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VISCOELASTIC PROPERTIES OF SEED COTTON AND THEIR EFFECT ON MODULE SHAPE AND DENSITY

Robert G. Hardin IV, Stephen W. Searcy, and Shay L. Simpson
Department of Biological and Agricultural Engineering
Texas A&M University
College Station, TX

Abstract

Modules should be constructed with a shape that will resist collecting water to maintain the quality of seed cotton during storage. Meeting this specification requires knowledge of the relationship between the applied compressive force, deformation, and time for seed cotton. Tests were conducted to determine the force-deformation relationship and the deformation as a function of time for creep loading and unloading. The effects of initial loading density, harvesting method, hold time, and number of compressions on density were examined. The initial loading density did not affect the compressed density, but a slight effect was observed in the recovered density due to the weight of the seed cotton. Picker harvested cotton was compressed to a greater density than stripper harvested cotton, but expanded more during recovery, resulting in similar final densities. Viscoelastic behavior was observed, however, the effect on density was small. Improved loading of the module builder is necessary to produce a desirably shaped module. More seed cotton needs to be placed in the center of the module, resulting in a surface that slopes down to the sides.

Introduction

Moisture damage during storage of modules may result in a significant decrease in the quality of seed cotton. This damage may be caused by rain collecting in depressions on top of the module and leaking through the cover. Module shapes that prevent the collection of water on the cover will maintain a higher level of seed cotton quality. Construction of a module with a desired shape requires a better understanding of the behavior of seed cotton when a compressive force is applied. The relationship between force, deformation, and the time-dependent recovery must be known in order to predict the final density and resulting shape of the module.

One of the few studies on the physical properties of seed cotton was performed by Brashears, Kirk, and Hudspeth (1970). The relationship between the applied force and resulting density of seed cotton in a die was examined. The effects of moisture and trash content were tested. An inelastic strain was observed after applying and removing a compressive force, however, no observation was made of the recovery over time. Measurement of viscoelastic properties have been made with lint cotton. Chimbombi measured the resilient force over time exerted by lint after being compressed to a maximum density and released to a lower final density (1998). This resilient force was measured to determine stresses in cotton bale ties. In computing these stresses, only the maximum resilient force was used, and the relationship between time and resilient force was not examined.

To predict module shape and density, the relationship between force, deformation, and time needs to be determined. Bilanski, et al. developed a relationship between applied stress and density for the compression of bulk forages (1985). The equation for this model is:

$$(\gamma_{max} - \gamma)/(\gamma_{max} - \gamma_0) = \exp(-\sigma/K)$$

The initial density, γ_0, can be determined from the data. The parameter γ_{max} represents the asymptotic density value that the material approaches and the parameter K is related to the combination of the elastic modulus and the plasticity of the material.

Mechanical models consisting of combinations of spring and damper elements have been developed to explain viscoelastic behavior. Many of these models are not suitable for agricultural materials, such as seed cotton, because these materials exhibit complex viscoelastic behavior. The four-element Burgers model is commonly used for agricultural materials (Mohsenin, 1986). The mechanical representation of a Burgers model consists of spring and damper elements in series with a parallel combination of a spring and damper.

This model will account for instantaneous elasticity in the material. With a constant force applied, the time-dependent strain has a decaying exponential component and a linearly increasing component. Upon removing the load, the recovery consists of an instantaneous component and a time-dependent component with a decaying exponential form. A permanent strain also results from compression and is directly related to the length of time the force is maintained. For a constant applied stress, the relationship between strain and time is:

$$\varepsilon(t) = \sigma_0(1/E_1 + t/\eta_1 + (1/E_2)(1-\exp(-E_2t/\eta_2)))$$

The applied stress is σ_0. The parameters E_1 and η_1 are the modulus of elasticity and viscosity coefficient for the spring and viscous element in series, while E_2 and η_2 are parameters representing the spring and viscous element in parallel.

The goal of this research was to investigate the viscoelastic properties of seed cotton and use this knowledge to develop a means for constructing modules that will not collect water on their top surfaces. This research has two main objectives in the determination of viscoelastic properties. The effects of different factors on the density of seed cotton after compression were tested. Models for compression and time-dependent effects were fit to the data from compression and creep curves of seed cotton. The adequacy of these models was examined to determine if these relationships can be useful in predicting module shape and density.

Materials and Methods

Compression of seed cotton in a manner similar to the action in a module builder was simulated in the laboratory. A compression testing apparatus was mounted on an existing frame, and force was applied using a hydraulic cylinder attached to a plate. The plate was constructed of ¾” plate steel and had a cross-sectional area of 699.4 cm^2. A load cell was mounted on the opposite end of the cylinder to record force, and a string potentiometer was used to measure the position of the plate. From this position measurement, the height and density of the seed cotton could be determined. The seed cotton was loaded into a PVC cylinder with a depth of 91.4 cm. The cylinder was split into two halves, and held together with quick-release hose clamps around the circumference. This design allowed the walls of the cylinder to be easily removed without disturbing the mass of seed cotton. Removing the sides of the cylinder after compression allowed expansion of the seed cotton following removal of the force uninhibited by the effects of wall friction.

Several independent factors were tested in this experiment. Three initial loading densities, 64, 96, and 128 kg/m^3 (4, 6, and 8 lb/ft^3), and two harvesting methods, picker and stripper harvested cotton, were tested in a factorial design. For these test conditions, the seed cotton was allowed to equilibrate with the ambient atmosphere (average moisture content of approximately 10%). The cylinder was filled completely with seed cotton and a hold time of 900 seconds during each compression was used. Tests were also conducted with a hold time of 15 seconds using picker harvested cotton at an initial density of 96 kg/m^3. The experiment was conducted as a completely random design with four replications of each test.

The seed cotton was loaded into the cylinder and compressed with a maximum applied force of 7200 N. This value corresponds to an applied stress of 104 kPa (15 psi), which is a typical value observed in module builders. As the seed cotton was compressed, the applied force and height of the column of seed cotton were recorded to develop a force-deformation curve. When the maximum force was reached, this value was maintained for the hold time specified for the particular test. During this time, the height of the seed cotton was recorded to develop a creep curve, a plot of strain against time. The force was removed, and the seed cotton was allowed to recover for 120 seconds. A total of five compression cycles were performed. After the final compression cycle, the cylinder was removed, and the height of the column of cotton was recorded at several time intervals.

For each compression cycle, the heights at the beginning of compression and at the start and end of the creep phase were determined. These values were identified by sorting the data recorded from the string potentiometer. The beginning of a compression cycle was identified as the height where the force began to increase. The height where three consecutive force readings were within 5 N was defined as the beginning of creep. The end of creep was easily identified as the last height reading before a substantial increase in height (greater than 0.5 mm, indicating retraction of the cylinder). An analysis of variance was done on this data to compare the effects of treatments and compression cycles. For factors with significant effects, Duncan’s multiple range test was performed on the height data to identify significant differences in the means of the treatments.

The heights of the columns of seed cotton were recorded at 0, 1, 2, 3, 4, 5, 10, 15, 30, and 60 minutes and 24 hours after removal from the cylinder. These heights were measured manually, and the average of two readings from the column was used. The recovered height data was analyzed using the same methods as the data from each compression cycle.

The compression data was sorted into compression and creep phases for each cycle. The compression phase consisted of the readings for all heights between the points identified as the beginning of a compression cycle and the start of the creep phase. The creep phase consisted of all the readings between the heights identified as the start and end of creep. Models were fit to the data from both the compression and creep phases using nonlinear, least squares regression, and the accuracy of these models was examined.

Results

The initial loading density was the most significant effect on the height of the column of seed cotton during creep loading and recovery. While the height of the compressed column of seed cotton differed greatly, the compressed density was similar for all three initial loading densities. However, the recovered density of these columns of seed cotton varied, with a greater mass of seed cotton resulting in a higher recovered density. This result was most likely due to a weight effect, with the majority of expansion in the top portion of the column. If the effect of the weight of seed cotton was insignificant, the change in height of each of the columns during recovery would be proportional to their height and, therefore, the initial loading density. However, the change in height during recovery only increased slightly with increasing initial density (Table 1).

Additional compressions increased the compressed density of the seed cotton, but this effect decreased with each compression. A similar effect was observed during creep loading. The largest increase in density was during the first creep loading, and subsequent cycles showed decreasing changes in density. The magnitude of the change in density obtained by maintaining the force was quite small compared to the compressed density, indicating that viscoelastic effects are minor (Table 2).

Stripper harvested cotton was not compressed to as high a density as the picker-harvested cotton (Figure 1), but the recovery was less, and the final mean height of the picker-harvested cotton after recovery was greater (Figure 2). Seed cotton compressed with a longer hold time during creep loading was compressed to a higher density. While the longer hold time treatments displayed a greater recovery, the final density was still greater than the shorter hold time treatments. These outcomes would be expected with a viscoelastic material. The longer hold time results in both a greater time-dependent permanent deformation and elastic strain (Figure 3).

The compression data was fitted to the stress-density model used by Bilanski for forage compaction (Figure 4). In estimating the parameters for the compression model, the initial density was defined as the density at the beginning of that particular compression cycle. The compression data fit this model well, with an R^2 statistic greater than .94 for all treatments.

The Burgers four-element model was used for the creep data (Figure 5). In modeling creep loading, only the time-dependent deformation was considered. When only time-dependent effects are examined, the instantaneous elasticity is ignored and the initial strain, (0), is zero. The strain, (t), predicted by the equation is then the change in strain as a result of application of a constant stress. The reason for this modification was that differences in the initial strain between replications resulted in an unacceptably high standard error for the parameter estimates. The standard error was often of the same magnitude as the parameter value. The initial strain had such an impact on the model because the magnitude of this initial strain is much greater than the time-dependent strain. Using the modified model, the R^2 statistic was greater than .975 for all treatments and the standard error for the parameter estimates was less than 1% of the actual value of the parameter.

Conclusions

The primary implication of this research involves loading of seed cotton into module builders, and the resulting module shapes that can be expected. This research indicates that with a constant compressive force, a similar compressed density is reached regardless of the initial density or mass of seed cotton. The mass of seed cotton will determine the resulting volume. Therefore, if different masses of seed cotton are loaded into the module builder at different locations and compressed evenly, the module will contain a similar final density of cotton. However, regions with different masses will occupy different volumes, and the resulting top surface will be uneven. This module surface may be subject to water ponding on the cover.

A common practice in forming a module (given that uniform loading is practically impossible) is to tramp until the module has a level or slightly crowned appearance. This operation may result in a module that appears to have a level top surface in the module builder. However, the cotton will continue to expand after the module builder has been removed, resulting in depressions where water will collect. This outcome is the result of several aspects of the physical properties of seed cotton.

Much of the deformation in seed cotton is a result of the time-independent strain that occurs when the void spaces in the material are compressed. This deformation occurs during the initial compression cycle. The differences in volume resulting from additional compression cycles are not practically significant after the second or third compression. Additional compressions with the same applied stress result in additional deformation due to the time-dependent plastic deformation. Since this time-dependent inelastic strain is small, additional compressions have little effect.

With a constant force, the dominant factor affecting the height of seed cotton after compression is the mass of seed cotton. Therefore, a module must be loaded according to the desired final shape. If the desired module should be crowned, then more seed cotton should be placed in the center of the module and less near the sides. This action may be accomplished with a mechanical device capable of distributing the seed cotton according to a desired pattern without interfering with the tramper foot.

Improved loading of the module builder is necessary when constructing modules with either picker or stripper harvested cotton. However, because the compressed density of stripper harvested cotton is less when the same pressure is applied, using a higher compressive stress with stripper harvested cotton may be more efficient. Further studies would need to be conducted to ensure that the quality of the stripper harvested cotton is not adversely affected by the higher applied stresses.

References

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Table 1. Density after compression and 24 hours of recovery and change in height during 24 hours of recovery for different initial loading densities. Means in the same column followed by the same letter are not significantly different at the 5% level.

Initial Density (kg/m^3)	**Compressed Density (kg/m^3)**	**Recovered Density (kg/m^3)**	**Change in Height (mm)**
64	291.6^a	149.9^a	63.5^a
96	293.9^a	163.2^b	72.2^a
128	292.3^a	175.4^c	89.7^b

Table 2. Effect of number of compressions on density. Means in the same column followed by the same letter are not significantly different at the 5% level.

Compression	**Compressed Density (kg/m^3)**	**Creep Change in Density (kg/m^3)**
1	276.0^a	14.8^a
2	289.8^b	8.3^b
3	295.9^c	6.1^c
4	299.4^d	5.0^d
5	302.0^d	4.3^e

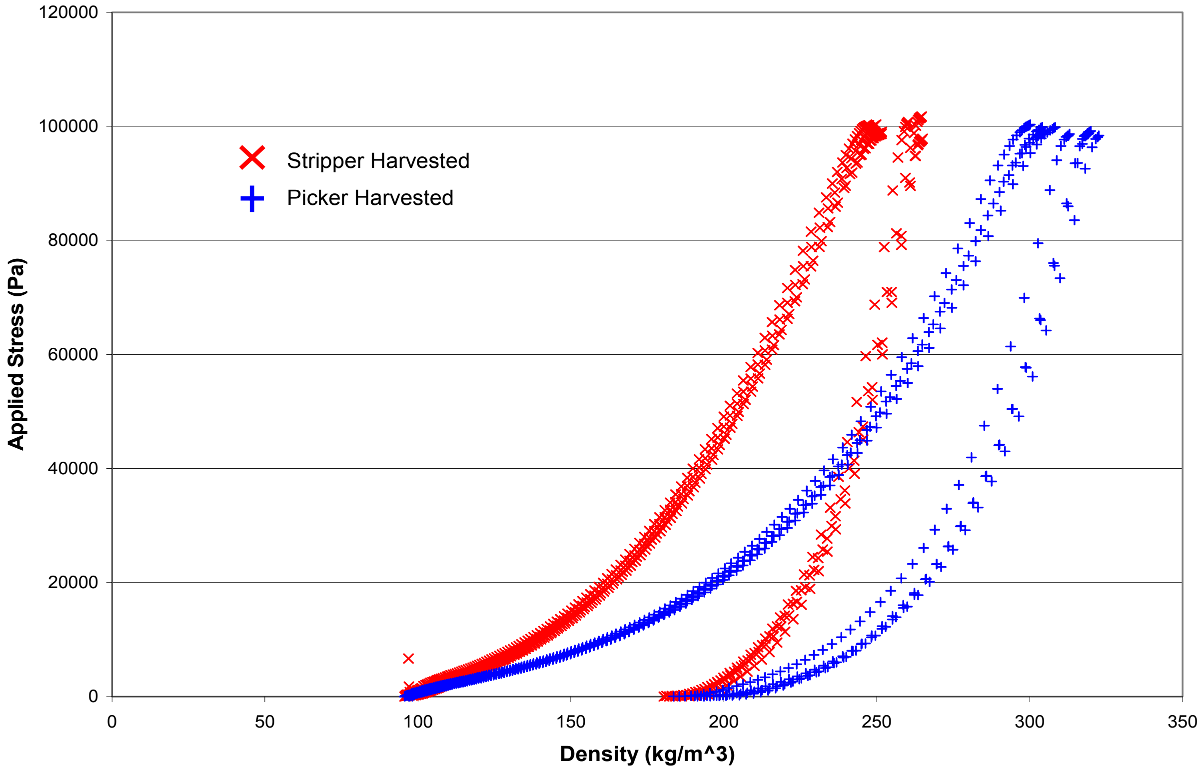

Figure 1. Stress-density relationship for the first and second compression cycles of stripper and picker harvested cotton with an initial density of 96 kg/m^3 and a hold time of 900 seconds.

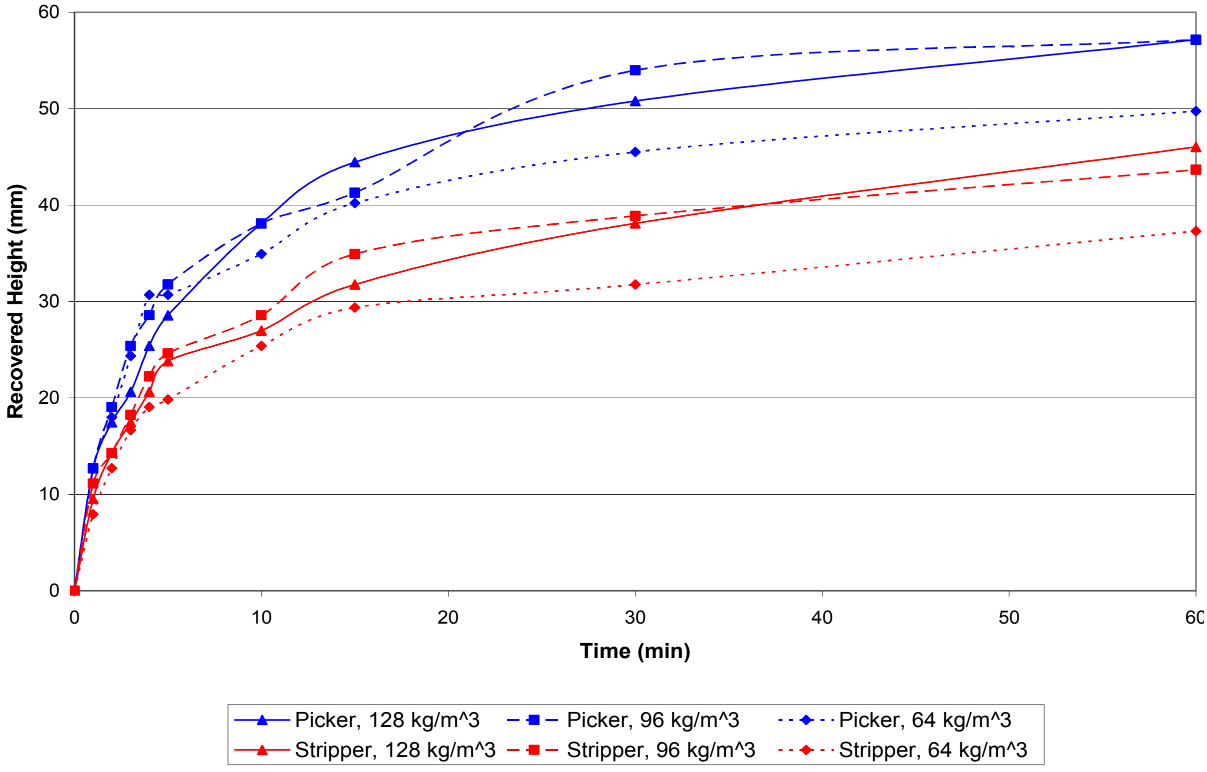

Figure 2. Recovery of picker and stripper harvested cotton.

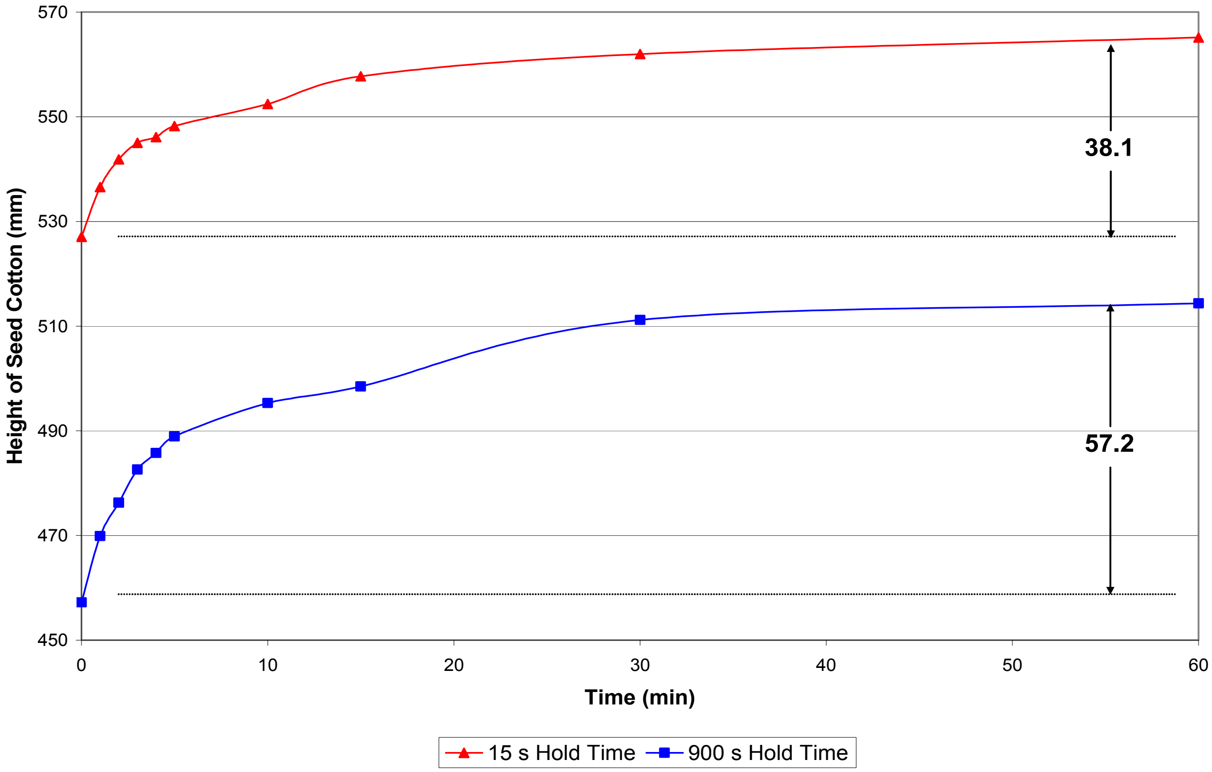

Figure 3. Recovery of seed cotton with force maintained for different lengths of time.

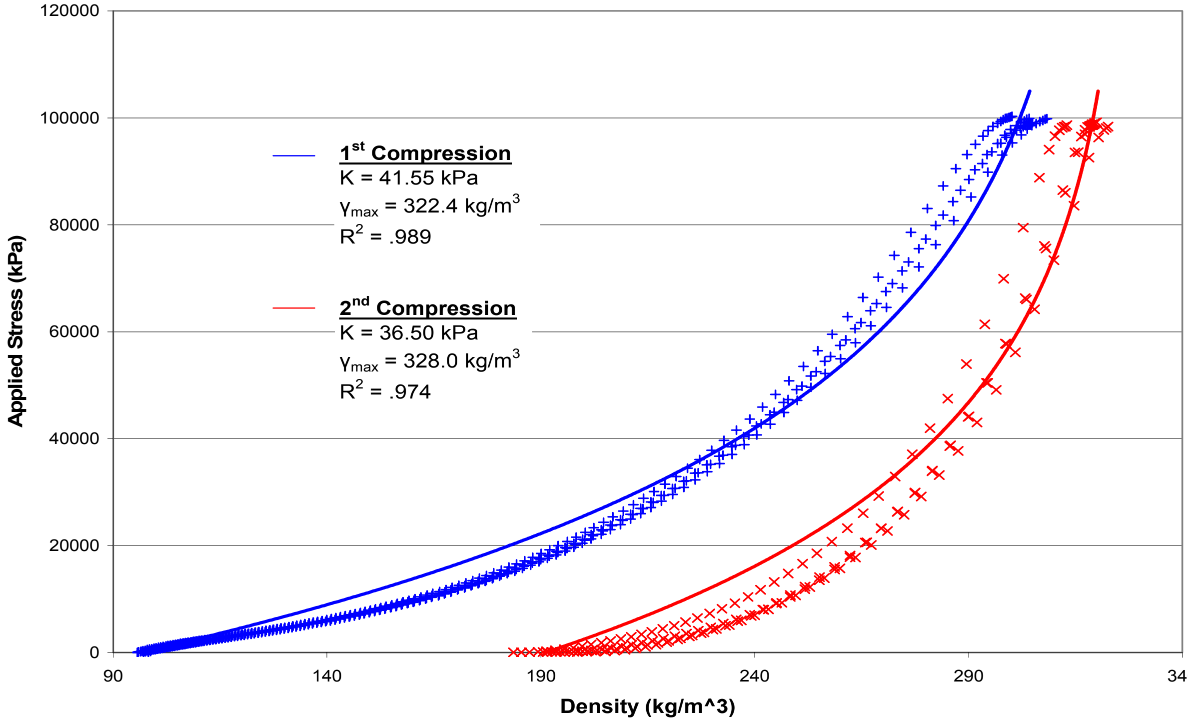

Figure 4. Compression model fit to first and second compression cycles of picker harvested cotton with an initial density of 96 kg/m^3 and a hold time of 900 seconds.

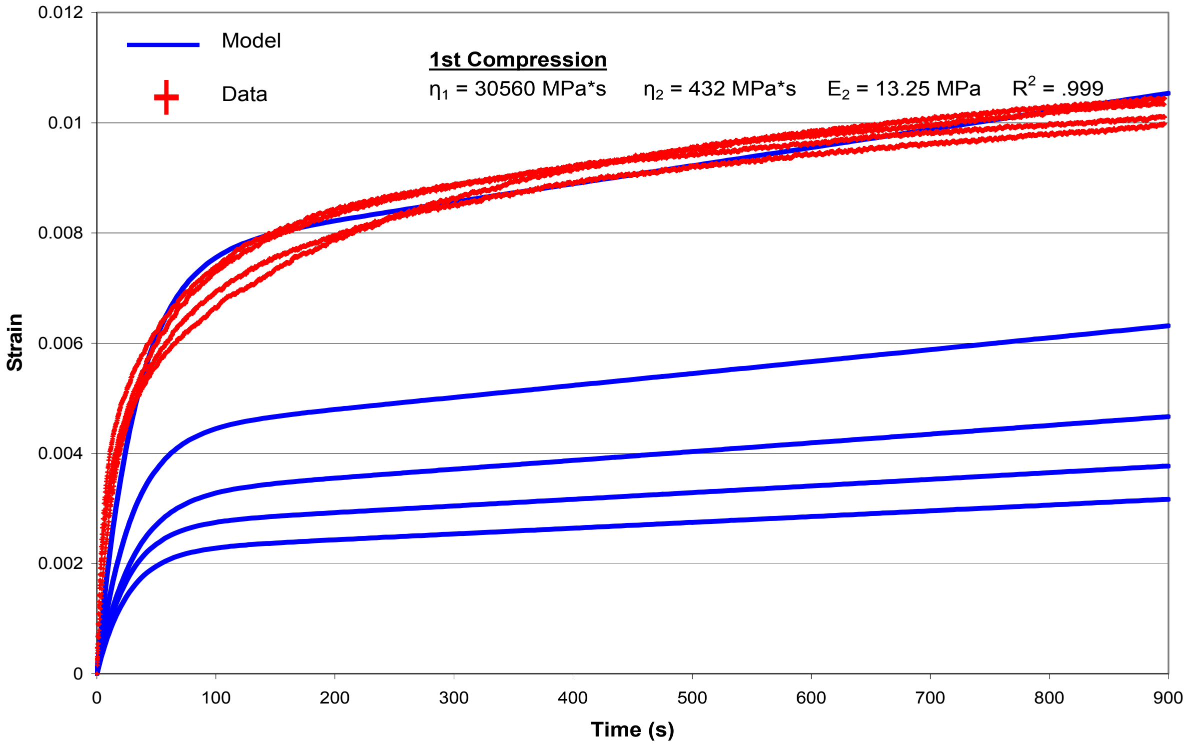

Figure 5. Creep data for first compression cycle of picker harvested cotton with an initial density of 64 kg/m^3 and a hold time of 900 s and Burgers four-element model fit to data for all five compression cycles.