (F=B-A) (gm)	161.5	169.2	168.7	166.47
Uncompacted Voids in Percent [((V-(F/G))/V*100] (%)	43.23	50.06	49.62	47.64

Additionally, the last two tests that were performed on the aggregates were to determine the specific gravity for the aggregates. The first test was the determination of the specific gravity of the coarse aggregate. This was done by finding the weight of a sample of the aggregate in the dry condition, saturated surface dry condition, weight in water, and the oven dried condition with these values the Apparent specific gravity of the aggregate, the Bulk specific gravity, Bulk saturated specific gravity, and Absorption was determined for the coarse aggregate. Table 3 shows the results from the test of the coarse aggregate used in this test, while Figure 9 shows the tests in progress.

TABLE 3: Coarse Aggregate Specific Gravity Test Results

1 Weight of Dry Bucket	1013.1	gm
2 Weight of Dry Bucket and Dry Aggregate	4011.8	gm
3 Weight of Dry Aggregate	2998.7	gm
4 Weight of Bucket and aggregate in water	1087.5	gm
5 Weight of Bucket in water	419.3	gm
6 Aggregate weight in water	668.2	gm
7 Weight of dry pan	351.7	gm
8 Weight of dry pan and SSD aggregate	3362.9	gm
9 SSD weight of aggregate	3011.2	gm
10 Weight of dry pan and OD aggregate	3283.3	gm
11 OD weight of aggregate	2931.6	gm

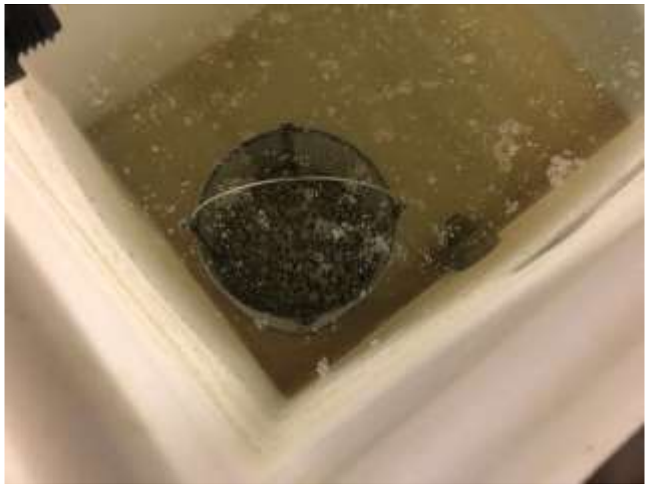

FIGURE 9: Coarse Aggregate Specific Gravity Water Weight Determination

The process for the fine aggregates was different, but the test had the same goals in mind regarding what was to be determined form the test. Table 4 is an overview of the results and calculations that were used for both the natural sand (NS) and the manufactured sand (MS). Figures 10- 12 show steps during the process of determining the specific gravities of the material.

TABLE 4: Fine Aggregate Specific Gravity Test Results

Specific Gravity of Fine Aggregates	NS		MS	
1 Weight of dry pan	902.7	gm	918.9	gm
2 Weight of dry pan and wet aggregate	2219.2	gm	2232.9	gm
3 Weight of wet aggregate	1316.5	gm	1314	gm
4 Weight of pycnometer filled with water to the calibration mark	1388.9	gm	1388.9	gm
5 Weight of dry pan 2	902.7	gm	918.9	gm
6 Weight of dry pan 2 and SSD aggregate	2060.5	gm	2158.6	gm
7 Weight of SSD aggregate	1157.8	gm	1239.7	gm
8 Weight of pycnometer with SSD aggregate and water to the calibration mark	1679.9	gm	1669	gm
9 Weight of dry pan 3	902.7	gm	918.9	gm
10 weight of dry pan 3 and OD aggregate	1979.2	gm	2000.9	gm
11 Weight of OD aggregate	1076.5	gm	1082	gm
Wt. SSD AGGREGATE (GM) S	1157.8	gm	1239.7	gm
Wt. of OD Aggregate (gm) A	1076.5	gm	1082	gm
Wt. of Pycnometer Filled with Water to Calibration Mark (gm) B	1388.9	gm	1388.9	gm
Wt. of Pycnometer with SSD aggregate and Water to Calibration Mark (gm) C	1679.9	gm	1669	gm
Apparent SG of Fine Aggregate [A/(B+A-C)]	1.370		1.349	
Bulk SG of Fine Aggregate [A/(B+S-C)]	1.242		1.128	
Bulk SSD SG of Fine Aggregate [S/(B+S-C]	1.336		1.292	
% Absorption	7%		13%	

FIGURE 10: Fine Aggregate Water Bath

FIGURE 11: Fine Aggregate Specific Gravity Flasks

FIGURE 12: Fine Aggregate SSD Condition

4.4 SAMPLE GENERATION

The generation of the sample that was used in the testing of creep was done in accordance to all standards in retrospect to the asphalt plant that the materials and mix design were obtained. All of the aggregates and the asphalt binder were placed in the oven to be heated to 350 ºF to allow for the binder to melt and to allow for any access water in the aggregate to be removed. Using the proportion mixes shown in Table 5, the aggregate was then measured out as shown in Figure 13.

TABLE 5: Trial Mix Design Table

GYRATIONS	Asphalt Binder Content	Mass Binder	Mass Solids	Couse Aggregate	Natural Sand	Manufactured Sand	Mineral Filler	Asphalt Binder
#	%	gm	gm	gm	gm	gm	gm	gm
50	6	279.92	4385.34	2587.35	1140.19	613.95	43.85	279.92
50	6.5	303.24	4362.02	2573.59	1134.13	610.68	43.62	303.24
50	5.5	255.59	4408.67	2601.12	1146.25	617.21	44.09	256.59

FIGURE 13: Aggregate Proportioning

After the aggregates were measured out, they were placed in the oven for an additional 15 minutes to allow for them to return to temperature. After tempering the aggregate, the materials were then combined in the mixing bucket. The binder was then measured and added to the bucket. The sample was then mixed in the bucket as shown in Figure 14.

FIGURE 14: Asphalt Mixing.

After mixing, the bucket was placed in the oven for 2 hours to temper the fresh asphalt. During this time the mold for the sample was prepped as shown in Figure 15.

Figure 15: Sample Mold

With the mold prep and the 2 hours passed, the sample was then placed in the mold between two circular sheets of filter paper. The mold was then placed in a Troxler Gyrator to be compacted and gyrated as per the standard requirements. The sample was required to be gyrated at 50 gyrations to allow for proper test analysis. The resultant cylindrical samples were to be 150 mm in diameter and between 110 mm and 120 mm in thickness for adequate sample sizes. Figures 16 and 17 show the sample in the Troxler Gyrator and the final resultant sample.

FIGURE 16: Sample Compaction

FIGURE 17: Final Sample

4.5 SAMPLE TESTING

Before the creep test could be performed, some final tests had to be performed for quality control in the mix construction on the samples. These tests were for the Bulk Specific Gravity (G_{mb}) and the Maximum Specific Gravity (G_{mm}) of the asphalt samples. These results can be found in Table 6.

TABLE 6: Gmb and Gmm Test Results

Gmb							
	Sample	Binder Content	Air Wt.	SSD Wt.	H_2O Wt.	BSG	ABS
	1	5.5	4898	4903.1	1785.6	1.571	0.164
	2	6	4692.4	4695.9	1754.5	1.595	0.119
	3	6.5	4846.6	4848.2	1809.1	1.595	0.053
Gmm							
	Sample	Binder Content	Air Wt.	Wt. of Container Water	Wt. container and sample in Water	Gmm	
	1	5.5	1517	1039.6	1502.6	1.439	
	2	6	1519.5	1052.3	1512	1.434	
	3	6.5	1515.6	1052.3	1642.8	1.638	

4.6 CREEP TESTING

For the creep testing for this project, the test was performed using Bradley Universities' new MTS testing machine. The test was performed by loading the sample with a load of 500 lb. for 2 minutes and recording the stress and strain which will be shown in the next section. The following figures show the testing in progress.

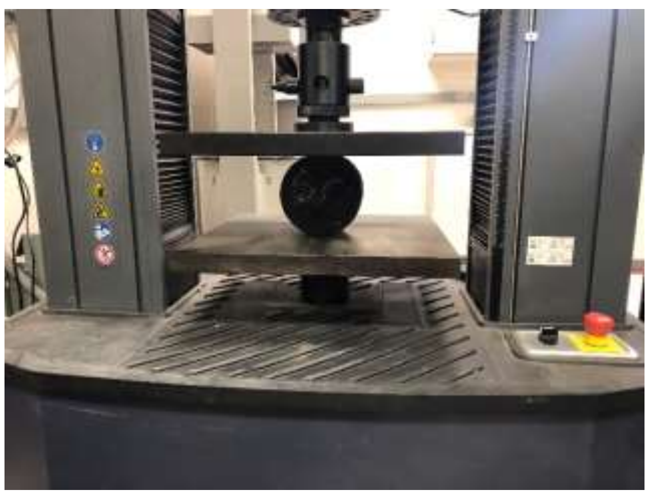

FIGURE 18a: Creep Test in Progress.

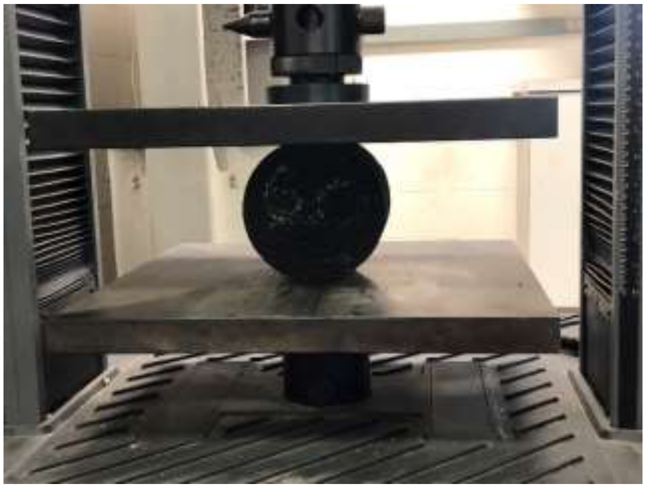

FIGURE 18b: Creep Test in Progress.

FIGURE 18c: Creep Test in Progress.

4.7 LAB RESULTS

In examining the data from the test, two graphs were generated. The first, shown in Figure 19, is load vs. time for the test of the asphalt sample. The second graph, Figure 20, is the relation of Strain and time. Figure 20 shows the increase in strain due to apply of creep load on the asphalt concrete sample.

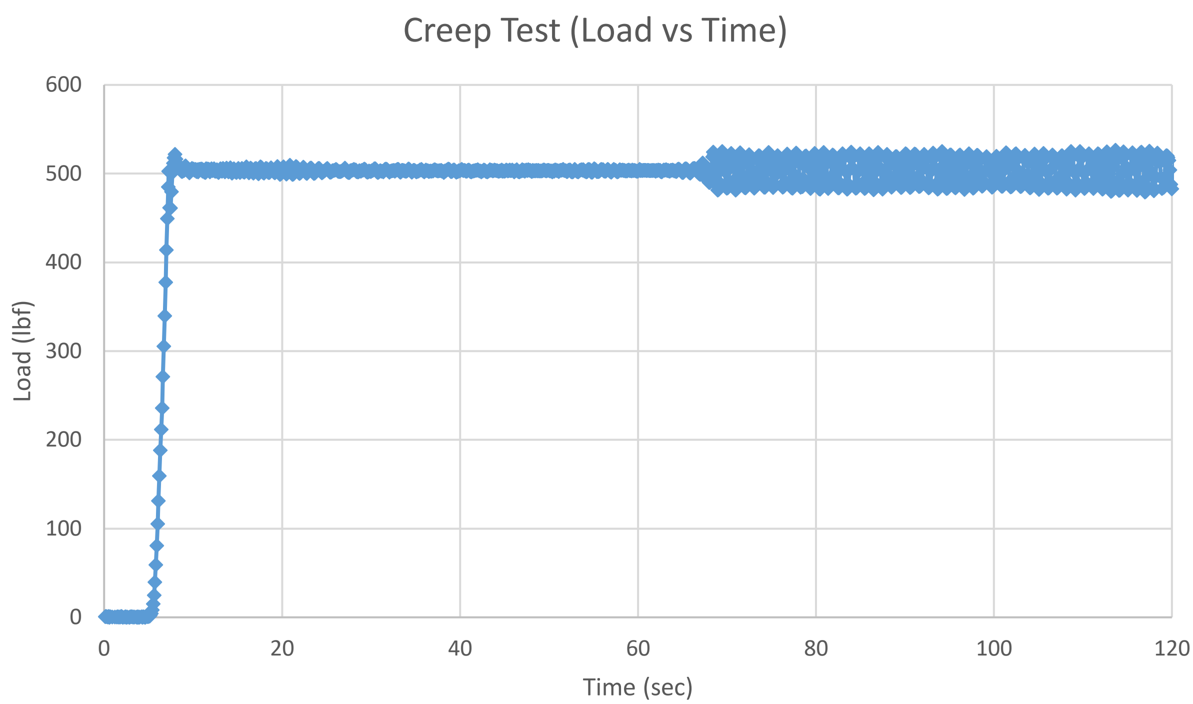

FIGURE 19: Load vs. Time Graph

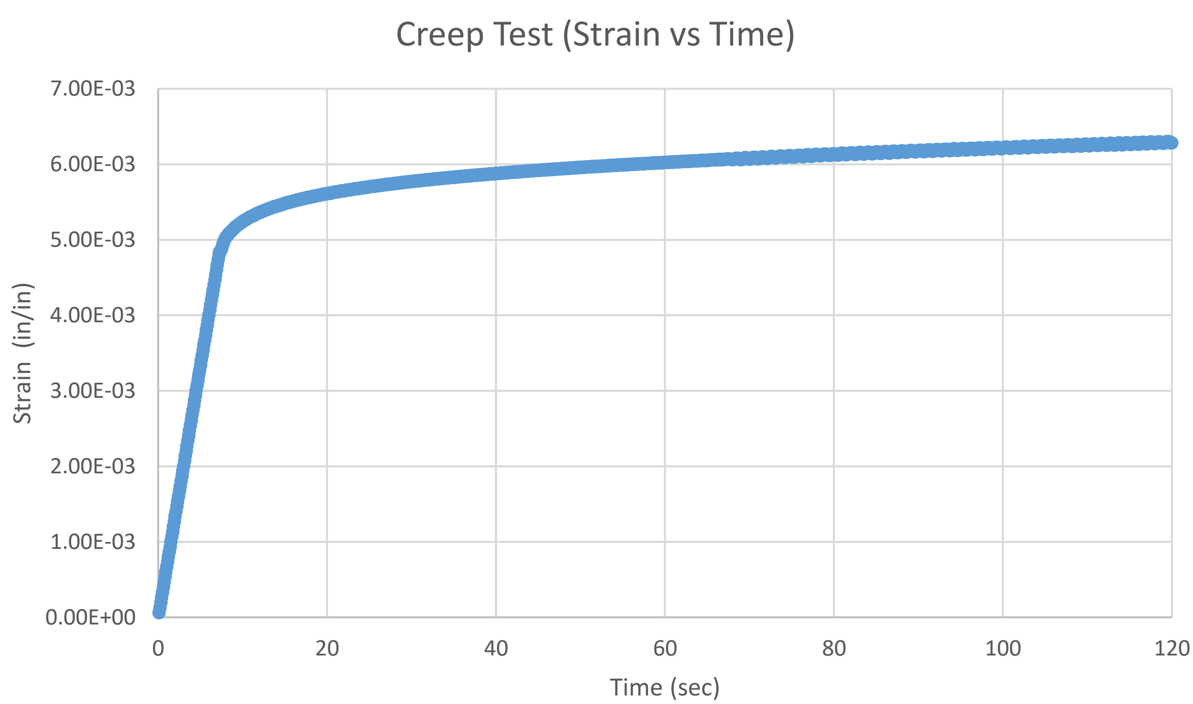

FIGURE 20: Strain vs. Time Graph

5.0 CONCLUSION

Creep is something that cannot be taken out of asphalt. However, as engineers, all percussions can be taken to reduce these effects on the asphalt paved roads. In order to do this the creep compliance tests, need to be periodically performed to ensure compliance with the standards of asphalt construction. Doing so will provide better mix designs that will stand the test of time, and reduce the need of repairs and reconstruction, which will allow for considerable savings in state and federal funds that are used to maintain these roads.

6.0 RECOMMENDATIONS

It is recommended by this report that creep is a required test when it comes to pavement design, as this will impact the final product of any road. Whether it is a brand-new road or a mill and repave reconstruction, rutting and fatigue cracking can and will impact any road in the life span of the road. The ability to prevent this will allow for significant improvements to the infrastructure to the city/ state that the road is located in. It would also be recommended to continue research into different methods to test these properties, the current standard for testing is 17 years old and may need to be updated to comply with current standards. Additionally, Engineers should delve into researching design mechanics to counteract creep and relaxation.

7.0 ACKNOWLEDGMENTS

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