STATE OF FLORIDA

Evaluation of Pavement Strain Gauge Repeatability Under Accelerated Pavement Testing

RESEARCH REPORT

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1 Executive Summary

Pavement instrumentation gauges have been in use for a long period of time, and have typically been used to measure and evaluate the response of a pavement system. Although information related to installation of these gauges and methodology for data collection and analysis has been well documented, literature regarding repeatability of these measurements is very limited. Since the response from these instrumentation gauges plays an important part in modeling pavement systems, it is necessary to have a high degree of confidence in their measurements.

The Florida Department of Transportation (FDOT) conducted this parametric experiment in an effort to evaluate the repeatability of pavement strain gauges currently used in its Accelerated Pavement Testing (APT) facility. Strain measurements using 28 strain gauges were made at five different temperatures, three levels of load, three levels of tire pressure and three levels of speed. The loading was applied to the pavement test section using the Heavy Vehicle Simulator (HVS) and five replicate load passes were made at each combination of variables. Statistical analysis of the measured strain data showed that the surface strain gauges are repeatable under various combinations of temperature, load, speed and tire pressure. The results of this study also showed that the strain measurements did not vary significantly with a change in the internal tire pressure.

This research report presents a detailed description of the testing program, data collection efforts, subsequent analysis and results obtained under accelerated pavement testing.

2 Background

2.1 INTRODUCTION

Pavement instrumentation such as strain gauges, pressure cells, single and multi-layer deflectometers, temperature and moisture gauges have all been used in the past with varying degrees of success. The measurement of pavement response using various instrumentation gauges and its correlation to mechanistic or theoretical values are crucial steps in understanding and modeling the performance of pavement systems. Although, several researchers have used and documented the response from various strain gauges, literature regarding the repeatability of these measurements is very limited. Several factors can affect the repeatability of in-situ instrumentation including inherent construction related variability in pavement structure and materials, presence or absence of moisture, air void content, layer thickness, gauge orientation etc. Other factors such as the asymmetric stress distribution under the wheel load can further make data interpretation difficult.

Obtaining repeatable strain measurements in flexible pavement is an arduous endeavor in many regards. For example, embedded (in-situ) strain gauges must be able to survive the high temperatures and stresses related to the paving process. The instrumentation must then be calibrated correctly and temperature compensation implemented. Perhaps the most difficult task to obtain repeatable data is condition control. Wheel speed, load, and lateral position relative to the gauge are an integral part in obtaining repeatable data. In FDOT's past experience, more than 70 percent of in-situ strain gauges have typically survived the construction process. However, the surviving gauges have always measured pavement strain with a high degree of variability. On the other hand, since surface strain gauges are installed after construction is completed, a high degree of control can be achieved during gauge installation and data collection process.

Top-down surface cracking is a prevalent form of pavement distress in a large percentage of Florida's pavements. This form of distress can result in a loss of structural capacity of the overall pavement, while at the same time severely affecting the pavement ride quality. Consequently, several research projects have focused on the initiation and propagation of top-down surface cracking, including an ongoing research project at the Materials Research Park. An important portion of this research focuses on the measurement of surface (lateral/radial) strains arising from the loaded tire. Surface strain gauges, installed properly on the pavement surface should theoretically be able to measure both transverse and longitudinal surface strains. Surface strain gauges are easier to install, and since they are placed on the pavement surface, their location can be accurately controlled. FDOT's initial experience with these gauges showed promising results in terms of data measurements and repeatability.

In an effort to better understand the variability of measurements obtained with surface strain gauges, this research project was initiated with the express purpose of evaluating the repeatability of surface strain gauges. In-situ strain gauges are critical to the overall research program, and were also considered during this experiment.

2.2 OBJECTIVES

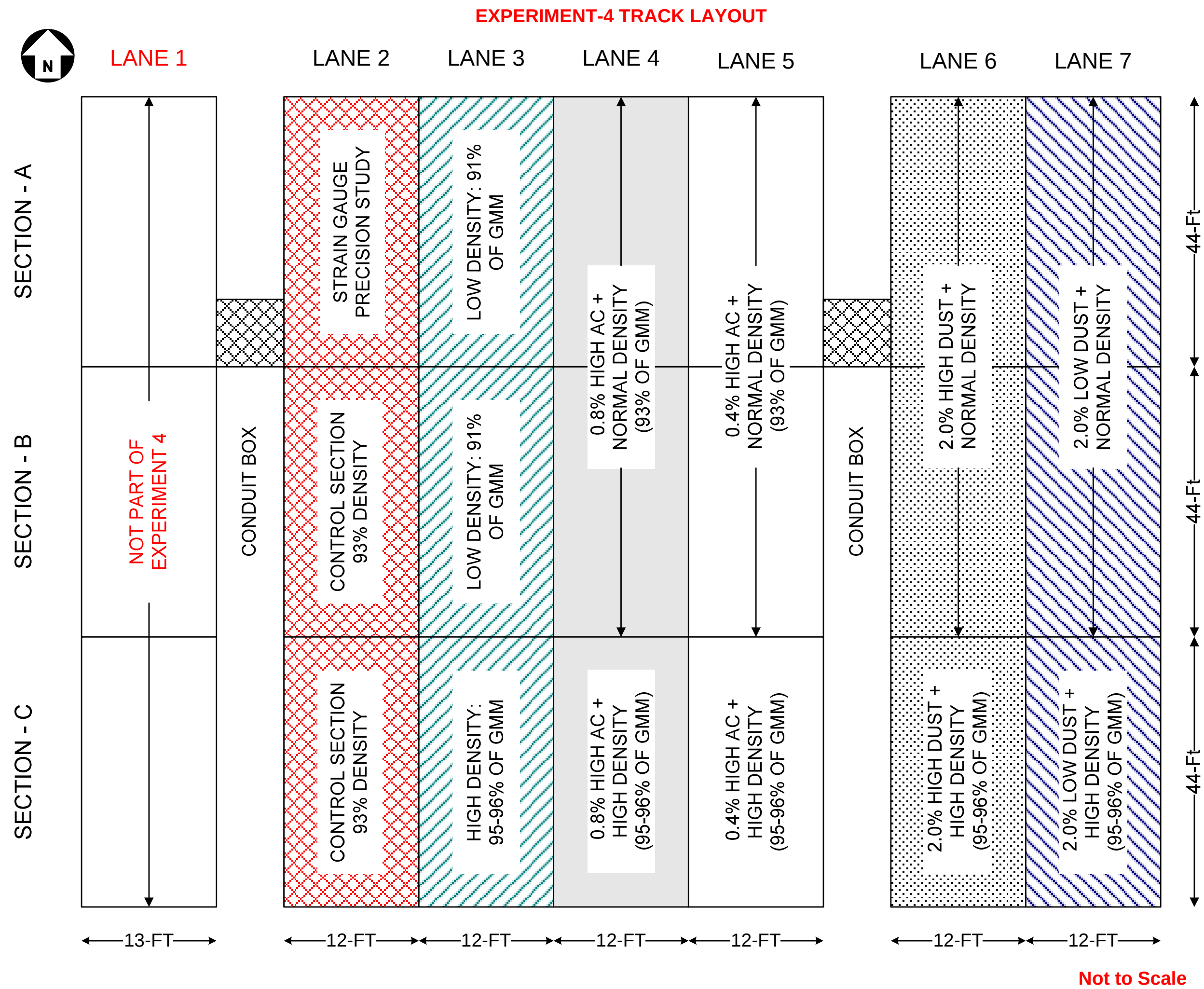
The primary objective of this research was to evaluate the repeatability of pavement strain gauges under varying conditions of temperature, load, tire pressure and speed of loading. A secondary objective of this research was to determine the significance level of the effect of the above mentioned variables on strain measurements.

3 Experiment Design

3.1 TEST TRACK LAYOUT

The Florida Department of Transportation (FDOT) initiated an Accelerated Pavement Testing program in early 2000, and is based within the State Materials Research Park in Gainesville, Florida. The testing site consists of seven linear test tracks with each test track measuring approximately 150 feet long (45 m) by 12 feet wide (3.6 m). Each of these test tracks is further divided into three replicate test sections to facilitate repeat measurements on the same material and/or pavement structure. Accelerated loading on the pavement test sections is achieved by means of a Heavy Vehicle Simulator (HVS), manufactured by Dynatest, Mark IV model. A complete description of the test facility and the initial experiment has been presented elsewhere (*1, 2*). To date, several pavement research projects have been successfully completed at FDOT, resulting in various construction and material properties specification changes. FDOT's pavement research program remains one of the most active APT programs in the world.

For this research study, one test section (Section 2A) was retained from a previous study on construction variability (FDOT APT Phase-4). The existing test track layout (from Phase-4) is presented in Figure 3.1. This test section was 44 feet (13.3 m) long and 12 feet (3.6 m) wide. The pavement structure consisted of a 1.5 inch (40 mm) friction course layer on top of 2 inch (50 mm) structural asphalt concrete. A 10.5 inch (265 mm) thick limerock base course on top of a 12 inch (305 mm) granular sub-base supports the overlying asphalt course layers, as detailed in Figure 3.2. Considerable effort was made to ensure uniform density and layer thickness during the construction of this test section.



NOTE: ONLY SECTION 2A WAS USED IN THE STRAIN GAUGE REPEATABILITY STUDY

Figure 3.1 Schematic of Test Track Layout.

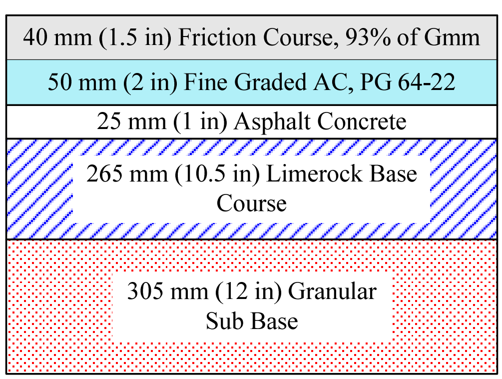


Figure 3.2 Pavement Design for Test Section 2A.

3.2 EXPERIMENT DESIGN

The main objective of this research was to evaluate the repeatability of pavement strain gauges (surface gauges and in-situ gauges) under varying conditions of temperature, load, speed, and tire pressure. A total of 8 embedded (in-situ) and 20 surface-strain gauges were considered. The strain gauges were divided into six functional groups (of 4 gauges each), with each group measuring a different pavement response. Strain gauge installation practices are included in Appendix A. A parametric experiment was then designed to include 5 levels of temperature, 3 levels of speed, 3 levels of tire pressure, and 3 levels of wheel load. The experimental matrix is shown in Table 3.1. A standard Goodyear G165 super-single tire was used in this study. One forward movement of the loaded HVS tire over the entire pavement test section comprised a HVS "pass", and only uni-directional loading was applied to the pavement to simulate realistic highway conditions. Five HVS wheel passes were made at every combination of test variables resulting in a total of 675 tire passes.

Table 3.1 Strain Gauge Repeatability Study Test Matrix.

Gauge	Tire Pressure (psi)	Load (lb)	Speed (mph)			Temperature (°C)					HVS Passes at each combination
14 Longitudinal	80	9,000	2	4	8	16	20	30	40	50	5
+	115	12,000	2	4	8	16	20	30	40	50	5
14 Transverse	125	15,000	2	4	8	16	20	30	40	50	5
Levels	3 Pressures	3 Loads	3 Speeds			5 Temperatures					5 HVS Passes
Total Number of Trials = 3 x 3 x 3 x 5 x 5 = 675 Trials											
Total Number of Gauge Readings = 28 Gauges x 675 Trials = 18,900 Gauge Readings											
Note: 4 transverse and 4 longitudinal gauges are embedded (in-situ) gauges											

CONVERSION 80 psi (552 kPa), 115 psi (793 kPa), 125 psi (862 kPa)
9,000 lb (40 kN), 12,000 lb (53.4 kN), 15,000 lb (66.7 kN)
2 mph (3.2 kmph), 4 mph (6.4 kmph), 8 mph (12.9 kmph)

As shown in Table 3.1, three load levels; 9,000 lb (40 kN), 12,000 lb (53.4 kN) and 15,000 lb (66.7 kN) we applied to the pavement. A Goodyear G165 super-single tire was used for loading, with wheel speeds varying from 2 mph (3.2 kmph), 4 mph (6.4 kmph) and 8 mph (12.9 kmph). As part of this research, the tire was inflated to three tire different pressures with the same amount of load. A low tire pressure was designated at 85 psi (586 kPa), a normal operating tire pressure at 115 psi (793 kPa) and a high tire pressure at 125 psi (862 kPa). The entire series of testing was conducted at five different pavement temperatures varying from cold (~16 °C) to hot (50 °C).

Essentially, the objective was to evaluate the repeatability of strain gauges at different cross-combinations of temperature, load, speed and tire pressure, and every effort was made to conduct the testing at all combinations of variables. Preliminary testing showed that the combination of high load - 15,000 lb (66.7 kN) and low tire pressure of 80 psi (552 kPa), caused the super-single to bulge outward alarmingly. This was deemed an unsafe condition, and was consequently removed from further consideration.

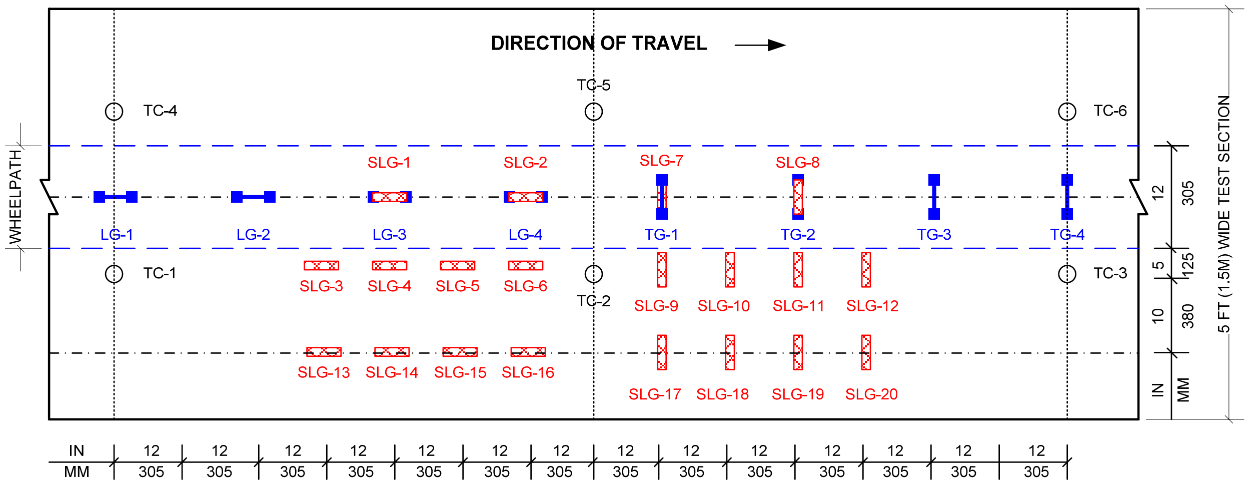
During actual testing and data collection, every effort was made to follow the original experiment design and test matrix. However, in reality, it was not possible to strictly adhere to the test plan. Moreover, at certain combination of variables, test data collected was found to be faulty or incomplete and was subsequently removed from further analysis consideration. The final as-tested matrix is shown below in Table 3.2. This table shows the actual number of HVS passes performed at the combination of test variables. Full description of the data files collected is presented in Appendix A.

Table 3.2 As-Tested Matrix, Showing Actual Number of HVS Passes

Pressure[1]	80									115									125								
Load[2]	9			12			15			9			12			15			9			12			15		
Speed[3]	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8
16 °C	3	3	3	3	3	3				3	3	3	3	3	3				3	3	3	3	3	3			
20 °C	5	5	5	5	5	5				5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
30 °C	5	5	5	5	5	5				2	5	5	5	5	5				5	5	5	5	5	5			
40 °C	3	5	5	3	5	5				5	5	5	5	5	5	5	5	5	3	5	5	3	5	5	3	5	4
50 °C	3	5	5	3	5	5				3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5

The surface strain gauges used in this research were manufactured by the Tokyo Sokki Kenkyojo Company of Japan, and were all 30 mm in length. The embedded gauges used in this study were H-type gauges, also manufactured by the Tokyo Sokki Kenkyojo Company of Japan. Each of the gauges was connected to the data acquisition system to ensure that it was working properly before being placed in/on top of the pavement test section. Accurate positioning of the strain gauges was a critical part of this study. Prior to construction, the center-line of the test section was accurately marked on the base layer. The in-situ strain gauges were positioned along this center-line at 2 foot (0.6 m) intervals. To ensure that these gauges would not be displaced by the construction of asphalt layers, the strain gauges were secured with wire and covered with asphalt mix. The Goodyear G165 tire used in this study is approximately 12 inches (305 mm) in width, and for testing purposes a loading pattern with zero lateral wander was adopted. The edges of this tire footprint were clearly marked on the pavement surface. Thereafter, the surface strain gauges were installed on the asphalt surface by first rough grinding a thin section of the surface, followed by gauge placement and protection by means of an epoxy adhesive.

Figure 3.3 shows the details of the strain gauge placement. The embedded gauges (Groups 5 and 6) were directly beneath the center of the applied load at the bottom of the asphalt layers; a depth of 3.5 inches (90 mm). The center-line of the gauges was designed to match the center-line of the wheel-load. Groups 1 and 2 comprise of surface strain gauges at a distance of 5 inches (125 mm) from the edge of the wheelpath, while Groups 3 and 4 comprise of surface strain gauges at a distance of 15 in (375 mm) from the edge of the wheelpath. Four surface gauges were also installed on the surface of the pavement, directly beneath the center line of the loaded wheel.



Group Number	Description	Strain Gauge Number	Location
Group-1	Longitudinal Surface Gauges, 5 in from Wheelpath	SLG-3, SLG-4, SLG-5, SLG-6	On Surface
Group-2	Transverse Surface Gauges, 5 in from Wheelpath	SLG-9, SLG-10, SLG-11, SLG-12	On Surface
Group-3	Longitudinal Surface Gauges, 15 in from Wheelpath	SLG-13, SLG-14, SLG-15, SLG-16	On Surface
Group-4	Transverse Surface Gauges, 15 in from Wheelpath	SLG-17, SLG-18, SLG-19, SLG-20	On Surface
Group-5	Longitudinal Embedded Gauges, in Wheelpath	LG-1, LG-2, LG-3, LG-4	4 in (100 mm) Depth
Group-6	Transverse Embedded Gauges, in Wheelpath	TG-1, TG-2, TG-3, TG-4	4 in (100 mm) Depth

Note: SLG: Surface strain gauge, LG: Embedded gauge (longitudinal), TG: Embedded Gauge (transverse), TC: Temperature gauge (thermocouple).

Figure 3.3 Strain Gauge Repeatability Study Gauge Layout.

4 Data Acquisition Methodology

All strain gauges were connected to a National Instruments (NI) Data Acquisition System (DAQ) mounted on a custom made chamber trolley. It is FDOT's experience and recommendation that the lead wires connecting instrumentation to the DAQ system be kept as short as possible. This reduces the amount of signal noise and other factors that may affect data collection. Another important factor to consider in dynamic strain data collection is the data-scan rate and the recording rate used by the data acquisition system. As can be expected, a very high scan and recording rate leads to a very large amount of collected data, which increases file-size tremendously. Moreover, approximately 90 to 95 percent of the data is collected when the strain gage is 'idle'; i.e., has no load applied on it. Under the current HVS configuration, it takes approximately 6.5 seconds for each load passage. For a load-wheel traveling at 8 mph (12.9 kmph), a typical strain pulse would only last for about 0.4 seconds, thus representing only 6 percent of the total collected data. Therefore, for this research, the scan rate for strain data collection was set at 10,000 Hz, and analyzed and stored by the DAQ system at 1,000 Hz. The processed data was transmitted to fully-automated NI LabView TM software housed securely inside the HVS control room via a radio frequency (RF) link. The DAQ system has 28 channels for simultaneous data acquisition. All gauges were shunt calibrated and zeroed before testing was begun. Data for each HVS pass was collected in a 15 to 30 second window depending on the load speed, and saved as a comma separated variable (CSV) file.

Pavement temperature was the most critical factor during the data collection process. The objective was to evaluate the repeatability of strain gauges under a wide a range of operating temperatures. The HVS has the functionality to heat the pavement surface using radiant heaters, but no pavement cooling device is present at this time. During the course of this study, the coldest pavement temperature was reached in late December 2008, with the pavement surface temperature reaching 16° C. Subsequently, the first test was conducted at this temperature. Since repeated loadings on a pavement section can cause permanent deformation (rutting), it was decided to conduct testing at lower temperatures first. Thus permanent deformation would be minimized.

The methodology for testing and data collection was as follows:

- At each target pavement temperature, the tire pressure of the HVS load-wheel was first set to the low tire pressure of 85 Psi (589 kPa). This was achieved by lifting the tire off the pavement surface and setting the internal tire pressure without any load. The wheel was then set on the pavement surface, outside the influence area of the strain gauges, and the target load was applied to the wheel. Note that before moving the loaded wheel across the pavement test section, the load (starting at 9 kips) was stabilized so that compounding effects from load variation would not affect the measured strain.
- After the load had stabilized, the first set of tests was performed at the low wheel speed of 2 mph (3.2 kmph). Five replicate HVS passes were made under the same condition of temperature, tire-pressure, load and speed. Data from all 28 surface strain gauges was collected at this time. After the first 5 HVS passes were applied, the next set of tests were conducted at 4 mph (6.4 kmph) and 8 mph (12.9kmph).
- Keeping the tire pressure constant, the next set of tests were performed at the next higher load level (12 Kips.) The entire test sequence was then repeated. Thus for each level of pavement temperature, various combinations of tire pressure, load and speed were applied. Data was acquired on all 28 channels in a 15 to 30 second window. At 8 mph (12.9 kmph), the HVS wheel-load takes approximately 6.5 seconds to complete one load passage, and therefore the data collection window for this speed was set at 15 seconds. For slower speeds, the data collection window was increased to 30 seconds.
- Each set of data was collected and stored as a CSV file. Each data file contains an ID column, a column of data containing the time-stamp, and strain data from each gauge. A filtered raw data file contains approximately 300,000 data points. Each data file was coded according to the test variables. For example, a file name "20C – 115 Psi – 9 Kips – 4 Mph – 5 Passes", contains raw strain data from all operational gauges at a test temperature of 20° C, a tire pressure of 115 psi, a test load of 9 kips, and a test speed of 4 Mph. Note that this data set contains strains measured for the 5 replicate HVS passes.

FDOT's HVS is equipped with a well-insulated environmental enclosure that covers the entire pavement section during testing. With the help of radiant heaters attached to the HVS, the pavement temperature

can be accurately controlled and monitored. The process of heating the entire pavement test section and stabilizing the target temperature at a depth of 2 inches (50 mm) takes approximately 24 hours.
As mentioned earlier, four surface strain gauges were installed on the pavement surface, directly underneath the path of the moving tire. As was suspected, these gauges did not survive for more than the first couple of HVS passes. The super-single tire, with its wide treads, crushed the surface strain gauges and their lead wires. Consequently, these four gauges were eliminated from the test matrix.

All of the remaining 24 gauges were; however, working properly and a preliminary analysis of the measurements revealed that the strain data was valid. Before beginning the combination of the next set of variables, it was always verified that the strain gauges were working properly.

The data collection process of this research took approximately three weeks of testing. An enormous amount of strain data was collected through the course of this research. A total of 32 million data points were thus collected from 24 operational strain gauges.

5 Data Analysis

5.1 DATA REDUCTION AND FILTERING

Typical strain gauge response pulses are shown in Figure 5.1. The strain response is a function of the gauge orientation (longitudinal or transverse), gauge location (near or away from the wheelpath) and depth of gauge location (surface or bottom of asphalt layers.) As shown in Figure 5.1, the response pulse varies significantly between different groups of gauges. To facilitate an evaluation of strain gauge repeatability, it was necessary to identify critical points in the strain gauge response pulse. Figure 5.2 shows a typical gauge response and 5 points that were identified for analysis purposes. Note that Figure 5.2 is an example strain pulse, and the 5 critical points were identified separately for each group of gauges.

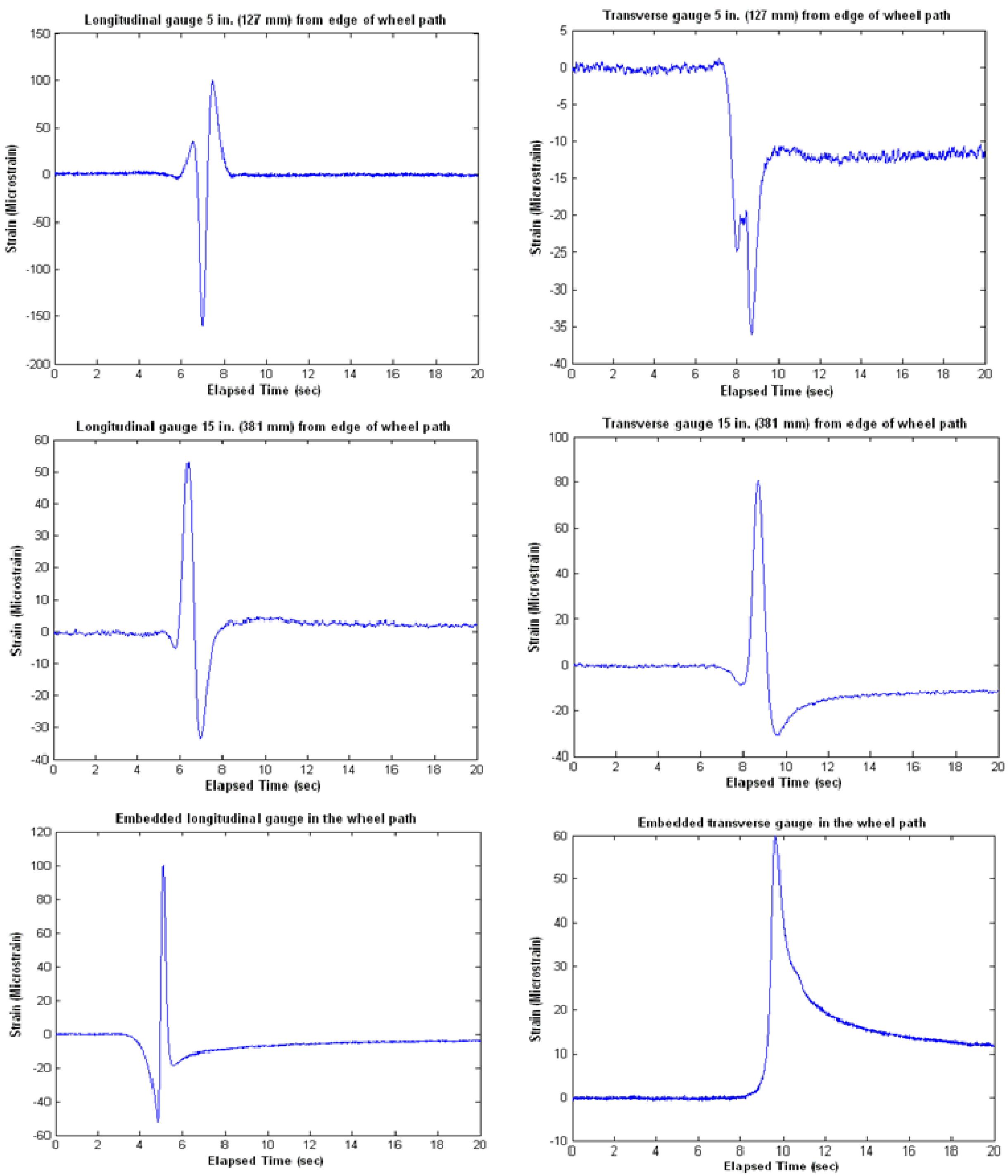


Figure 5.1 Typical Strain Pulse Obtained from Various Gauges.

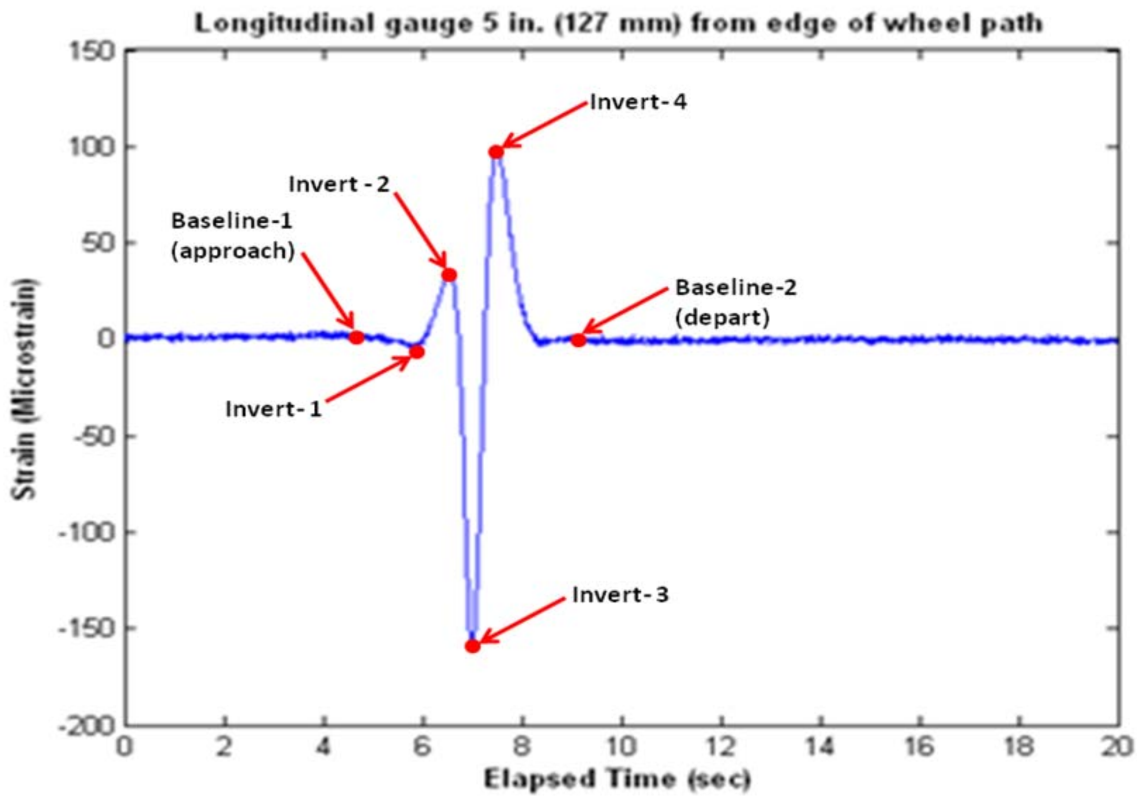


Figure 5.2 Typical Strain Pulse and Key Points of Interest.

Using MATLABTM, an analysis algorithm was developed that processed the raw data files and compiled the 5 critical points for each gauge. Essentially, the MATLABTM program identified the portion of the strain gauge pulse where the gauge recorded strain data and further analyzed it to obtain the 5 critical points as identified in Figure 5.2.

The processed, or reduced, strain data was further compiled and analyzed through a program written with MS Excel and Visual Basic for Applications. To evaluate the repeatability of strain gauges, the magnitude of strain, herein defined as the absolute difference between the minimum and maximum strain value of the strain pulse, was used as the response variable. For example, in Figure 5.2, the magnitude of the strain was defined as the absolute value of the difference between points 2 (Invert 1) and 3 (Invert 2). Table 5.1 shows an example of the critical points extracted from a typical strain data pulse and the calculation of the strain magnitude.

Table 5.1 Critical Strain Points Extracted from a Strain Pulse.

Group 1 (Longitudinal surface strain gauges 5 in from wheelpath)	Critical points (in Microstrain)					Magnitude[1] (Microstrain)
	Approach	Invert-1	Invert-2	Invert-3	Depart	
	1	2	3	4	5	
SLG-3	-285.93	-254.14	-384.59	-261.87	-286.49	130.45
SLG-4	-824.58	-787.03	-933.13	-803.66	-826.16	146.12
SLG-5	-853.47	-823.96	-961.82	-832.12	-853.64	137.85
SLG-6	-798.35	-769.26	-910.33	-772.09	-797.45	141.07
					Mean	138.87
					St. Dev.	6.55
					COV	4.72%

[1]The magnitude is calculated as the absolute difference between points 2 and 3

NOTE: These measurements were made at a surface temperature of 20 °C, 80 psi (552 kPa) tire pressure, 12,000 lb (53.4 kN) load and a speed of 8 mph (12.9 kmph).

6 Evaluation of Strain Data Repeatability

To evaluate the repeatability of strain measurements, a statistical analysis procedure similar to that outlined in *ASTM C 802, Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials*, was applied to the processed/reduced data (*3*). This methodology included the determination of variances within and between similar gauges making the same measurement. The result of the analysis is interpreted in terms of within and between coefficient of variations (COV), which indicate the degree of variability associated with making repeat measurements with the same gauge (within) and the variability associated with repeat measurements using similar gauges (between). An example of these calculation is shown in Table 6.1. In this example, the repeatability estimates for within gauge and between gauges are 0.9 percent and 4.5 percent respectively. This procedure was performed for all groups of gauges and for all combination of variables to provide an overall estimate of strain gauge repeatability.

Table 6.1 Example Calculation of Repeatability Estimates.

Gauge	Pass-1	Pass-2	Pass-3	Pass-4	Pass-5	Average	Variance
SLG-3	130.45	133.82	130.97	133.61	134.01	132.57	2.94
SLG-4	146.09	146.51	146.43	147.49	148.09	146.93	0.70
SLG-5	137.85	135.94	136.59	137.39	136.23	136.80	0.64
SLG-6	141.07	138.62	140.86	140.86	139.34	140.32	1.67
					Average	139.16	1.49

$$p = Number\ of\ Gauges = 4$$

$$n = Number\ of\ trials = 5$$

$$\bar{x}_i = Sum\ of\ n\ trials\ for\ one\ Gauge\ divided\ by\ n = (\sum x_i / n) = 132.57$$

$$\bar{x}_A = Average\ of\ Gauge\ Averages = 139.16$$

$$S_A^2(pooled) = Average\, of\ Gauge\, Variances = 1.49$$

$$S\,\overline{x}_A^{\,2}\ (Component\ of\ Variance - within\, Gauge) = (\sum \overline{x}_i^2 - p(\overline{x}_A)^2)/(p-1)$$

$$SL_A^2\ (Component\ of\ Variance - between\, Gauges) = (S\overline{x}_A^2) - (S_A^2(pooled)/n) = 36.61$$

$$Variance\ within\, Gauges = 1.49$$

$$Variance\ between\, Gauges = 38.1$$

$$Coefficient\ of\ Variation\,(COV)\ within\, Gauges = 0.9$$

$$Coefficient\ of\ Variation\,(COV)\ between\, Gauges = 4.5$$

For this study, a COV of ≤ 10 percent (between gauges) was deemed acceptable in terms of repeatability. A COV between 10 percent and 20 percent was defined as marginal, and a COV $\geq$ 20 percent was defined as inadequate or high variability. The results of all analyses were compiled into a matrix for all the variables (temperature, tire-pressure, load and speed) to provide an overall picture of the repeatability estimate. As an example, Table 6.2 shows the results of the statistical analysis for strain gauges in Group-1, with the tire pressure set at 115 psi (793 kPa) Table 6.2 shows both the average magnitude of strain ($\overline{x}_A$), and the COV (between gauges) in percent. Complete details of all analyses are presented in Appendix A.

The results of the repeatability analysis have been presented in the form of coded tables for each group of gauges. Table 6.3 through Table 6.8 show the results for gauge Groups 1 through 6 respectively. The grey shaded boxes in the table indicate that the COV was less than 10 percent, indicating good repeatability between the gauges.

The following observations were made about the repeatability analysis. In general, surface strain gauges seem to be reasonably repeatable (COV < 10 percent) for any given set of conditions. Although, the embedded strain gauges were installed with utmost care, both groups 5 and 6 showed marginal repeatability at best. Group 5 (embedded longitudinal gauges) actually performed worst in terms of repeatability. Also, most gauges show marginal or bad repeatability at 50 °C.

Overall, Group 2 (transverse gauges close to the wheelpath), showed a marginal or high degree of variability for any combination of test conditions. This was a surprising observation, as the transverse gauges further away from the wheelpath showed a very high degree of repeatability. Top-down surface cracking at the edge of the wheelpath is a critical distress in Florida's pavements, and measurement of strains at the edge of the wheelpath is an important factor in modeling pavement response. However, these strain gauges did not perform as expected and showed a high degree of variability in measurements. One possible explanation may be that in addition to transverse surface strains, shear strains at the edge of the wheelpath produce compounding effects which are measured differently by the transverse strain gauges, causing a high degree of variability. This effect is being further investigated by the authors.

Table 6.2 Estimates of Strain Gauge Repeatability (Group 1, Tire Pressure at 115 psi).

Tire Pressure		115 psi								
Load (lb)		9,000			12,000			15,000		
Speed (mph)		2	4	8	2	4	8	2	4	8
16 °C	Avg[1].	105.1	92.86	86.18	134.2	123.7	110.3	--	--	--
	COV[2]	6.1	5.4	5.2	5.6	5.8	5.6	--	--	--
20 °C	Avg.	123.4	112.3	99.4	161.2	148.8	128.9	190.3	176.7	157.6
	COV	6.6	5.2	4.9	5.3	4.6	4.4	5.4	4.9	4.5
30 °C	Avg.	175.1	159.3	139.7	161.5	194.7	170.9	--	--	--
	COV	6.8	7.4	11.6	7.6	6.9	6.7	--	--	--
40 °C	Avg.	200.6	194.4	177.2	240.6	237.6	217.6	268.0	270.9	252.1
	COV	9.2	8.7	8.7	9.0	8.8	8.7	9.5	9.0	8.8
50 °C	Avg.	165.1	176.1	175.5	182.3	198.9	200.8	192.5	212.7	217.7
	COV	14.6	13.1	12.4	15.4	14.0	13.4	15.9	14.3	13.4

Table 6.3 Repeatability Estimates for Strain Gauges in Group 1 (Longitudinal Gauges, 5 in away from the edge of wheelpath)

Pressure[1]	80									115									125								
Load[2]	9			12			15			9			12			15			9			12			15		
Speed[3]	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8
16 °C	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	-	-	-
20 °C	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
30 °C	x	x	x	x	x	x	-	-	-	x	x	•	x	x	x	-	-	-	x	x	x	x	x	x	-	-	-
40 °C	•	x	x	x	x	x	-	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
50 °C	•	•	•	•	•	•	-	-	-	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•

Table 6.4 Repeatability Estimates for Strain Gauges in Group 2 (Transverse Gauges, 5 in away from the edge of wheelpath)

Pressure[1]	80									115									125								
Load[2]	9			12			15			9			12			15			9			12			15		
Speed[3]	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8
16 °C	•	•	•	•	•	x	-	-	-	•	•	x	•	•	x	-	-	-	•	•	•	•	•	x	-	-	-
20 °C	•	•	•	•	•	•	-	-	-	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
30 °C	■	■	•	■	•	•	-	-	-	•	•	•	•	•	•	-	-	-	•	•	•	•	•	•	-	-	-
40 °C	■	•	•	•	•	•	-	-	-	■	•	•	■	•	•	■	•	•	■	•	•	•	•	•	•	•	•
50 °C	■	■	■	■	■	■	-	-	-	■	■	■	•	■	■	■	■	•	•	■	■	■	■	■	■	■	■

-	Not tested
x	COV < 10%
•	10% < COV < 20%
■	COV > 20%

[1] Pressure is in psi

[2] Load is in multiples of 1,000 lb

[3] Speed is in mph

Table 6.5 Repeatability Estimates for Strain Gauges in Group 3 (Longitudinal Gauges, 15 in away from the edge of wheelpath)

Pressure[1]	80									115									125								
Load[2]	9			12			15			9			12			15			9			12			15		
Speed[3]	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8
16 °C	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	-	-	-
20 °C	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
30 °C	x	x	x	x	x	x	-	-	-	x	x	•	x	x	x	-	-	-	x	x	x	x	x	x	-	-	-
40 °C	•	x	x	x	x	x	-	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
50 °C	•	•	•	•	•	•	-	-	-	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Table 6.6 Repeatability Estimates for Strain Gauges in Group 4 (Transverse Gauges, 15 in away from the edge of wheelpath)

Pressure[1]	80									115									125								
Load[2]	9			12			15			9			12			15			9			12			15		
Speed[3]	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8
16 °C	•	•	•	x	x	x	-	-	-	•	•	x	x	•	•	-	-	-	•	x	x	•	•	x	-	-	-
20 °C	x	x	•	x	x	x	-	-	-	x	x	x	x	x	x	x	x	x	x	x	•	x	x	x	x	x	x
30 °C	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	-	-	-
40 °C	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
50 °C	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

-	Not tested
x	COV < 10%
•	10% < COV < 20%
	COV > 20%

[1] Pressure is in psi

[2] Load is in multiples of 1,000 lb

[3] Speed is in mph

Table 6.7 Repeatability Estimates for Strain Gauges in Group 5 (Embedded Longitudinal Gauges, center-line of wheelpath)

Pressure[1]	80									115									125								
Load[2]	9			12			15			9			12			15			9			12			15		
Speed[3]	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8
16 °C	■	■	■	■	■	■	-	-	-	■	■	■	x	x	x	-	-	-	x	x	x	x	x	x	-	-	-
20 °C	■	■	■	■	■	■	-	-	-	■	■	■	■	■	■	■	■	■	x	x	x	x	x	x	x	x	■
30 °C	■	■	■	■	■	■	-	-	-	■	■	■	■	■	■	-	-	-	■	■	■	■	■	■	-	-	-
40 °C	■	■	■	■	■	■	-	-	-	•	■	■	•	■	■	•	■	■	■	■	■	•	■	■	•	■	■
50 °C	x	•	•	x	x	•	-	-	-	x	•	•	•	•	•	•	•	•	x	•	•	x	•	•	x	x	x

Table 6.8 Repeatability Estimates for Strain Gauges in Group 6 (Embedded Transverse Gauge, center-line of wheelpath)

Pressure[1]	80									115									125								
Load[2]	9			12			15			9			12			15			9			12			15		
Speed[3]	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8	2	4	8
16 °C	•	•	•	•	•	•	-	-	-	•	•	•	•	•	•	-	-	-	•	•	•	■	•	•	-	-	-
20 °C	•	•	•	x	x	•	-	-	-	•	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
30 °C	•	•	•	x	x	x	-	-	-	•	x	•	x	x	x	-	-	-	x	x	x	x	x	x	-	-	-
40 °C	x	x	•	x	x	x	-	-	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
50 °C	•	•	•	•	•	•	-	-	-	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

-	Not tested
x	COV < 10%
•	10% < COV < 20%
■	COV > 20%

[1] Pressure is in psi

[2] Load is in multiples of 1,000 lb

[3] Speed is in mph

7 Trend Analysis

7.1 TEST VARIABLES

The statistical analysis performed during the course of this study, allowed a reasonable degree of confidence to be placed on the measured strains for most conditions. A secondary objective of this research was to evaluate the effect of temperature, tire pressure, load and speed on the measured strains.

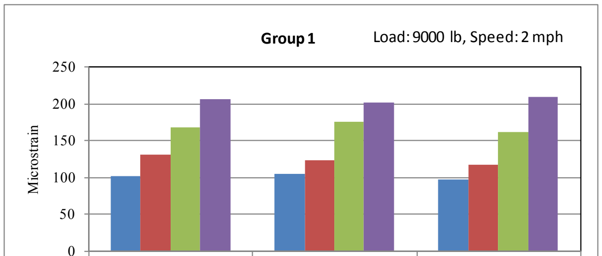
This section of the report shows plots of average strains measured for a given group of gauges. A parametric analysis matrix was set up with the following test cases:

	CASE I	CASE II	CASE III
	Effect of Tire Pressure	Effect of Load	Effect of Speed
A	80 psi	9,000 lb	2 mph
B	115 psi	12,000 lb	4 mph
C	125 psi	15,000 lb	8 mph

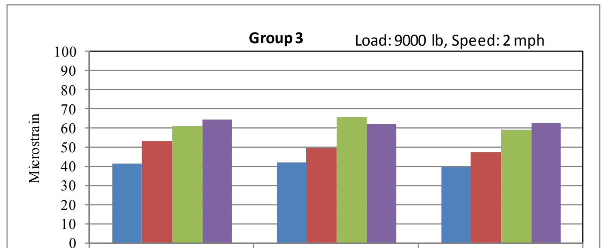
NOTE Measurements made at all temperatures.

Data from each combination of variables has been plotted in Figure 7.1 through Figure 7.27 for easy reference. Individual details including the average strain measured for each group of gauges, and the corresponding coefficients of variation are presented in Table C.1 through Table C.6 in Appendix B.

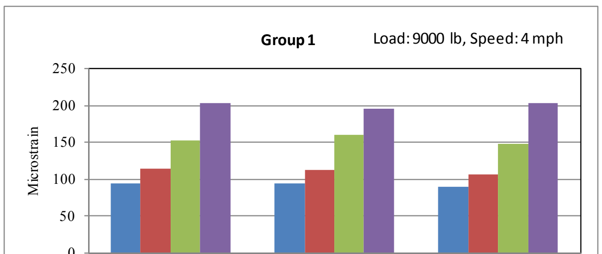
7.1.1 Effect of Tire Pressure



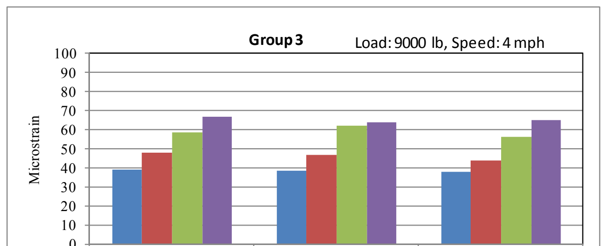
Tire Pressure (psi)	80	115	125
16 C	102	105	97
20 C	131	123	116
30 C	167	175	161
40 C	206	201	209



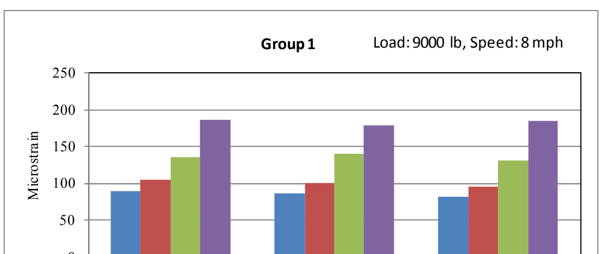
Tire Pressure (psi)	80	115	125
16 C	41	42	40
20 C	53	50	47
30 C	61	66	59
40 C	64	62	63



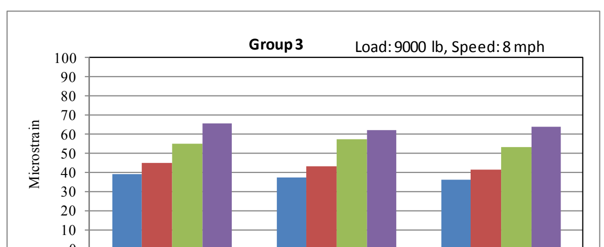
Tire Pressure (psi)	80	115	125
16 C	93	93	89
20 C	114	112	106
30 C	152	159	147
40 C	202	194	203



Tire Pressure (psi)	80	115	125
16 C	39	38	38
20 C	48	47	44
30 C	58	62	56
40 C	67	64	65

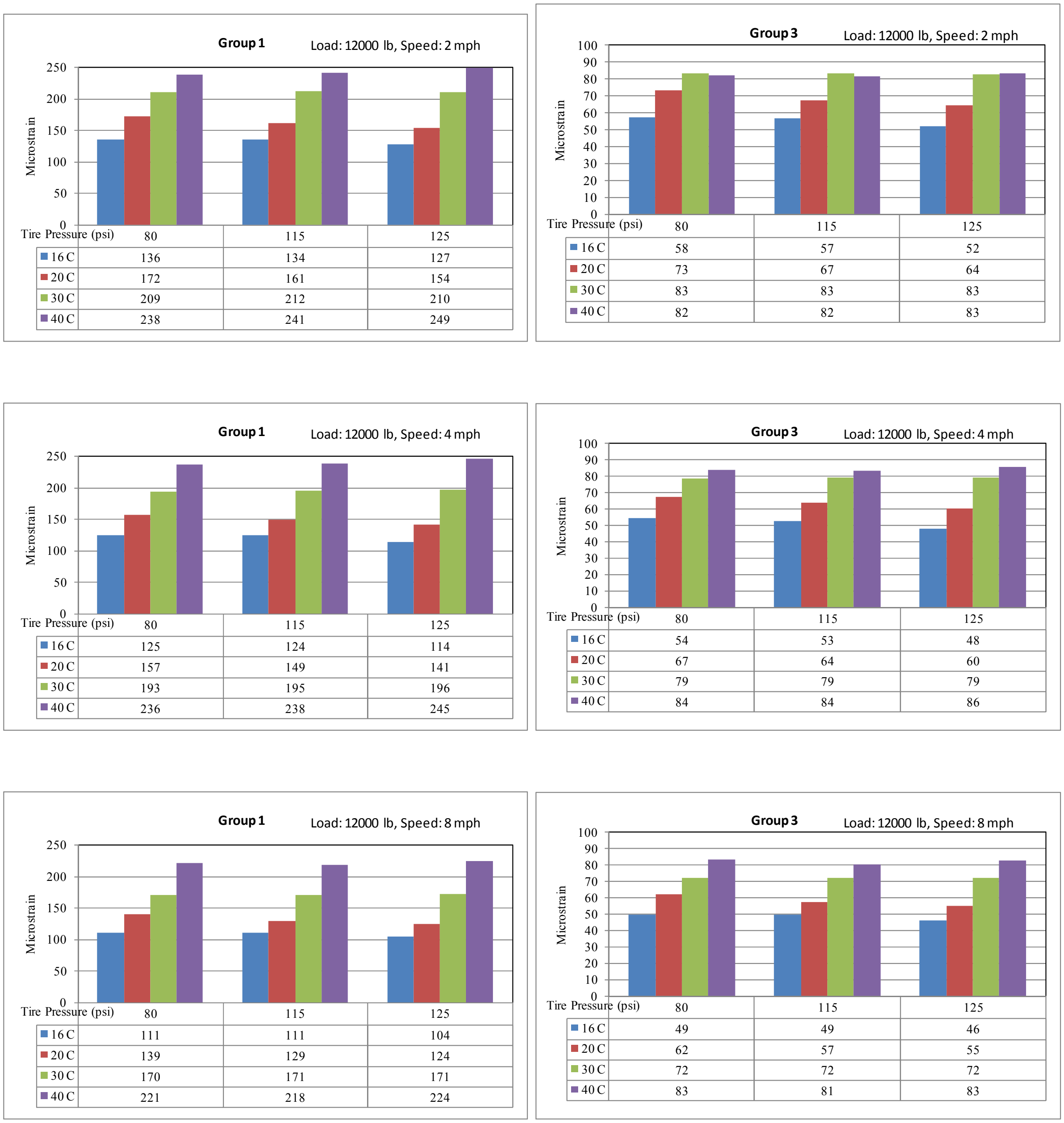


Tire Pressure (psi)	80	115	125
16 C	90	86	82
20 C	104	99	95
30 C	136	140	131
40 C	185	177	185



Tire Pressure (psi)	80	115	125
16 C	39	37	36
20 C	45	43	42
30 C	55	57	53
40 C	65	62	64

Figure 7.1 Group 1 and 3 Strains at a Constant Load of 9,000 lb



Group 1 — Load: 12000 lb, Speed: 2 mph

Tire Pressure (psi)	80	115	125
16 C	136	134	127
20 C	172	161	154
30 C	209	212	210
40 C	238	241	249

Group 3 — Load: 12000 lb, Speed: 2 mph

Tire Pressure (psi)	80	115	125
16 C	58	57	52
20 C	73	67	64
30 C	83	83	83
40 C	82	82	83

Group 1 — Load: 12000 lb, Speed: 4 mph

Tire Pressure (psi)	80	115	125
16 C	125	124	114
20 C	157	149	141
30 C	193	195	196
40 C	236	238	245

Group 3 — Load: 12000 lb, Speed: 4 mph

Tire Pressure (psi)	80	115	125
16 C	54	53	48
20 C	67	64	60
30 C	79	79	79
40 C	84	84	86

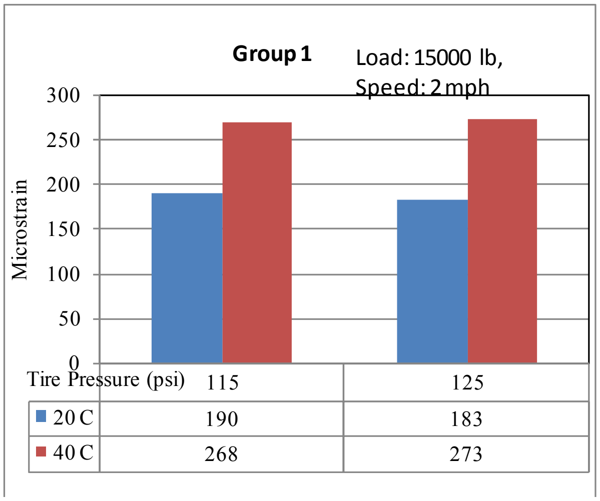
Group 1 — Load: 12000 lb, Speed: 8 mph

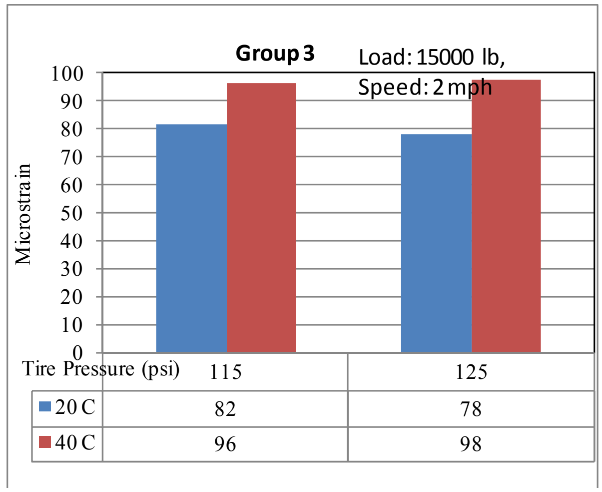
Tire Pressure (psi)	80	115	125
16 C	111	111	104
20 C	139	129	124
30 C	170	171	171
40 C	221	218	224

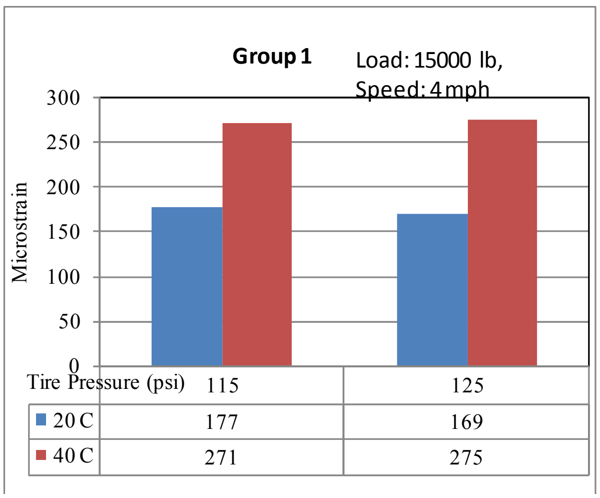
Group 3 — Load: 12000 lb, Speed: 8 mph

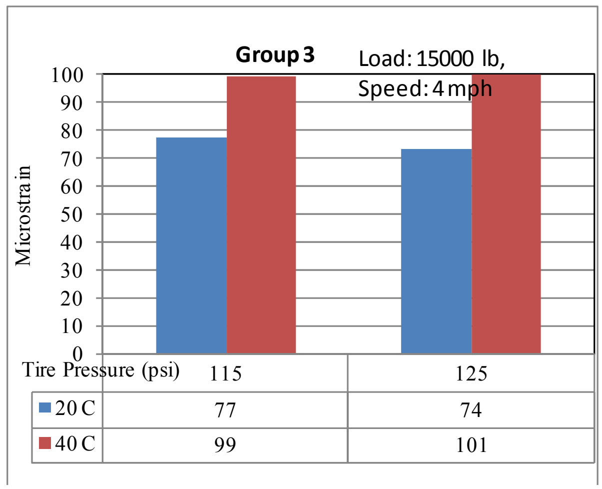
Tire Pressure (psi)	80	115	125
16 C	49	49	46
20 C	62	57	55
30 C	72	72	72
40 C	83	81	83

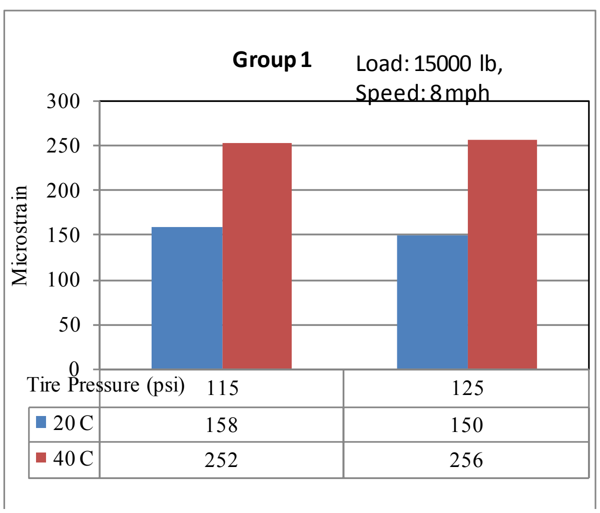
Figure 7.2 Group 1 and 3 Strains at a Constant Load of 12,000 lb











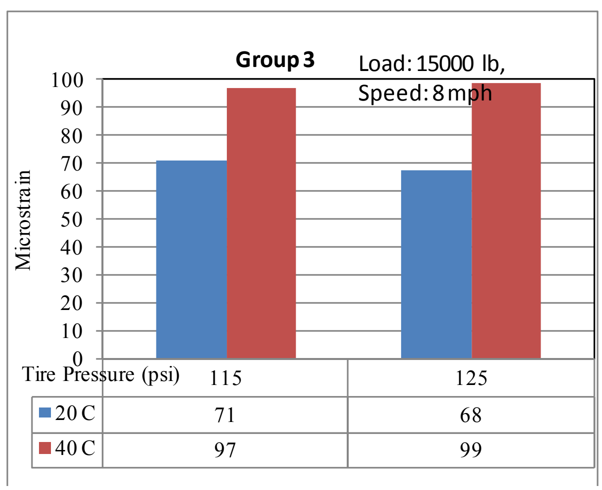
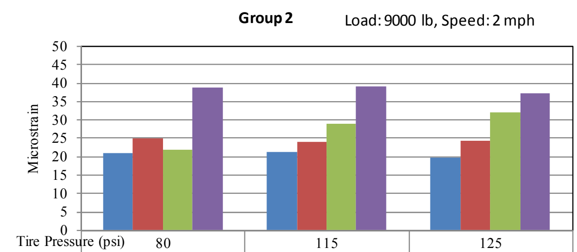
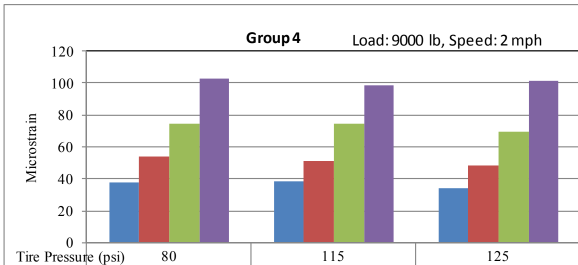


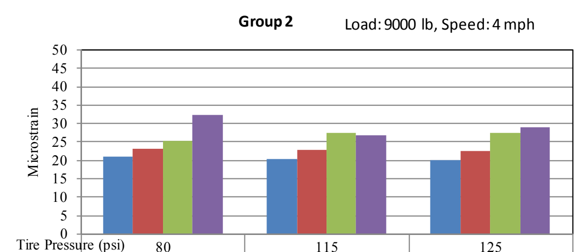
Figure 7.3 Group 1 and 3 Strains at a Constant Load of 15,000 lb



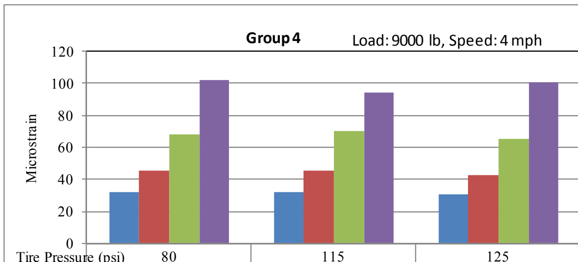
Tire Pressure (psi)	80	115	125
16 C	21	21	20
20 C	25	24	24
30 C	22	29	32
40 C	39	39	37



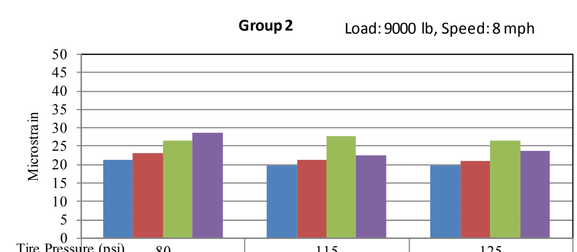
Tire Pressure (psi)	80	115	125
16 C	38	38	34
20 C	54	51	49
30 C	75	74	70
40 C	103	99	102



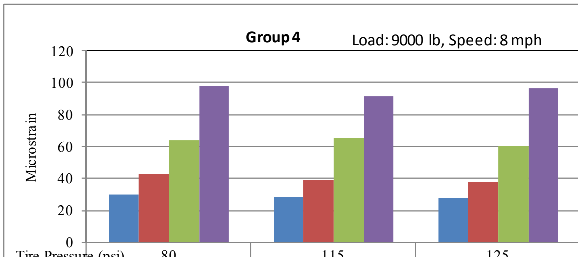
Tire Pressure (psi)	80	115	125
16 C	21	20	20
20 C	23	23	22
30 C	25	27	27
40 C	32	27	29



Tire Pressure (psi)	80	115	125
16 C	32	32	30
20 C	45	45	42
30 C	69	70	65
40 C	102	95	101

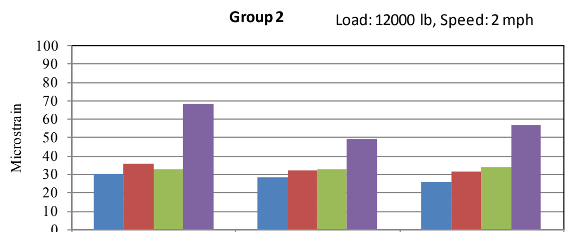


Tire Pressure (psi)	80	115	125
16 C	21	20	20
20 C	23	21	21
30 C	26	27	26
40 C	28	22	24

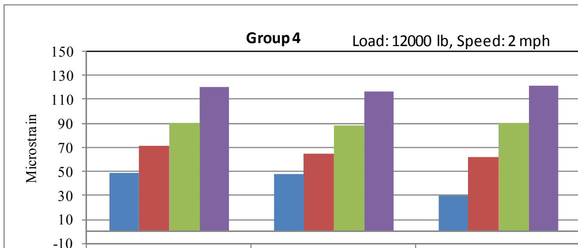


Tire Pressure (psi)	80	115	125
16 C	30	29	28
20 C	43	39	38
30 C	64	65	61
40 C	98	92	97

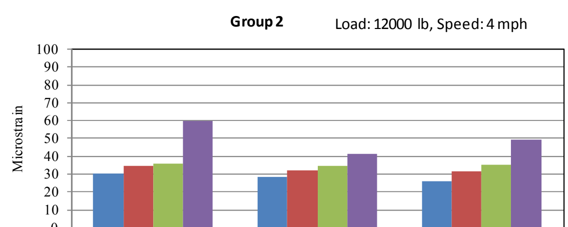
Figure 7.4 Group 2 and 4 Strains at a Constant Load of 9,000 lb



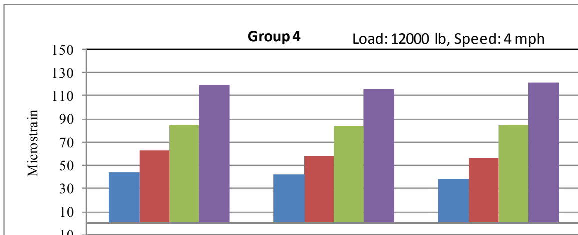
Tire Pressure (psi)	80	115	125
16 C	30	28	26
20 C	36	32	32
30 C	33	32	34
40 C	68	49	56



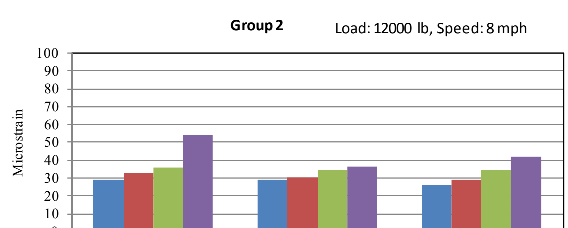
Tire Pressure (psi)	80	115	125
16 C	49	48	30
20 C	71	65	62
30 C	90	89	90
40 C	120	117	122



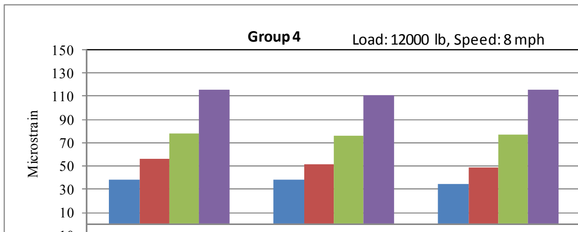
Tire Pressure (psi)	80	115	125
16 C	30	29	26
20 C	34	32	31
30 C	36	34	35
40 C	59	41	49



Tire Pressure (psi)	80	115	125
16 C	44	42	38
20 C	63	58	56
30 C	85	83	85
40 C	120	116	122

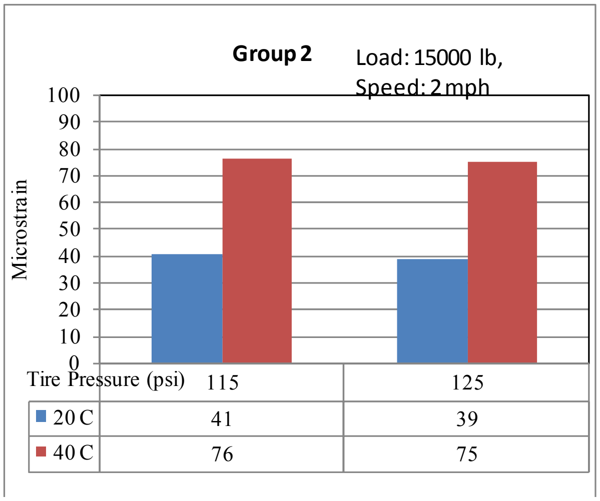


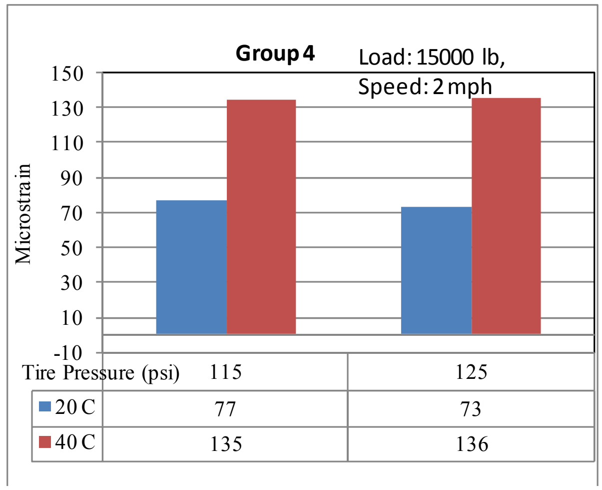
Tire Pressure (psi)	80	115	125
16 C	29	29	26
20 C	32	30	29
30 C	36	34	34
40 C	54	36	42

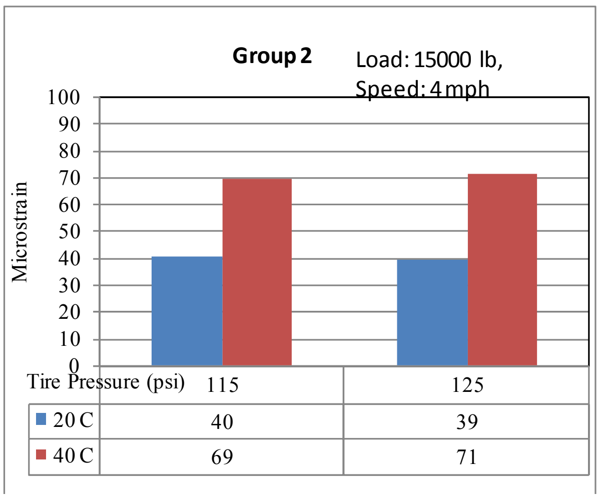


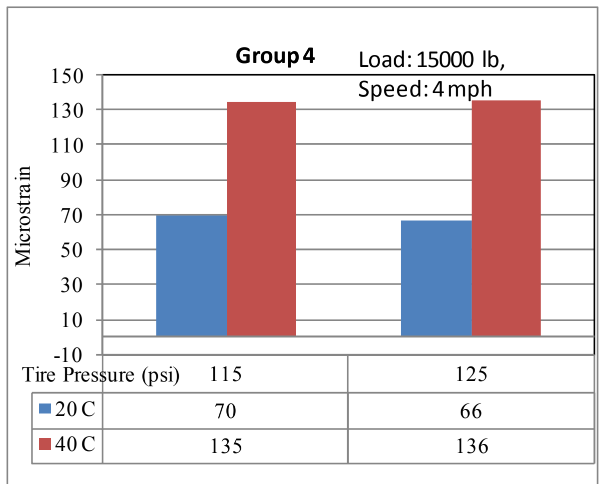
Tire Pressure (psi)	80	115	125
16 C	38	38	35
20 C	57	52	49
30 C	78	76	77
40 C	116	111	116

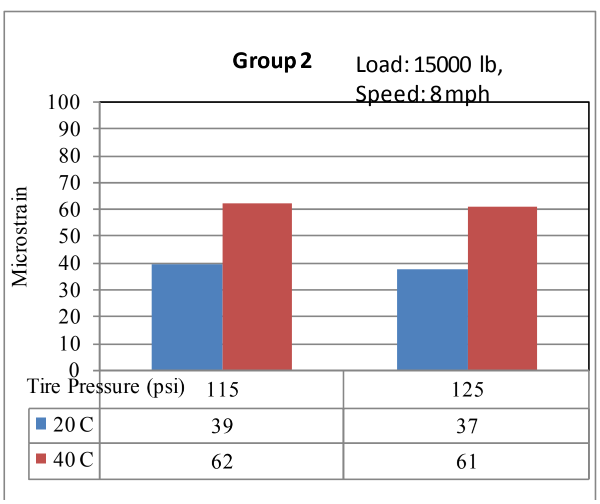
Figure 7.5 Group 2 and 4 Strains at a Constant Load of 12,000 lb











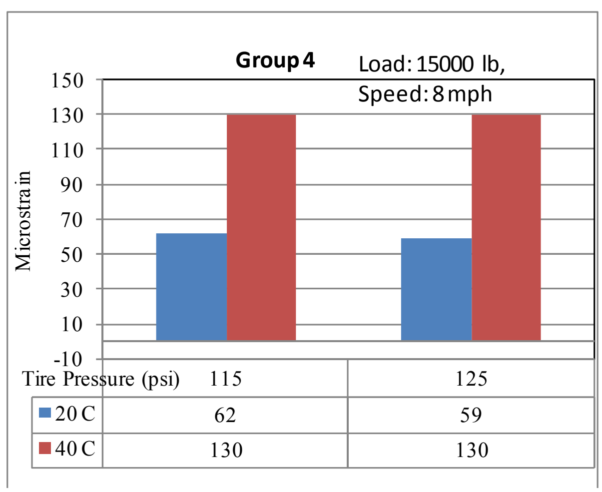
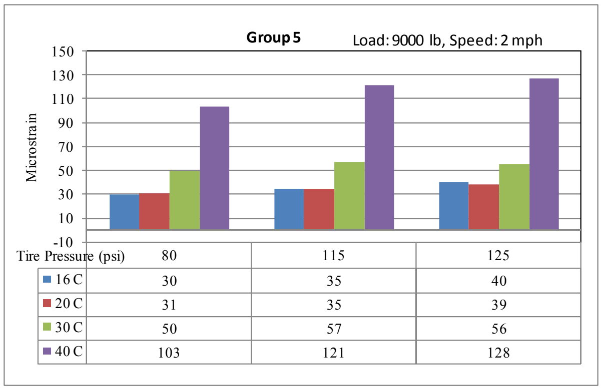
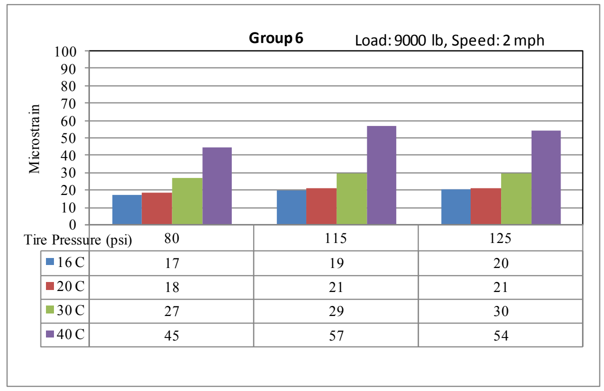


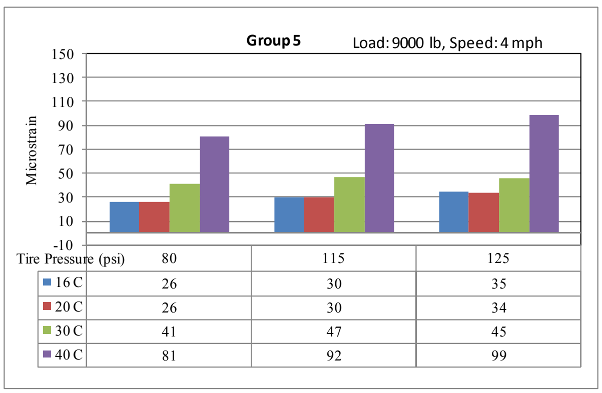
Figure 7.6 Group 2 and 4 Strains at a Constant Load of 15,000 lb



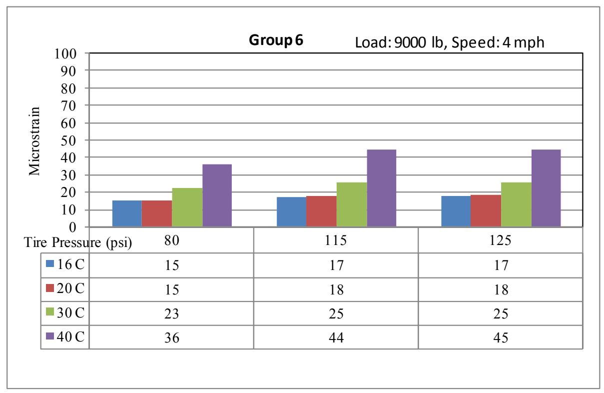
Tire Pressure (psi)	80	115	125
16 C	30	35	40
20 C	31	35	39
30 C	50	57	56
40 C	103	121	128



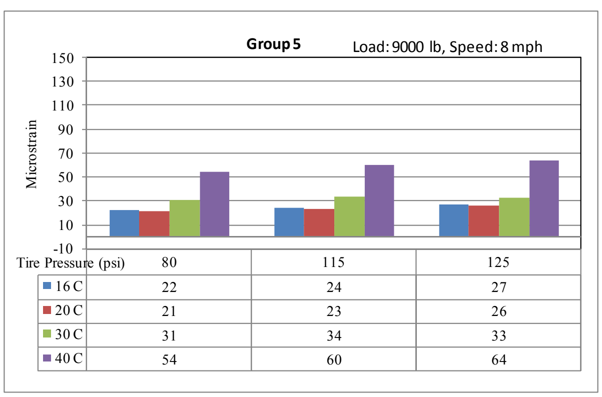
Tire Pressure (psi)	80	115	125
16 C	17	19	20
20 C	18	21	21
30 C	27	29	30
40 C	45	57	54



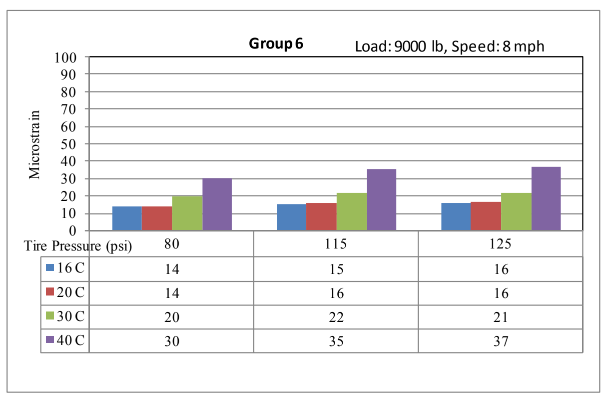
Tire Pressure (psi)	80	115	125
16 C	26	30	35
20 C	26	30	34
30 C	41	47	45
40 C	81	92	99



Tire Pressure (psi)	80	115	125
16 C	15	17	17
20 C	15	18	18
30 C	23	25	25
40 C	36	44	45

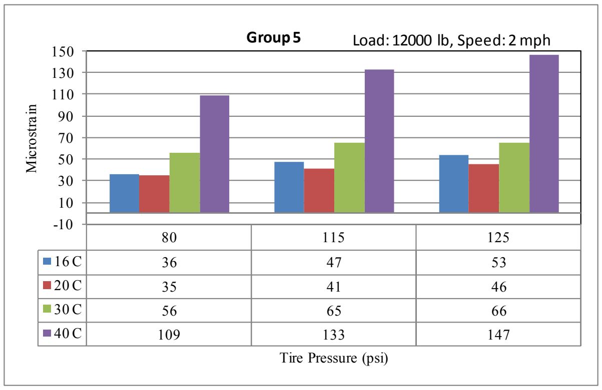


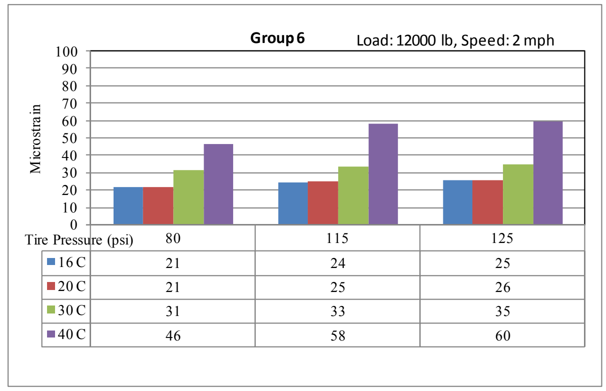
Tire Pressure (psi)	80	115	125
16 C	22	24	27
20 C	21	23	26
30 C	31	34	33
40 C	54	60	64

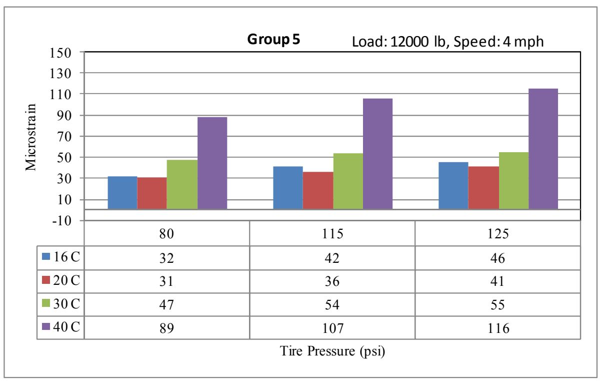


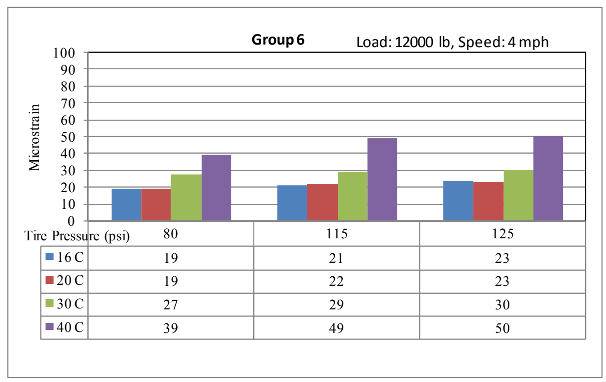
Tire Pressure (psi)	80	115	125
16 C	14	15	16
20 C	14	16	16
30 C	20	22	21
40 C	30	35	37

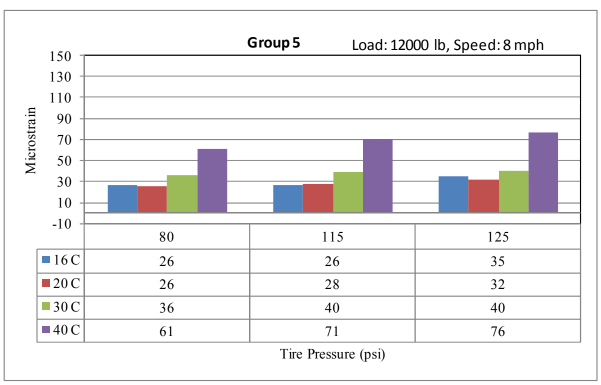
Figure 7.7 Group 5 and 6 Strains at a Constant Load of 9,000 lb











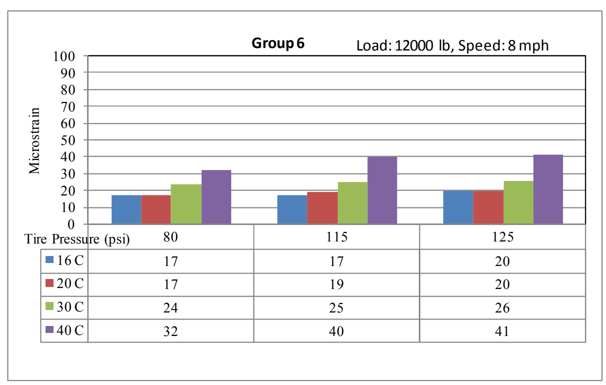
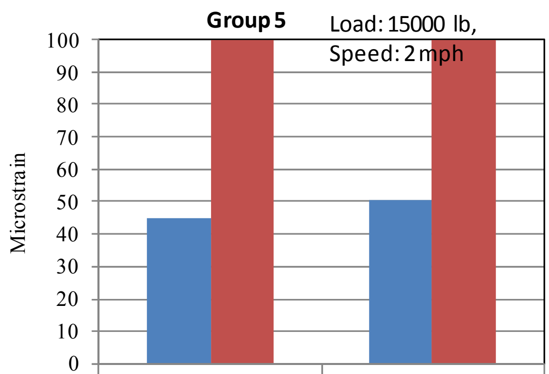
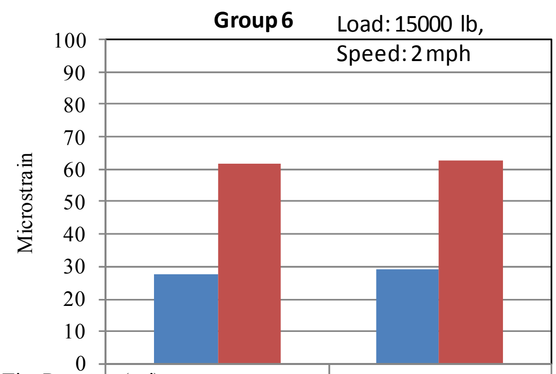


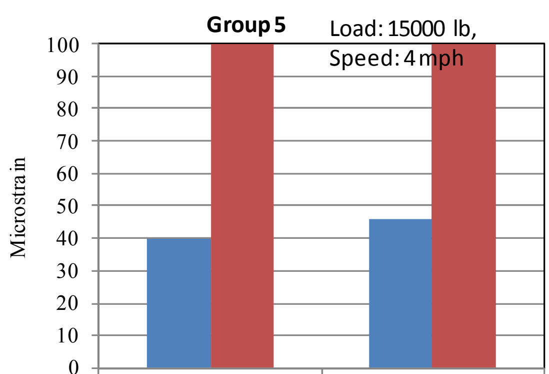
Figure 7.8 Group 2 and 4 Strains at a Constant Load of 12,000 lb



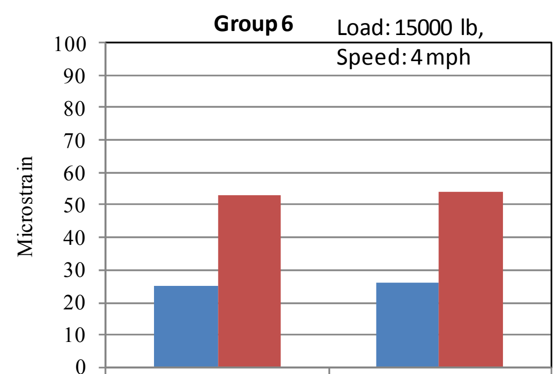
Tire Pressure (psi)	115	125
20 C	45	51
40 C	143	155



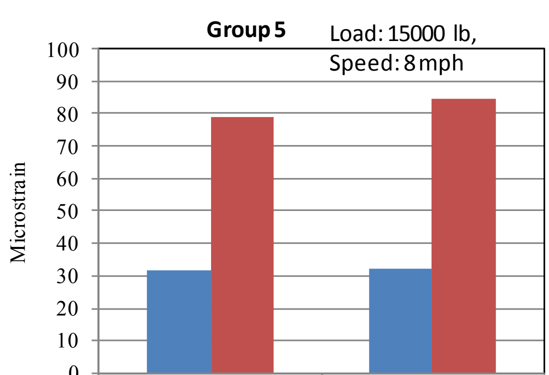
Tire Pressure (psi)	115	125
20 C	28	29
40 C	62	63



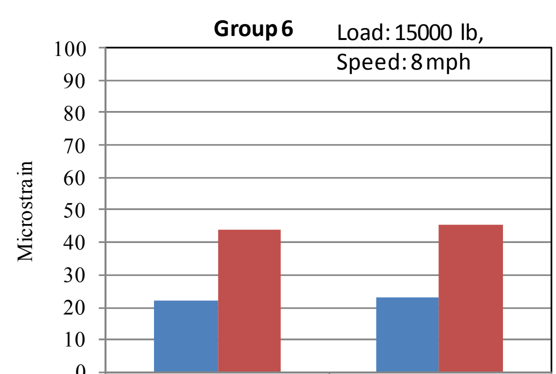
Tire Pressure (psi)	115	125
20 C	40	46
40 C	115	125



Tire Pressure (psi)	115	125
20 C	25	26
40 C	53	54



Tire Pressure (psi)	115	125
20 C	32	32
40 C	79	85



Tire Pressure (psi)	115	125
20 C	22	23
40 C	44	46

Figure 7.9 Group 2 and 4 Strains at a Constant Load of 15,000 lb

7.1.2 Effect of Load

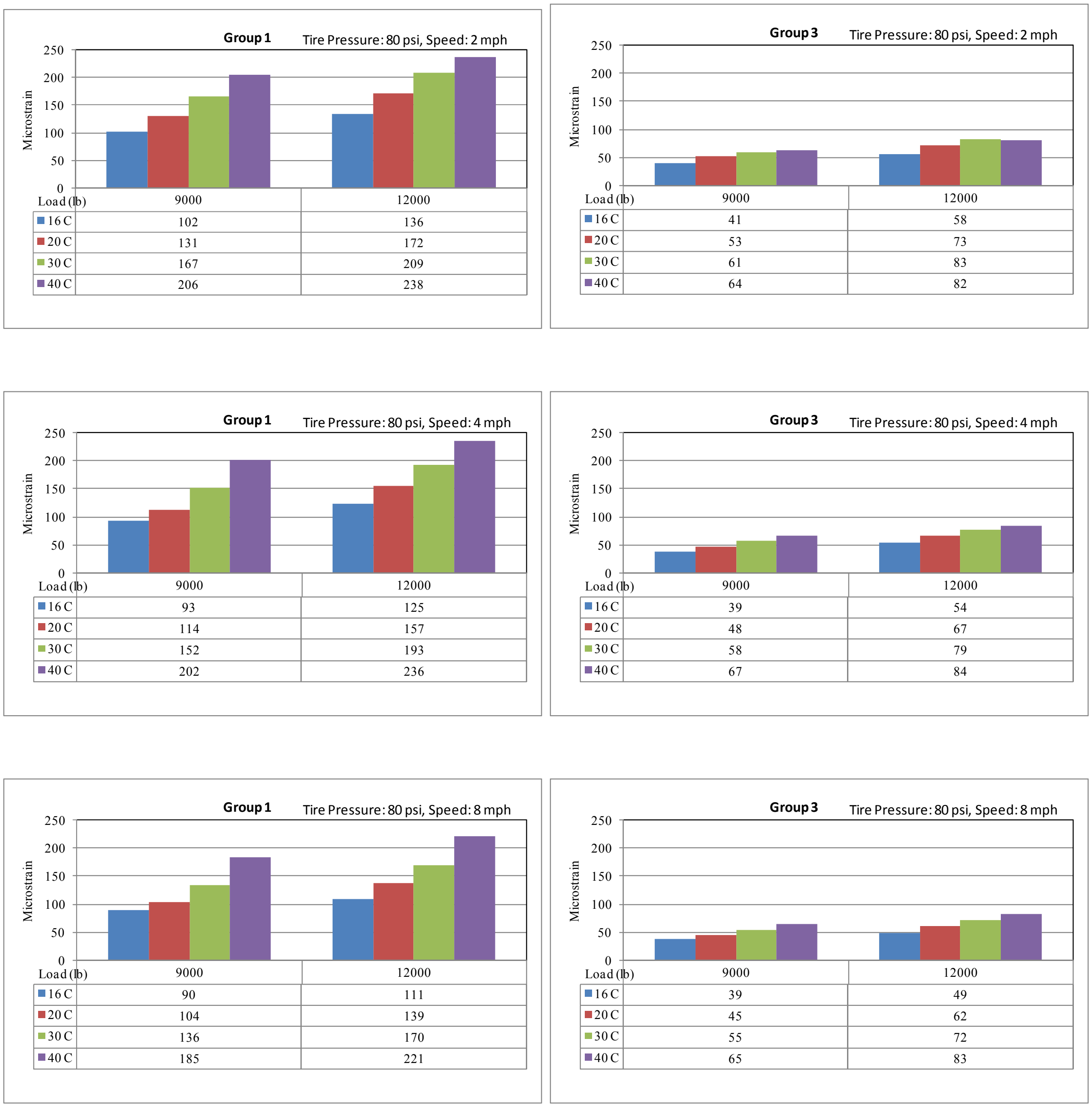
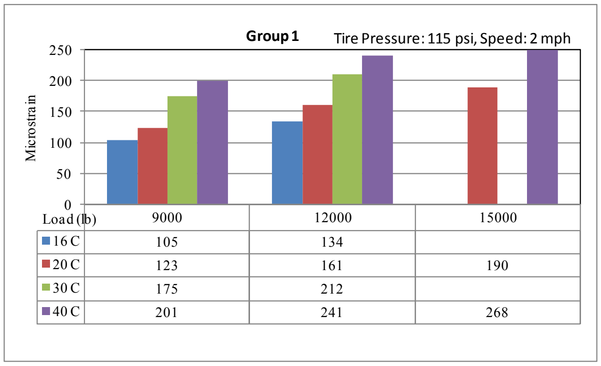
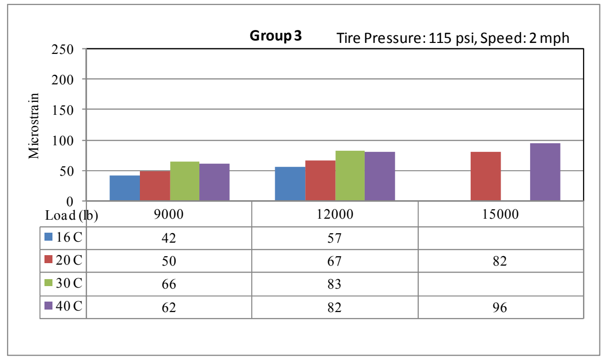


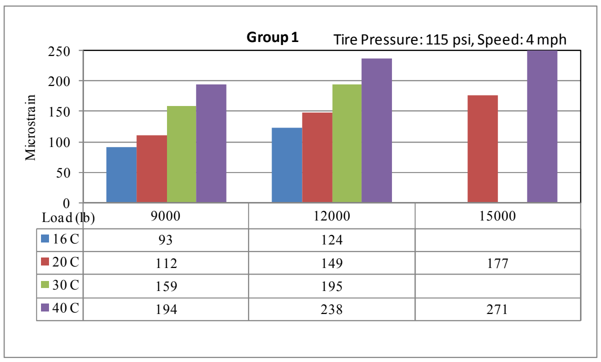
Figure 7.10 Group 1 and 3 Strains at a Constant Tire Pressure of 80 psi.



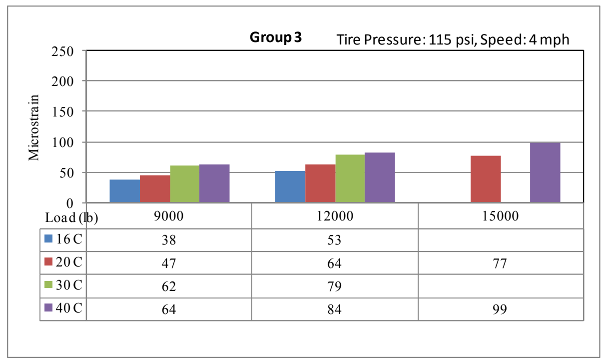
Load (lb)	9000	12000	15000
16 C	105	134	
20 C	123	161	190
30 C	175	212	
40 C	201	241	268



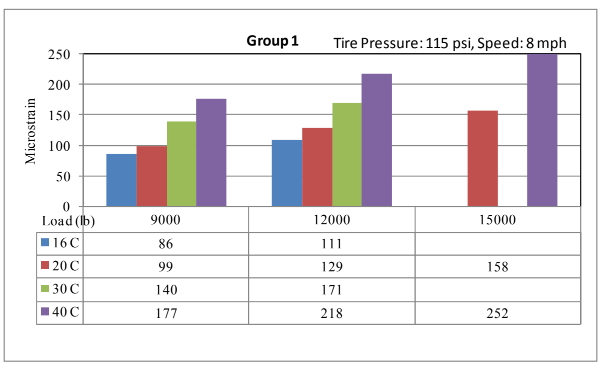
Load (lb)	9000	12000	15000
16 C	42	57	
20 C	50	67	82
30 C	66	83	
40 C	62	82	96



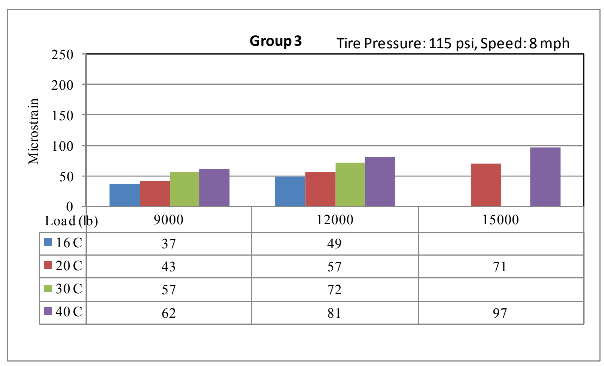
Load (lb)	9000	12000	15000
16 C	93	124	
20 C	112	149	177
30 C	159	195	
40 C	194	238	271



Load (lb)	9000	12000	15000
16 C	38	53	
20 C	47	64	77
30 C	62	79	
40 C	64	84	99

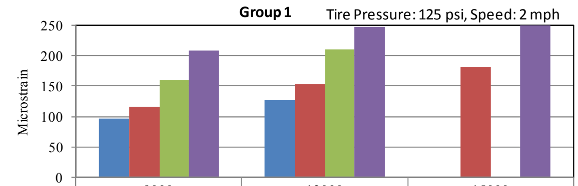


Load (lb)	9000	12000	15000
16 C	86	111	
20 C	99	129	158
30 C	140	171	
40 C	177	218	252

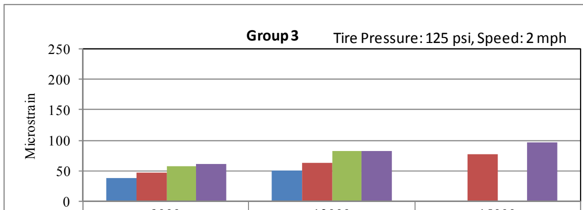


Load (lb)	9000	12000	15000
16 C	37	49	
20 C	43	57	71
30 C	57	72	
40 C	62	81	97

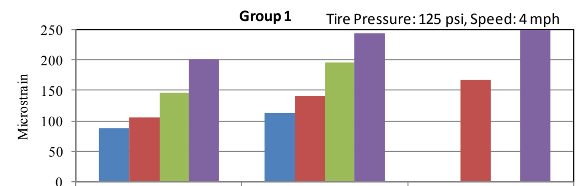
Figure 7.11 Group 1 and 3 Strains at a Constant Tire Pressure of 115 psi.



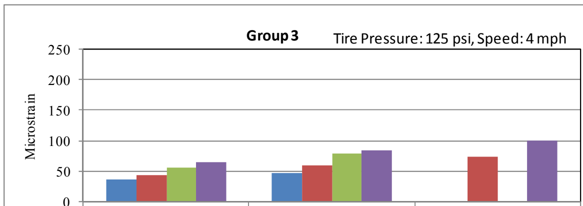
Load (lb)	9000	12000	15000
16 C	97	127	
20 C	116	154	183
30 C	161	210	
40 C	209	249	273



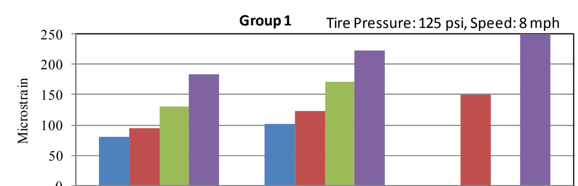
Load (lb)	9000	12000	15000
16 C	40	52	
20 C	47	64	78
30 C	59	83	
40 C	63	83	98



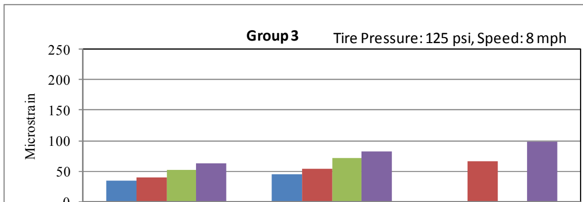
Load (lb)	9000	12000	15000
16 C	89	114	
20 C	106	141	169
30 C	147	196	
40 C	203	245	275



Load (lb)	9000	12000	15000
16 C	38	48	
20 C	44	60	74
30 C	56	79	
40 C	65	86	101

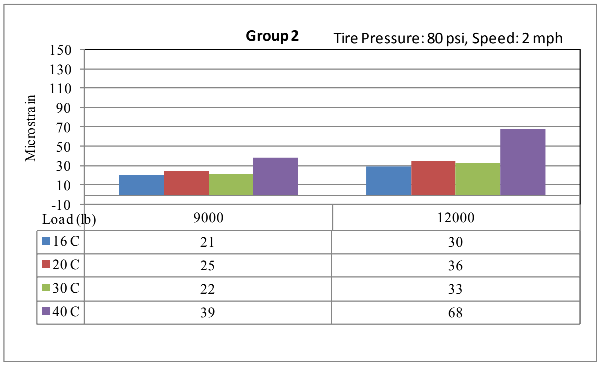


Load (lb)	9000	12000	15000
16 C	82	104	
20 C	95	124	150
30 C	131	171	
40 C	185	224	256

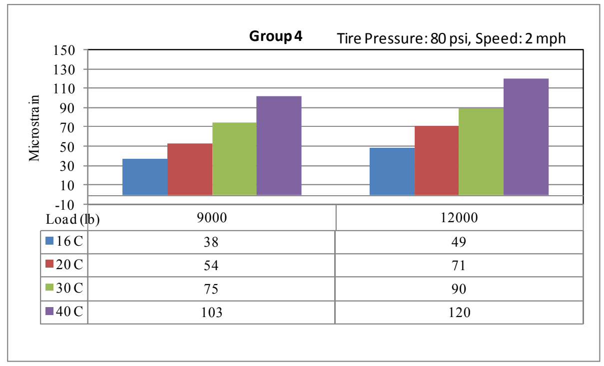


Load (lb)	9000	12000	15000
16 C	36	46	
20 C	42	55	68
30 C	53	72	
40 C	64	83	99

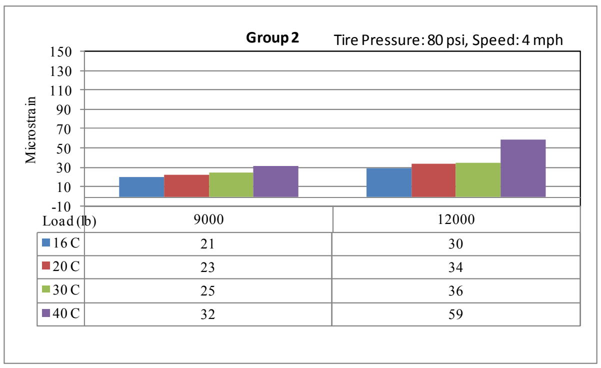
Figure 7.12 Group 1 and 3 Strains at a Constant Tire Pressure of 125 psi.



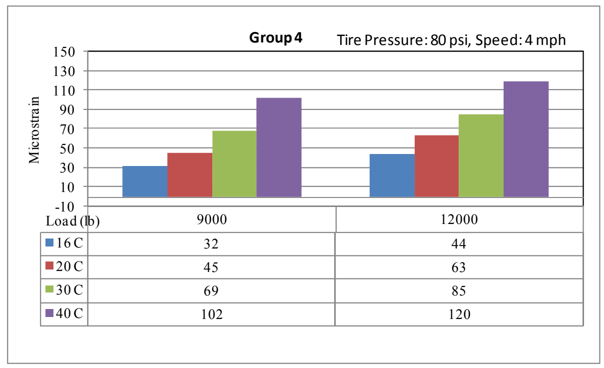
Load (lb)	9000	12000
16 C	21	30
20 C	25	36
30 C	22	33
40 C	39	68



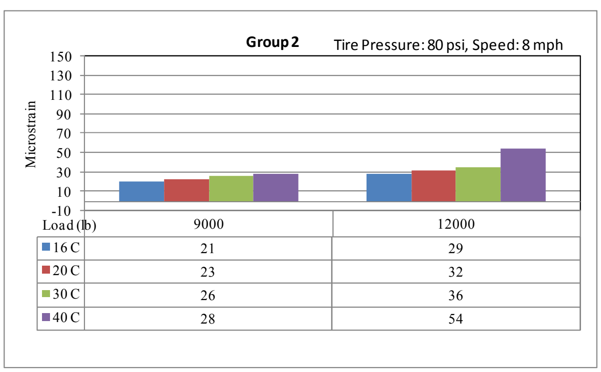
Load (lb)	9000	12000
16 C	38	49
20 C	54	71
30 C	75	90
40 C	103	120



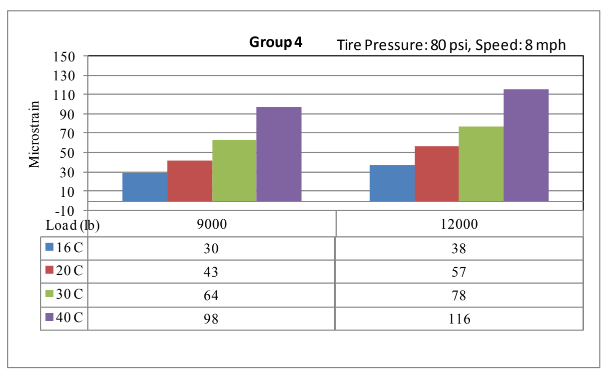
Load (lb)	9000	12000
16 C	21	30
20 C	23	34
30 C	25	36
40 C	32	59



Load (lb)	9000	12000
16 C	32	44
20 C	45	63
30 C	69	85
40 C	102	120

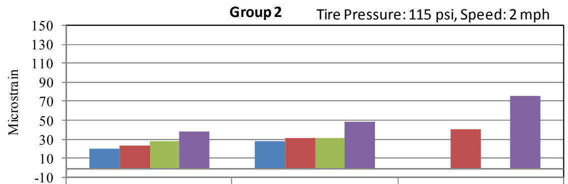


Load (lb)	9000	12000
16 C	21	29
20 C	23	32
30 C	26	36
40 C	28	54

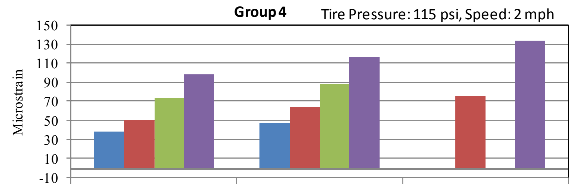


Load (lb)	9000	12000
16 C	30	38
20 C	43	57
30 C	64	78
40 C	98	116

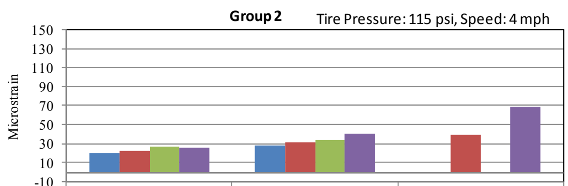
Figure 7.13 Group 2 and 4 Strains at a Constant Tire Pressure of 80 psi.



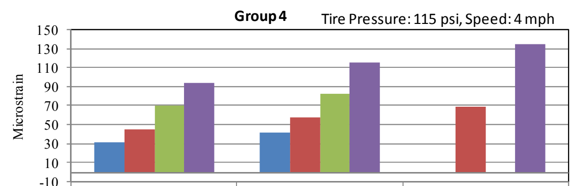
Load (lb)	9000	12000	15000
16 C	21	28	
20 C	24	32	41
30 C	29	32	
40 C	39	49	76



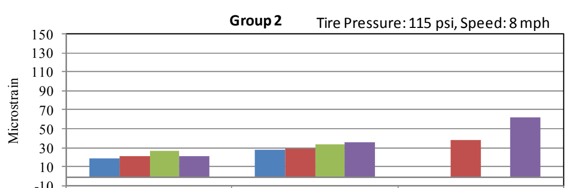
Load (lb)	9000	12000	15000
16 C	38	48	
20 C	51	65	77
30 C	74	89	
40 C	99	117	135



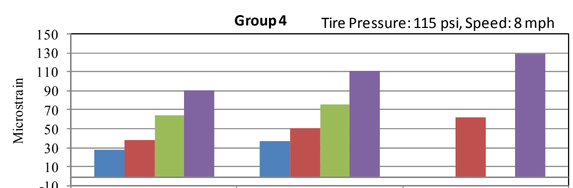
Load (lb)	9000	12000	15000
16 C	20	29	
20 C	23	32	40
30 C	27	34	
40 C	27	41	69



Load (lb)	9000	12000	15000
16 C	32	42	
20 C	45	58	70
30 C	70	83	
40 C	95	116	135

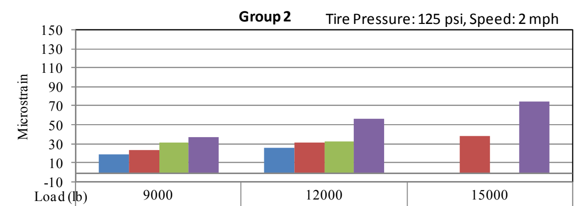


Load (lb)	9000	12000	15000
16 C	20	29	
20 C	21	30	39
30 C	27	34	
40 C	22	36	62

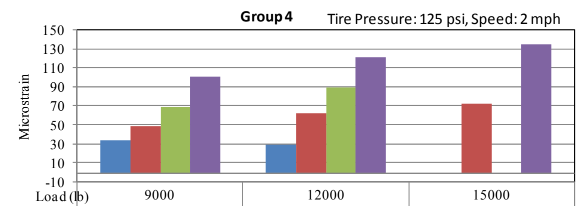


Load (lb)	9000	12000	15000
16 C	29	38	
20 C	39	52	62
30 C	65	76	
40 C	92	111	130

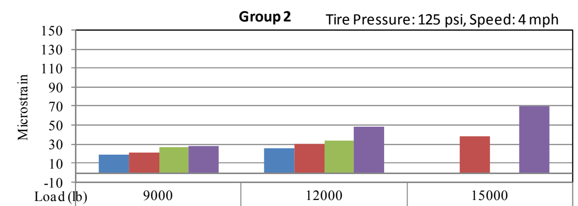
Figure 7.14 Group 2 and 4 Strains at a Constant Tire Pressure of 115 psi.



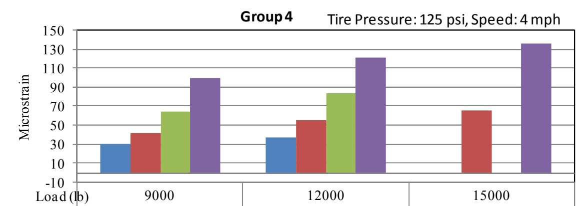
Load (lb)	9000	12000	15000
16 C	20	26	
20 C	24	32	39
30 C	32	34	
40 C	37	56	75



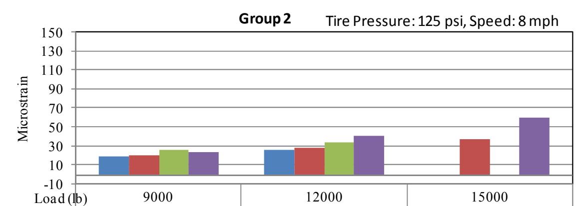
Load (lb)	9000	12000	15000
16 C	34	30	
20 C	49	62	73
30 C	70	90	
40 C	102	122	136



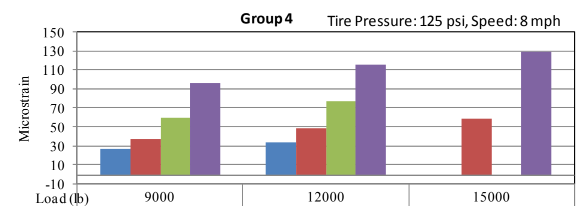
Load (lb)	9000	12000	15000
16 C	20	26	
20 C	22	31	39
30 C	27	35	
40 C	29	49	71



Load (lb)	9000	12000	15000
16 C	30	38	
20 C	42	56	66
30 C	65	85	
40 C	101	122	136

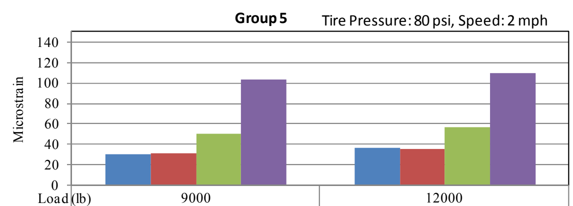


Load (lb)	9000	12000	15000
16 C	20	26	
20 C	21	29	37
30 C	26	34	
40 C	24	42	61

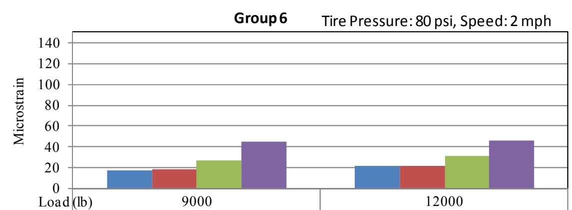


Load (lb)	9000	12000	15000
16 C	28	35	
20 C	38	49	59
30 C	61	77	
40 C	97	116	130

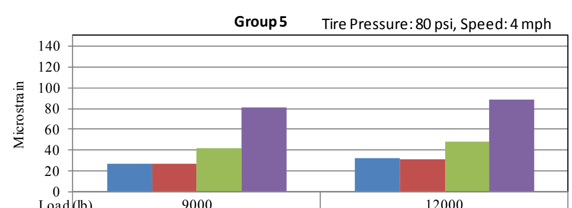
Figure 7.15 Group 2 and 4 Strains at a Constant Tire Pressure of 125 psi.



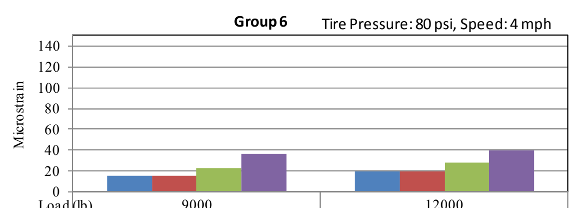
Load (lb)	9000	12000
16 C	30	36
20 C	31	35
30 C	50	56
40 C	103	109



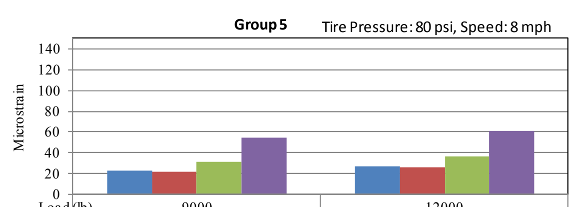
Load (lb)	9000	12000
16 C	17	21
20 C	18	21
30 C	27	31
40 C	45	46



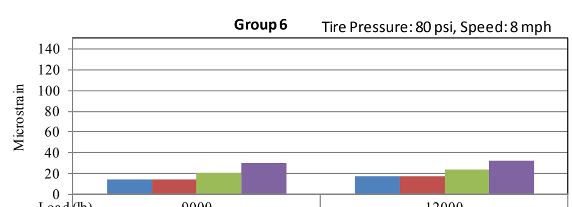
Load (lb)	9000	12000
16 C	26	32
20 C	26	31
30 C	41	47
40 C	81	89



Load (lb)	9000	12000
16 C	15	19
20 C	15	19
30 C	23	27
40 C	36	39

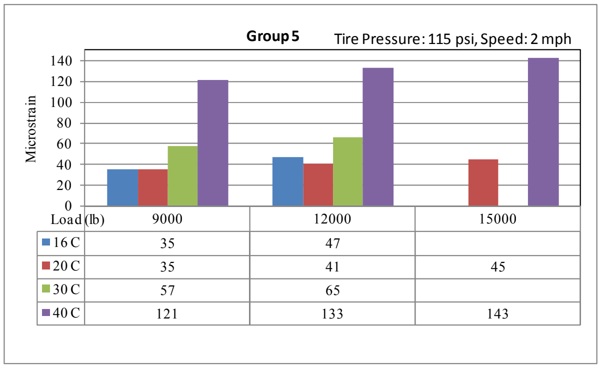


Load (lb)	9000	12000
16 C	22	26
20 C	21	26
30 C	31	36
40 C	54	61

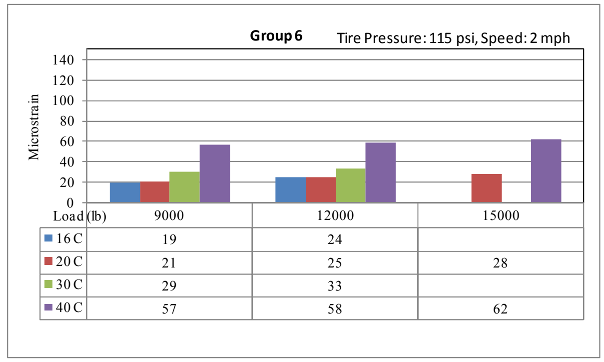


Load (lb)	9000	12000
16 C	14	17
20 C	14	17
30 C	20	24
40 C	30	32

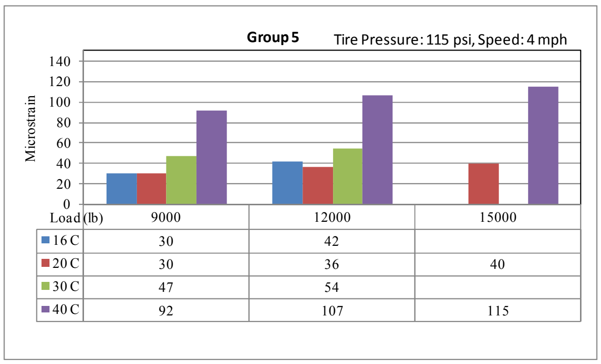
Figure 7.16 Group 5 and 6 Strains at a Constant Tire Pressure of 80 psi.



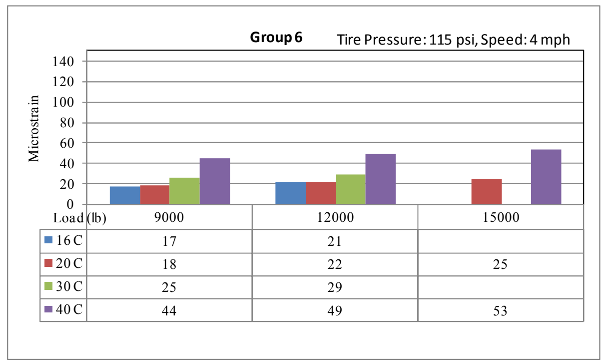
Load (lb)	9000	12000	15000
16 C	35	47	
20 C	35	41	45
30 C	57	65	
40 C	121	133	143



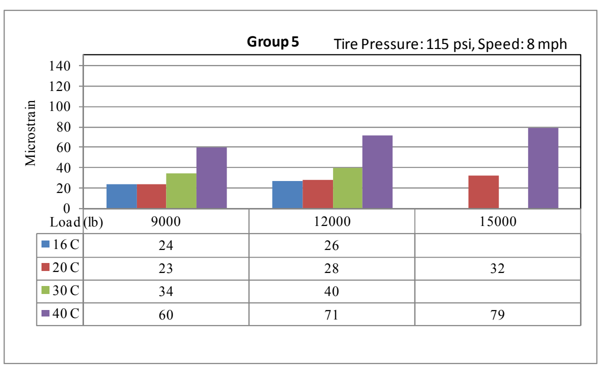
Load (lb)	9000	12000	15000
16 C	19	24	
20 C	21	25	28
30 C	29	33	
40 C	57	58	62



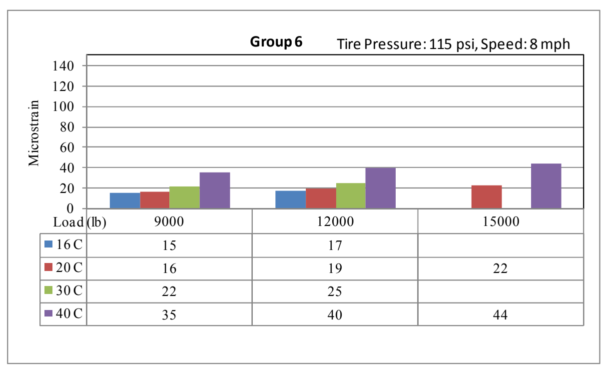
Load (lb)	9000	12000	15000
16 C	30	42	
20 C	30	36	40
30 C	47	54	
40 C	92	107	115



Load (lb)	9000	12000	15000
16 C	17	21	
20 C	18	22	25
30 C	25	29	
40 C	44	49	53

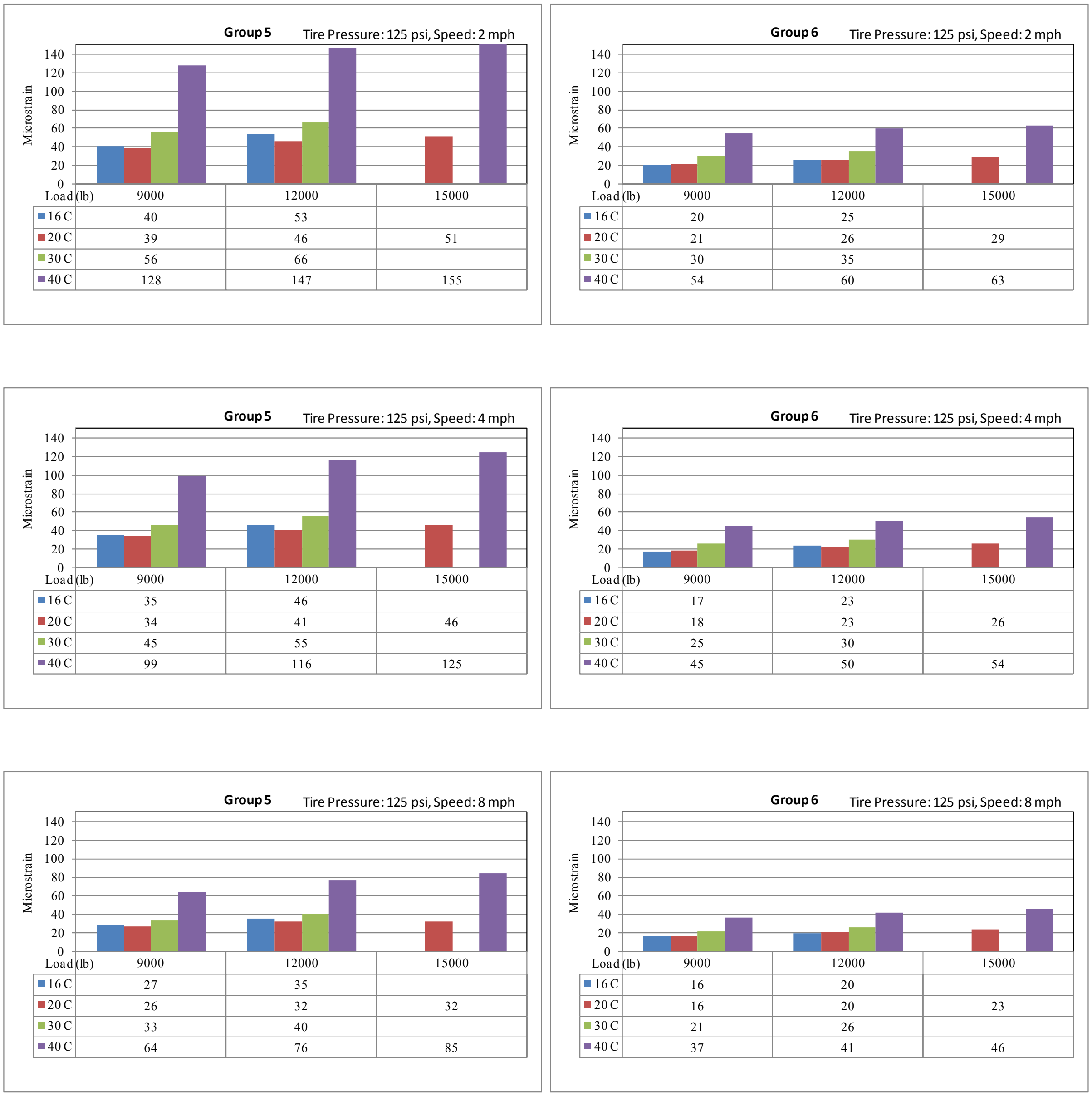


Load (lb)	9000	12000	15000
16 C	24	26	
20 C	23	28	32
30 C	34	40	
40 C	60	71	79



Load (lb)	9000	12000	15000
16 C	15	17	
20 C	16	19	22
30 C	22	25	
40 C	35	40	44

Figure 7.17 Group 5 and 6 Strains at a Constant Tire Pressure of 115 psi.



Group 5 — Tire Pressure: 125 psi, Speed: 2 mph

Load (lb)	9000	12000	15000
16 C	40	53	
20 C	39	46	51
30 C	56	66	
40 C	128	147	155

Group 6 — Tire Pressure: 125 psi, Speed: 2 mph

Load (lb)	9000	12000	15000
16 C	20	25	
20 C	21	26	29
30 C	30	35	
40 C	54	60	63

Group 5 — Tire Pressure: 125 psi, Speed: 4 mph

Load (lb)	9000	12000	15000
16 C	35	46	
20 C	34	41	46
30 C	45	55	
40 C	99	116	125

Group 6 — Tire Pressure: 125 psi, Speed: 4 mph

Load (lb)	9000	12000	15000
16 C	17	23	
20 C	18	23	26
30 C	25	30	
40 C	45	50	54

Group 5 — Tire Pressure: 125 psi, Speed: 8 mph

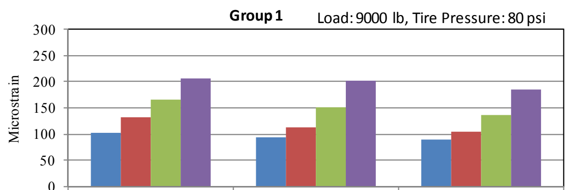
Load (lb)	9000	12000	15000
16 C	27	35	
20 C	26	32	32
30 C	33	40	
40 C	64	76	85

Group 6 — Tire Pressure: 125 psi, Speed: 8 mph

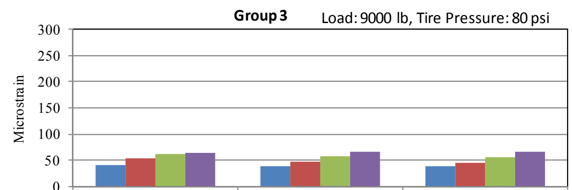
Load (lb)	9000	12000	15000
16 C	16	20	
20 C	16	20	23
30 C	21	26	
40 C	37	41	46

Figure 7.18 Group 5 and 6 Strains at a Constant Tire Pressure of 125 psi.

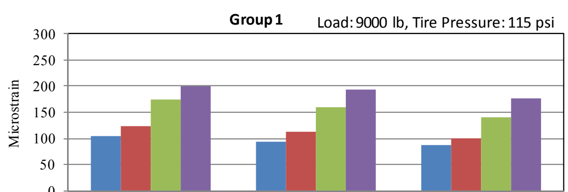
7.1.3 Effect of Tire Speed



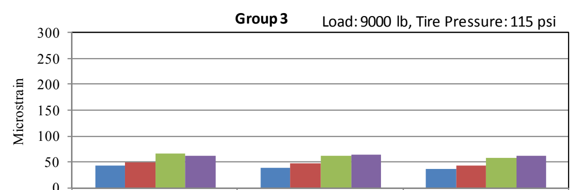
Speed (mph)	2	4	8
16 C	102	93	90
20 C	131	114	104
30 C	167	152	136
40 C	206	202	185



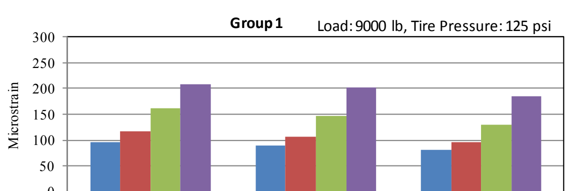
Speed (mph)	2	4	8
16 C	41	39	39
20 C	53	48	45
30 C	61	58	55
40 C	64	67	65



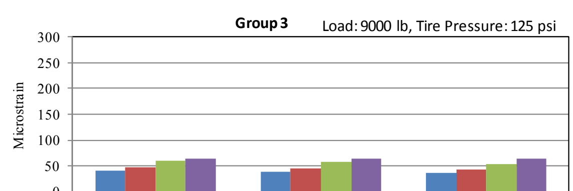
Speed (mph)	2	4	8
16 C	105	93	86
20 C	123	112	99
30 C	175	159	140
40 C	201	194	177



Speed (mph)	2	4	8
16 C	42	38	37
20 C	50	47	43
30 C	66	62	57
40 C	62	64	62

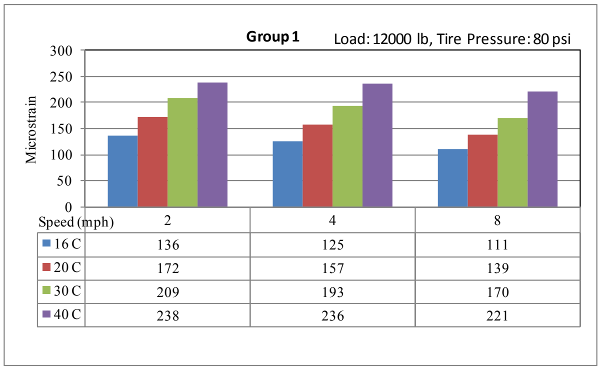


Speed (mph)	2	4	8
16 C	97	89	82
20 C	116	106	95
30 C	161	147	131
40 C	209	203	185

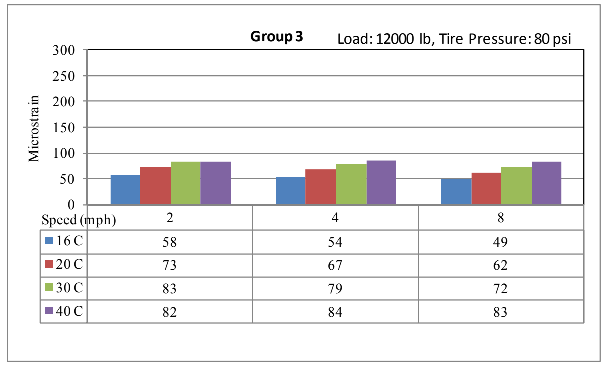


Speed (mph)	2	4	8
16 C	40	38	36
20 C	47	44	42
30 C	59	56	53
40 C	63	65	64

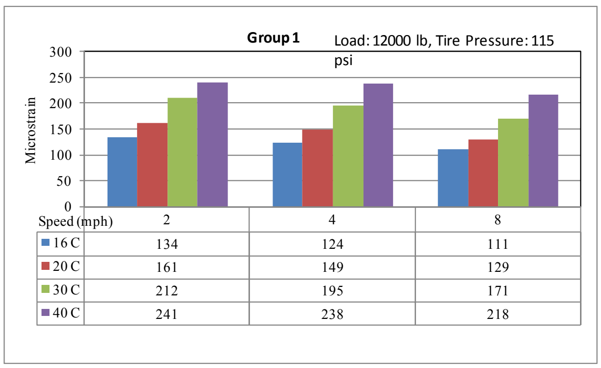
Figure 7.19 Group 1 and 3 Strains at a Constant Load of 9,000 lb.



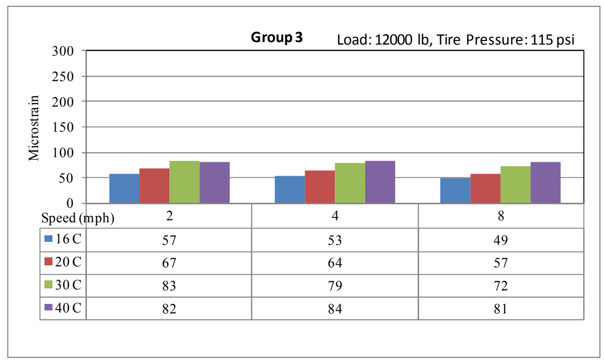
Speed (mph)	2	4	8
16 C	136	125	111
20 C	172	157	139
30 C	209	193	170
40 C	238	236	221



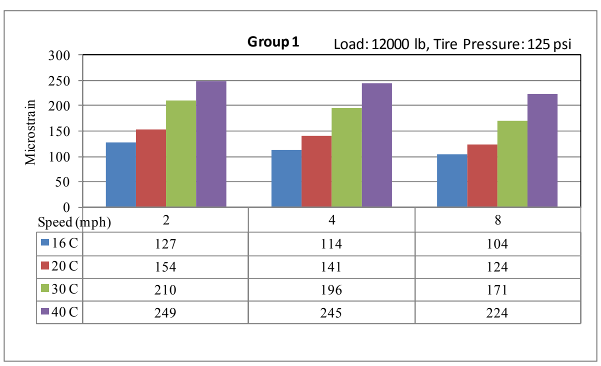
Speed (mph)	2	4	8
16 C	58	54	49
20 C	73	67	62
30 C	83	79	72
40 C	82	84	83



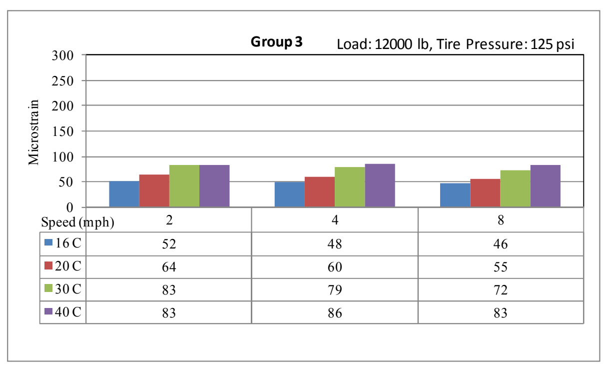
Speed (mph)	2	4	8
16 C	134	124	111
20 C	161	149	129
30 C	212	195	171
40 C	241	238	218



Speed (mph)	2	4	8
16 C	57	53	49
20 C	67	64	57
30 C	83	79	72
40 C	82	84	81



Speed (mph)	2	4	8
16 C	127	114	104
20 C	154	141	124
30 C	210	196	171
40 C	249	245	224



Speed (mph)	2	4	8
16 C	52	48	46
20 C	64	60	55
30 C	83	79	72
40 C	83	86	83

Figure 7.20 Group 1 and 3 Strains at a Constant Load of 12,000 lb.

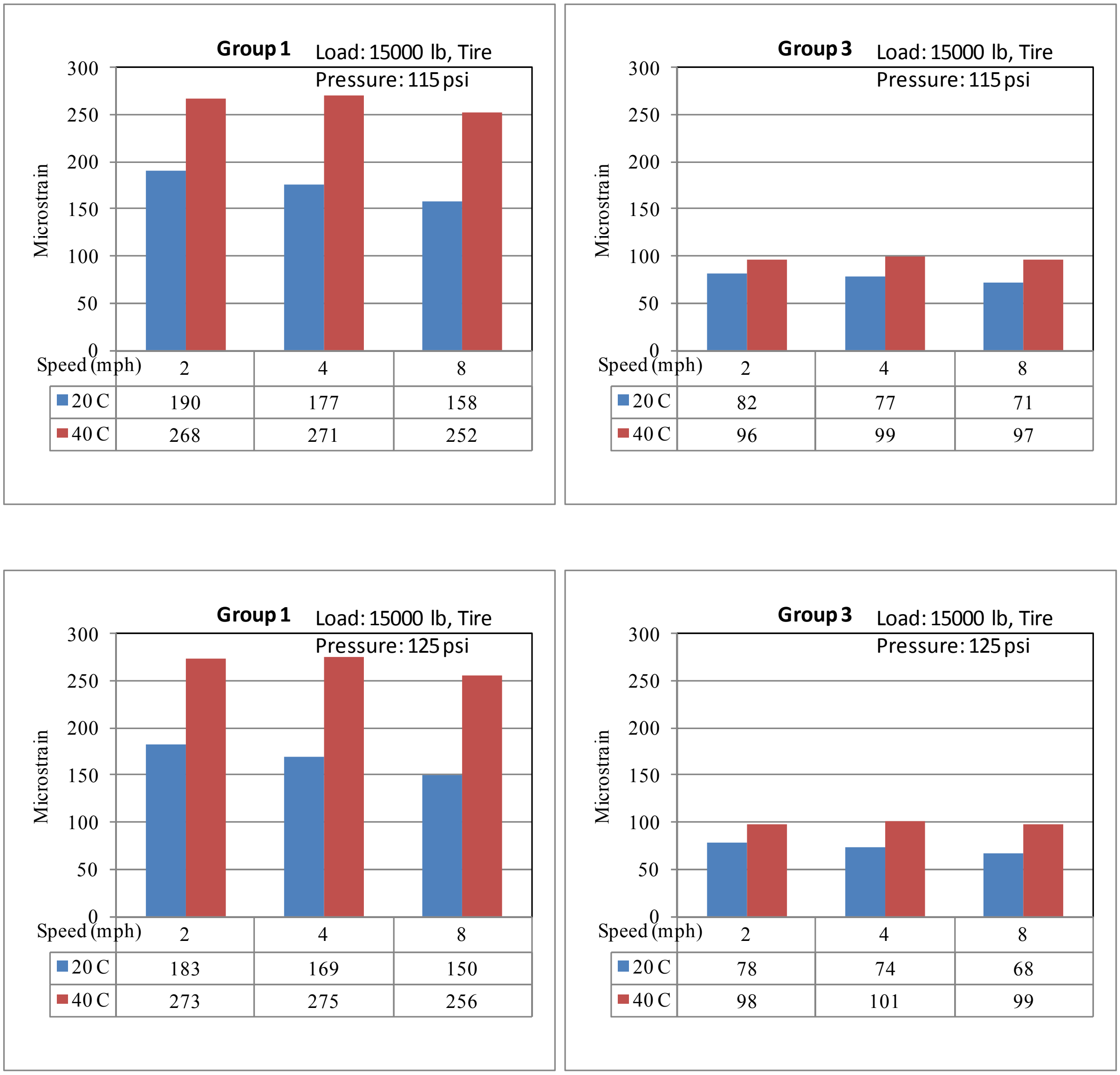


Figure 7.21 Group 1 and 3 Strains at a Constant Load of 15,000 lb.

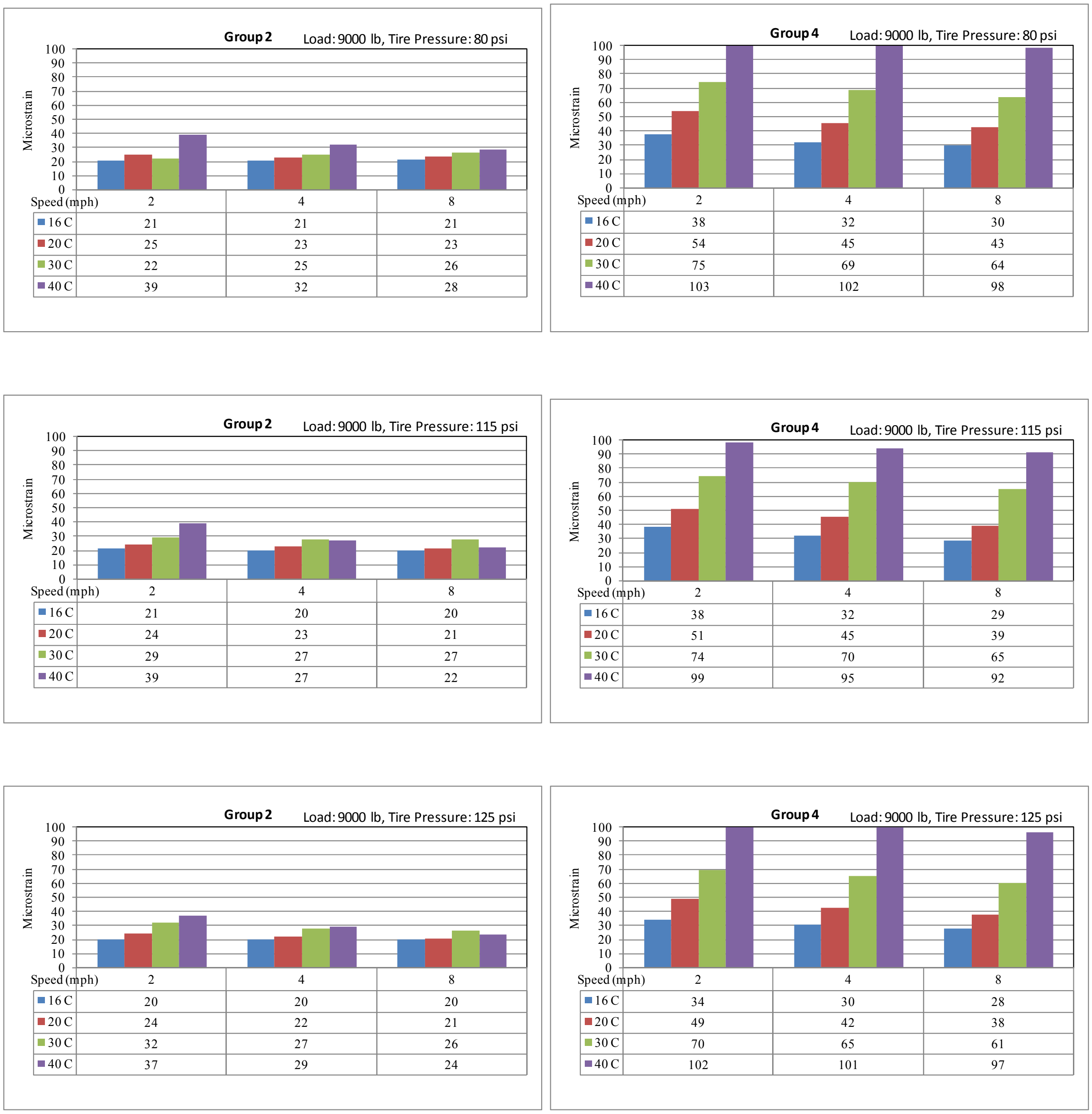
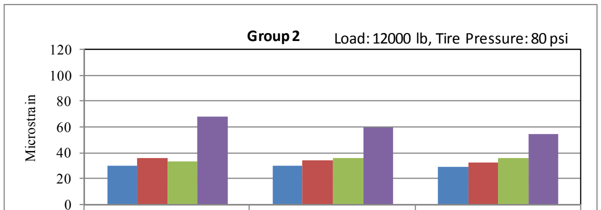
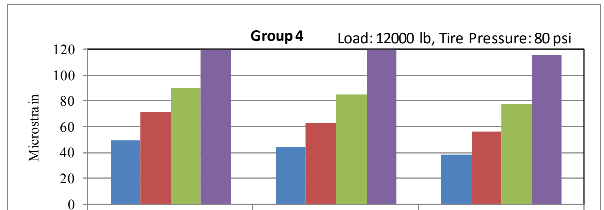


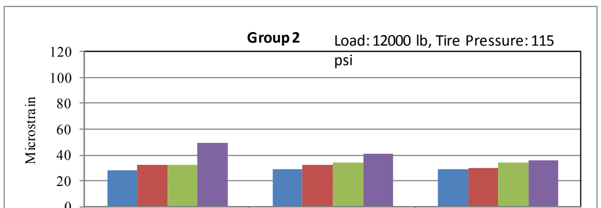
Figure 7.22 Group 2 and 4 Strains at a Constant Load of 9,000 lb.



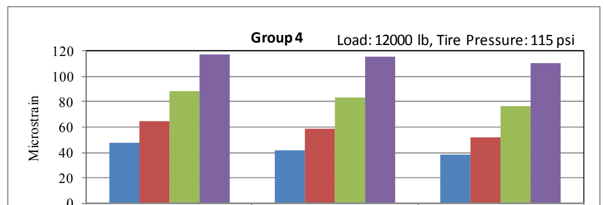
Speed (mph)	2	4	8
16 C	30	30	29
20 C	36	34	32
30 C	33	36	36
40 C	68	59	54



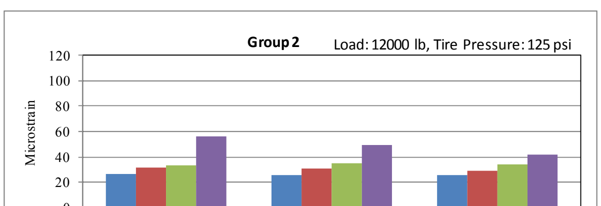
Speed (mph)	2	4	8
16 C	49	44	38
20 C	71	63	57
30 C	90	85	78
40 C	120	120	116



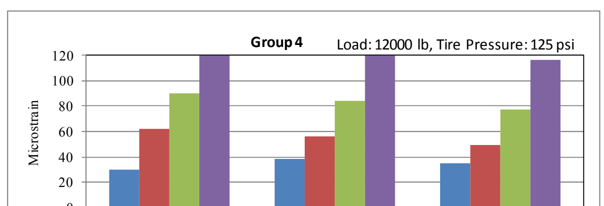
Speed (mph)	2	4	8
16 C	28	29	29
20 C	32	32	30
30 C	32	34	34
40 C	49	41	36



Speed (mph)	2	4	8
16 C	48	42	38
20 C	65	58	52
30 C	89	83	76
40 C	117	116	111



Speed (mph)	2	4	8
16 C	26	26	26
20 C	32	31	29
30 C	34	35	34
40 C	56	49	42



Speed (mph)	2	4	8
16 C	30	38	35
20 C	62	56	49
30 C	90	85	77
40 C	122	122	116

Figure 7.23 Group 2 and 4 Strains at a Constant Load of 12,000 lb.

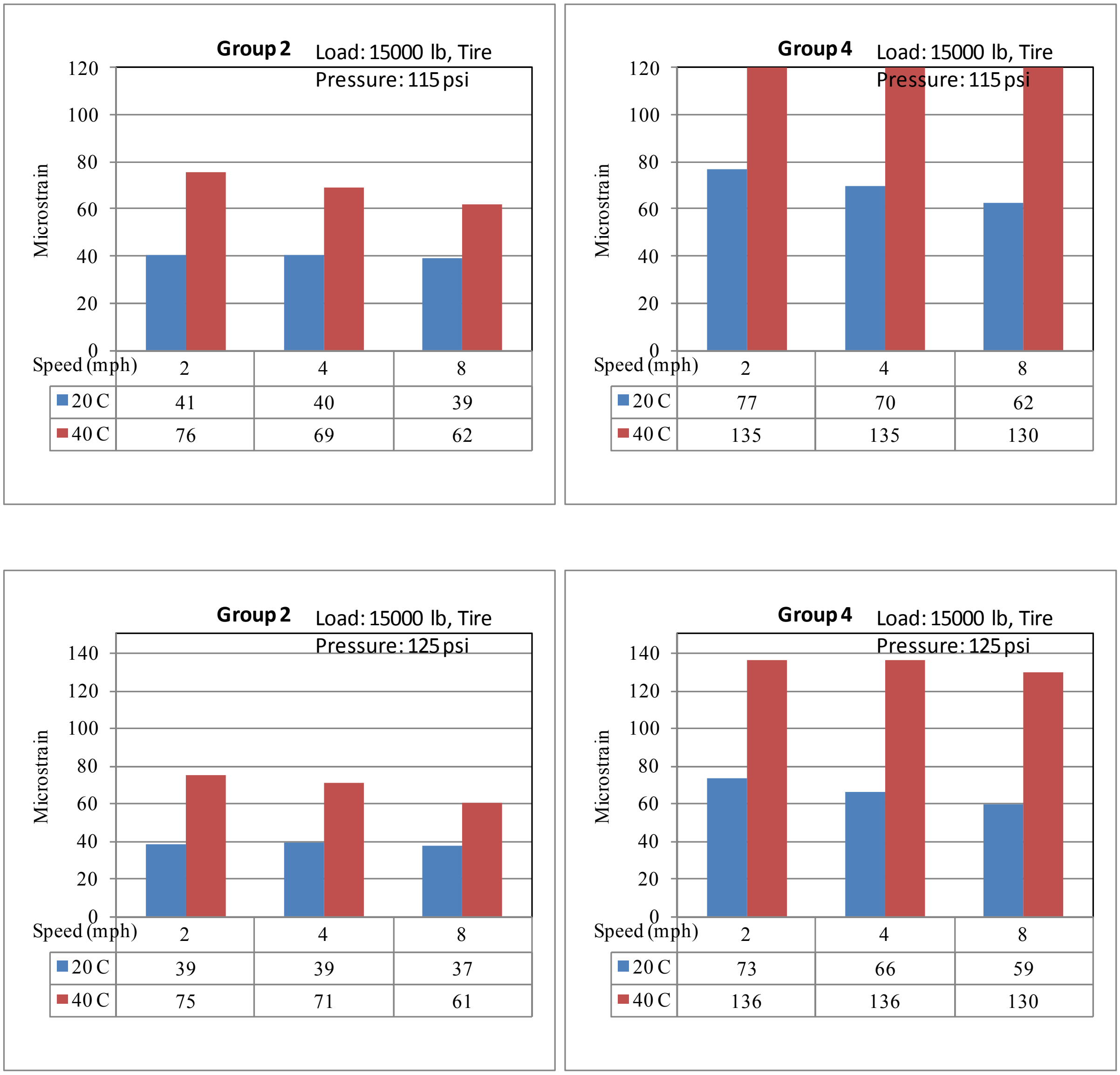
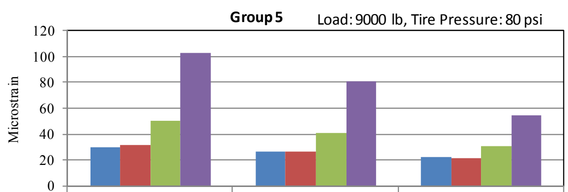
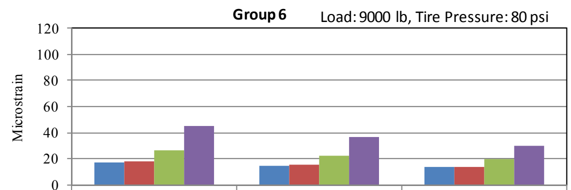


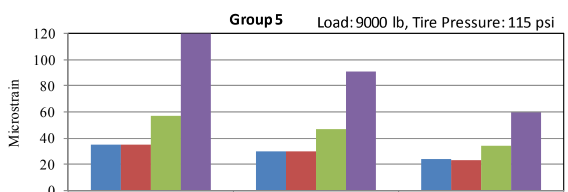
Figure 7.24 Group 2 and 4 Strains at a Constant Load of 15,000 lb.



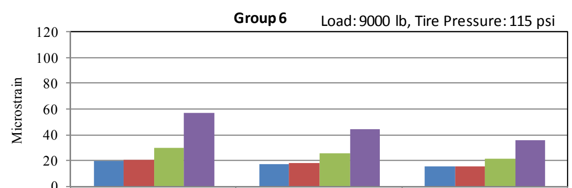
Speed (mph)	2	4	8
16 C	30	26	22
20 C	31	26	21
30 C	50	41	31
40 C	103	81	54



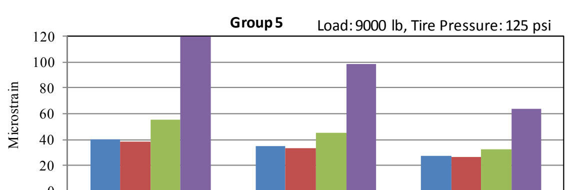
Speed (mph)	2	4	8
16 C	17	15	14
20 C	18	15	14
30 C	27	23	20
40 C	45	36	30



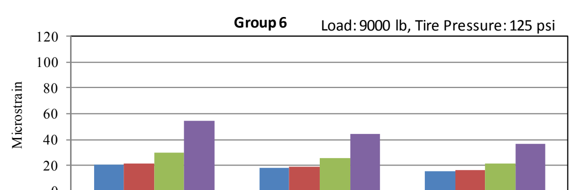
Speed (mph)	2	4	8
16 C	35	30	24
20 C	35	30	23
30 C	57	47	34
40 C	121	92	60



Speed (mph)	2	4	8
16 C	19	17	15
20 C	21	18	16
30 C	29	25	22
40 C	57	44	35

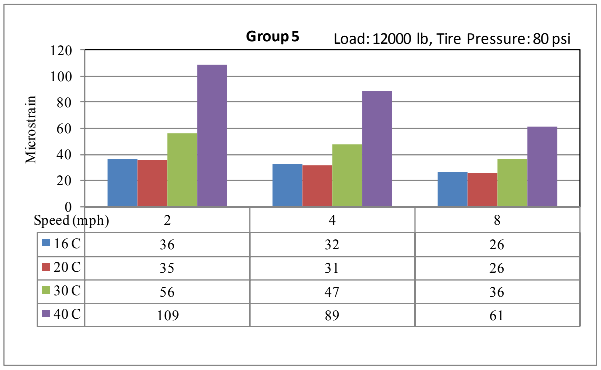


Speed (mph)	2	4	8
16 C	40	35	27
20 C	39	34	26
30 C	56	45	33
40 C	128	99	64

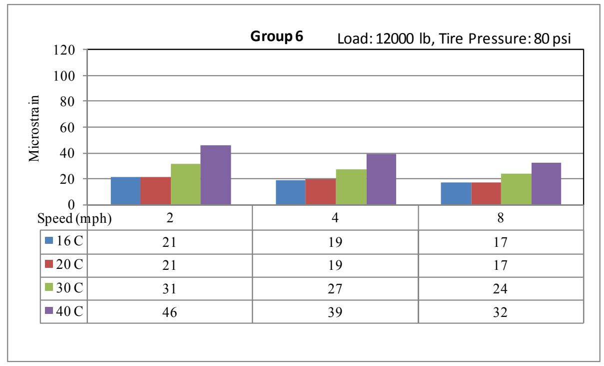


Speed (mph)	2	4	8
16 C	20	17	16
20 C	21	18	16
30 C	30	25	21
40 C	54	45	37

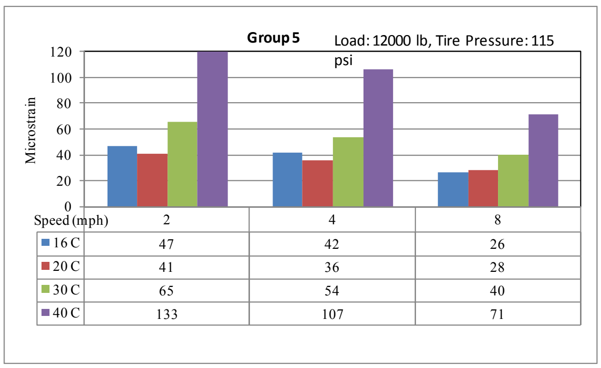
Figure 7.25 Group 5 and 6 Strains at a Constant Load of 9,000 lb.



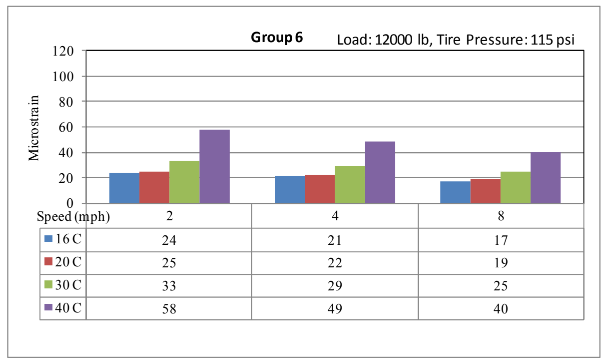
Speed (mph)	2	4	8
16 C	36	32	26
20 C	35	31	26
30 C	56	47	36
40 C	109	89	61



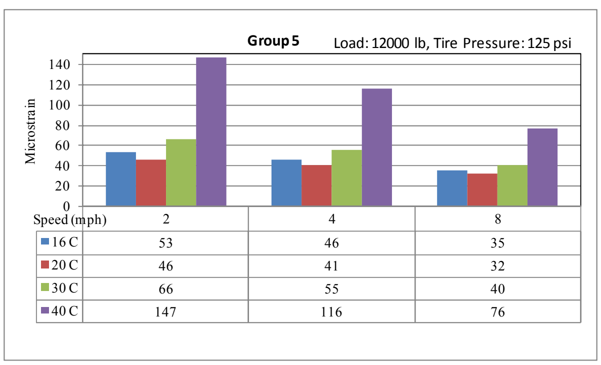
Speed (mph)	2	4	8
16 C	21	19	17
20 C	21	19	17
30 C	31	27	24
40 C	46	39	32



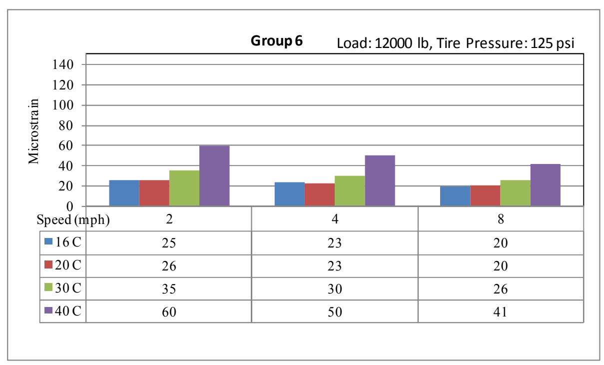
Speed (mph)	2	4	8
16 C	47	42	26
20 C	41	36	28
30 C	65	54	40
40 C	133	107	71



Speed (mph)	2	4	8
16 C	24	21	17
20 C	25	22	19
30 C	33	29	25
40 C	58	49	40



Speed (mph)	2	4	8
16 C	53	46	35
20 C	46	41	32
30 C	66	55	40
40 C	147	116	76



Speed (mph)	2	4	8
16 C	25	23	20
20 C	26	23	20
30 C	35	30	26
40 C	60	50	41

Figure 7.26 Group 5 and 6 Strains at a Constant Load of 12,000 lb.

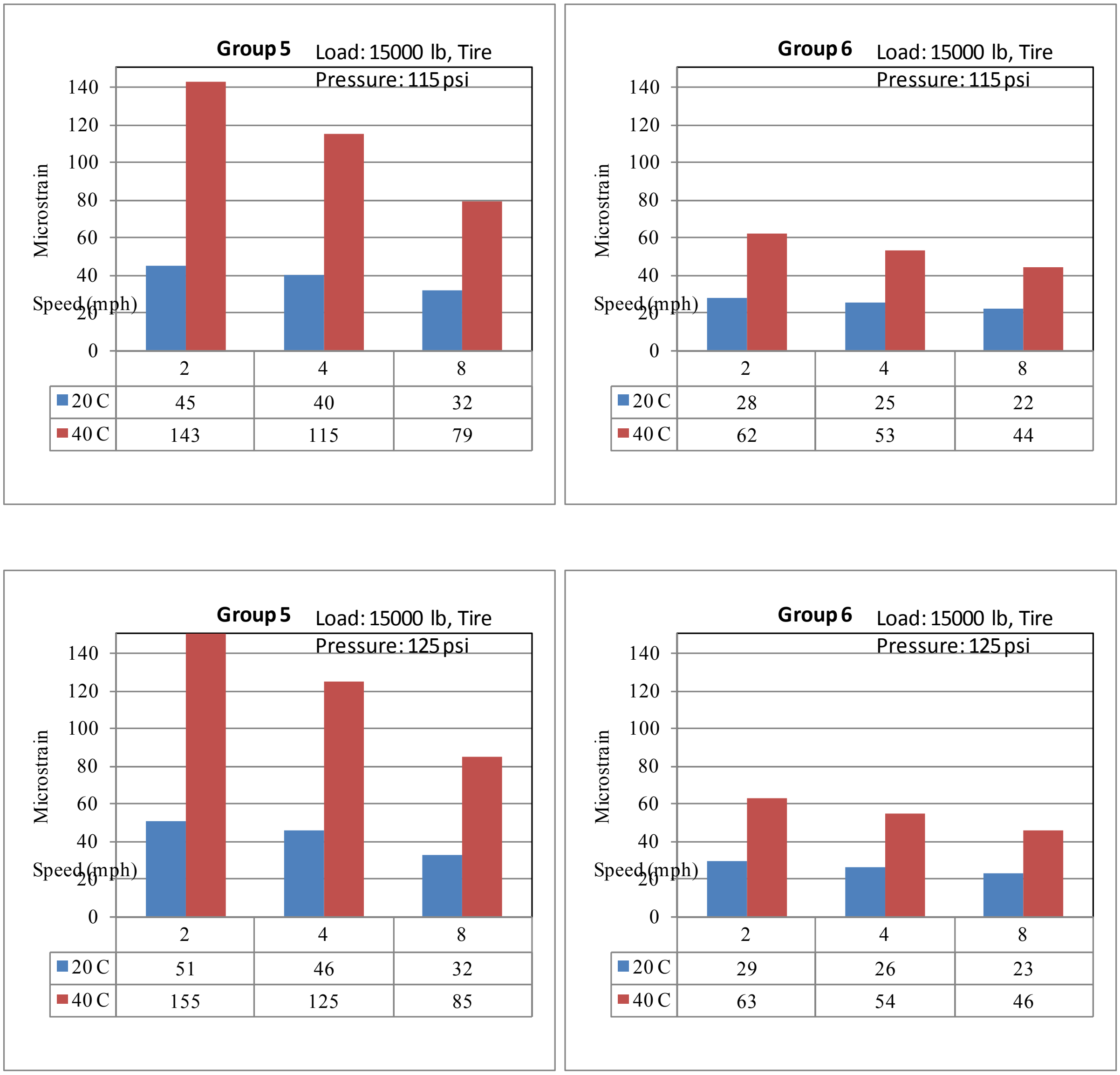


Figure 7.27 Group 5 and 6 Strains at a Constant Load of 15,000 lb.

8 Effect of Tire Pressure on Measured Strain

A preliminary investigation of the strain results suggested that a change in tire pressure did not significantly affect measured strains. This was a surprising observation and did not conform to common belief. To investigate this effect further a statistical analysis was performed on the measured strain data.

As described earlier, and shown in Table 3.1, the tire pressure was varied at three levels of 80 psi (552 kPa), 115 psi (793 kPa), and 125 psi (862 kPa). At each tire pressure, the wheel load was varied at three levels – 9,000 lb (40 kN), 12,000 lb (53 kN) and 15,000 lb (67 kN). For a given combination of tire pressure and wheel load, five runs each were made with the HVS at three speeds of 2 mph (3.2 kmph), 4 mph (6.4 kmph), and 8 mph (12.9 kmph). This data collection process was repeated at five temperatures, viz. 16 °C, 20 °C, 30 °C, 40 °C, and 50 °C. As shown in the previous section, the repeatability of the strain gauges at 50 °C was marginal at best, and was subsequently excluded from the ensuing analysis.

Figure 8.1 and Figure 8.2 show the effect of change in tire pressure at 9,000 lb (40 kN) and 12,000 lb (53 kN) wheel load at all temperatures at 8 mph (12.9 kmph) respectively. As illustrated in Figure 8.1 and Figure 8.2, the strain response for all groups of gauges indicated that tire pressure did not have a significant effect on the measured strains by either surface gauges (Groups 1 through 4) or by the embedded gauges (Groups 5 and 6). An Analysis of Variance (ANOVA) was further conducted (at $\alpha = 0.05$) to investigate this effect. Note that the ANOVA was performed separately for each group of gauges and for different levels of load, speed and temperature.

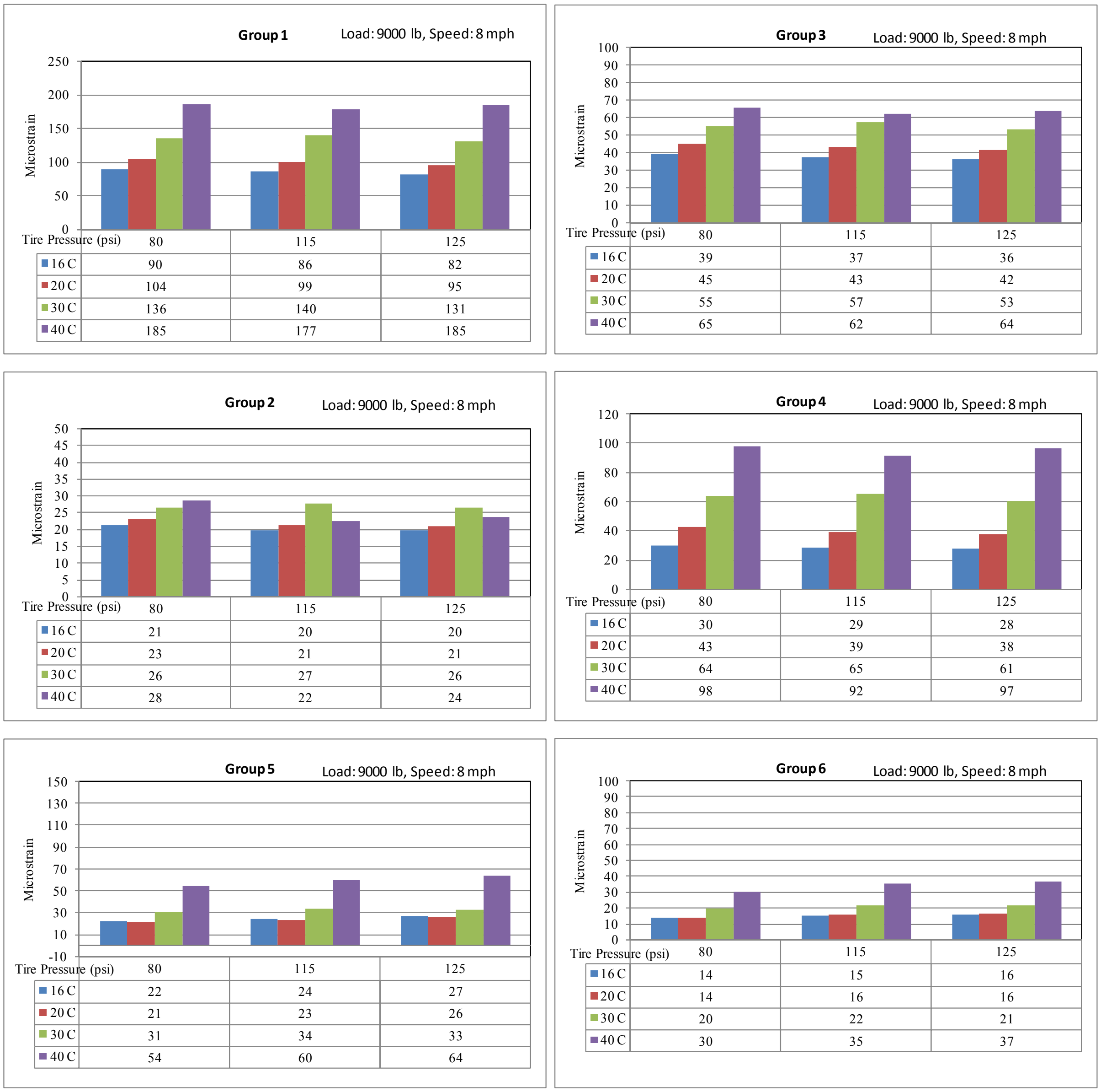


Figure 8.1 Effect of Tire Pressure on Measured Strain (constant wheel load of 9,000 lb/40 kN) and Wheel Speed of 8 mph (12.9 kmph).

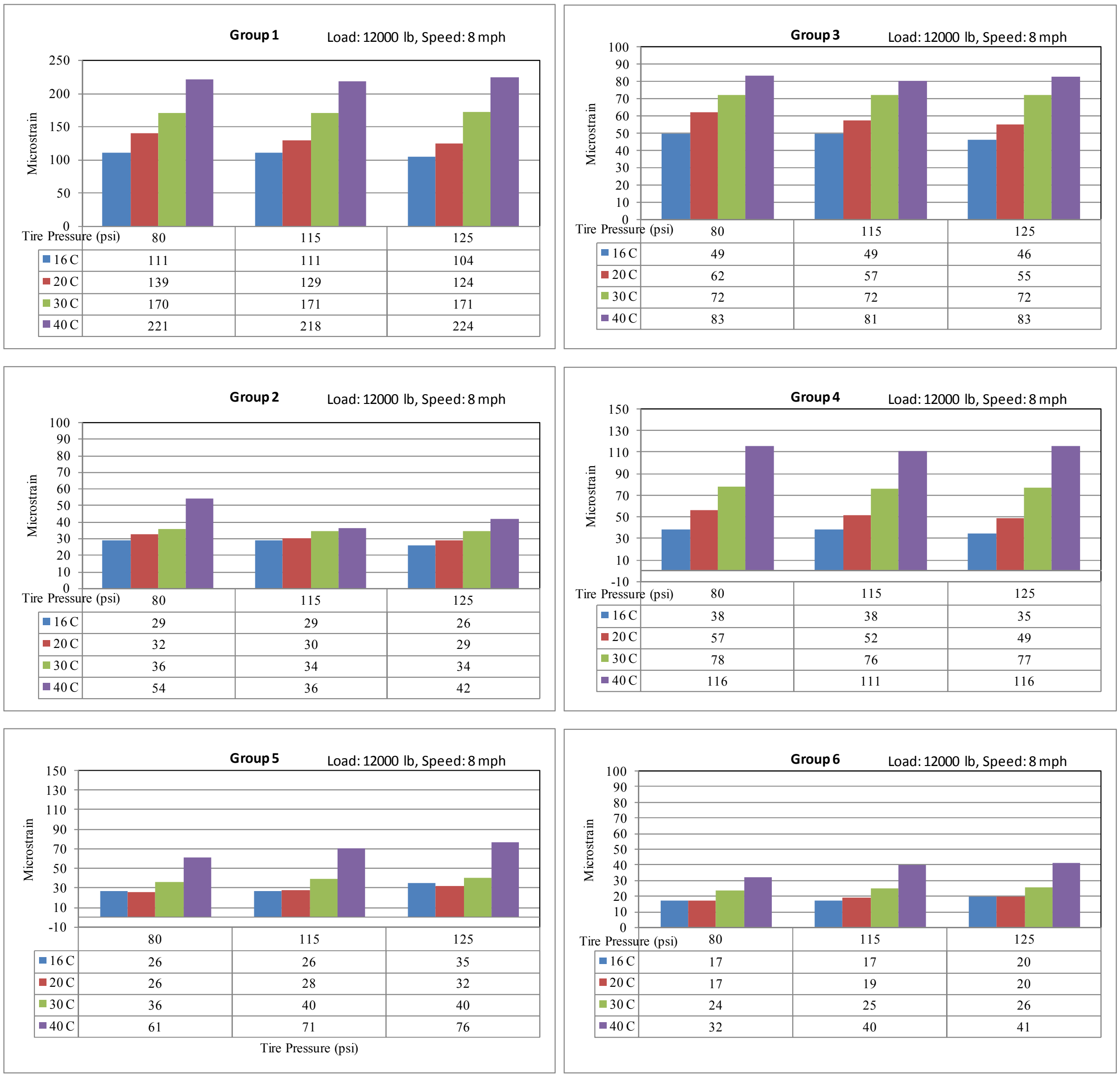


Figure 8.2 Effect of Tire Pressure on Measured Strain (constant wheel load of 12,000 lb/53.4 kN) and Wheel Speed of 8 mph (12.9 kmph).

Results of the ANOVA are presented in Table 8.1 through Table 8.3 for speeds of 2, 4 and 8 mph respectively. As shown in these tables, under most conditions, the magnitude of strains at different tire pressures (but same conditions of temperature, load and speed) were statistically similar. Out of a possible 60 combinations of temperature and wheel load (speed being a constant at 8 mph), only 6 instances were found where tire pressure appeared to have an effect on the measured strains. At wheel speeds of 2 mph (3.2 kmph) and 4 mph (6.4 kmph), similar results were observed (13 instances out of a possible 120 combinations, where the strain magnitudes were not statistically similar.) The combinations of temperature and wheel load where these magnitudes are not statistically similar appear to be randomly distributed in the test matrix, and no particular reason could be determined to cause this effect.

In common belief, for a given load, a higher tire pressure would result in a smaller contact area, thereby resulting in a higher level stress (and therefore higher strain) experienced by the pavement. However, under the limited set of test conditions in this study, strain measurements did not significantly vary with a change in tire pressure. It is possible that the tire structure (number of ribs etc.) and tread pattern play a more crucial role in the transfer of stress to the pavement. Since only one type of tire was used in this study, it is recommended that the effect of tire pressure be further studied using different makes and types of tires.

Table 8.1 ANOVA Results for Effect of Tire Pressure on Measured Strain, Wheel Speed at 2 mph (3.2 kmph)

	Group 1			Group 2			Group 3		
Load	9	12	15	9	12	15	9	12	15
16 °C	0.138	0.201	--	0.761	0.270	--	0.376	0.063	--
20 °C	**0.039**	0.051	0.336	0.957	0.531	0.632	0.061	0.059	0.336
30 °C	0.285	0.976	--	**0.038**	0.966	--	**0.000**	0.523	--
40 °C	0.834	0.773	0.787	0.935	0.095	0.915	0.807	0.939	0.823

	Group 4			Group 5			Group 6		
Load	9	12	15	9	12	15	9	12	15
16 °C	0.239	**0.003**	--	0.290	0.065	--	0.236	0.135	--
20 °C	0.220	0.060	0.406	0.509	0.392	0.450	0.119	**0.049**	0.426
30 °C	0.360	0.925	--	0.729	0.623	--	0.282	0.305	--
40 °C	0.726	0.700	0.858	0.497	0.264	0.626	**0.007**	**0.004**	0.791

NOTE This table shows the *p*-value for each level of load and temperature. *p*-values < 0.05 are shown in bold red font.

Table 8.2 ANOVA Results for Effect of Tire Pressure on Measured Strain, Wheel Speed at 4 mph (6.4 kmph)

	Group 1			Group 2			Group 3		
Load	9	12	15	9	12	15	9	12	15
16 °C	0.340	**0.046**	--	0.797	0.167	--	0.310	0.055	--
20 °C	0.126	**0.035**	0.210	0.957	0.604	0.705	0.310	0.146	0.349
30 °C	0.301	0.941	--	0.702	0.969	--	**0.002**	0.903	--
40 °C	0.755	0.800	0.818	0.128	**0.019**	0.834	0.628	0.884	0.708

	Group 4			Group 5			Group 6		
Load	9	12	15	9	12	15	9	12	15
16 °C	0.725	0.105	--	0.375	0.109	--	0.286	0.158	--
20 °C	0.478	0.072	0.374	0.477	0.424	0.429	**0.042**	0.070	0.468
30 °C	0.327	0.925	--	0.823	0.770	--	0.194	0.374	--
40 °C	0.313	0.557	0.898	0.704	0.527	0.723	**0.010**	**0.001**	0.625

Table 8.3 ANOVA Results for Effect of Tire Pressure on Measured Strain, Wheel Speed at 8 mph (12.9 kmph)

	Group 1			Group 2			Group 3		
Load	9	12	15	9	12	15	9	12	15
16 °C	**0.033**	0.077	--	0.501	0.172	--	0.242	0.192	--
20 °C	0.053	**0.011**	0.164	0.493	0.376	0.568	0.340	0.128	0.387
30 °C	0.423	0.992	--	0.923	0.924	--	**0.022**	0.988	--
40 °C	0.725	0.897	0.831	0.096	**0.003**	0.795	0.454	0.717	0.644

	Group 4			Group 5			Group 6		
Load	9	12	15	9	12	15	9	12	15
16 °C	0.446	0.196	--	0.538	0.230	--	0.479	0.166	--
20 °C	0.219	0.061	0.340	0.576	0.517	0.927	0.104	0.134	0.496
30 °C	0.334	0.928	--	0.921	0.878	--	0.380	0.515	--
40 °C	0.359	0.504	0.980	0.813	0.652	0.779	**0.027**	**0.011**	0.505

9 Conclusions

Twenty-four surface and embedded strain gauges were tested for repeatability through the course of this study. The strain gauges were divided into six functional groups and were tested under various conditions of temperature, tire pressure, load and wheel speed. A total of 32 Million data points were collected and analyzed during the course of this study. After a thorough evaluation of the data and subsequent analysis, the following conclusions have been made:

1. If installed properly, surface strain gauges can be repeatable and yield reliable measurements.
2. The strain gauges evaluated in this study are not repeatable at operating temperatures greater than 40 °C.
3. As expected, an increase in pavement temperature caused an increase in magnitude of strain.
4. As expected, an increase in wheel load caused an increase in the magnitude of strain.
5. The magnitude of strain decreased as the speed of the wheel load increased.
6. Internal tire pressure did not seem to cause an increase or decrease in strain magnitude.

The first three observations mentioned above have been well documented in the past, and were anticipated during the course of this study. However, literature regarding the effects of internal tire pressure on pavement strains is very limited. This study presented an opportunity to investigate this effect under carefully controlled conditions.

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11 Disclaimer

The content of this paper reflects the views of the authors who are solely responsible for the facts and accuracy of the data as well as for the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Florida Department of Transportation. This paper does not constitute a standard, specification, or regulation. In addition, the above listed agency assumes no liability for its contents or use thereof.

12 References

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APPENDIX A GAUGE INSTALLATION

Foil Surface Strain Gauge Installation

1. On the pavement surface, mark the approximate spots that the sensors will be placed.
2. Grind surface with asphalt wheel to remove surface voids and produce a smooth surface.

3. Clean grinded pavement surface of all debris and dust. Use a shop rag and alcohol to make sure that all fine dust particles have been removed.
4. Optional: If a considerable number of surface voids are still present, mix two part strain gauge cement and brush onto surface where gauges will be placed. Allow the cement to dry, then rough up the epoxy with steel wool pad and repeat step three.
5. Apply CN strain gauge glue liberally to the pavement surface and the underside of the foil gauge.

6. Place the strain gauge on the glued surface. Use wax paper sheets provided with gauges to apply pressure by gently rocking back and forth with your fingers. After it adheres (1-2 minutes), leave wax paper on top and move onto the next gauge and repeat steps.

7. Once all the gauges are applied allow to sit for a few minutes and then remove the wax paper.
8. After all gauges are wired to the data acquisition box, neatly bind wires with zip ties and tape them to the surface using masking tape.
9. Heat wax up in a saucer/pot until melted. Pour onto wires in order to keep them held in place.

10. For gauges that will be under the wheel path mix up two part epoxy and coat top of gauge and any wire that will be in the loaded wheel path.

Embedded H-Strain Gauge Installation

1. On the base or milled pavement surface, mark locations where strain gauges are to be placed.
2. Use a fixed reference point that will be available before and after paving and measure distance and offset to each strain gauge using string lines or more advanced survey methods.
3. Within the area to be paved, saw cut a path for the gauge wires. The path should be the most direct possible to the outside edge of the paving lane to reduce the amount of wire to be paved over.

4. Place gauges in correct location and orientation. Place gauge wires into cut path.

5. Seal gauge wire path with silicon sealant.

6. Place thermal reflective tape across strain gauge wire path.

7. Double-check the functionality of gauges. This will likely be the last chance to replace non-functioning or problem gauges.
8. Just prior to paving, use a sample of the same hot-mix to be paved and hand-compact around the gauge. Some hot-mix will need to placed under the gauge as well.

9. Pave instrumented area using normal practices, with care to minimize disturbance of gauges.
10. After paving, mark the locations of the embedded strain gauges on the pavement surface using the reference point established earlier.
11. Check gauge functionality to make sure they survived the construction process.

APPENDIX B DATA FILE NAMES

Table B.1 Data File Names for Strain Measurements at 80 psi

Pressure	80 psi								
Load	9,000 lb			12,000 lb			15,000 lb		
Speed	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 °C	1039	1048	1054	1019	1026	1032	--	--	--
	1041	1050	1055	1021	1028	1034	--	--	--
	1045	1052	1058	1023	1030	1036	--	--	--
	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--
20 °C	1344	1359	1415	1433	1453	1500	--	--	--
	1346	1402	1417	1435	1455	1501	--	--	--
	1348	1405	1419	1437	1456	1502	--	--	--
	1351	1408	1420	1439	1457	1503	--	--	--
	1354	1411	1422	1441	1458	1504	--	--	--
30 °C	1105	1121	1133	1143	1155	1203	--	--	--
	1108	1123	1135	1147	1156	1204	--	--	--
	1111	1126	1136	1149	1157	1205	--	--	--
	1114	1129	1138	1151	1158	1206	--	--	--
	1117	1131	1140	1153	1159	1207	--	--	--
40 °C	1101	1108	1118	1128	1135	1140	--	--	--
	1104	1110	1120	1130	1136	1141	--	--	--
	1106	1112	1122	1133	1137	1142	--	--	--
	--	1114	1124	--	1138	1143	--	--	--
	--	1116	1125	--	1139	1144	--	--	--
50 °C	0824	0835	0847	0857	0910	0920	--	--	--
	0829	0837	0849	0901	0913	0921	--	--	--
	0832	0840	0851	0908	0915	0922	--	--	--
	--	0842	0853	--	0917	0923	--	--	--
	--	0845	0855	--	0918	0924	--	--	--

Table B.2 Data File Names for Strain Measurements at 115 psi

Pressure	115 psi								
Load	9,000 lb			12,000 lb			15,000 lb		
Speed	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
	0952	0959	1005	0929	0935	0945	--	--	--
	0954	1001	1006	0931	0937	0947	--	--	--
16 °C	0956	1003	1007	0933	0943	0949	--	--	--
	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--
	1101	1111	1124	1136	1149	1158	1212	1222	1235
	1103	1116	1125	1138	1150	1159	1214	1224	1237
20 °C	1105	1118	1127	1140	1152	1200	1216	1226	1239
	1107	1120	1128	1144	1154	1201	1218	1228	1241
	1109	1122	1129	1147	1156	1202	1220	1233	1243
	1625	1655	1707	1732	1726	1715	--	--	--
	1627	1657	1708	1734	1727	1716	--	--	--
30 °C	--	1659	1709	1736	1728	1722	--	--	--
	--	1702	1711	1738	1729	1723	--	--	--
	--	1704	1713	1740	1730	1724	--	--	--
	0834	0915	0927	0936	0946	0952	0958	1013	1023
	0836	0918	0928	0938	0948	0953	1001	1015	1026
40 °C	0838	0920	0930	0940	0949	0954	1004	1017	1028
	0841	0922	0932	0942	0950	0955	1006	1019	1030
	0912	0924	0934	0944	0951	0956	1008	1021	1032
	1111	1120	1130	1223	1231	1242	1252	1300	1310
	1114	1122	1132	1225	1233	1243	1254	1302	1312
50 °C	1116	1124	1134	1228	1234	1248	1257	1304	1314
	--	1126	1136	--	1236	1249	--	1306	1316
	--	1128	1221	--	1240	1250	--	1308	1318

Table B.3 Data File Names for Strain Measurements at 125 psi

Pressure	115 psi								
Load	9,000 lb			12,000 lb			15,000 lb		
Speed	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 °C	0903 0906 0909 -- --	0912 0914 0916 -- --	0918 0919 1922 -- --	0741 0744 0747 -- --	0751 1807 0811 -- --	0847 0858 0901 -- --	-- -- -- -- --	-- -- -- -- --	-- -- -- -- --
20 °C	0755 0758 0801 0804 0807	0812 0814 0816 0818 0821	0823 0825 0826 0828 0830	0845 0847 0849 0851 0853	0859 0901 0903 0905 0907	0909 0911 0915 0917 0918	0930 0936 0938 0940 0942	0944 0946 0948 0950 0952	0954 0956 0958 1000 1002
30 °C	1440 1443 1447 1450 1453	1456 1459 1502 1505 1508	1511 1512 1513 1514 1516	1547 1550 1552 1555 1558	1601 1609 1610 1611 1612	1614 1615 1616 1617 1618	-- -- -- -- --	-- -- -- -- --	-- -- -- -- --
40 °C	1206 1209 1212	1215 1217 1219 1221 1223	1253 1255 1256 1257 1259	1303 1305 1307 -- --	1309 1311 1312 1313 1314	1315 1316 1317 1318 1319	1322 1324 1327 -- --	1330 1332 1334 1336 1338	1349 1351 1355 1357 --
50 °C	0936 0938 0940	0942 0944 0946 0948 0950	0952 0954 0955 0956 0959	1001 1003 1005 -- --	1007 1009 1014 1016 1020	1022 1024 1026 1027 1028	1030 1032 1035 -- --	1037 1039 1041 1045 1048	1051 1053 1055 1057 1059

APPENDIX C DETAILED TEST RESULTS

Table C.1 Test Results for Group-1 (Longitudinal Gauges, 5 in away from edge of the wheelpath)

GROUP - 1		80 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	101.97	93.38	89.64	135.58	124.97	110.59			
	COV B/L	8.9	5.6	2	0.4	0.6	0.7			
	COV W/L	**8.9**	**6.2**	**4.4**	**4.8**	**4.7**	**4.2**			
20 C	Avg. Strain	131.01	113.59	104.19	172.32	156.61	139.16			
	COV B/L	3.3	1.1	3.6	1.4	2.4	0.9			
	COV W/L	**6.2**	**4.8**	**5.7**	**5.9**	**5.5**	**4.5**			
30 C	Avg. Strain	166.97	151.95	135.56	209.43	192.84	170.19			
	COV B/L	2.8	3.3	3.5	0.6	1	1.1			
	COV W/L	**7.4**	**7.8**	**7.6**	**6.6**	**7.2**	**6.9**			
40 C	Avg. Strain	205.94	201.98	184.93	237.7	235.92	220.92			
	COV B/L	3.7	2.4	2	0.6	0.8	0.9			
	COV W/L	**10.2**	**9.3**	**8.7**	**9.8**	**9.2**	**9.1**			
50 C	Avg. Strain	135.32	153.15	158.46	155.73	175.83	184.29			
	COV B/L	3.9	1.4	1.7	1.6	1.3	0.8			
	COV W/L	**14.8**	**13**	**12.6**	**15.5**	**13.4**	**12.6**			

GROUP - 1		115 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	105.05	92.86	86.18	134.22	123.67	110.28			
	COV B/L	1.6	1.7	2.3	1.2	1.8	1.5			
	COV W/L	**6.1**	**5.4**	**5.2**	**5.6**	**5.8**	**5.6**			
20 C	Avg. Strain	123.43	112.23	99.41	161.21	148.83	128.93	190.25	176.74	157.62
	COV B/L	4.1	2.8	3.2	0.9	0.7	1.6	0.8	0.7	0.8
	COV W/L	**6.6**	**5.2**	**4.9**	**5.3**	**4.6**	**4.4**	**5.4**	**4.9**	**4.5**
30 C	Avg. Strain	175.07	159.28	139.65	161.45	194.71	170.89			
	COV B/L	1.5	2.3	10.5	4.1	0.6	0.8			
	COV W/L	**6.8**	**7.4**	**11.6**	**7.6**	**6.9**	**6.7**			
40 C	Avg. Strain	200.59	194.38	177.17	240.57	237.56	217.56	268.03	270.91	252.1
	COV B/L	1.8	3.1	2.4	0.9	0.8	1.1	1.2	1.1	1.2
	COV W/L	**9.2**	**8.7**	**8.7**	**9**	**8.8**	**8.7**	**9.5**	**9**	**8.8**
50 C	Avg. Strain	165.07	176.1	175.49	182.29	198.99	200.82	192.54	212.72	217.69
	COV B/L	1.6	2.2	2.1	1.8	0.9	0.9	2.3	0.8	0.7
	COV W/L	**14.6**	**13.1**	**12.4**	**15.4**	**14**	**13.4**	**15.9**	**14.3**	**13.4**

GROUP - 1		125 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	96.71	89.29	81.53	127.12	113.55	103.69			
	COV B/L	3.1	1.8	1	3.7	1.1	1			
	COV W/L	**5.3**	**3.7**	**3.6**	**5.3**	**4.3**	**3.5**			
20 C	Avg. Strain	116.35	105.84	95.47	154.13	141.15	124.14	182.86	168.91	149.93
	COV B/L	4	3.1	1.9	1.2	1.4	1	0.8	0.7	0.6
	COV W/L	**6.4**	**5.3**	**4.5**	**5.4**	**4.4**	**4.1**	**5.4**	**4.3**	**4.5**
30 C	Avg. Strain	161.45	146.6	130.7	161.45	196.18	171.18			
	COV B/L	4.1	4.5	2.2	4.1	1.5	1.1			
	COV W/L	**7.6**	**8**	**7.1**	**7.6**	**7.1**	**6.7**			
40 C	Avg. Strain	208.66	202.66	184.69	248.86	245.48	223.97	273.13	275.07	255.54
	COV B/L	2	1.7	1.7	0.7	0.9	0.9	1.2	0.6	1.6
	COV W/L	**9.3**	**8.5**	**8.3**	**9.1**	**8.8**	**8.6**	**9.5**	**9**	**8.6**
50 C	Avg. Strain	161.09	173.37	171.41	179.7	196.19	200.58	189.98	212.45	219.72
	COV B/L	0.9	0.9	3.1	1.1	1	2.8	1.1	1	0.8
	COV W/L	**13.7**	**12.3**	**13.2**	**14.7**	**13**	**13.4**	**14.9**	**13.4**	**12.8**

Table C.2 Test Results for Group-2 (Transverse Gauges, 5 in away from edge of the wheelpath)

GROUP 2		80 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	20.89	20.92	21.2	30.2	30.11	28.92			
	COV B/L	12	5.7	2.4	2.3	2.7	2.1			
	COV W/L	**17.7**	**12.4**	**10.4**	**11.6**	**10.3**	**9**			
20 C	Avg. Strain	24.75	23.04	23.05	35.54	34.22	32.49			
	COV B/L	4	2.6	3.5	3.7	5.8	2.2			
	COV W/L	**17**	**15.2**	**12.1**	**14.6**	**14.6**	**11.4**			
30 C	Avg. Strain	21.83	25.15	26.41	32.81	35.55	35.74			
	COV B/L	5	6.4	4.2	3.7	3.4	2.5			
	COV W/L	**26.1**	**20.7**	**18.6**	**22.6**	**19.7**	**16.5**			
40 C	Avg. Strain	38.68	32.22	28.42	67.8	59.39	54.24			
	COV B/L	20.9	9.6	9.5	3.7	6.1	4.4			
	COV W/L	**23.5**	**17.7**	**17.6**	**17.3**	**16.5**	**13.5**			
50 C	Avg. Strain	70.15	51.53	40.37	67.84	60.71	52.29			
	COV B/L	11.3	3.5	5	6.6	4.9	6.9			
	COV W/L	**28.1**	**26.2**	**32.2**	**23**	**23.7**	**22.8**			

GROUP 2		115 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	21.06	20.11	19.66	28.5	28.52	26.62			
	COV B/L	2.4	4	1.5	3.5	2.8	3.4			
	COV W/L	**14.2**	**11.4**	**9.7**	**12.6**	**11.2**	**7.5**			
20 C	Avg. Strain	24.06	22.68	21.3	32.08	31.99	29.98	40.71	40.41	39.26
	COV B/L	5.4	4.4	5.6	3.7	2.5	2.7	2.7	1.7	2
	COV W/L	**15.4**	**16.8**	**14.1**	**16.2**	**14.7**	**11.3**	**14.7**	**12.1**	**11**
30 C	Avg. Strain	28.73	27.45	27.46	31.92	34.39	34.38			
	COV B/L	4.5	3.3	8.4	4.4	1.5	2.6			
	COV W/L	**15.3**	**16**	**16**	**13.2**	**19.2**	**17.2**			
40 C	Avg. Strain	39.04	26.66	22.26	49.12	41.17	36.07	75.88	69.21	62.06
	COV B/L	12.3	7.9	8.1	3.5	3.9	2.8	6.5	5.1	6.6
	COV W/L	**24.3**	**10.1**	**16.2**	**23.6**	**15.8**	**13.9**	**22.7**	**18.2**	**15**
50 C	Avg. Strain	72.31	57.59	46.12	67.64	59.18	49.18	70.59	66.92	60.27
	COV B/L	3	4.9	11.7	4.7	3.9	3.9	5.1	3.3	5.3
	COV W/L	**21.4**	**21.7**	**29.1**	**19.7**	**23.7**	**25.2**	**23.9**	**20.9**	**19.6**

GROUP 2		125 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	19.62	19.92	19.71	26.03	25.78	25.83			
	COV B/L	5.6	3.5	2	1.9	3.5	3.1			
	COV W/L	**15.8**	**10**	**10.1**	**12.7**	**10.9**	**8.9**			
20 C	Avg. Strain	24.12	22.3	20.86	31.58	31.02	28.83	38.6	39.03	37.47
	COV B/L	3.7	6.7	3.4	2.8	2.9	3.5	3.6	1.8	2.7
	COV W/L	**13.3**	**16.6**	**12**	**17.7**	**13.9**	**13.5**	**15.8**	**13.1**	**11.2**
30 C	Avg. Strain	31.92	27.35	26.36	31.92	34.77	34.26			
	COV B/L	4.4	6.2	4.9	4.4	2.3	1.5			
	COV W/L	**13.2**	**13.2**	**17.1**	**13.2**	**19**	**16.9**			
40 C	Avg. Strain	37.23	28.97	23.58	56.42	49.33	41.51	74.71	70.95	60.55
	COV B/L	8.1	3.8	7.2	3.7	6.9	4.8	3.6	4.4	8.8
	COV W/L	**20.1**	**10**	**15.7**	**16.1**	**12.6**	**10.4**	**17.7**	**14.9**	**14**
50 C	Avg. Strain	76.29	61.85	50.53	74.81	65.98	57.35	79.27	73.27	67.3
	COV B/L	2.8	2.6	11.5	3.3	2.4	12	4.9	2.7	5.8
	COV W/L	**18.1**	**22**	**29.1**	**23.8**	**29.4**	**26.3**	**22.1**	**24**	**21.1**

Table C.3 Test Results for Group-3 (Longitudinal Gauges, 15 in away from edge of the wheelpath)

GROUP 3		80 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	41.48	39.03	38.93	57.51	54.18	49.43			
	COV B/L	10.4	6.4	2.3	1	0.9	2			
	COV W/L	**9.9**	**7.7**	**6.2**	**4.7**	**5.7**	**6.1**			
20 C	Avg. Strain	53.48	47.76	45.22	73.1	67.46	62.27			
	COV B/L	4.1	2.1	4	2.2	3	1.1			
	COV W/L	**6**	**6.9**	**7.7**	**5.6**	**6.5**	**6.4**			
30 C	Avg. Strain	61.12	58.44	55.01	83.4	78.71	72.37			
	COV B/L	2.6	3.9	4.2	1.1	1	1.2			
	COV W/L	**2.6**	**4.3**	**4.9**	**1.2**	**2.4**	**3.6**			
40 C	Avg. Strain	64.34	66.63	65.42	81.96	84.32	83.19			
	COV B/L	5.8	3.5	2.4	0.5	1.1	0.8			
	COV W/L	**10.1**	**8**	**6.4**	**9.3**	**7.4**	**6**			
50 C	Avg. Strain	41.14	43.9	47.13	50.65	55.89	59.68			
	COV B/L	3.9	2.5	2.5	0.8	0.9	1.2			
	COV W/L	**13.9**	**13**	**11**	**16**	**13.8**	**12.2**			

GROUP 3		115 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	42.22	38.2	37.14	56.73	52.68	48.21			
	COV B/L	1.7	1.8	2.2	1.8	2.3	1.9			
	COV W/L	**5.9**	**6**	**6.7**	**5.6**	**6.1**	**6.6**			
20 C	Avg. Strain	49.84	46.82	43.31	67.21	63.73	57.39	81.79	77.47	71.29
	COV B/L	4	3.4	3.7	2.1	0.9	1.2	0.9	0.8	0.7
	COV W/L	**6.4**	**6.8**	**6.7**	**5.4**	**5.6**	**6.4**	**5.1**	**5.8**	**6.7**
30 C	Avg. Strain	65.97	62.02	57.35	59.32	79.3	72.16			
	COV B/L	1.4	2.7	12.2	5.1	0.8	1.2			
	COV W/L	**1.4**	**3.5**	**11.3**	**4.6**	**2.4**	**3.3**			
40 C	Avg. Strain	61.9	63.63	62.16	81.76	83.65	80.77	96.18	99.39	96.79
	COV B/L	2.9	3.9	2.9	1.5	1.1	1.1	1.2	1	1.1
	COV W/L	**8.1**	**7.4**	**5.8**	**8.1**	**6.2**	**5.3**	**8.6**	**7**	**5.8**
50 C	Avg. Strain	41.47	45.49	50.03	52.3	58.85	61.69	60.97	67.88	73.1
	COV B/L	3.4	4.2	6.4	0.8	1.4	0.8	1.6	0.9	1.9
	COV W/L	**18.1**	**14.3**	**13.4**	**16.6**	**14.1**	**12.2**	**17.5**	**14.4**	**12.2**

GROUP 3		125 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	39.87	37.98	35.83	52.04	48.09	45.92			
	COV B/L	3.8	1.8	2	3.1	1.5	2.2			
	COV W/L	**6.8**	**7.1**	**7.3**	**6.7**	**7.1**	**6.3**			
20 C	Avg. Strain	47.3	43.87	41.58	64.45	60.24	55.08	78.12	73.62	67.62
	COV B/L	4	3.9	2.2	1.6	1.7	1.3	1	0.7	0.6
	COV W/L	**6.3**	**7.1**	**6.7**	**5.3**	**6.5**	**6.4**	**5.2**	**6.1**	**6.7**
30 C	Avg. Strain	59.32	56.43	53.24	59.32	79.25	72.09			
	COV B/L	5.1	5.5	3.2	5.1	2.1	1			
	COV W/L	**4.6**	**5.3**	**4.3**	**4.6**	**3**	**3.3**			
40 C	Avg. Strain	62.89	64.89	63.72	83.4	85.61	83.07	97.56	101.28	98.64
	COV B/L	3.3	2.6	2.2	0.6	1.1	1.1	1.2	0.7	2.1
	COV W/L	**8.7**	**6.5**	**5.5**	**8.8**	**6.7**	**5.8**	**8.8**	**6.5**	**5.6**
50 C	Avg. Strain	41.42	46.12	50.12	52.32	58.21	63.64	60.08	67.39	72.39
	COV B/L	1.7	1.7	9.2	1.5	1.2	6.9	0.8	1.5	2.5
	COV W/L	**16.7**	**13.9**	**14**	**16.6**	**14.6**	**13.8**	**18.1**	**14.7**	**12.8**

Table C.4 Test Results for Group-4 (Transverse Gauges, 15 in away from edge of the wheelpath)

GROUP 4		80 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	37.66	31.82	30.04	49.17	44.06	38.12			
	COV B/L	8.5	6.9	5	2	2	3.9			
	COV W/L	**10.4**	**11.6**	**10.7**	**7.3**	**7**	**7.9**			
20 C	Avg. Strain	54.04	45.41	42.67	71.21	63.33	56.58			
	COV B/L	2.6	2.9	3.5	0.7	3	1.6			
	COV W/L	**7.8**	**9**	**10.5**	**6.7**	**6.8**	**7.4**			
30 C	Avg. Strain	74.6	68.5	63.99	89.95	84.76	77.73			
	COV B/L	4	4.1	2.7	0.9	1.1	1.4			
	COV W/L	**8.2**	**7.9**	**7.3**	**5.8**	**6.1**	**6.3**			
40 C	Avg. Strain	102.61	102.06	98.22	120.19	119.84	116.27			
	COV B/L	4.1	2.4	2.6	0.7	0.7	0.6			
	COV W/L	**8.3**	**7.4**	**7.7**	**6.6**	**6.6**	**6.5**			
50 C	Avg. Strain	85.77	90.03	94.23	101.94	109.29	112.32			
	COV B/L	2	1.9	1.6	0.9	1	0.9			
	COV W/L	**9.6**	**8.9**	**8.6**	**9.7**	**9.1**	**8.5**			

GROUP 4		115 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	38.36	31.95	28.56	47.54	41.83	36.23			
	COV B/L	1.8	5.9	1.8	2.9	4.3	3.9			
	COV W/L	**10.2**	**10.3**	**7**	**9.5**	**10.3**	**11.6**			
20 C	Avg. Strain	50.94	45.14	39.23	65.08	58.5	51.83	76.72	69.54	62.36
	COV B/L	4.9	3.5	4.8	1.8	1.4	1.2	1.4	1	1.1
	COV W/L	**9.2**	**8.2**	**9.9**	**7.7**	**7.2**	**7.1**	**7.2**	**6.9**	**7.2**
30 C	Avg. Strain	74.33	70.21	65.28	69.77	83.37	76.36			
	COV B/L	1.5	1.7	7	4.3	1.3	1.6			
	COV W/L	**6.9**	**7.1**	**9.5**	**7.7**	**6.4**	**6.9**			
40 C	Avg. Strain	98.62	94.63	91.56	117.03	115.69	110.9	134.64	135.16	130
	COV B/L	2.5	2.2	2.9	0.6	0.8	0.9	1	1	0.9
	COV W/L	**7.3**	**6.9**	**6.9**	**6.2**	**6.1**	**6.2**	**6.2**	**6.3**	**5.9**
50 C	Avg. Strain	95.03	97.21	103.98	108.66	116.93	118.87	120.01	129.49	133.7
	COV B/L	4	2.6	5.6	0.7	0.9	1.2	0.9	0.7	1.8
	COV W/L	**9.9**	**8.7**	**9.8**	**8.7**	**8.2**	**8.2**	**8.5**	**8.5**	**8.1**

GROUP 4		125 psi								
		9,000 lb			**12,000 lb**			**15,000 lb**		
		2 mph	**4 mph**	**8 mph**	**2 mph**	**4 mph**	**8 mph**	**2 mph**	**4 mph**	**8 mph**
16 C	Avg. Strain	34.25	30.46	27.86	30	38.01	34.61			
	COV B/L	6.4	3.9	4.7	65.3	3.7	4.3			
	COV W/L	**11.1**	**8.5**	**8.3**	**61**	**10**	**9.5**			
20 C	Avg. Strain	48.59	42.45	37.5	62.08	55.82	48.95	73.33	66.3	59.15
	COV B/L	3.9	5.7	3.2	1.9	1.6	2.5	1.4	1.1	1
	COV W/L	**9.1**	**9.9**	**10.7**	**7.4**	**7.2**	**8.4**	**7.2**	**7.2**	**7.3**
30 C	Avg. Strain	69.77	65.07	60.52	69.77	84.52	77.35			
	COV B/L	4.3	4.6	3	4.3	1.5	1.4			
	COV W/L	**7.7**	**7.7**	**7.3**	**7.7**	**6.6**	**7**			
40 C	Avg. Strain	101.77	100.62	96.68	121.75	121.53	116.28	135.76	135.95	129.86
	COV B/L	3.6	1.2	1.7	0.6	0.9	1	1.3	0.9	0.8
	COV W/L	**7.8**	**7.1**	**6.7**	**7**	**6.5**	**6.4**	**6.4**	**6.2**	**6**
50 C	Avg. Strain	93.03	96.87	100.92	108.48	115.72	122.87	120.65	130.55	135.46
	COV B/L	1.6	1.1	5.8	1	0.6	5	2.2	0.8	2.3
	COV W/L	**9.7**	**9**	**9.7**	**8.8**	**8.6**	**9.3**	**9**	**8.8**	**8.6**

Table C.5 Test Results for Group-5 (Longitudinal Gauges, Embedded, centerline of wheelpath)

GROUP 5		80 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	30.07	26.22	22.21	36.2	32.05	26.35			
	COV B/L	5.3	4.6	1.8	0.8	1.2	1.5			
	COV W/L	**21.9**	**24**	**22.5**	**21.5**	**22.5**	**22.4**			
20 C	Avg. Strain	31.18	26.18	21.18	35.42	31.3	25.53			
	COV B/L	1.6	1.1	3.3	0.8	1.3	1.2			
	COV W/L	**23.4**	**25.6**	**26**	**23.7**	**25.6**	**24.7**			
30 C	Avg. Strain	49.87	41.12	30.91	56.05	47.44	36.2			
	COV B/L	0.6	1.9	2.6	0.9	0.8	1.7			
	COV W/L	**22.9**	**27**	**27.8**	**21.4**	**25.3**	**25.7**			
40 C	Avg. Strain	103.18	80.56	54.3	109.07	88.55	60.88			
	COV B/L	1.7	0.9	1.7	2.4	0.6	1.1			
	COV W/L	**22.7**	**29.7**	**31.3**	**21.5**	**28.6**	**30.4**			
50 C	Avg. Strain	229.09	184.48	123.54	229.86	193.77	134.49			
	COV B/L	3.9	1.6	1.9	2	0.8	1			
	COV W/L	**4.5**	**11.1**	**11.9**	**3.4**	**9.6**	**10.3**			

GROUP 5		115 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	34.86	29.54	23.68	47.21	41.6	33.22			
	COV B/L	0.9	1.4	3.4	0.8	0	0.9			
	COV W/L	**21.5**	**24**	**22.4**	**3**	**6.7**	**5.4**			
20 C	Avg. Strain	34.61	29.57	22.97	40.87	35.82	27.99	44.66	39.61	31.71
	COV B/L	2.3	2.7	2.2	1	1.1	1.8	1.1	1	0.6
	COV W/L	**20.8**	**24**	**23.9**	**20.8**	**23.5**	**23.2**	**21**	**23.2**	**22.4**
30 C	Avg. Strain	57.39	47.05	33.78	55.64	53.94	39.58			
	COV B/L	0.9	1.5	8	2.9	0.6	1.3			
	COV W/L	**21.3**	**26.8**	**27.8**	**21.4**	**26.1**	**26.3**			
40 C	Avg. Strain	121.18	91.64	59.82	133.39	106.59	70.97	142.72	115.23	78.99
	COV B/L	1.7	2.5	2.7	1.8	0.6	1.3	2	0.8	1.3
	COV W/L	**19.8**	**27**	**29.3**	**18.6**	**26.6**	**28**	**18.5**	**26.2**	**27.9**
50 C	Avg. Strain	287.28	227.44	150.1	290.52	235.04	154.6	295.2	242.89	169.46
	COV B/L	1.1	1.9	3.7	3.2	1.5	1.5	3.4	1	1.7
	COV W/L	**4.5**	**10.5**	**10.7**	**11.9**	**16.6**	**19.6**	**12.5**	**17.2**	**17.1**

GROUP 5		125 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	40.35	34.81	27.27	53.4	45.8	35.14			
	COV B/L	3.2	1.1	2.2	1.5	2.4	1.4			
	COV W/L	**5**	**7.8**	**7.7**	**5.2**	**8.1**	**6.3**			
20 C	Avg. Strain	38.51	33.59	26.23	45.73	40.86	31.99	50.72	45.88	32.27
	COV B/L	2.3	1.5	2.7	1.5	0.7	1.6	0.8	0.4	0.9
	COV W/L	**2.9**	**5.1**	**6.5**	**1.7**	**4.4**	**4.7**	**1.4**	**3.5**	**21.4**
30 C	Avg. Strain	55.64	45.45	32.69	55.64	54.8	40.13			
	COV B/L	2.9	2.6	2.4	2.9	0.5	1			
	COV W/L	**21.4**	**26**	**25.7**	**21.4**	**25.4**	**26.2**			
40 C	Avg. Strain	127.66	98.53	63.6	146.82	115.68	76.43	154.54	124.78	84.51
	COV B/L	1.3	1.5	1.7	0.7	0.5	1.4	1.4	0.9	1.2
	COV W/L	**21.1**	**28.9**	**28.3**	**19.4**	**26.9**	**28.8**	**18.6**	**25.2**	**27.2**
50 C	Avg. Strain	289.69	235.78	152.33	313.24	257.94	172.89	318.3	267.18	183.97
	COV B/L	3	1.1	4.9	3.6	0.9	3.3	3.1	0.7	1.6
	COV W/L	**4.3**	**10.7**	**11.3**	**4.2**	**10.2**	**10.1**	**3.4**	**9.2**	**8**

Table C.6 Test Results for Group-6 (Transverse Gauges, Embedded, centerline of wheelpath)

GROUP 6		80 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	16.82	14.86	13.83	21.26	19	16.83			
	COV B/L	7.1	4.7	1.4	1.4	1.6	0			
	COV W/L	**14.3**	**13.5**	**13**	**13.2**	**13.2**	**11.9**			
20 C	Avg. Strain	18.16	15.28	13.81	21.33	19.19	17.07			
	COV B/L	3.3	1.3	2.9	0	2.6	1.8			
	COV W/L	**10.5**	**10.5**	**10.1**	**8.9**	**9.9**	**10**			
30 C	Avg. Strain	26.65	22.5	19.74	31.2	27.35	23.64			
	COV B/L	3	2.2	2	1.3	1.5	1.3			
	COV W/L	**10.5**	**10.2**	**10.1**	**9.6**	**9.5**	**9.3**			
40 C	Avg. Strain	44.69	36.27	29.78	46.25	38.92	32.21			
	COV B/L	3.6	1.9	2	1.7	1.8	1.6			
	COV W/L	**9**	**8.8**	**10.1**	**8.6**	**8.7**	**9.6**			
50 C	Avg. Strain	95.01	73.45	58.57	83.27	71.96	59.59			
	COV B/L	8.1	2.9	2.4	2.9	3.3	2			
	COV W/L	**12.3**	**11.8**	**12.8**	**14.4**	**14.6**	**12.3**			

GROUP 6		115 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	19.49	16.72	15	23.99	21.12	18.46			
	COV B/L	1.5	1.8	2	1.7	1.9	1.1			
	COV W/L	**14.9**	**14.4**	**14.7**	**14.2**	**13.3**	**14.1**			
20 C	Avg. Strain	20.61	17.87	15.63	24.53	21.73	18.94	27.6	24.87	21.95
	COV B/L	3.4	2.2	1.9	1.6	0.9	1.6	1.1	1.2	0
	COV W/L	**10.7**	**9.5**	**9.6**	**9.4**	**8.7**	**9.5**	**9.4**	**8.8**	**9.6**
30 C	Avg. Strain	29.41	25.36	21.62	29.72	28.9	24.92			
	COV B/L	1.4	2	6	3.4	1.4	1.6			
	COV W/L	**10.2**	**9.5**	**11.1**	**9.4**	**9**	**9.6**			
40 C	Avg. Strain	56.87	44.2	35.47	58.14	48.93	39.79	61.65	52.84	43.63
	COV B/L	3.3	2.3	2.5	2.2	1.4	2	2.1	1.5	1.6
	COV W/L	**9.1**	**8.6**	**9.6**	**8.4**	**8.4**	**9.8**	**8.6**	**7.8**	**8.9**
50 C	Avg. Strain	111.31	94.82	77.55	109.66	97.53	81.5	109.37	98.99	79.86
	COV B/L	2.6	0.8	3.5	2.8	2.1	1.8	2.5	1.9	5.4
	COV W/L	**15.1**	**11.5**	**13.8**	**15.1**	**13.8**	**13.4**	**15.7**	**14.5**	**16**

GROUP 6		125 psi								
		9,000 lb			12,000 lb			15,000 lb		
		2 mph	4 mph	8 mph	2 mph	4 mph	8 mph	2 mph	4 mph	8 mph
16 C	Avg. Strain	20.17	17.5	15.54	25.39	23.31	19.63			
	COV B/L	4	1.1	0	31.5	1.3	1.5			
	COV W/L	**14.9**	**13.7**	**11.6**	**26.4**	**13.7**	**12.2**			
20 C	Avg. Strain	21.22	18.46	16.15	25.58	22.65	19.7	29.15	26.03	23
	COV B/L	3.3	2.2	2.5	1.6	1.3	2	1	1.2	0.9
	COV W/L	**9.4**	**8.7**	**9.3**	**8.6**	**8.4**	**8.6**	**8.9**	**8.1**	**8.7**
30 C	Avg. Strain	29.72	25.2	21.42	29.72	30.09	25.55			
	COV B/L	3.4	3.2	1.9	3.4	1.3	1.6			
	COV W/L	**9.4**	**9.5**	**9.3**	**9.4**	**9**	**9.4**			
40 C	Avg. Strain	54.23	44.58	36.64	59.63	50.04	41.1	62.66	54.29	45.57
	COV B/L	3.5	1.6	1.6	2	1.6	1.7	2.2	1.3	1.8
	COV W/L	**7.9**	**7**	**8.5**	**7.7**	**7.4**	**8.3**	**8.3**	**7.2**	**8.6**
50 C	Avg. Strain	113.43	96.72	78.32	112.38	100.75	81	113.28	104.27	85.32
	COV B/L	2.9	1.4	3.6	2.6	1.8	4.1	3.7	1.9	5.4
	COV W/L	**13.9**	**10.3**	**11.9**	**13.6**	**11.6**	**14.1**	**14.8**	**13**	**14.7**