# Quantifying the Biomechanical Properties of Bovine Skin under Uniaxial Tension

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***Abstract*— Skin is an important organ and many studies have been carried out to understand its functions and behaviour. Nevertheless, there is still lack of reliable data and theory that could best define skin deformation behaviour. Therefore, this paper aims to quantify the biomechanical properties of bovine under uniaxial tension skin utilising experiment-numerical approach. Bovine skin samples were tested according to ASTM D2209-00 standard to obtain stress-stretch data. Based on the experiment data, a programme is written using Matlab to quantify and determine the bovine skin biomechanical properties. The Ogden parameters are found to be $\mu = 0.4$ and $\alpha = 4.6$. These values are important for future reference and therefore proving that the current study is significant and has contributed to the pool of knowledge in the area of skin biomechanics.**

***Index Terms*—biomechanical properties, bovine skin, ogden constitutive model**

## I. Introduction

Skin is one of important organs in human and animal bodies, nevertheless its behavior is still not well defined [1]. Traumatic accident, burning, plastic surgery and cosmetic are few examples that need further study on human skin which requires observation of the actual skin behaviour at certain condition. Therefore, prior to any *in vivo* procedure and experiment, the *in vitro* process should be undertaken to ensure safety and reduce risk on human. For that reason, this paper for the first time attempts to integrate an *in vitro* experiment of bovine skin and numerical method to quantify their Ogden parameters. This study is important as up to date, no single specific numerical value has been defined for bovine skin.

According to previous researches, the *in vitro* experiment was perform on animal skin such as murine, bovine, rabbit and etc [1]-[3]. The important parameters from their analysis and investigation were skin deformation and displacement. In another finding, several approaches such as experiment and numerical assessment were used to quantify its mechanical parameters such as Odgen materials constant, $\mu$ and exponent, $\alpha$. Li and Li, Khaothong, Manan are among that focusing on finite element (numerical approach) analysis of mimicking agar-agar phantom and inner forearm of human skin [4]-[6]. On the other hand, Digital imaging is also used widely in physical skin analysis [7]-[10]. Dynamics Optical Coheren Elastography (OCE) and Digital Image Correlation technique were introduced by Liang et al. in determining biomechanical properties of human skin [7], [9], [10] while Laser and High Frequancy Ultrasonic (LUS) technique were used by other researchers [4], [8]. For further investigation on skin, this paper analyzed the shaved bovine skin to observe the effect of bovine hair in the mechanical properties.

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## II. Methodology

The research comprise of physical experiment on bovine skin and its numerical implementation via finite element analysis. Towards the end, the integration of both methods will be matched together as validation. The flow chart in Fig. 1 illustrates the methodology for the study.

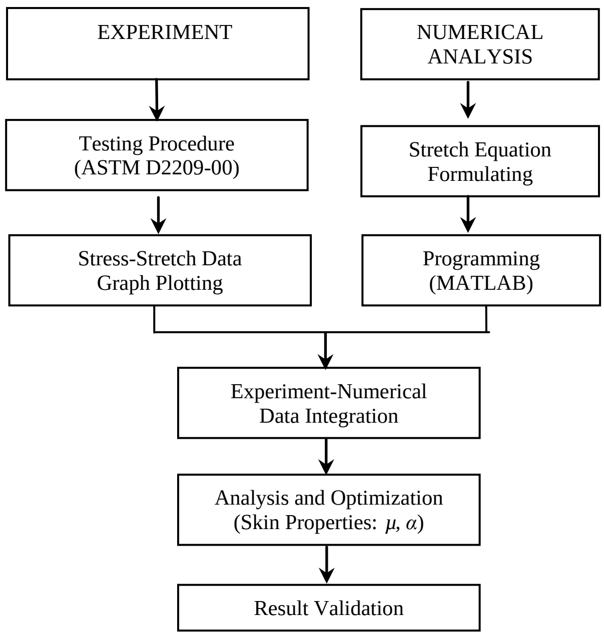


Figure 1. The overall process flow of determining the Bovine skin properties.

### A. Experimental Investigation

The works begin with *sample preparation*. With reference from ASTM Standard, the size and dimension of samples were prepared. The source of samples was obtained from a fresh slaughtered male bovine skin of the age of two years old. Preparation is a very important step in most analytical techniques as four samples of skin was


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taken at butt-bend of whole skin. The procedure for the experiment was conducted based on standard testing method for tensile strength of leather according to International ASTM (D2209-00). All four samples of I-shape with dimension of 171mm length and 31.8mm width were illustrated in Fig. 2. The step taken to ensure the samples satisfy the exact dimension, firstly: actual drawing size printed on paper (schematic drawing) and mapped with plastic mould board (blue color) as shown in figure 2(a) to provide an accurate cutting shape as standard required. Then, the plastic mould with I-shape will help in cutting the bovine skin as much as accurate it can for the samples as shown in Fig. 2(b).

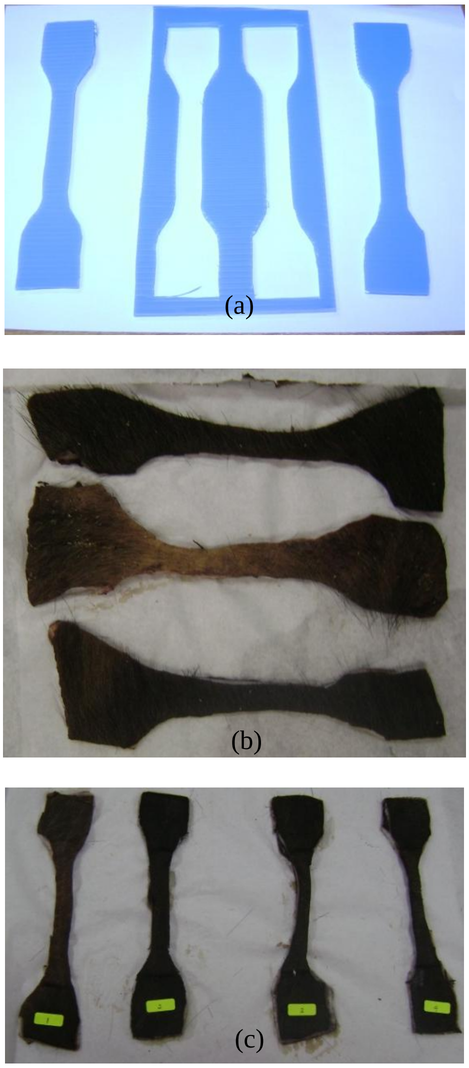


Figure 2. (a) Template of plastic mould, (b) Skin before shave, (c) Shaved and tested skin

Next step was *specimens testing*. Testing was held at Strength of Materials laboratory, Faculty of Mechanical Engineering UiTM Shah Alam, Selangor. Instron Mechanical test machine (Instron, Dynatup 9250) was used to perform the tensile test. The load of 240N was applied together with the speed of 254 ± 50 mm/min. A wide jigs with knurling was used to clamped the samples at the both end of I-Shape and tighten as much as it could because it quite slippery. Few samples were disposed due to slip-faulty during testing. It cannot be reuse because of the samples already stretched even it not reach the maximum load applied.

For a moment of testing, the absolute result was obtained only from the successful sample until the maximum loading applied. The mechanical properties were determined from tensile testing machine and the parameters obtained were tensile stress, elongation, strain and etc. The skin properties can be determined from formula of stretch-strain by having these basic mechanical properties from the tensile test. The tested skin on experiment procedure was illustrated in Fig. 2(c).

### B. *Numerical Programming*

MATLAB (ver. 2009) programming was used to tabulate and synthesis the mechanical properties of bovine skin obtained compared to experimental result. The formulated stretch equation was compiled as finite element programming. Data of stretch was integrated by debugging the program.

### C. *Integration Analysis*

The best match curve between experimental and numerical assessment in MATLAB will integrate the skin properties. In this research, the material is considered to be hyperelastic with the characteristic of skin is represented by strain energy function, *W*. Thus, the formulation for the following numerical computation is served by Ogden theory. Ogden proposed the strain energy function [11] as:

$$W=\sum_{i=1}^{N}\frac{\mu_i}{\alpha_i}\left(\lambda_1^{\alpha_i}+\lambda_2^{\alpha_i}+\lambda_3^{\alpha_i}-3\right) \qquad (1)$$

$\lambda_i$ are the principal stretches; $\mu_i$ and $\alpha_i$ are the material parameters with the function's order of *N*. This assumption was used by Evan in his research [12].

Considering Ogden model in Eq. 1, where the material is assumed to be isotropic, hyperelastic and incompressible, the relation of engineering stress, $\sigma_E$ and principal stretches, $\lambda$, is described by Eq. 2 below:

$$\sigma_E=\frac{\mu}{\lambda}\left(\lambda^{\alpha}-\lambda^{-\alpha/2}\right) \qquad (2)$$

Evans and Holt used this equation to compare their results with others [10]. Before this approach is applied to the experimental result, a parametric study is designed to investigate the sensitivity of Eq. 2 to the variation of $\mu$ and $\alpha$.

## III. Analysis & Result

### A. *Experimental Assessment*

Data from experiment were processed into mechanical properties of biomechanical characteristic i.e. stretch and was tabulated and illustrated in Table I, Table II and Fig. 3. The tensile test performed gives the connections between stress and strain.

TABLE I. STRETCH VALUES FOR BOVINE SKIN EXPERIMENT SAMPLES

| No | Stress (MPa) | Sample (Stretch) | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| 1 | 0.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 0.2000 | 1.1491 | 1.1193 | 1.2716 | 1.2889 |
| 3 | 0.4000 | 1.1839 | 1.1484 | 1.3553 | 1.3422 |
| 4 | 0.6000 | 1.2080 | 1.1739 | 1.4318 | 1.3813 |
| 5 | 0.8000 | 1.2268 | 1.1960 | 1.4946 | 1.4163 |
| 6 | 1.0000 | 1.2426 | 1.2143 | 1.5383 | 1.4489 |
| 7 | 1.2000 | 1.2573 | 1.2300 | 1.5652 | 1.4864 |

TABLE II. STATISTICAL RESULT

| No | Stress (MPa) | Stretch | | |
|---|---|---|---|---|
| | | Mean | Std. Dev. | Variance |
| 1 | 0.0000 | 1.0000 | 0.0000 | 0.0000 |
| 2 | 0.2000 | 1.2072 | 0.0855 | 0.0073 |
| 3 | 0.4000 | 1.2574 | 0.1066 | 0.0114 |
| 4 | 0.6000 | 1.2987 | 0.1269 | 0.0161 |
| 5 | 0.8000 | 1.3334 | 0.1451 | 0.0210 |
| 6 | 1.0000 | 1.3610 | 0.1578 | 0.0249 |
| 7 | 1.2000 | 1.3847 | 0.1664 | 0.0277 |

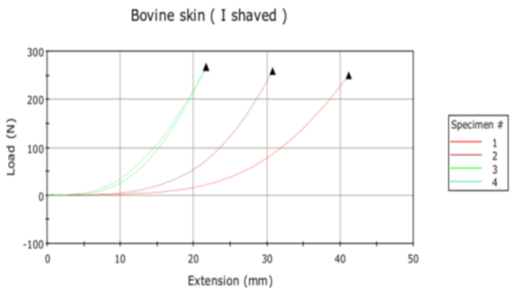

Figure 3. Comparison of the bovine skin samples result.

### *B. Numerical Result*

Simulation of skin properties was performed using MATLAB programming based on Ogden theory formulation. Computational results plotted similar behavior as experimental curve in Fig. 3 (see Fig. 4). Optimization was done by varying the value of skin parameter ($\mu$ and $\alpha$) in purpose of obtaining accurate plotting to the experimental results. The bovine skin parameter were found to be $\mu = 0.4$ and $\alpha = 4.6$.

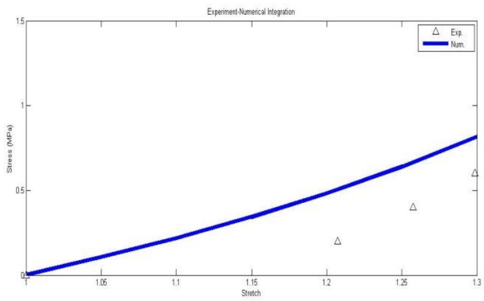

Figure 4. Integration between experimental and the numerical result graphs

## IV. DISCUSSION & CONCLUSION

According to experimental result in Table II, the variance of stretch values between minimum of 0% to the maximum of 0.027%. Hereby it apparent that the experimental results are consistently performed since the variances is less than 5%. Therefore these data are reliable to be proceeding with numerical analysis. From Table I and II, the stretch value for each sample and its average value (mean) in the mechanical testing conducted are comparable. All stretch values and mean varies by7.85% and 13.04% for minimum and maximum stretch values respectively. Again, with the minor differences and less than 20% of error, the data is suitable for next numerical analysis. When referring to previous research by Manan et. al. on bovine skin without shaving [2], the result are slightly varied with maximum value of 7.95%. It is signified here that presence of hair on bovine skin may affecting the properties.

From Fig. 4, it is apparent that the experimental and the numerical results obtained are in good agreement with only a slightly difference of only 4% on the constructed line of the numerical results at stress 0.5 MPa. Therefore, it could be established that the Odgen formulation in the developed FE programme is reliable and accurate enough to further investigate the mechanical properties of skin.

This paper highlights the success of integrating experiment-numerical approach in quantifying bovine skin under uniaxial tension.

The quantified and determined biomechanical properties of bovine skin are important and could be used as a reference for future research.

Furthermore, the investigation on the effect of hair on bovine skin was successful since the result showing the 50% improvement on the mean value obtained compared to the previous research [2]. In addition, new characteristic of bovine skin's biomechanical properties without hair was also determined.

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