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Uniaxial Loading of Biological Specimens

INTRODUCTION:

In the medicinal industry, it is sometimes crucial to find replacements for certain biologically-produced material, such as the skin, when the original has been injured. An ideal replacement for such a substance should be able to serve as a substitute for the original in its entirety, and should thus have the same structural property as the original. In the case of the skin, this would require that the artificial skin stretches and releases tension like real skin.

Stress, strain, Young's modulus, and stiffness are quantities used to measure the properties of materials. Stress is the amount of force applied over a cross sectional area. Stress induces strain, which is the amount of stress-induced displacement exhibited per original unit length. Young's modulus (E) is the quotient of stress divided by strain. Stiffness (k) is force applied over displacement resulted. Strain, Young's modulus and stiffness indicate the strength of the material.

In this lab, we attempt to determine the values of E and k for the Spenco® Skin Care Pad and the chicken skin by applying uniaxial loads. As more and more force is applied, both materials will stretch more and more in a linear fashion. However, we expect that the two materials will yield different results. We expect that the chicken skin will experience plastic deformation with less force applied and will be stiffer, although the E and k for the chicken skin samples should be more inconsistent overall because it is a biologically-produced material, and would therefore not be as structurally uniform as the mass industrial produced skin care pad. In addition, we expect E to be a material property and be constant for all samples of a material regardless of dimension. We expect k to be a structural property that is affected by the material as well as the geometry of the sample: it should be smaller for a lengthier sample and larger for a shorter sample.

MATERIALS AND METHODS:

The materials used for this experiment include:

- Spenco® Medical Corporation skin pad samples, in different dimensions
- Frozen chicken skin samples, in different dimensions
- Ring stand
- Laboratory clamps
- Metal binder clips
- Ruler and caliper
- Weight set
- Scalpel and cutting board

Testing samples of various dimensions, measured with a ruler, were cut from the provided skin pads and chicken skin. Samples were cut in pairs as a precaution for possible tearing and plastic deformation from axial loading. Three pairs were cut for both the skin pad and chicken skin.

In performing this experiment, we attempted to cut samples of the skin in which two variables, such as the length and the thickness, are kept the same while the third changes. However, as we were unable to keep the clamps in the same places in all specimens, we were not able to keep constant lengths overall. Thus, the dimensions that we ultimately ended up in the skin pad samples were of the following dimensions: 17.00 x 20.00 x 3.85mm, 10.45 x 20.00 x 3.85mm, 13.10 x 15.00 x 3.85mm, and finally 52.50 x 20.00 x 3.85mm. Note that the first two and the last samples have the same thickness and width but different lengths. The chicken skin dimensions are as follows: 14.30 x 19.91 x 0.85mm, 13.25 x 14.80 x 1.10mm, and 34.25 x 14.80 x 1.05mm.

The apparatus consisted of a ring stand to which a buret clamp was fastened. A laboratory clamp was attached to this clamp from which our samples were hung. First, each sample was attached to the top clamp. The length was taken, by means of a caliper, from the bottom of the top clamp to a marked point where the bottom clamp would be placed. Measurements of width and thickness (approximately at the center of the sample) were also recorded. The second clamp was then attached to the bottom of the testing sample. The second clamp had a wire attached at the bottom from which the weights were hung. The first weight was then hung and measurements of length, width and thickness were once again taken. It should be noted that the thickness measurements for the skin pad were more accurate than those obtained for the chicken skin because of the non-homogeneous geometry of the chicken skin.

Subsequent loads were applied in the following fashion: axial loads were applied by attaching standard metric weights in increasing magnitude starting with a minimum of 20g and up to a potential maximum of 1000g. For all samples of the skin care pad, the weights were added in 20g intervals starting with 20g. The maximum weight applied varied between the samples depending on the ability of the sample to withstand greater loads. After testing the first chicken skin sample, it was observed that the chicken skin was able to withstand a greater magnitude of loads in comparison to the skin care pad. Consequently, loads were added to the second and third chicken skin samples in intervals of 50g (starting with 50g and reaching a potential maximum of 1kg depending on sample strength).

RESULTS:

To determine the stiffness values (k) of individual samples, a force versus displacement graph must be plotted. The slope of the initial linear portion of the curve represents k since k correlates how much an applied force would displace/stretch an object. The portion after the straight curve represents the sample in a state of plastic deformation. Force is calculated by multiplying the applied load with the acceleration due to gravity (9.81 m/s^2). The percent error for each value of force ($\%e_{force}$) is determined by the following, where e_{mass} is the error for the mass used and F is the calculated force:

$$e_{force} = 9.81 \times e_{mass}$$

$$\%e_{force} = \frac{e_{force}}{F} \times 100\%$$

Displacement of the object is determined by subtracting the deformed length with the initial length. The percent error for the displacement values ($\%e_{displacement}$) is calculated by the following fashion, where e_L is the deformed length, e_{Lo} is the initial length, and d is the net displacement:

$$e_{displacement} = \sqrt{(e_L)^2 + (e_{Lo})^2}$$

$$\%e_{displacement} = \frac{e_{displacement}}{d} \times 100\%$$

To determine the Young's Modulus (E) of a material, a stress versus strain graph must be plotted. Similarly, E is represented as the slope of the initial linear portion of the curve. Stress is calculated by dividing the uniaxial force with the perpendicular cross-sectional area. The percent error for stress ($\%e_{stress}$) is dependent on the percent error of the force and of the area ($\%e_{area}$) in the following manner:

$$\%e_{stress} = \sqrt{(e_{force})^2 + (e_{area})^2}$$

$$\text{where } \%e_{area} = \frac{\sqrt{(e_{width})^2 + (e_{thickness})^2}}{A}$$

Strain felt by an object is determined by dividing the displacement in length with the initial length. The percent error for the strain values ($\%e_{strain}$) is calculated with the equation below:

$$\%e_{stress} = \sqrt{(e_{displacement})^2 + (e_{Lo})^2}$$

Tables 1 and 2 display some of these calculated values for the skin care pad and chicken skin data set respectively. Figures 1, 2, 3, and 4 and Figures 9, 10, and 11 displays the force versus displacement graphs for the skin care pad samples and the chicken skin samples respectively. The initial linear portions of these graphs were determined via inspection. Linear fits were performed on the data points corresponding to this line to determine the k values.

Figures 5, 6, 7, and 8 and Figures 12, 13, and 14 displays the stress versus strain graphs for the skin care pad samples and the chicken skin samples respectively. Corresponding to the same method described above, the E values were determined for each test sample.

Since there are inherent errors in each value of force, displacement, stress, and strain, there are also errors in each value of k and E generated from the graphs. To determine this, the maximum possible value of the slope is subtracted by the minimum possible value. The difference is then divided by two. If *m* is the average slope value, then the acceptable range for *m* is:

$$slope = m \pm \frac{m_{\max} - m_{\min}}{2}$$

Tables 3 and 4 display the values of k and E for each sample of the skin care pad and chicken skin. The average value of E for the skin care pad is calculated to be: 34800 ± 8600 N/m^2.

DISCUSSION:

Investigation of the material properties of each of the materials at hand via the methods previously described yielded incongruent material properties. Empirically, the organic chicken skin maintained a more rigid structure, as it was able to sustain a larger axial load. Consequently, the relative rigidity of the chicken skin when compared to its inorganic complement brings about an increased affinity to undergo plastic deformation. The experimental results play testament to the above statements, as can be observed by the fact that the chicken skin experiences less strain than does the artificial skin at given stresses and the fact that both the stiffness value and Young’s modulus of the chicken skin are considerably larger than those of the skin pad.

Although Young’s modulus and stiffness values are related to the displacement occurring along the axis on which the loads are placed, changes in dimension were observed to occur along all axes of the samples. Data shows that the addition of loads on the z-axis resulted in dimension alterations along the x and y-axes as well. This shows that uniaxial loading does not simply result in uniaxial deformation, but affects the entire geometry of the sample. The complementary axial deformation of the horizontal axes is attributed to shearing strain in those directions. Thus it is critical to examine both normal and shearing strains on specimens to acquire a comprehensive knowledge of the material properties at hand.

In theory, Young's modulus is a fundamental material property of matter and consequently should be affected only by material properties and not those related to the geometry of specimens. Our results, however, do not correspond with the theory, as the different dimensions of both the skin pad and chicken skin generated different values of Young's modulus. It should also be noted that the values obtained for the skin pad samples were more precise than those of the chicken skin samples. These variations are largely due to homogeneity. The skin pad is a manufactured product and therefore has homogeneous material properties and thickness, resulting in samples with equivalent thickness and constant material properties. On the other hand, the chicken skin, being a biological specimen, does not have uniform material properties or thickness. The result of this was having samples containing wide variance in thickness within individual samples as well as from sample to sample.

We cannot determine errors in the variances in the stiffness constants of both the chicken skin and skin pad specimens either, as stiffness is a mutual property of material and geometry, but geometrical dimensions were not kept so that only one dimension was the same while others changed as originally intended.

There are some significant sources of error in the experiment. One factor that produced inaccurate results is the plastic deformation that resulted with the addition of loads to the samples. Specifically, the average percent plastic deformation of the skin pad was 2.58% while that of the chicken skin measured 3.89%. According to Riley's textbook Statics and Mechanics of Materials, plastic deformation is defined as the deformation remaining after an applied load is removed. The plastic deformation that occurred with each load addition resulted in the skewed measurements that were obtained for the corresponding values of stress and strain. This phenomenon cannot be averted unless a fresh sample is used for each weight addition, which is not feasible in the experimental procedure.

Another source of error in this experiment is the limitation in equipment. On the samples, we marked with marker lines where we have clamped the samples and where we were to determine the width. As such, we have noticed that as the loads became heavier and heavier, the clamp began to slide from where it was previously. Attempts to fix it back to where it was before as indicated by the line cannot correct the problem, as there always exist a discrepancy between the original location and the fixed one.

Human sources also figured significantly in the experiment. Sometimes we would tend to clamp the caliper more tightly than we were supposed to, or vice versa. This is especially relevant to the measurement of the thickness of the chicken skin: because the chicken skin was so thin, it was very difficult to determine its thickness exactly using a caliper.

Additional limitations were also present in measuring the thickness of the chicken skin. As time passed while measurements were being taken, the chicken skin lost a portion of its intrinsic flexibility. Thus the measurement of the chicken skin was greatly impaired: as heavier loads were placed on the skin, the chicken skin became less shriveled and almost “stretched back” to its original dimensions.

From data collected within this laboratory experiment, we believe that the material properties of the artificial skin make it a feasible candidate for skin replacement, specifically as a temporary augmentation to victims of burns. Its elastic attributes resist shearing very well. It may also prevent scar tissue from forming, which is generally much stiffer than normal skin, often causing a decreased range of motion.

Obviously, the use of chicken skin to simulate the properties of human skin has various limitations. Human skin, though organic, may have vastly different material properties—a disparity due to genetic variance between organisms as a product of natural selection. Furthermore, the chicken skin was not tested in its original state, that is the skin (rather than being tested on a live chicken) had long since been removed from a chicken and placed in storage. Proteins and such, which play a significant role in the skin's material properties, may have deteriorated thus altering those properties.

The artificial skin tested in this experiment is also not a perfect substitute for skin. Due to its lack of stiffness, it is quite possible that the skin pad may not resist abrasion as well as skin. Moreover, the material itself may be less permeable than skin, hindering the body's ability to excrete water and waste at the point of contact; such an occurrence is commonplace among bandages that have been placed over skin for extended periods of time, in which the skin becomes pale and increasingly supple. In any case, our lack of knowledge of supplementary physical characteristics impedes our ability to make accurate judgments of the severity of the discrepancies.

CONCLUSION:

We determined the average value of Young's modulus for the skin pad as 34800 ± 8600 N/m^2. The stiffness values for the skin care pad ranged from 68±7 to 223±17N/m with the highest stiffness value corresponding to the sample with the shortest length.. For the chicken skin sample, our values for the stiffness ranged from 1060±80 N/m to 2100± 180 N/m and the E values ranged from 1780000±15400 Pa to 3263000± 256100 Pa. An average value for Young's Modulus was not calculated for the chicken skin due to the spread in values from sample to sample. The lack of precision among the values obtained for the chicken skin is attributed to the non-homogeneous geometries inherent in biological specimens.

From these values we concluded that, in general, chicken skin demonstrates more rigidity than the skin care pad. This shows that the Spenco® skin care pad, although not able to withstand as much force and resistance to tearing as human skin, retains material properties similar enough to be declared a viable temporary skin surrogate. The actual material used to manufacture the skin care pad could be modified to be more consistent with the material and structural properties of chicken skin, however. In this way the chicken skin, although not perfect, can be used as a model of human skin. Although the skin care pad did not exactly match the properties of skin, it has been used as an aid in the healing of burns by providing suitable flexibility while protecting the affected area.

This experiment has very significant applications in the medical field specifically in the area of wound treatment and healing. Artificial skin manufactured for the purpose of wound and burn therapy must possess properties similar to those of human skin. The manufactured skin requires that it can withstand the same daily stresses as natural skin does so that it can be beneficial and comfortable for the patient.

APPENDIX:

Tables:

Table 1: Skin Care Pad Calculations

Sample #	**Force**	%Error	**Displacement**	%Error	**Stress**	%Error	**Strain**	%Error
1.1	0.476	1.031	0.00680	1.040	6.18E+03	1.677	4.00E-01	1.081
	1.064	0.461	0.01255	0.563	1.38E+04	1.401	7.38E-01	0.636
	1.653	0.297	0.01615	0.438	2.15E+04	1.355	9.50E-01	0.527
	2.242	0.219	0.01840	0.384	2.91E+04	1.341	1.08E+00	0.484
	2.830	0.173	0.02065	0.342	3.68E+04	1.334	1.21E+00	0.451
	3.419	0.143	0.02268	0.312	4.44E+04	1.330	1.33E+00	0.429
1.2	0.476	1.031	0.00545	1.297	6.18E+03	1.677	5.22E-01	1.383
	1.064	0.461	0.00898	0.787	1.38E+04	1.401	8.59E-01	0.921
	1.653	0.297	0.01033	0.685	2.15E+04	1.355	9.89E-01	0.835
	2.242	0.219	0.01260	0.561	2.91E+04	1.341	1.21E+00	0.737
	2.830	0.173	0.01399	0.505	3.68E+04	1.334	1.34E+00	0.696
	3.419	0.143	0.01490	0.475	4.44E+04	1.330	1.43E+00	0.674
	4.007	0.122	0.01594	0.444	5.20E+04	1.328	1.53E+00	0.652
	4.596	0.107	0.01693	0.418	5.97E+04	1.327	1.62E+00	0.635
	5.185	0.095	0.01802	0.392	6.73E+04	1.326	1.72E+00	0.619
	5.773	0.085	0.01893	0.374	7.50E+04	1.325	1.81E+00	0.607
2.1	0.476	1.031	0.00938	0.754	8.23E+03	1.691	7.16E-01	0.845
	1.064	0.461	0.01438	0.492	1.84E+04	1.418	1.10E+00	0.622
	1.653	0.297	0.01742	0.406	2.86E+04	1.373	1.33E+00	0.557
	2.242	0.219	0.01971	0.359	3.88E+04	1.359	1.50E+00	0.524
	2.830	0.173	0.02172	0.326	4.90E+04	1.352	1.66E+00	0.502
	3.419	0.143	0.02350	0.301	5.91E+04	1.348	1.79E+00	0.486
	4.007	0.122	0.02529	0.280	6.93E+04	1.346	1.93E+00	0.473
	4.596	0.107	0.02690	0.263	7.95E+04	1.345	2.05E+00	0.463
3.1	0.476	1.031	0.00480	1.473	6.18E+03	1.677	9.14E-02	1.476
	1.064	0.461	0.01763	0.401	1.38E+04	1.401	3.36E-01	0.412
	1.653	0.297	0.02520	0.281	2.15E+04	1.355	4.80E-01	0.296
	2.242	0.219	0.03100	0.228	2.91E+04	1.341	5.90E-01	0.247
	2.830	0.173	0.03499	0.202	3.68E+04	1.334	6.66E-01	0.223
	3.419	0.143	0.03875	0.182	4.44E+04	1.330	7.38E-01	0.206
	4.007	0.122	0.04273	0.165	5.20E+04	1.328	8.14E-01	0.191
	4.596	0.107	0.04555	0.155	5.97E+04	1.327	8.68E-01	0.182
	5.185	0.095	0.04875	0.145	6.73E+04	1.326	9.29E-01	0.174
	5.773	0.085	0.05325	0.133	7.50E+04	1.325	1.01E+00	0.163
	6.362	0.077	0.05675	0.125	8.26E+04	1.325	1.08E+00	0.157

Table 2: Chicken Skin Calculations

Sample #	Force	%Error	Displacement	%Error	Stress	%Error	Strain	%Error
1.1	0.476	1.031	0.00330	2.143	2.81E+03	1.213	2.31E-01	2.171
	1.261	0.389	0.00360	1.964	7.45E+03	0.749	2.52E-01	1.995
	2.045	0.240	0.00385	1.837	1.21E+04	0.683	2.69E-01	1.870
	2.830	0.173	0.00440	1.607	1.67E+04	0.663	3.08E-01	1.645
	3.615	0.136	0.00460	1.537	2.14E+04	0.654	3.22E-01	1.576
	4.400	0.111	0.00455	1.554	2.60E+04	0.649	3.18E-01	1.593
	5.185	0.095	0.00485	1.458	3.06E+04	0.647	3.39E-01	1.499
	5.969	0.082	0.00497	1.423	3.53E+04	0.645	3.48E-01	1.465
	6.754	0.073	0.00550	1.286	3.99E+04	0.644	3.85E-01	1.332
	7.539	0.065	0.00575	1.230	4.46E+04	0.643	4.02E-01	1.278
	8.324	0.059	0.00638	1.108	4.92E+04	0.642	4.46E-01	1.162
2.1	0.770	0.637	0.00785	0.901	4.72E+04	4.602	5.92E-01	0.977
	2.242	0.219	0.00864	0.818	1.38E+05	4.563	6.52E-01	0.901
	3.713	0.132	0.01030	0.687	2.28E+05	4.560	7.77E-01	0.783
	4.694	0.104	0.01124	0.629	2.88E+05	4.559	8.48E-01	0.734
3.1	0.770	0.637	0.00830	0.852	4.97E+04	4.816	2.42E-01	0.864
	2.242	0.219	0.00950	0.744	1.45E+05	4.779	2.77E-01	0.759
	3.713	0.132	0.01045	0.677	2.40E+05	4.776	3.05E-01	0.692
	5.185	0.095	0.01140	0.620	3.34E+05	4.775	3.33E-01	0.637
	6.656	0.074	0.01224	0.578	4.29E+05	4.774	3.57E-01	0.596
	8.128	0.060	0.01265	0.559	5.24E+05	4.774	3.69E-01	0.578
	9.599	0.051	0.01280	0.552	6.19E+05	4.774	3.74E-01	0.571

Table 3: k and E values for Skin Care Pad

Sample #	k	%Error	E	%Error
1.1	117	±8	25900	±2100
1.2	223	±17	31600	±2600
2.1	155	±29	35200	±2700
3.1	68	±7	46300	±3100

Table 4: k and E values for Chicken Skin

Sample #	k	%Error	E	%Error
1.1	2100	±180	178000	±15400
2.1	1060	±80	858000	±69700
3.1	1480	±110	3263000	±256100

Figures:

Figure 1: Skin Care Pad 1.1 - Force vs. Displacement

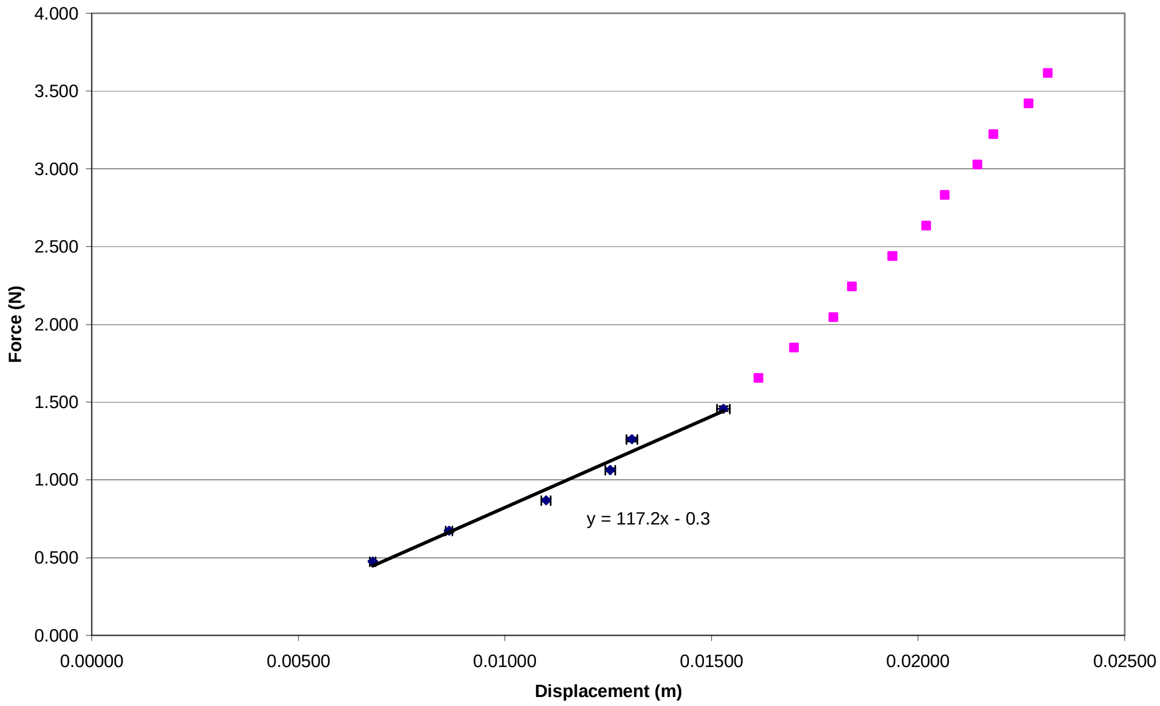

Figure 2: Skin Care Pad 1.2 - Force vs. Displacement

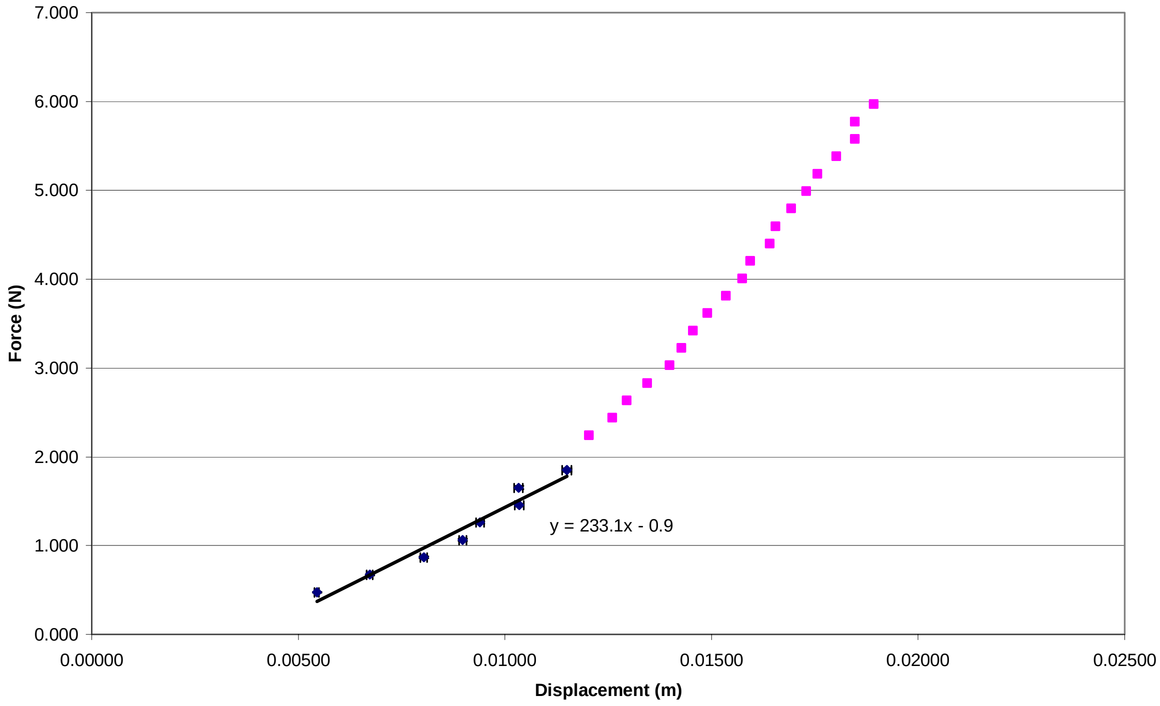

Figure 3: Skin Care Pad 2.1 - Force vs. Displacement

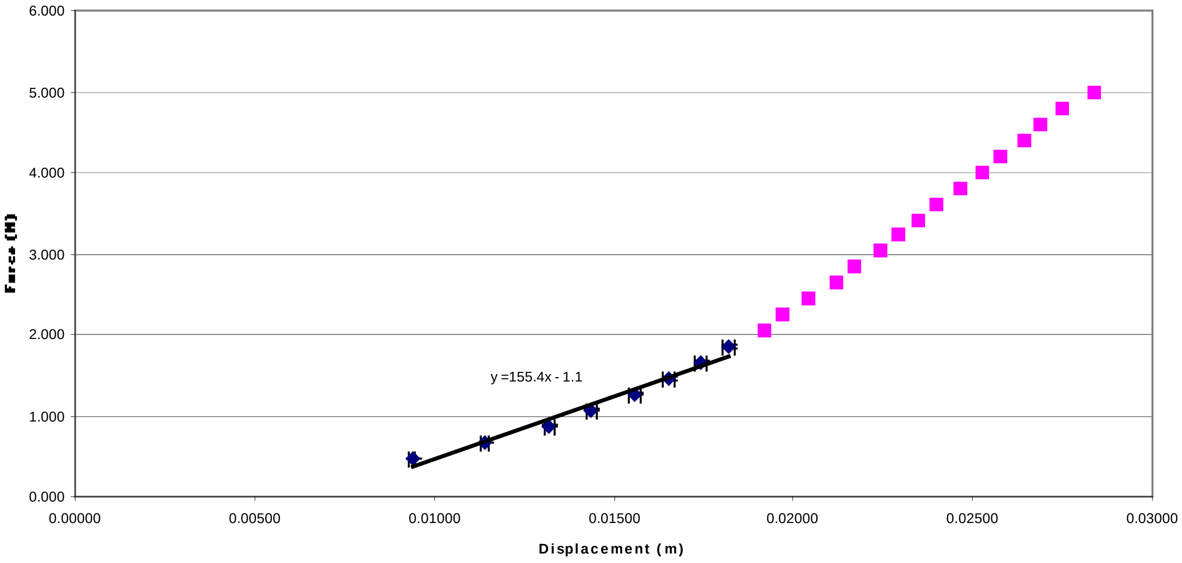

Figure 4: Skin Care Pad 3.1 - Force vs. Displacement

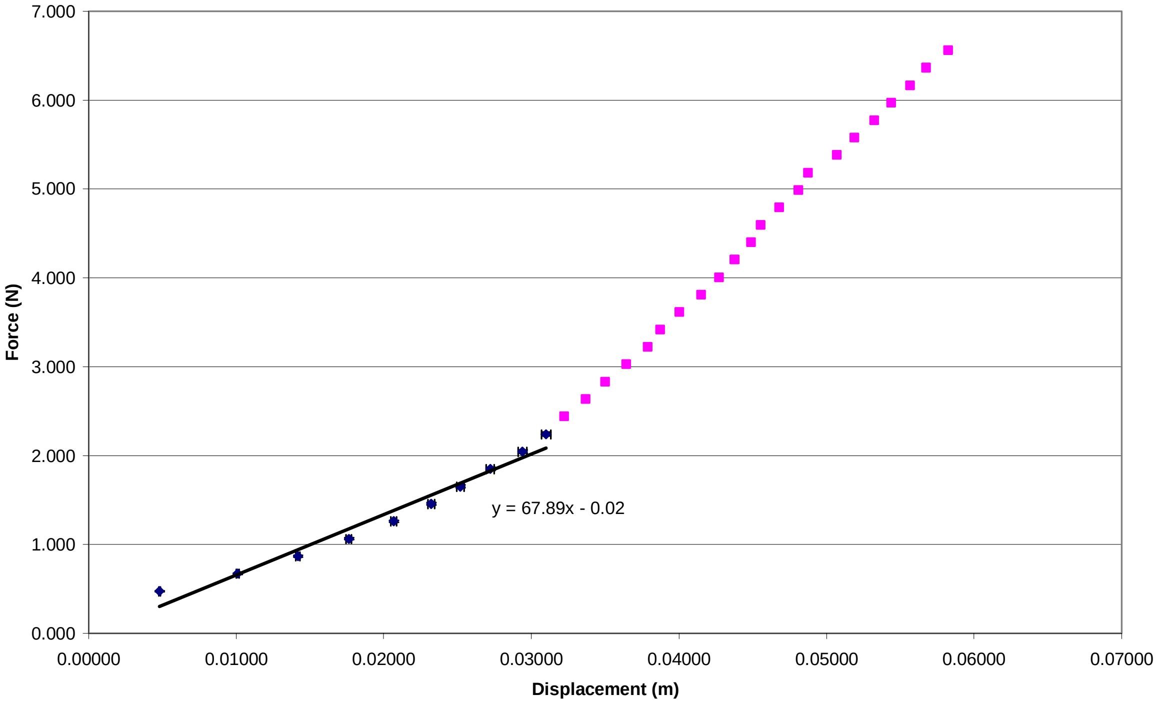

Figure 5: Skin Care Pad 1.1 - Stress vs. Strain

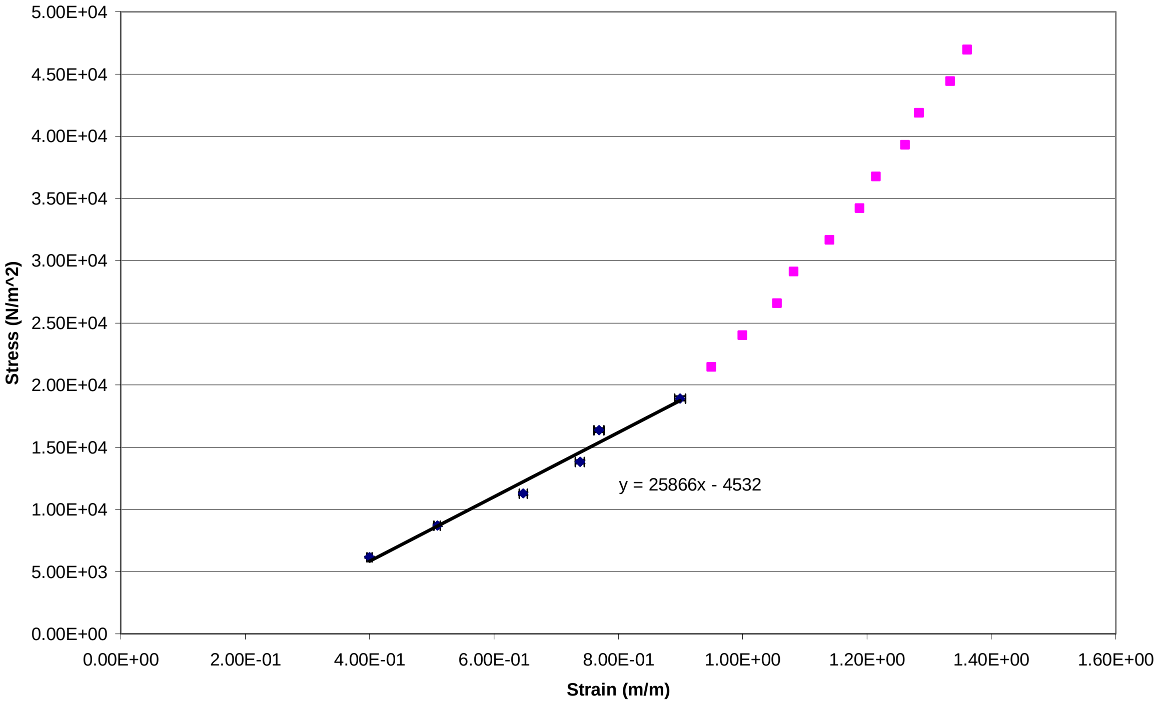

Figure 6: Skin Care Pad 1.2 - Stress vs. Strain

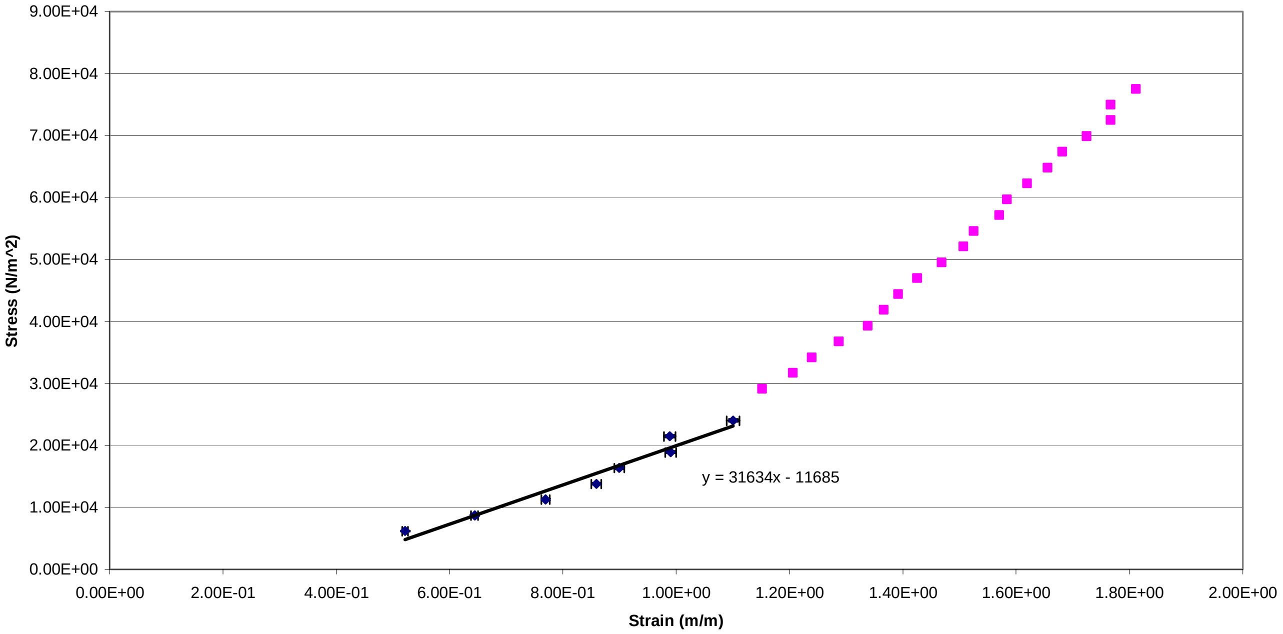

Figure 7: Skin Care Pad 2.1 - Stress vs. Strain

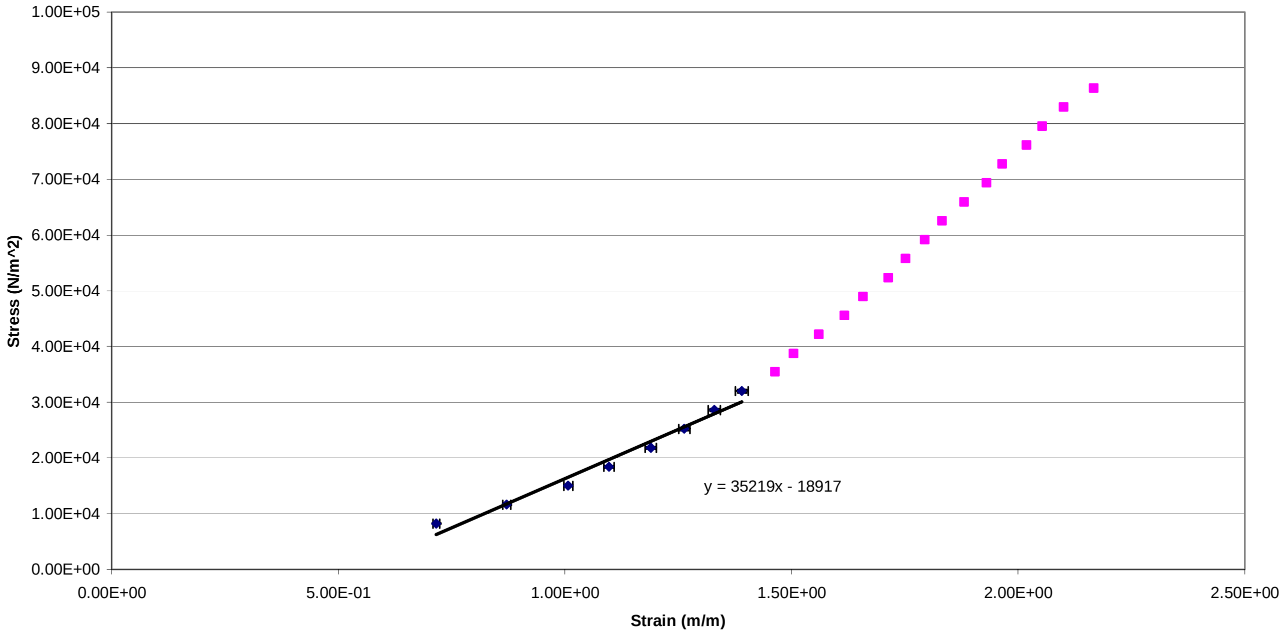

Figure 8: Skin Care Pad 3.1 - Stress vs. Strain

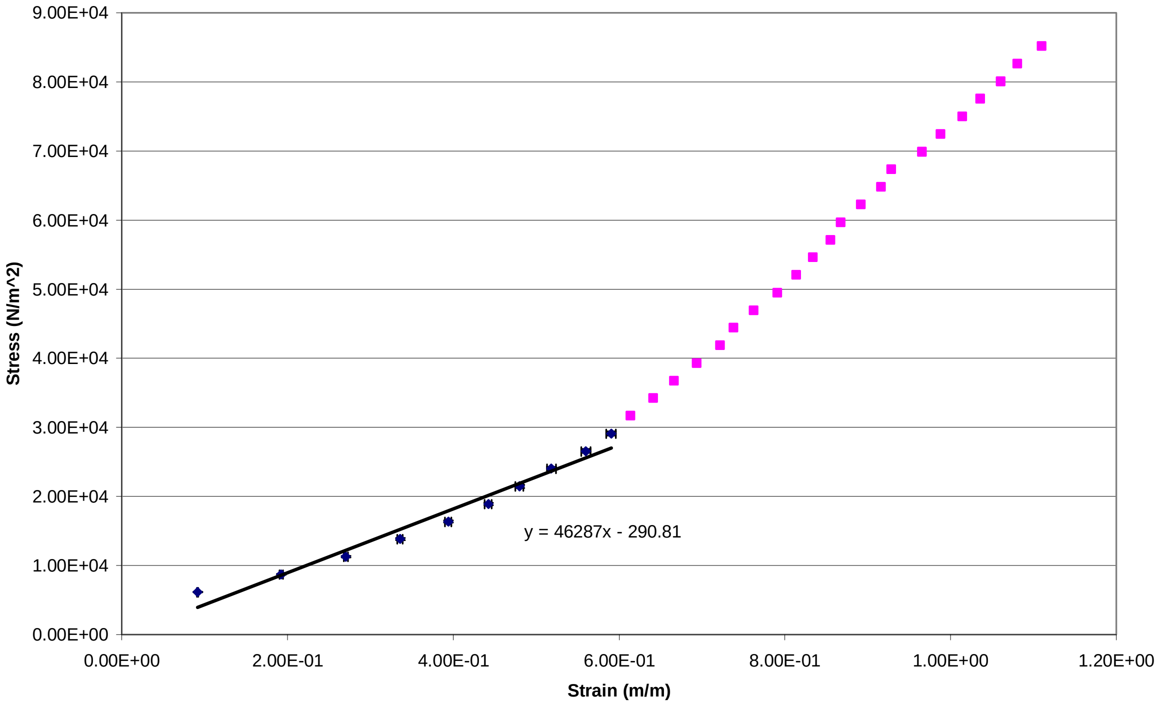

Figure 9: Chicken Skin 1.1 - Force vs. Displacement

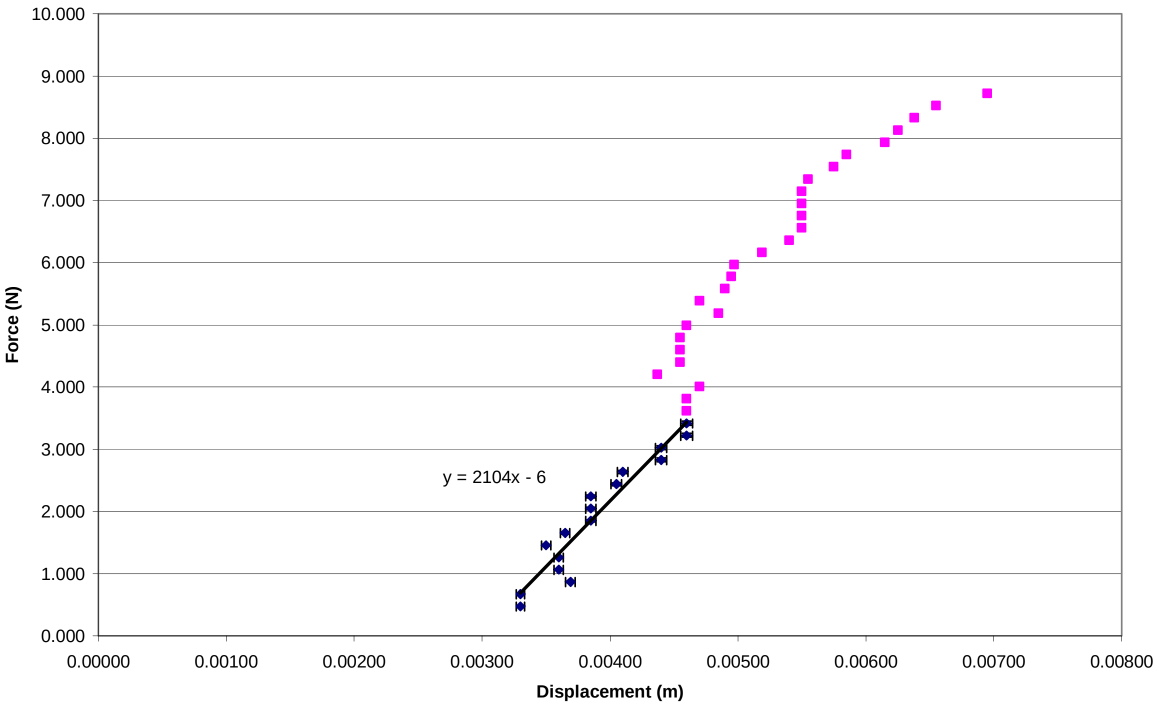

Figure 10: Chicken Skin 2.1 - Force vs. Displacement

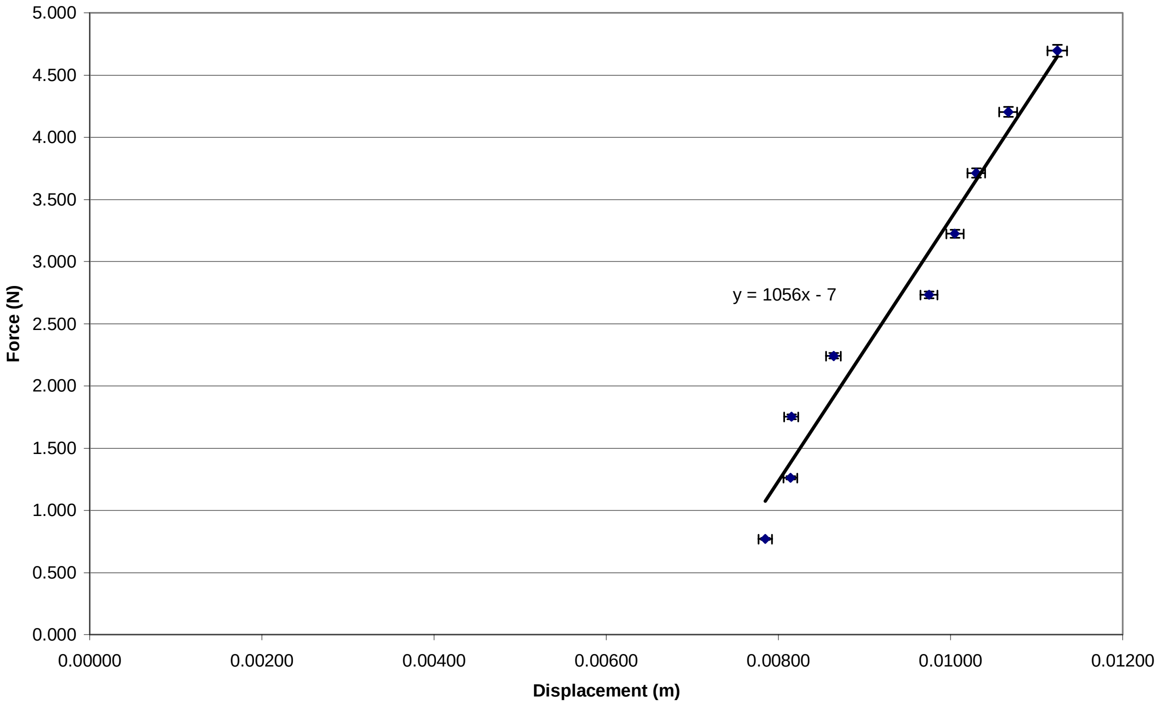

Figure 11: Chicken Skin 3.1 - Force vs. Displacement

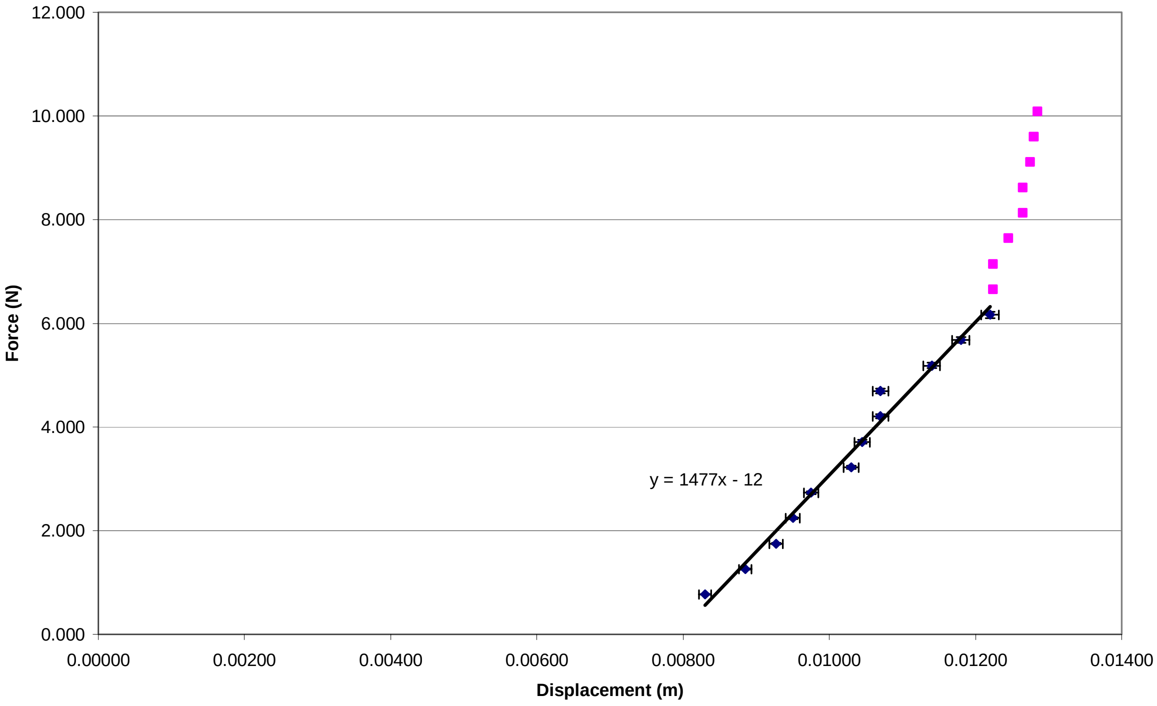

Figure 12: Chicken Skin 1.1 - Stress vs. Strain

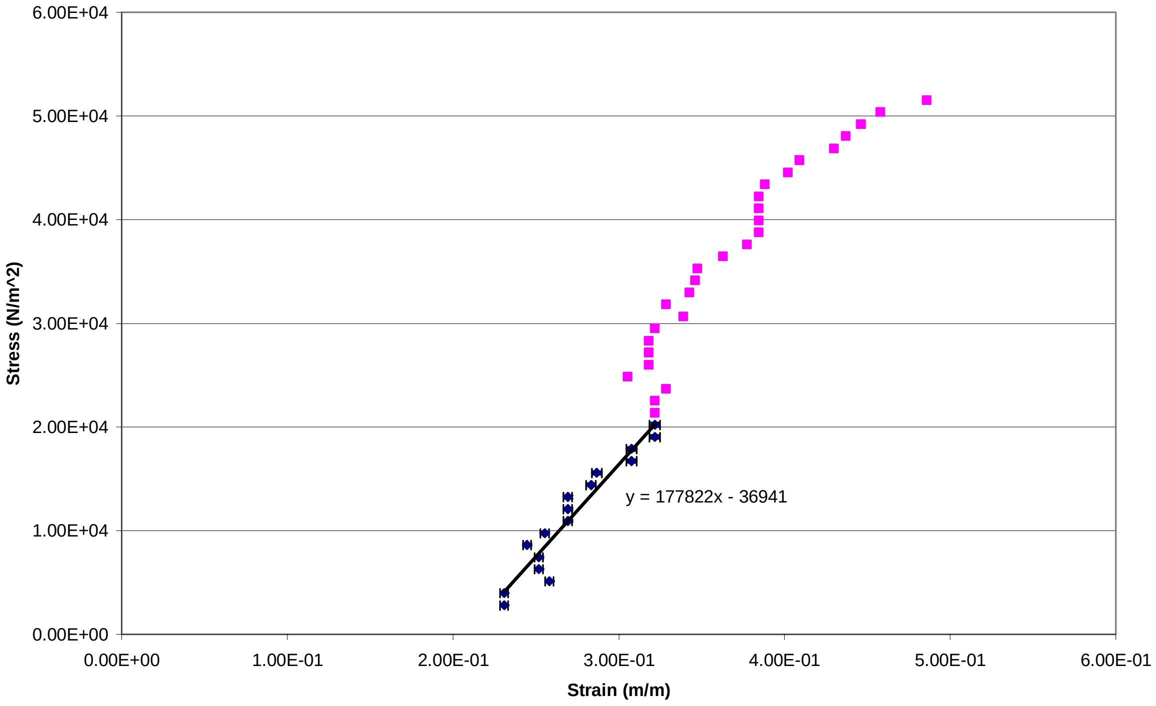

Figure 13: Chicken Skin 2.1 - Stress vs. Strain

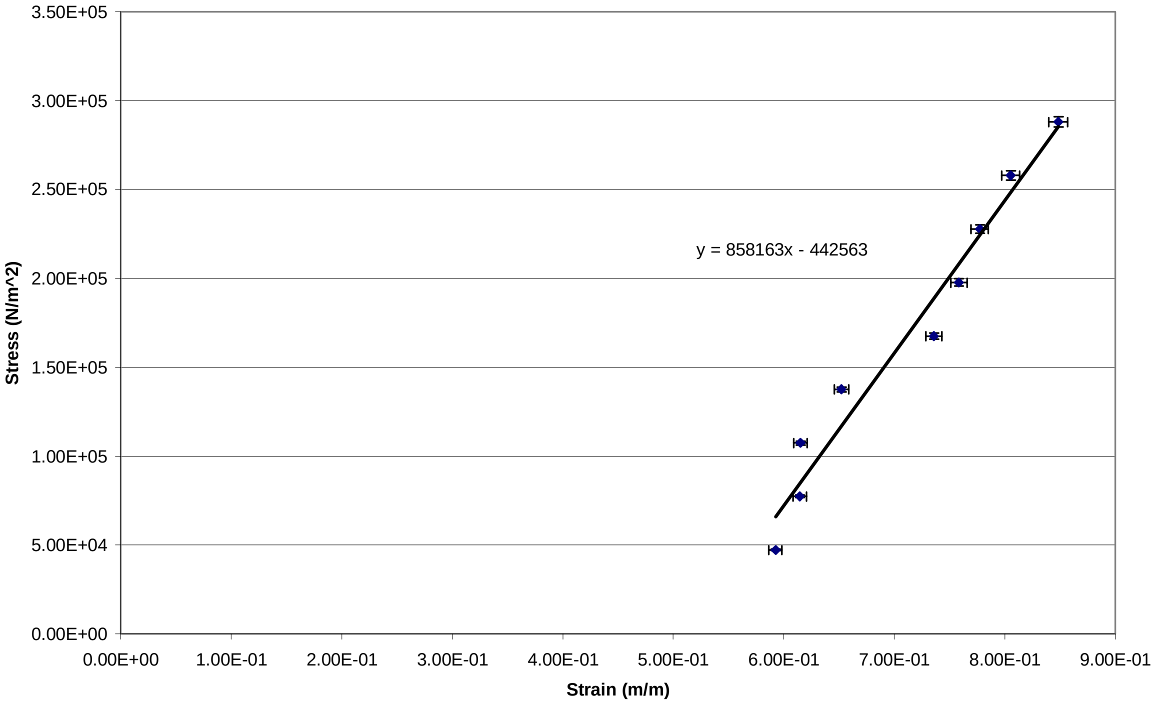

Figure 14: Chicken Skin 3.1 - Stress vs. Strain