Analysis of Dryness Effect on Skin by Adapting Hyperelastic Constitutive Model

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ABSTRACT

The El Nino phenomenon can damage the skin and cause sickness such as skin cancer, heat stroke and heat exhaustion. Due to this phenomenon, an analysis on mechanical properties on animal skin is carried out, where sheepskin is used for investigation through uniaxial tensile test. The aim of this study is to investigate the effect of varied temperature on mechanical properties of animal skin. The process consists of an integration between experimental and numerical approach. A uniaxial tensile test is performed first to measure the basic mechanical parameter of stress-stretch by following the ASTM D2209-00 International testing standard. Next, the hyperelastic constitutive model Arruda and Boyce (A&B) equation is simplified via numerical approach for finding the material parameter. Then, a graph of Stress – Stretch (σ-λ) is plotted for a curve fit with the experimental data to obtain the mechanical properties of the material parameter. As a result, the material parameter which are Arruda and Boyce coefficient, μ and Arruda and Boyce exponent, N are 4.967(MPa) and 3.116, respectively, for SL Temp 33. However, μ and N for SNL Temp 33 are 5.134 (MPa) and 2.357. In contrast, the value of the value of μ and N for SL Temp 36 are 4.943(MPa) and 2.728 and for SNL Temp 36 are 5.199(MPa) and 2.209 .Therefore, this study could be useful for future studies in analysis of skin by adapting hyperelastic constitutive model.

Keyword: *Sheep, Skin, Hyperelastic, Arruda and Boyce*

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Introduction

Recently, countries in South East Asia have suffered the hot and dry environment due to the El Nino phenomenon. Malaysia will not experience the hot and dry spell caused by the El Nino every year because the phenomenon only happens once in two to seven years [1]. The normal day temperature that can rise up to 31°C, but the current El Nino level was recognized to be very intense and had caused the country's temperature to rise between 0.5 to 2.0 °C [2]. The phenomenon can affect almost everyone's daily routines due to heat exposure. Overexposure to the heat can damage the skin and could cause skin cancer. This paper aims to help to investigate the skin behavior exposed to that heat. The main objective of the study is to quantify the biomechanical properties of the skin that undergoes a variation of heat exposure.

To study the biomechanical properties of the skin, most researchers had used human and animal skins for different purposes and investigations. As an example, A. N. Annaidh had used excised human skin for characterizing the anisotropic Mechanical properties of excised human skin [3]. Next, T.A. Andrade was investigating the Ex vivo model of human skin as an alternative to animal use for cosmetic tests [4]. As for animal skin researches purpose, N. F. A. Manan had used bovine skin in quantifying the biomechanical properties of skin via uniaxial tension [5]. Then, O. A. Shergol had used pig skin to study the uniaxial stress vs. strain response of pig skin and silicone rubber at low and high stain rates [6]. Besides that, M. M. Derakhshanfar used 30 male Sprague Dawley rats in evaluating the role of Peganum harmala extract on experimental skin wound healing and biomechanical experiments [7]. Another research used 24 adult female mice to study the hyperelastic material properties of mouse skin under compression tests [8]. This shows that there is a similarity between the human skin texture with the animal skin texture, where it sustains this work which uses sheepskin as the main material for study.

Biomechanical properties of the skin can behave and react differently based on the several factors that affect the skin. According to N. F. A. Manan [9], he studied the effect of skin orientation on biomechanical properties by using sheepskin as a specimen that was prepared into two groups between hair and shaved fur. Based on the result, the unshaved skin was declared as skin that is stronger compared to the shaved skin because the unshaved category has greater strain and stretch value. Another factor that can affect the biomechanical properties of the skin is the tanning agent. According to C. Lu [10], the use of different tanning agents such as chrome, gluetaraldehyde and chestnut extract can influence the water absorption capacity of goatskin. The tanning agent functions to stabilize the collagen fibers structure and increase the degrees of crosslinking of collagen matrices. Based on the results, it is not easy for tanned collagen matrices to swell and the water absorption capacity of samples was subsequently reduced. Thus, in this study, the specimen is prepared to undergo the heating treatment process for various temperatures and also have the tanning agent applied.

Methodology

In general, four phases involve in methodology for this research as illustrate in Figure 1.

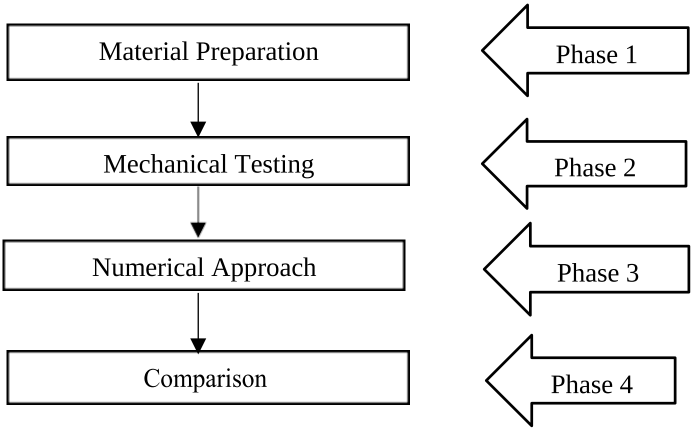

Figure 1: Overall process flow of Experiment-Numerical Integration on Sheepskin

Material Preparation (Phase 1)

For material preparation, the material that will be used for this project is sheepskin, which was obtained from a slaughterhouse near Section 15, Shah Alam. The sheepskin was obtained from a 13 months old male sheep, and he was free from any skin or limbs infection through a confirmation from the slaughterhouse representative. The sheepskin condition was ensured to be dried and remain unshaved before the specimen was prepared.

Specimen Preparation

The first thing to do in specimen preparation is to maintain the sheepskin unshaved and prepared into a dumbbell shape, with the size and dimension with reference from an ASTM International Standard. The specimen will be prepared based on standard testing method for tensile strength of leather according to International ASTM (D2209-00). In order to obtain the accurate dimension as standards require, a dumbbell shaped template was first prepared by schematic diagram on vinyl cardboard. Then, the template acts as guidelines when cutting the skin according to the outer line of the dumbbell shaped template to obtain the specimen. The specimens were prepared into two main categories that had been predetermined based on heat treatment temperature which are 33°C and 36°C. Each of these will be divided into two groups of specimens, one with non-lanolin (SNL) and another with lanolin (SL). Within each categories or groups, four (4) specimens will be tested. Table 1 highlights the notation used for every category. Overall, sixteen (16) specimens is prepared for the testing.

Table 1: Notation for each category

Specimen categories	**Description**
SL Temp 33	Specimen with lanolin, 33°C of heat treatment temperature
SNL Temp 33	Specimen with non-lanolin, 33°C of heat treatment temperature
SL Temp 36	Specimen with lanolin, 36°C of heat treatment temperature
SNL Temp 36	Specimen with non-lanolin, 36°C of heat treatment temperature

Experimental Approach (Phase 2)

The specimens undergoes heating treatment at different temperatures (33 ºC, 36 ºC) using a heating machine in a controlled environment and the heat treatment time is four (4) hours which is fixed for all specimens. The uniaxial tensile test was conducted using the tensile test machine model INSTRON 3382 located in the Strength of Material Laboratory, Faculty of Mechanical Engineering, UiTM Shah Alam. The testing procedure was conducted accordance to the Standard Test Method for strength of leather (D2209-00). A load of 240 N was applied together with the speed of 254 ± 50 mm/min. There are tendencies of specimens to slip during testing, so a wide jig with knurling was used to clamp at the both ends of the specimen and tighten as much as it could. The parameters obtained from the tensile testing are stress, elongation, and strain that can help in determining the mechanical properties of skin by applying formula of stretch-strain.

Numerical Approach (Phase 3)

From the basic mechanical parameter obtained from experimental methods, a conversion of stress-stretch (σ-λ) was done. The Arruda and Boyce model equation was derived into a simpler hyperelastic equation so that the integration of experimental stress-stretch (σ-λ) data and simplify Arruda and Boyce equation can be done using the Microsoft Excel software. For determining the material parameter, a graph of stress- stretch is plotted and curve fitting the experimental graph along with stress- stretch graph was established.

The hyperelastic constitutive Arruda and Boyce model equation [11] was reviewed and simplified before applying the equation in the analysis. The main equation is

$$\sigma = 2(\lambda - \lambda^{-2})\, \mu_0 \sum_{p=1}^{5} \frac{p\, C_p}{N^{p-1}}\, I_{uni}^{p-1} \qquad (1)$$

After considering it incompressible and isotropic characteristic material and under uniaxial tensile, the simplified equation is

$$\sigma = \frac{\mu}{N}\left(\lambda - \frac{1}{2}\right) \qquad (2)$$

Where, σ = Predicted stress

μ = Arruda and Boyce coefficient (MPa)

N = associated with maximum stretch (no unit)

Comparison (Phase 4)

In order to describe the sheepskin behavior, the results will be compared to each other. Firstly, the results are compared in groups of specimen categories which are specimens with lanolin and with non-lanolin, and the different heating treatment temperature. The comparison will discuss maximum value stress, strain and stretch. Then, both results from the experimental data will be compared to the result from the numerical approach which is the Arruda and Boyce model. Lastly, the comparison of material parameter of current studies of mechanical properties with previous studies.

Results and Discussion

The discussion is divided into three parts which are basic mechanical properties, biomechanical properties and comparison with previous study. Basic mechanical properties focuses on the relationship between stress and strain, while the biomechanical properties will discuss the relationship between stress and stretch.

Basic Mechanical Properties

<u>SL Temp 33</u>

Figure 2 shows a plotted graph of stress-strain curve for specimen with lanolin which is heated at temperature of 33°C. All the specimens produce good stress-strain curve for non-linear elastic material as shown in Figure 2, same as the other categories. Although they produce good stress-strain curve, all of the specimens did not perform in an alike manner. It can be seen that the first two specimens and last two specimens are not within the consistent range of strain. The maximum strain value recorded for SL Temp 33 is 0.921 at maximum stress of 3.017 MPa.

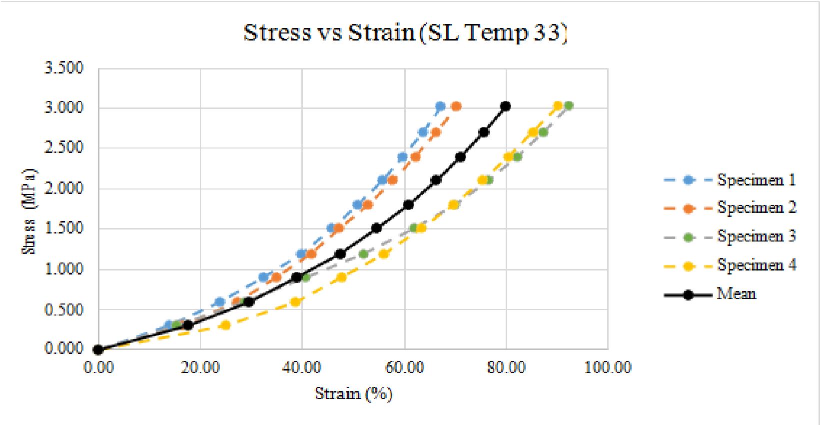

Figure 2: Graph of stress against strain for SL Temperature 33

<u>SNL Temp 33</u>

Figure 3 shows a plotted graph of stress-strain curve for specimen with non-lanolin and heat treated at 33°C. All the specimens produce good stress-strain curve for non-linear elastic material as shown in Figure 3, similar to the previous category. The curve line for specimen 4 performed in a slightly different manner from the other specimens, where they perform in consistent range of strain. The maximum strain value recorded for SNL Temp 33 is much lower than SL Temp 33 category which is 0.638 at the same maximum stress of 3.017 MPa.

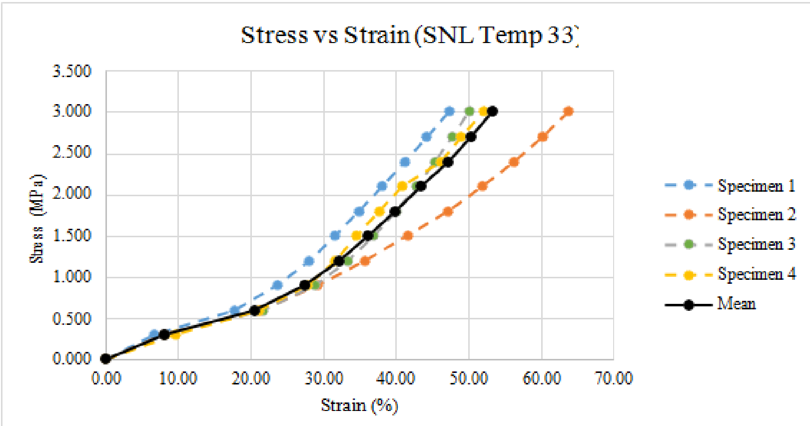

Figure 3: Graph of stress against strain for SNL Temperature 33

SL Temp 36

Figure 4 shows a plotted graph of stress-strain curve for specimen with lanolin which is heated at temperature of 36°C. From Figure 4, it can be seen that all the specimens produce good stress-strain curve for non-linear elastic materials. Specimens 1, 2 and 3 performed in an alike manner while specimen 4 performed slightly further away from other specimens. The maximum strain value recorded is 0.776 for specimen 3 at the maximum stress of 3.017 MPa. Furthermore, the maximum strain value for SL Temp 33 is higher compared to SL Temp 36 category. The difference between the highest and lowest strain at maximum stress is 0.23.

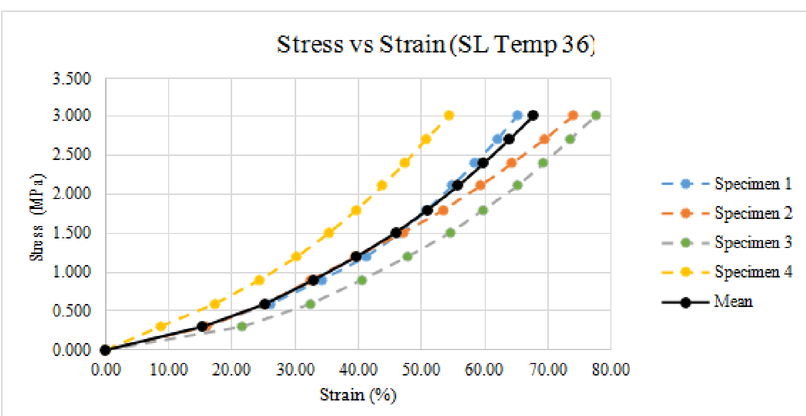

Figure 4: Graph of stress against strain for SL Temperature 36

SNL Temp 36

There were total of four (4) specimens actually, but one of the specimens performed differently and did not show signs of extension which indicated a defective specimen. Thus, only three (3) specimens was analyzed for SNL Temp 36 category. Figure 5 shows a plotted graph of stress-strain curve for specimens with non-lanolin heated at temperature of 36°C. Based on Figure 5, the curve line also shows good stress-strain curve for non-linear elastic material for soft tissue. The maximum strain value which is seen in specimen 1 is 0.565 at maximum stress of 3.017 MPa.

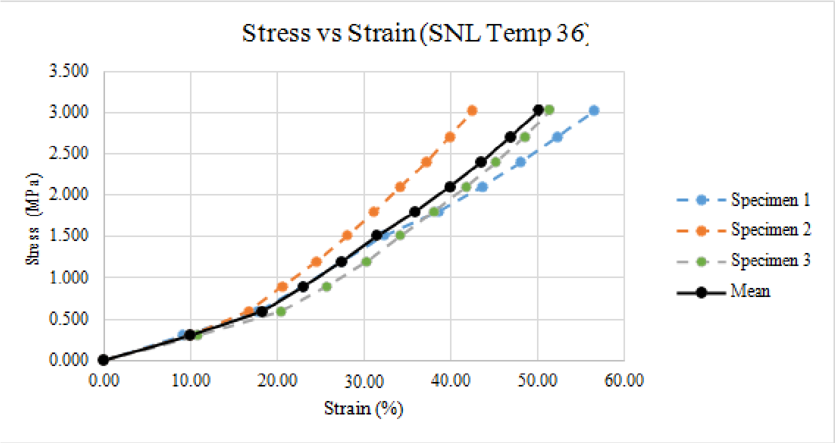

Figure 5: Graph of stress against strain for SNL Temperature 36

Standard Deviation Stress and Strain

Figure 6 and Figure 7 shows the standard deviation for tensile stress and strain value for four (4) specimen categories which are referred from Table 4.5. It can be seen that both figures indicate a small result dispersion in the experimental data. As a result, it shows a good test performed and homogeneous results. The variant values for tensile stress is acceptable at SL Temp 33 and SL Temp 36 because both values are less than 5%. As for the strain, all of the variance proved to be acceptable as well since all categories values are less than 5%.

Table 2: Mechanical properties of Sheepskin

	SL Temp 33	**SNL Tem p 33**	**SL Temp 36**	**SNL Temp 36**
Tensile Stress (MPa)	3.729	5.132	4.005	4.305
Standard Deviation	0.637	1.063	0.103	1.050
Variance	0.405	1.129	0.011	1.102
Strain	0.902	0.730	0.805	0.618
Standard Deviation	0.119	0.138	0.111	0.037
Variance	0.014	0.019	0.012	0.001

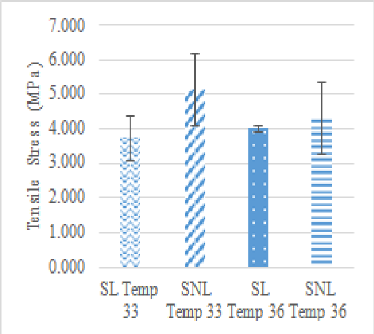

Figure 6: Tensile stress for sheepskin

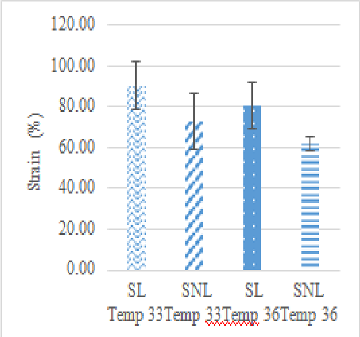

Figure 7: Strain for sheepskin

Biomechanical Properties

All four (4) specimen categories are plotted for Stress-Stretch graph as shown in Figure 8, Figure 9, Figure 10 and Figure 11. From the graphs (Figure 8 to 11), each of the specimen categories produced worthy stress-stretch curve trend of hyperelastic and also showing a small dispersion at the maximum stretch. For specimens with lanolin on both heat treatment temperature, whether at 33°C or 36°C, the curve lines are approximately still within the consistent range, which means that the test performed resulted in a homogeneous reading. These are clearly shown in Figure 8 and Figure 10 where these figures come from specimens with lanolin. Furthermore, the data is also acceptable due to the small percentage variance for all specimen categories as shown in Table 7.

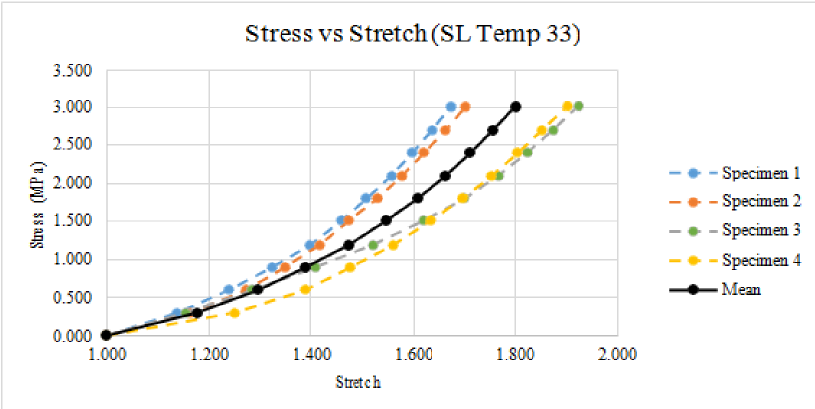

Figure 8: Graph of stress against stretch for SL Temp 33

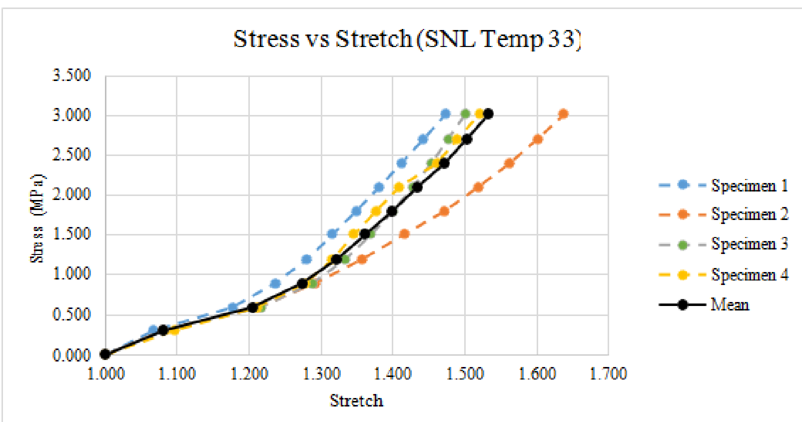

Figure 9: Graph of stress against stretch for SNL Temp 33

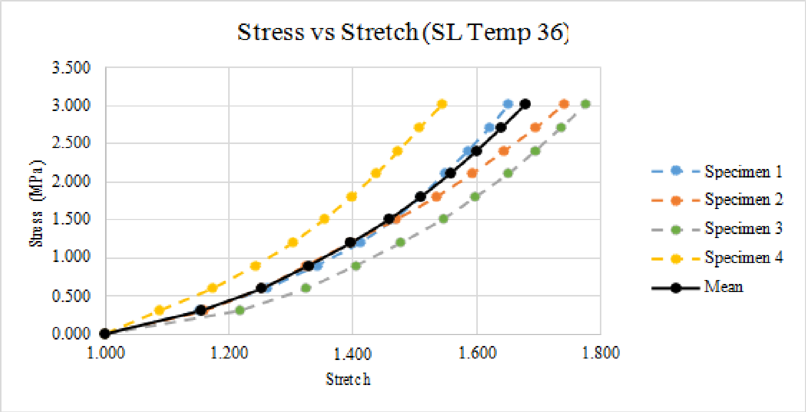

Figure 10: Graph of stress against stretch for SL Temp 36

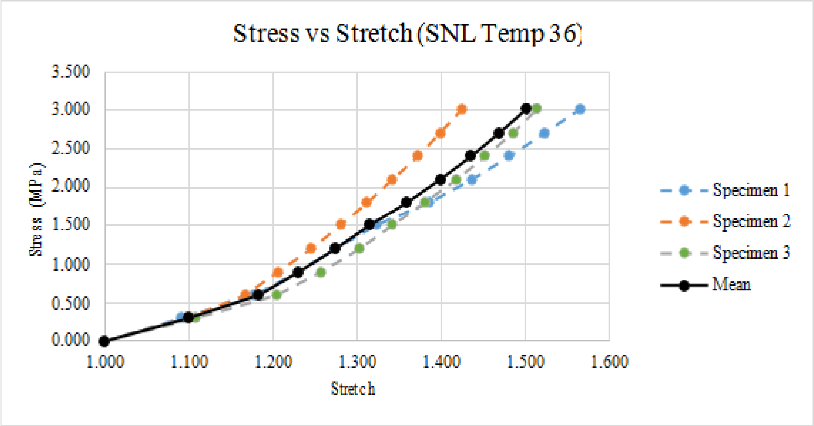

Figure 11: Graph of stress against stretch for SNL Temp 36

Based on Table 3, Table 4, Table 5, and Table 6 at maximum stress of 3.017 MPa, the range stretch value of maximum and minimum are 0.249, 0.165, 0.232, and 0.14 for SL Temp 33, SNL Temp 33, SL Temp 36, and SNL Temp 36, respectively. After comparing the mean stretch value for all specimen categories, it is obvious that specimens with lanolin has higher mean stretch value compared to the specimens with non-lanolin. Furthermore, by viewing the heat treatment category, the results show that that the temperature of 33°C had the highest mean stretch value compared to the temperature of 36°C.

Based on Table 7, SL Temp 33 holds the highest stretch value while SNL Temp 36 hold the lowest stretch value.

Table 3: Stretch values for SL Temp 33

Stress (MPa)	S1	S2	S3	S4	Mean
0.000	1.000	1.000	1.000	1.000	1.000
0.303	1.139	1.164	1.153	1.250	1.177
0.597	1.238	1.273	1.286	1.388	1.296
0.901	1.324	1.349	1.407	1.477	1.389
1.196	1.398	1.417	1.520	1.561	1.474
1.509	1.459	1.473	1.618	1.633	1.546
1.801	1.508	1.529	1.700	1.696	1.608
2.107	1.557	1.578	1.765	1.753	1.663
2.403	1.597	1.621	1.822	1.805	1.711
2.709	1.637	1.663	1.873	1.852	1.756
3.017	1.672	1.702	1.921	1.900	1.799

Table 4: Stretch values for SNL Temp 33

Stress (MPa)	S1	S2	S3	S4	Mean
0.000	1.000	1.000	1.000	1.000	1.000
0.303	1.067	1.080	1.081	1.096	1.081
0.597	1.177	1.212	1.216	1.211	1.204
0.901	1.236	1.292	1.288	1.278	1.274
1.196	1.280	1.356	1.333	1.316	1.321
1.509	1.316	1.415	1.369	1.346	1.362
1.801	1.349	1.472	1.400	1.376	1.399
2.107	1.381	1.519	1.428	1.409	1.434
2.403	1.411	1.562	1.453	1.461	1.472
2.709	1.443	1.601	1.477	1.490	1.503
3.017	1.473	1.638	1.501	1.520	1.533

Table 5: Stretch values for SL Temp 36

Stress (MPa)	**S1**	**S2**	**S3**	**S4**	**Mean**
0.000	1.000	1.000	1.000	1.000	1.000
0.303	1.153	1.160	1.216	1.086	1.154
0.597	1.261	1.253	1.325	1.173	1.253
0.901	1.342	1.325	1.405	1.244	1.329
1.196	1.411	1.394	1.477	1.303	1.396
1.509	1.466	1.470	1.545	1.354	1.459
1.801	1.508	1.535	1.597	1.397	1.509
2.107	1.548	1.592	1.651	1.438	1.557
2.403	1.584	1.643	1.693	1.473	1.598
2.709	1.620	1.694	1.735	1.507	1.639
3.017	1.651	1.740	1.776	1.544	1.678

Table 6: Stretch values for SNL Temp 36

Stress (MPa)	**S1**	**S2**	**S3**	**Mean**
0.000	1.000	1.000	1.000	1.000
0.303	1.092	1.100	1.109	1.100
0.597	1.178	1.166	1.204	1.183
0.901	1.229	1.206	1.257	1.231
1.196	1.274	1.245	1.303	1.274
1.509	1.322	1.280	1.342	1.315
1.801	1.385	1.312	1.380	1.359
2.107	1.436	1.342	1.418	1.399
2.403	1.481	1.372	1.452	1.435
2.709	1.523	1.398	1.485	1.469
3.017	1.565	1.425	1.514	1.501

Table 7: Mechanical properties of Sheepskin

	SL Temp 33	**SNL Tem p 33**	**SL Tem p 36**	**SNL Temp 36**
Stretch	1.902	1.730	1.805	1.618
Standard Deviation	0.119	0.138	0.111	0.037
Variance	0.014	0.019	0.012	0.001

Based on Table 8, the values of each material parameters for the hyperelastic model, which are μ and N for Arruda & Boyce model, can be compared. The values of μ for SL Temp 33 and SNL Temp 33 are 4.967 and 5.134, respectively. However, the values of μ for SL Temp 36 and SNL Temp 36 are 4.943 and 5.199, respectively. Additionally, the value of μ for SNL Temp 36 recorded highest than SNL Temp 33 for specimen with non-lanolin category. For material parameter of N, for SL Temp 33 and SNL Temp 33 are 3.116 and 2.357 respectively. In contrast, the value of N for SL Temp 36 and SNL Temp 36 are 2.728 and 2.209, respectively. As a result, SL Temp 36 held the lowest value of μ at 4.943, while SNL Temp 36 holds the highest value which is 5.199. Moreover, the highest value of N is 3.116 from SL Temp 33, while SNL Temp 36 recorded the lowest value at 2.209.

Table 8: Material parameter values of μ and N for Arruda & Boyce Model

Arruda and Boyce material parameter	**Temperature 33**		**Temperature 36**	
	Lanolin (SL)	**Non-Lanolin (SNL)**	**Lanoli n (SL)**	**Non-Lanolin (SNL)**
μ (MPa)	4.967	5.134	4.943	5.199
N	3.116	2.357	2.728	2.209

In order to compare the biomechanical properties, a stress-stretch graphs was plotted for all the specimen categories as shown in Figure 12 to Figure 15. The stress-stretch graphs were plotted according to the stress and stretch data from said numerical approach using the Arruda and Boyce model equation and experimental data. As shown in Figure 12 to Figure 15, it is seen that all the graph shows a similar curve line trend where Arruda and Boyce model line and is inversed from the experimental stress-stretch curve line behavior. The curve line behaved in an inverse trend because stress is inversely proportional to the stretch according to the simplified Arruda and Boyce model equation. Moreover, Arruda and Boyce model can be considered as a generalization of Treloar's model which is frequently referred to as the Neo-Hookean law [12], and the curve line for Neo-Hookean law also show an inversed trend for stress-stretch graph. Although they are different, they still maintain a worthy agreement with other researchers they also found the curve shape to be the same [13].

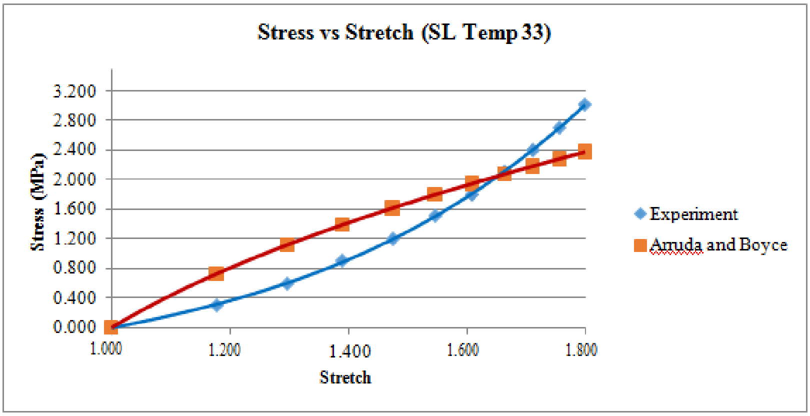

Figure 12: Comparison of Experimental and Arruda & Boyce model for SL Temp 33

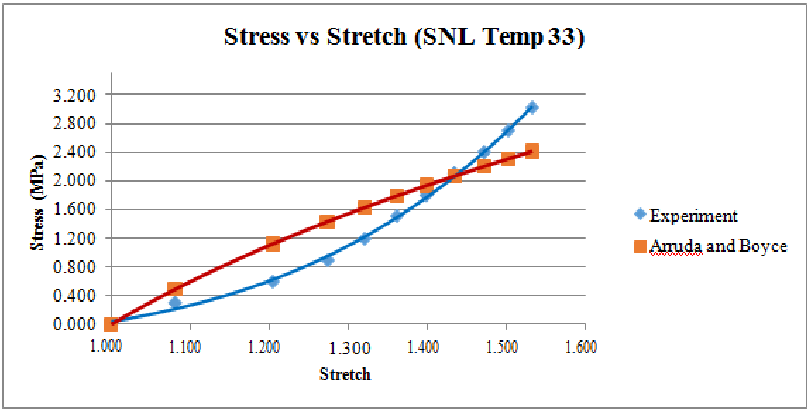

Figure 13: Comparison of Experimental and Arruda & Boyce model for SNL Temp 33

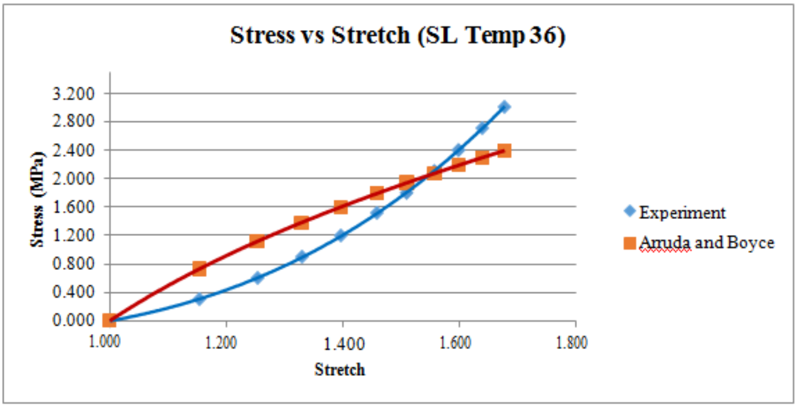

Figure 14: Comparison of Experimental and Arruda & Boyce model for SL Temp 36

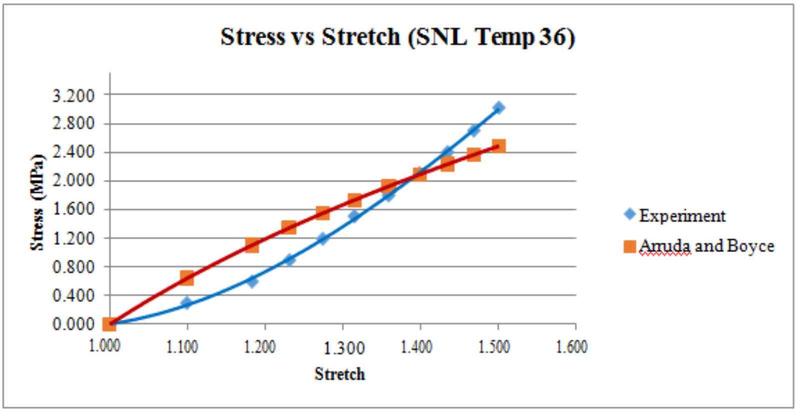

Figure 15: Comparison of Experimental and Arruda & Boyce model for SNL Temp 36

Comparison

Below is a table showing the material constants for Arruda and Boyce model from previous and current study. It can been see that not many researchers have done their research by adapting Arruda and Boyce model. They preferred to deal with Ogden model, Yeoh model, and Mooney-Rivlin model instead. The current result can be considered to be acceptable although yielding different end results since it agrees with other researchers [13].

Table 9: Compilation of Arruda and Boyce Material Constant (μ and N) from previous studies

μ	N	Author	Test sample	Test	Ref
4.87 MPa	2.5	Jamil et al. (2012)	Silicone rubber	Tensile	[13]
4.943 - 5.199 (MPa)	2.209-3.116	Current study	Sheepskin	Uniaxial	

Conclusion

At the end of this study, the results portrayed that the objective has been achieved which were to analyze the dryness effect on skin based on variation of heat exposure and to quantify the biomechanical properties of skin by using experimental and numerical approach. Moreover, it can be concluded that in term of specimens, the ones with lanolin has higher value of stretch and strain than specimens of non-lanolin. This indicates that the skin applied with tanning agents, particularly lanolin, is stronger than normal skin (non-lanolin). Furthermore, in terms of heat treatment, it can be stated that different heat treatment temperatures can influence the biomechanical properties. The stretch and strain value for heat treatment with a temperature of 33°C is much higher than the heat treatment with a temperature of 36°C. Therefore, higher temperature results lower stretch capability of the skin. Therefore, by having determined the Arruda and Boyce material parameter for sheepskin, it can contribute to the future investigation with finite element analysis model.

References

[1] Bernama. “El Nino not yearly phenomenon: Mosti” *New Straits Times*. [Online]. Available: http://www.nst.com.my/news/2016/04/139981/el-nino-not-yearly- phenomenon-mosti. [Accessed: 23-May-2016].

[2] Bernama. “Strong’ El Nino to cause low rainfall in Malaysia” *Malaysiakini*.[Online].Available:https://www.malaysiakini.com/news/326165. [Accessed: 23-May-2016]

[3] N. Annaidh, K. Bruyere, M. Destrade, M. D. Gilchrist, and M. Ottenio, “Characterising the Anisotropic Mechanical Properties of Excised Human Skin,” *Journal of the Mechanical Behavior of Biomedical*

Materials. (5). 139-148 (2012).

[4] T. A. Andrade, A. F. Aguiar, F. A. Guedes, M. N. Leite, G. F. Caetano, E. B. Coelho, P. K. Das, and M. A. Frade, “Ex vivo model of human skin (hOSEC) as alternative to animal use for cosmetic tests,” *Procedia Eng.*, vol. 110, no. 16, pp. 67–73, (2015).

[5] Nor Fazli Adull Manan, Jamaluddin Mahmud, and M. H. Ismail, “Quantifying the Biomechanical Properties of Bovine Skin under Uniaxial Tension,” *Journal of Medical and Bioengineering*, vol. 2, no. 1, pp. 45–48, (2013).

[6] O. A. Shergold, N. A. Fleck, and D. Radford, “The uniaxial stress versus strain response of pig skin and silicone rubber at low and high strain rates,” *Int. J. Impact Eng.*, vol. 32, no. 9, pp. 1384–1402, (2006).

[7] M. M. O. and M. M. Derakhshanfar, “Study on the effect of Peganum harmala extract on experimental skin wound healing in rat: Pathological and biomechanical findings,” *Comp. Clin. Path.*, pp. 169–172, (2010).

[8] Y. Wang, K. L. Marshall, Y. Baba, G. J. Gerling, and E. A. Lumpkin, “Hyperelastic Material Properties of Mouse Skin under Compression,” *PLoS One*, vol. 8, no. 6, (2013).

[9] Nor Fazli Adull Manan and Jamaluddin Mahmud, “The Effect of Skin Orientation on Biomechanical Properties,” *Journal of Mechanical Engineering*, vol. 12, no. 01, pp. 67–81, 2015

[10] C. Lü, K. Wang, X. Zheng, JieLiu, and KeyongTang, “WaterAbsorption Mechanismof Goatskin Collagen Fibers,” *Coll. Mater. Sci. Eng.*, vol. 6, no. 2, pp. 34–38, (2015).

[11] Ali, M. H. Fouladi, and B. Sahari, “A Review of Constitutive Models for Rubber-Like Materials,” *Am. J. Eng. Appl. Sci.*, vol. 3, no. 1, pp. 232–239, (2010).

[12] Berdichevsky, “On the Use of the Arruda-Boyce Model,” no. 1, pp. 105–115, (2004).

[13] Y. J. Adeel, A. I. Muhammad, and A. Zeeshan. “Characterization of Hyperelastic (Rubber) Material Using Uniaxial and Biaxial Tension Tests,” *Advanced Materials Research*, vol. 570, pp. 1-7, (2012).