UNIVERSITI TEKNOLOGI MARA

JMechE

Journal of mechanical engineering

Regular Issue **September** 2021 | Volume No.**18-3**
ISSN : 1823 - 5514
e-ISSN : 2550 - 164X
jmeche.uitm.edu.my

JOURNAL OF
MECHANICAL ENGINEERING

An International Journal

Vol 18 (3)	15 September 2021	ISSN 1823-5514	eISSN 2550-164X

Journal of Mechanical Engineering Vol 18(3), 1-20, 2021

The Numerical Analysis of Hyperelastic Properties in Commercial and Original Aloe Vera Gels

*Nur Nabila Mohd Nazali, Nor Fazli Adull Manan**
School of Mechanical Engineering, College of Engineering,
Universiti Teknologi MARA (UiTM), Shah Alam, Selangor
**fazli_am@yahoo.com*

ABSTRACT

A basic purpose of a good healing patch is to reduce the reproduction of bacteria in the wounded area with minimal effect of mechanical properties. This study focuses on the basic mechanical and biomechanical properties of the material for a healing patch application with a new composition of biodegradable ingredients by using the estimation of hyperelastic models to fit with the experimental data and the comparison between the commercial Aloe vera gels and original Aloe vera leaves. This project was started with a material selection which is gelatine and Aloe vera leaves as the main ingredient. Secondly, the specimen sets undergo a uniaxial tensile test to obtain the raw data. For numerical phases, the conventional theory of large deformation based on hyperelastic constitutive equations and Stress-Strain Energy Theory were identified. The final step for this project is curve fitting between experimental data (Ogden and Mooney-Rivlin hyperelastic models). New parameters were carried out for healing patch materials made of hybrid biomaterials from the hyperelastic theory. The Ogden and Mooney Rivlin trends were closely followed by the curve fit presented with a minor difference. Overall, the original Aloe vera leaves' values were Ogden (α=1.8792, μ=0.1881 Mpa) and Mooney-Rivlin (C_1=0.0713, C_2=0.0304) respectively. The significance of this project is to expand the knowledge about mechanical properties of natural polymers for wound healing application instead of depending on semi-synthetic polymers.

Keywords: *Commercial Aloe vera; Mooney-Rivlin; Ogden; Minor cuts; Biomaterial*

ISSN 1823-5514, eISSN 2550-164X

Received for review: 2021-02-09
Accepted for publication: 2021-08-19
Published: 2021-09-15

Introduction

Aloe vera (Aloe barbadensis Miller) is a longstanding plant of a liliaceous family with swollen green leaves attached to the stem in a rosette pattern [1]. It was produced by a thick Aloe vera epidermis layer containing the largest amount of healing properties for cure burns and minor cuts. In terms of leaf composition, Maan considered that Aloe vera is a moist and breakable plant containing a high water content (99–99.5%) while solid contents range from 0.5–1% and consist of a variety of active components i.e. fat and water-soluble minerals, vitamins, simple/complex polysaccharides, organic acids, enzymes and phenolic compounds [2]. In addition, Baghersad noted that the lack of electrospinnability and adequate mechanical properties are the main limitations to the use of this natural extract in the form of nano-fibrous mats [3].

In this project, gelatine was the main material for combining it with Aloe vera gels to obtain the raw data. Technically, the gelatine was harvested from pigskin (46%), bovine (29.4%), cattle bones (29.4%), and 1.5% from fish [4]. Therefore, gelatine generally can be divided into two major types which are Type A (porcine skin) and Type B (bovine and fish skin). Type A gelatine is more elastic and has greater acidity than Type B.

The case studies in the dermatology field were related to this project for wound dressing application. The crucial minor cuts that often occur are on the face, elbow, forearm, and legs, whereas our bare eyes can easily notice it. The basic wound dressing instruction, such as the laceration procedure, can easily be followed by anyone. After the laceration procedure, the aesthetic value is rarely taken care of. The material composition did not get much attention especially if it could be made of natural biopolymer. The basic mechanical and biomechanical capacity of gelatine combined with natural biopolymer, particularly the load capacity, had to be uncovered. Load capacity refers to axial load, vertical load, horizontal load, and many more. However, in this project, the axial or vertical load has been put into practice.

Commercial Aloe Vera

The commercial Aloe vera is the processed Aloe vera gels with a combination of controlled preservatives, proper manufacturing methods, and increasing the healing period on human skin. Originally, Aloe vera (AV) has been known as a venerable therapeutic herb belonging to the Liliaceae family [5]. Both the original Aloe vera extract and the commercial Aloe vera have a good treatment effect, but the healing period and mechanical effect on the skin differ. The minimum mechanical characteristics would therefore be presented in this project in order to carry out the raw data. Based on the review paper by Ramachandra, the Aloe vera gels were usually processed through three methods which are traditional hand filleted Aloe processing, whole-leaf Aloe vera processing, and total process Aloe vera processing [1].

The benefits of processed Aloe vera as an output of a commercial product are, rapid processing to prevent the breakdown of bioactive components, optimum tested and proven biologically active, and enhancing bioactivity on human skin. The entire leaf Aloe vera processing has a simple procedure, although the filtration process took a long time taken to complete. The mechanical properties of the end product would be affected by tiny particles such as fibers or the finest soil inside the gel. However, 99 % of aloin (the yellow-brown coloured compound) and Aloe-emodin were removed.

Hyperelastic models for incompressible materials

Hyperelastic models are one of the mechanical terminologies for nonlinear material. An extra strain ratio of every 100 percent is called the stretch ratio. The stretch ratio is the maximum hyperelasticity contained within the incompressible material. The hyperelastic models such as Ogden and Mooney-Rivlin are the reference for identifying the material constants for producing a healing patch through the curve fit performance. The closer the experimental data to the models of Ogden or Mooney-Rivlin, the more ideal the material it is for the application of healing patches.

Stress-strain energy theory

The Stretch-Strain Energy Theory was defined as the material failure prediction when any combination of the load has been added at axially or compression. In other words, the Stress-Strain Energy Theory defines the energy ability of the incompressible material after deformation. Stress is directly proportional to strain, which contributes to general Equation (1), based on Hooke's Law. The elasticity modulus or Young's modulus (E) indicates the elasticity of the material.

First, due to the external force applied, the linear elastic material starts to elongate, and the internal force reacts to allow the material to retain the original shape when releasing the external force. Secondly, in Equation (2), the material deformation and elongation are derived from elastic modulus (Young's Modulus). Third, the stress-strain curve represents the linear or straight line in the curve of material behaviour (Hooke's Law). A law stating that the strain in a solid is proportional (also known as linear) to the stress applied within the elastic limit of that solid was stated by Hooke's law. As the material conducts beyond the elastic region, this opposes the hyperelastic theory. In addition, the stress-strain relationship represents the non-linear curve along with the loading or unloading in the curve diagram [6], [7]. The stress-strain curve is crucial to indicate the loading ability of the material. The basic formula of strain is referred to Equation (1).

$$\varepsilon = \frac{l - l_0}{l_0} \tag{1}$$

$$E = \frac{\sigma}{\varepsilon} \tag{2}$$

Where:
l_o = Original length, mm
l = Extended length, mm
Ɛ =Strain, no unit
E = Young's Modulus, GPa

Ogden constitutive model

Ogden hyperelastic model is a numerical guide to a material that can be used for predicting the nonlinear stress-strain behaviour of materials such as rubber, silicone, or any incompressible polymers. Practically, the gelatine was categorized in food technology and pharmaceutical products as a natural biopolymer category. The model of Ogden differs from the other models (Neo-Hookean, Mooney-Rivlin, model of Arruda-Boyce) expressed by invariants known as alpha and μ. In addition, it has the advantage that the experimental data can be directly used, and it shows good agreement with the test data up to 700% of the tensile test results [8]. It was founded in 1972 by Ogden until he quantifies a general Equation (3) while Equation (4) shows the adoption of first-order Ogden constitutive equation for an incompressible material.

$$W = \sum_{i=1}^{N} \frac{\mu}{\alpha} \left(\lambda_1^{\alpha_1} + \lambda_2^{\alpha_2} + \lambda_3^{\alpha_3} - 3 \right) \tag{3}$$

$$\sigma = \frac{2\mu}{\alpha} \left(\lambda^{\alpha} - \lambda^{-\frac{\alpha}{2}} \right) \tag{4}$$

where;

$\lambda_{j,}$	=	(j=1,2,3) is the principal stretch ratio, no unit
σ	=	Predicted tensile stress, MPa
α_i or α	=	Material constant related with strain hardening, no unit
μ_i or μ	=	Material constant related with shear modulus, MPa

Mooney-Rivlin constitutive model

Melvin Mooney and Ronald Rivlin have carried out two invariants of the left Cauchy-Green deformation tensor B [8]. In Equation (5), W is the energy density of the hyperelastic material from the general formula, while Equation

(6) shows the equation for incompressible material expressed. The denominator U was designated as the internal energy density. Overall, the output is identical.

Based on N. Kumar and V. Rao [9], Mooney-Rivlin material constants can be classified into 2 to 9 parameters. In this project, the two material constants were sufficient which were identified as α and μ for Ogden while C_1 and C_2 for Mooney-Rivlin respectively. Most of the curve fitting by the specimen set was obey both Ogden and Mooney-Rivlin's single curvature until the constants were carried out.

$$W = C_1(I_1 - 3) + C_2(I_2 - 3) \tag{5}$$

$$\sigma = 2(1 - \lambda^{-3})\lambda(C_1 - C_2) \tag{6}$$

where;

C_1, C_2	=	Mooney-Rivlin's material constants
σ	=	Predicted tensile stress
I_1	=	First invariant deviator component of the left Cauchy-Green deformation tensor
I_2	=	Second invariant deviator component of the left Cauchy-Green deformation tensor
		For incompressible material, I_3 is considered as 1

Methodology

This section summarises the steps involving material selection, mechanical experimentation, numerical analysis, and data comparison for original Aloe vera gels and commercial Aloe vera. The commercial Aloe vera data was excluded from material preparation to mechanical experiment stages. There were different versions of journals referring to experiments based on gelatine from a journal paper written by Nazali [10]. The material composition was distributed uniformly through the double boiling method and let them solidify at room temperature. The data comparison between original Aloe vera leaves and commercial Aloe vera was simplified to identify the mechanical properties differences.

Material preparation

To ensure longer shelf life and greater productivity on human skin, commercial Aloe vera has a long-lasting material composition. The material was consisting of gelatine, glycerine, distilled water, and original Aloe vera. The purpose of using the same ratio is to balance the water content within the sample. At the same time, the texture of the material would be able to be almost exactly to human skin. The material composition for the original Aloe vera specimen set was gelatine (25 g), distilled water (50 ml), Aloe vera gels (25 g), and glycerine (25 ml).

The mixture was heated up to 90 °C in twenty (20) minutes on the water bath by the double boiling method. The maximum temperature was set up at 90 °C to increase the viscosity and improve the molecules' bonding. The longer the heating duration, the mixtures would be tackier or loses a lot of water. Thus, 20 minutes was an acceptable temperature. Technically, the double boiling method was applied to avoid direct heating in gelatine mixtures. If the mixtures are heated up directly using stoves, the water content could lose rapidly. Based on the fresh Aloe vera leaves, the aloin and emodin extracts were not filtered as suggested because we need to test the material combination of whole content inside the Aloe vera leaves and its mechanical effects.

Mechanical experiment procedures

This mechanical experiment was inclusive of original Aloe vera leaves to obtain the original raw data. The main challenge in using natural polymers for wound dressing applications is their poor mechanical and biomechanical properties and adaption to the patient movements [11]. That was the reason researchers combine synthetic polymer to enhance their mechanical skin, adaptable to human skin. Furthermore, the tensile test is one of the compatible mechanical experiments for an incompressible material to execute the internal rubber characteristics inside the natural biopolymer. The specimen dimension as illustrated in Figure 1 based on ASTM D412 Type C with 3 mm thickness.

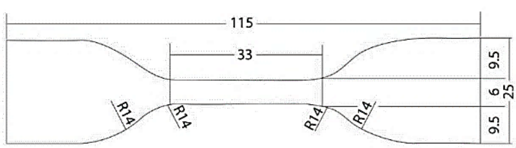

Figure 1: Specimen dimension (mm).

Data analysis by numerical approaches

The hyperelastic models' equations were adopted to carry out the material constants. The material constants are consisting of shear modulus and maximum tensile test. The larger the material constant ratio, the quality of the specimen tested has a higher chance to be improved in the future. For example, artificial skin needs a higher shear modulus and maximum tensile test to ensure that the material is most compatible with human skin. Based on Ogden's model, Equation (4) would carry out the strain hardening and shear modulus, while Equation (6) by Mooney-Rivlin would carry out C_1 and C_2.

Results and Discussion

The Aloe vera leaves contain polysaccharide extracts that make the texture thicker and heat reversible. Furthermore, Baghersad was confirmed that the incorporation of Aloe vera increased the cell viability without any toxicity [3]. Apart from Aloe vera, the hydrogel is also one of the potential biomaterials in the tissue engineering industry, but higher costs need to be bear. In addition, Vedadghavami stated that the hydrogel biomaterial has a benefit from retaining a large amount of water, similarity to natural tissues, and the ability to form any different shapes [12]. The final texture of the specimen in Figure 2 shows a clear textured healing patch skin with minimal bubbles. Therefore, as a precaution, the double boiler should be installed with a vertical vacuum to reduce the bubbles due to oxidation between water particles. The bubbles would influence the data error during the mechanical experiment because it is considered as a breaking point on a specimen.

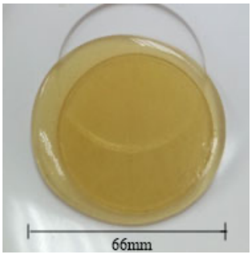

Figure 2: Specimen texture after a pilot test.

Mean load and tensile stress

Original Aloe Vera

The basic mechanical properties presented in this project were consisting of external load (N), extension (mm), strain ratio (no unit), and tensile stress (MPa). There were thousands of data recorded for every second. However, the highest range for every set was selected based on the similarity of each specimen. For example, the mean external load for both two samples at the 50 mm/min tensile speed was 9.416 N. Beyond the load in a static condition, the graph trends will show fluctuate lines because of unstable polymer reaction on the specimen. In the field of tissue engineering or biomaterial sciences, the mechanical properties of scaffolds in both macroscopic and microscopic scales play crucial roles in the regulation of cell behaviour [12]. The biomechanical properties are the interactions between the extracellular matrix (ECM) of the structure. A poor mechanical strength is a limiting factor for using the Aloe vera alone. Thus, the combination with other polymers is an effective method to modify the biodegradation rate and to optimize the mechanical properties of

Aloe vera [13]. The mean load tabulated in Table 1 shows a large gap range between 50 mm/min to 500 mm/min. The load was based on the specimen dimension and complied with different speeds to observe the physical and raw data effects. The higher the tensile speed, the larger the external load needed until the specimen breaks into two pieces. In the end, the specimen sets were unable to be returned to their original length which should be 115 mm. The other terminology for this situation is hyperelasticity properties.

As referred to a research article written by Garcia, the slight differences found between the membranes tensile strength lied in the different compositions of the membranes, since the Aloe vera extract gave the nanofibers more elasticity to endure tensile different compositions of the membranes [14]. Moreover, the mechanical properties of the membranes indicated that commercial and original Aloe vera leaves are adequate for wound dressing application, since the obtained values were very similar to the human skin tensile strength, within an acceptable range between 5.7 MPa to 12.6 MPa according to Jacquemoud et al. [14].

Table 1: Mean load based on tensile speed

Tensile Speed, mm/min		50	500
Mean load, N		9.416	14.772
Mean Tensile Stress, MPa		0.408	0.7
Mean Strain		2.7298	3.3081
Mean Stretch		3.7298	4.3081
Ogden	α	2.8192	1.8792
	μ	0.0366 MPa	0.1881 MPa
Mooney-Rivlin	C_1	0.0714 MPa	0.0713 MPa
	C_2	-0.0706 MPa	0.0304 MPa

Commercial Aloe Vera

Based on the commercial Aloe vera combined with chitosan which was conducted by Shirin, the Aloe vera reduces the significant modulus after being combined with a semi-synthetic polymer. The minimum elongation break at 13.24% with 30.54 MPa tensile stress while the maximum elongation break at 4.33% with 49.81 MPa tensile stress [11]. Based on the mechanical data obtained from the experiment, the mean tensile stress was at 0.408 MPa to 0.7 MPa with elongation more than three times from its original length. The different material combinations would show the different mechanical strengths. The tensile strength of original Aloe vera leaves combined with gelatine was lower than commercial Aloe vera with chitosan. The main difference was between the combination of natural polymer (Aloe vera and gelatin) and semi-synthetic polymers (Aloe vera and chitosan).

Load and extension

Original Aloe Vera

The load versus extension in Figure 3 for 50 mm/min and 500 mm/min tensile speed shows the almost linear graph from the beginning. The difference was only from the beginning of the mechanical experiment process with the maximum extension of 118.3 mm while the maximum load on this speed was 13.37 N in Table 2. The graph trends by both specimen sets were differing from each other. Therefore, the texture of the specimen itself was thicker in a small force. If the graph performance becomes almost linear, it shows that the specimen's texture is thicker and needs a higher tensile speed to tear it into two pieces.

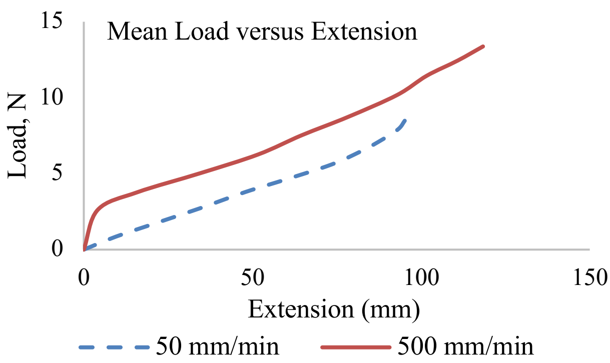

Figure 3: Load versus Extension nonlinear graph.

Table 2: Load and extension data

Mean Load, N		Mean Extension, mm	
50 mm/min	500 mm/min	50 mm/min	500 mm/min
0	0	0	0
0.8603	2.6208	9.5834	4.1463
1.7476	3.7744	21.4167	15.8336
2.7162	5.0348	34.3751	34.5833
3.7901	6.2626	47.8751	51.6668
4.6114	7.5270	59.7917	64.5838
5.5936	8.7347	73.3334	78.3332
6.4463	10.1820	81.9168	92.9168
7.0881	11.4456	87.2916	101.6667
7.9044	12.4435	93.0834	110.8337
8.5056	13.3737	95.2084	118.3334

Commercial Aloe Vera

The natural fiber that was contained in Aloe vera leaves influenced the viscoelasticity properties. Arulmurugan [15] supported that the applications of natural fibers are versatile, and the composite is used in various manufacturing industries due to its low cost, flexibility, biodegradable, renewable, low specific weight, and suitable for an eco-friendly environment. Discussing low specific weight, the load exerted on the specimen is variable and can be decided as low as possible, or vice versa. An experiment with 54 N maximum force at the breaking point for the specimen of Aloe vera powder in the year 2013 [5]. Thus, it is possible to increase the tensile speed or maximum load for the other material composition involving natural biopolymers.

Stress and strain

Original Aloe Vera

Stress and strain have a strong theory relation to Strain Energy Density Function. In other definition, the stress on the specimen was dependent on the load by the tensile machine. As Aloe vera is one of the potential materials for healing patch and tissue engineering, the mechanical properties are one of the most important properties to be considered as scaffolds for skin tissue engineering, which maintains the scaffold stability when it is used as a skin substitute.

However, the approximation of tensile speed plays an important part which is to illustrate the toughness of artificial skin after it is stretched by human hands. The stress-strain graph in Figure 4 was a bit unstable from the middle of the tensile testing process. Baghersad stated that artificial skin similar in structure to the natural tissue has a tensile strength of 5–10 kPa, Young's modulus of ≥5 kPa, and a maximum strain of ≥35% [3]. Technically, the graph trends are supposed to be nonlinear at the first order of derivation from the general equations.

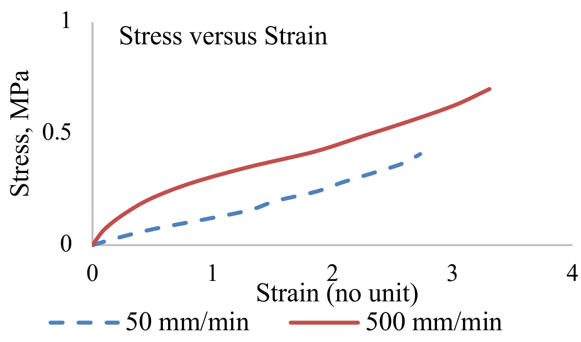

Figure 4: Stress versus strain ratio.

However, the second set (500 mm/min) specimen indicated a smooth and arranged order. The maximum mean strain obtained was three times its original length as refer to the Table 3.

Table 3: Stress and strain data

Mean Stress, MPa		Mean Strain	
50 mm/min	500 mm/min	50 mm/min	500 mm/min
0	0	0	0
0.03	0.07	0.1919	0.0992
0.072	0.14	0.5076	0.2652
0.114	0.21	0.9205	0.4924
0.156	0.28	1.303	0.8333
0.198	0.35	1.5278	1.3005
0.24	0.42	1.8636	1.8561
0.282	0.49	2.0859	2.2601
0.324	0.56	2.3409	2.6641
0.366	0.63	2.5833	3.0303
0.408	0.7	2.7298	3.3081

Commercial Aloe Vera

The stress-strain graph in Figure 5 shows the strain breaking point for respective polyvinyl alcohol (PVA) and nanocomposite materials. The Aloe vera was also included as a nanocomposite material which was denoted as PVA as their first specimen set. The breaking point of the commercial Aloe vera after the mixture with polyvinyl alcohol was greater than other nanocomposites such as cellulose [16]. However, as the commercial Aloe vera and original Aloe vera data were compared, the commercial Aloe vera has higher tensile stress but a lower strain ratio. It was due to the tensile speed as an influencing factor.

Biomechanical properties

The biomechanical properties of biomaterials determine the micro-movement between the polymers including stretch (no unit), and material constants. The material constants indicate the maximum shear modulus and strain hardening if tensile happens on the healing patch. In other applications, Tran said that biopolymers are the source of inexpensive materials that possess excellent mechanical properties and are easy to process, making them the first consideration to be a part of the material for tissue engineering [5]. Therefore, the biomechanical properties in biopolymers such as Aloe vera itself contributing to medical or tissue engineering industries.

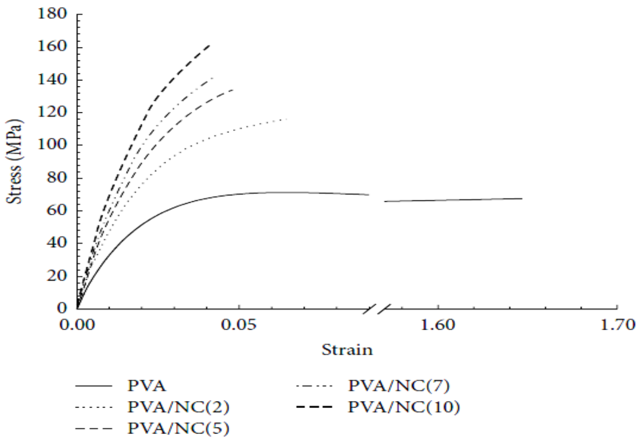

Figure 5: Stress versus strain ratio for PVA and its nanocomposites [16].

Stress and stretch

The stretch is an additional 100% from the strain ratio to indicate the maximum hyperelasticity of a material. The maximum stretch was indicated in Table 4 proves that Aloe vera were able to elongate more than 4 times from their original length which was 33 mm. The second set has a good elasticity after the specimen was elongated at 500 mm/min tensile speed. Despite the fibers or other unfiltered components, the second set in Figure 6 remains to have a good mechanical performance. The other application of Aloe vera is tissue scaffolding that was combining with other biomaterials such as tetracycline hydrochloride (TCH) through electrospinning. It was found that the fabricated nanofibrous scaffolds possessed potential mechanical properties within the range of human skin [17]. Therefore, the hybrid natural polymer would execute a group of biomechanical properties after combination in respective proportion. During extraction of the biomechanical data, the variance between each specimen set was manually tabulated in separate programming to reduce numerical errors. Chaitanya supported that Aloe Vera fibers have a strong potential to be used as a reinforcement in polymer matrix composites used in various structural and non-structural applications [18].

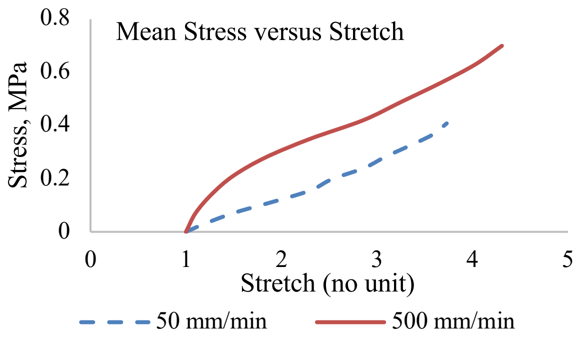

Figure 6: The Stress-Stretch nonlinear graph.

Table 4: Stress and stretch data

Mean Stress, MPa		Mean Stretch		Variance	
50 mm/min	500 mm/min	50 mm/min	500 mm/min	50 mm/min	500 mm/min
0	0	1	1	0	0
0.03	0.07	1.1919	1.0992	0.0003	0
0.072	0.14	1.5076	1.2652	0.0000	0.0003
0.114	0.21	1.9205	1.4924	0.0007	0.0003
0.156	0.28	2.3030	1.8333	0.0003	0.0013
0.198	0.35	2.5278	2.3005	0.0008	0.0080
0.24	0.42	2.8636	2.8561	0.0001	0.0080
0.282	0.49	3.0859	3.2601	0.0001	0.0386
0.324	0.56	3.3409	3.6641	0.0013	0.0258
0.366	0.63	3.5833	4.0303	0.0001	0.0625
0.408	0.7	3.7298	4.3081	0.0005	0.1033

Curve fitting

The curve fitting between the experimental value and hyperelastic constitutive models was meant to indicate the gap error on the graph. The closer the curve fitting, the material constants would be more accurate and reliable. The Ogden hyperelastic model was one of the oldest references but still relevant to be the main reference during data validation. At the same time, the graph should be nonlinear and smooth. Moreover, the polycaprolactone (PCL) nanofibrous scaffolds with 10% aloe vera showed that finer fiber morphology with improved hydrophilic properties and higher tensile strength of 6.28 MPa with Young's modulus of 16.11 MPa that are desirable properties for skin tissue engineering [19]. In biological conditions, human skin is incredible and stretchable in all areas but different in thicknesses. For example, the skin grafting technology can be cultured by the original (host) stem cells and reducing skin donors gradually. Besides that, there would be less DNA confusion between the host and donor. Therefore, the material that has potential usage in dermatology or tissue engineering could be compatible with human skin.

The predicted tensile stress was calculated to ensure the similarity with experimental tensile stress. The curve fit in Figure 7 shows the almost linear trends between Ogden, Mooney-Rivlin, and experiment data. Even though the gap between them was very close, the trends were not too acceptable as a hyperelastic material from a slower tensile speed. On the other side, the curve fit from Figure 8 illustrates a smooth and very close gap compared to Figure 7.

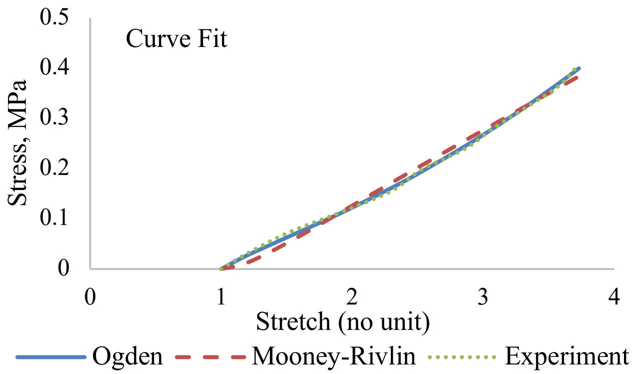

Figure 7: The curve fit at the speed of 50 mm/min.

However, the strain hardening in Table 5 which is 2.82 while 1.89 from Table 6 were within an average range. As we can observe from the previous tables, both sample sets were on average strain hardening and shear modulus. In terms of the Mooney-Rivlin model, both sample sets have almost the same material constants for each invariant (C_1 and C_2). Overall, the material constants for Ogden and Mooney-Rivlin are acceptable and relevant to be used for validation purposes. Chaitanya proved that an optimum fiber treatment time of 72 hours exhibited the highest improvement in tensile, flexural, and compressive behaviour of the developed biocomposites, which is the biocomposites incorporating treated (72 hours) Aloe Vera fibers exhibited 104.9% higher impact strength as compared to neat polylactic acid (PLA) [20].

Table 5: The material constants for 50 mm/min

No.	Model	Constants	Value
1	Ogden	α	2.8192
		μ	0.0366 MPa
2	Mooney-Rivlin	C_1	0.0714 MPa
		C_2	-0.0706 MPa

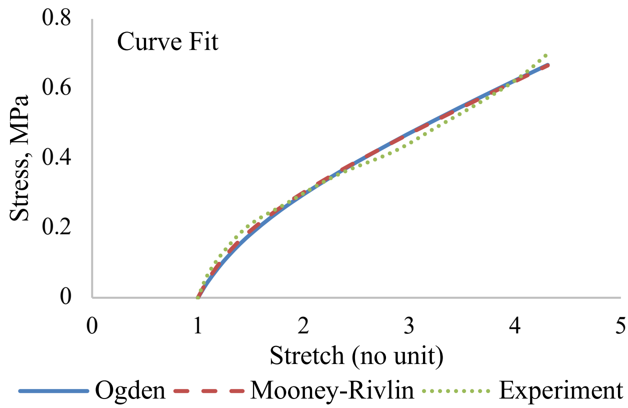

Figure 8: The curve fit at the speed of 500 mm/min.

Table 6: The material constants for 500 mm/min

No.	Model	Constants	Value
1	Ogden	α	1.8792
		μ	0.1881 MPa
2	Mooney-Rivlin	C_1	0.0713 MPa
		C_2	0.0304 MPa

Data comparison with previous researchers

Based on research completed by Czerner in Table 7, the strain hardening from bovine skin has related data to the current study in this project. The collagen content inside bovine (cow) skin has high compatibility with human skin. The gelatine with Aloe vera gels mixture is acceptable to improvise as a future biodegradable healing patch. At the same time, the commercial Aloe vera also has the potential as a future healing patch with a longer lifespan. Based on average, the strain hardening from the specimen set was 1.5 times lower than the rubber or human skin. Minjares-Fuentes concluded that it is a normal effect when all processed Aloe vera (commercial products) exhibited lower water activity (<0.4), higher solubility (>90%), and higher hygroscopy (>80%) than the Aloe vera leaves [21]. Moreover, a shear-thinning behavior, exhibited by the fresh Aloe vera gel, was modified to a Newtonian group. Biodegradable products especially in medical lines are gradually marked as an important industry to the world. In the future, we need to improvise the Aloe vera healing patch which could comply with human skin. Apart from that, Shahzad has completed an experiment on rubber material through planar shear and equi-biaxial tensile test until the result came out at $\alpha = 3.2898$, $\mu = 4.3753$ MPa as their shear modulus [22]. As expected from the beginning of the procedure, the rubber material was incompressible condition almost as human skin.

The specific material constants from Mooney-Rivlin comparison also show the large differences in Table 8. Among the materials compared, the rubber or silicone material has good hyperelasticity properties. However, the material is not compatible with all the human skin types as a healing patch. It was preferable as a permanent derma transplant with upcoming side effects such as thermal sensitivity and itchiness. To avoid further complications, the material from natural sources is recommended.

Table 7: Compilation of Ogden material constants results between the current study and previous researchers

Author	Tests	Sample	Result		Source
			Concluded description	Data	
Current study	Uniaxial tensile test	Gelatine with Aloe vera gels	Smooth, clear texture, incompressible	Ogden: α= 1.8792 μ=0.1881 MPa	-
Czerner	Uniaxial compres sion test	Bovine and porcine gelatine	The material was incompressible	Bovine, α= -1.44 ± 0.01 μ= 12.07 ± 0.06 kPa Porcine, α= -1.38 ± 0.04 μ= 13.52 ± 0.19 kPa	[23]
Evans	In-plane compre-ssion	In vitro human skin	Wrinkling simulation	α = 3 μ = 10 kPa	[24]

Table 8: Compilation of Mooney-Rivlin material constants results between the current study and previous researchers

Author	Tests	Sample	Result		Source
			Concluded description	Data	
Current study	Uniaxial tensile test	Gelatine with Aloe vera gels	Smooth, clear texture, incompressible	C_1 = 0.0713 C_2 = 0.0304	-
Shahzad	Planar shear and equi-biaxial tensile test	Rubber	The rubber is compressible	C_1 = 0.3339 C_2=– 0.000337	[22]
Lagan	Uniaxial tensile test	Abdomen and spine region from pig skin (130 kg, 8 months old)	Abdomen region was more elastic than spine region	C_1 = 0.057 C_2 = 7.728	[25]

Shirin simplified that an ideal wound dressing is not the one with high modulus or tensile strength, but it is soft, flexible, and easy to handle [11]. Apart from that, Zhang concluded that four major components in the commercial powdered aloe juice samples-organic acids, minerals, monosaccharides, and polysaccharides accounted for 78–84% of the total composition [26]. The major constituents of Aloe vera fresh leaf are fibers, proteins, organic acids, minerals, monosaccharides, and polysaccharides, which were approximated to about 85–95% of the total composition [26]. In a mathematical term, there were slight percentage differences in respective major components. It was a normal effect after the natural polymers combine with other materials to be commercial products. The crosslinked natural rubber and Aloe vera are hydrophilic (water absorbent). A stabilizer or emulsifier is necessary to produce a uniformed mixture of artificial skin if involving the hydrophilic (water absorbent) and hydrophobic (water repellent) material. The other factor influenced during extracting the mechanical data was the fiber content inside the original Aloe vera leaves. In the future, the Aloe vera gels extraction needs to be refined to reduce the data error in the mechanical testing phase.

Conclusion

The first objective that was to classify the suitable composition between gelatine and Aloe vera gels was successfully achieved. Both gelatine and Aloe vera needs an equal ratio to maintain their elasticity during mechanical testing. The effect on exceeding distilled water ratio could distract the connection between polymers. However, the stabilizer or any supportive ingredients that could improve the texture need to be explored soon. Secondly, basic mechanical and biomechanical data were successfully extracted. Overall, the second specimen set with 500 mm/min tensile speed indicates a smooth nonlinear graph. The strain ratio decreasing is influenced by the tensile speed. Therefore, the tensile speed would be more improvised based on the composition constructed. The final objective which was to carry out the material constants of hyperelastic models also follows the Ogden and Mooney-Rivlin trends with minimal gap. The original Aloe vera leaves also have their mechanical properties after combining with other natural polymers such as gelatine. As a recommendation, sustainable sources of the natural polymer are necessary to be produced as a biodegradable healing patch. The commercial Aloe vera also has a good potential as a conventional healing patch with a good aesthetical value compared to original Aloe vera leaves.

Acknowledgment

I want to extend my appreciation to the Ministry of Higher Education for the Fundamental Research Grant Scheme (FRGS) as referring to the grant number 600-IRMI/FRGS 5/3 (363/2019) as our official funding during my research.

References

[1] C. T. Ramachandra and P. Srinivasa Rao, "Processing of Aloe vera leaf gel: A review," *Am. J. Agric. Biol. Sci.*, vol. 3, no. 2, pp. 502–510, 2008.
[2] A. A. Maan *et al.*, "The therapeutic properties and applications of Aloe vera: A review," *J. Herb. Med.*, vol. 12, pp. 1–10, 2018.
[3] S. Baghersad, S. Hajir Bahrami, M. R. Mohammadi, M. R. M. Mojtahedi, and P. B. Milan, "Development of biodegradable electrospun gelatin/aloe-vera/poly(ε-caprolactone) hybrid nanofibrous scaffold for application as skin substitutes," *Mater. Sci. Eng. C*, vol. 93, pp. 367–379, 2018.
[4] M. C. Gomez-Guillen, B. Gimenez, M. E. Lopez-Caballero, and M. P. Montero, "Functional and bioactive properties of collagen and gelatin from alternative sources: A review," *Food Hydrocoll.*, vol. 25, no. 8, pp. 1813–1827, 2011.

[5] T. T. Tran, Z. A. Hamid, and K. Y. Cheong, "A Review of Mechanical Properties of Scaffold in Tissue Engineering: Aloe Vera Composites," *J. Phys. Conf. Ser.*, vol. 1082, no. 1, 2018.

[6] W. A. B. Wan Abas and J. C. Barbenel, "Uniaxial tension test of human skin in vivo," *J. Biomed. Eng.*, vol. 4, no. 1, pp. 65–71, 1982.

[7] H. Zahouani, C. Pailler-Mattei, B. Sohm, R. Vargiolu, V. Cenizo, and R. Debret, "Characterization of the mechanical properties of a dermal equivalent compared with human skin in vivo by indentation and static friction tests," *Ski. Res. Technol.*, vol. 15, no. 1, pp. 68–76, 2009.

[8] B. Kim *et al.*, "A comparison among Neo-Hookean model, Mooney-Rivlin model, and Ogden model for Chloroprene rubber," *Int. J. Precis. Eng. Manuf.*, vol. 13, no. 5, pp. 759–764, 2012.

[9] N. Kumar and V. V. Rao, "Hyperelastic Mooney-Rivlin Model : Determination and Physical Interpretation of Material Constants," *MIT Int. J. Mech. Eng.*, vol. 6, no. 1, pp. 43–46, 2016.

[10] N. N. Mohd Nazali, N. A. A. Anirad, and N. F. Adull Manan, "The Mechanical Properties of Mimic Skin," *Appl. Mech. Mater.*, vol. 899, pp. 73–80, 2020.

[11] S. Rafieian, H. Mahdavi, and M. E. Masoumi, "Improved mechanical, physical and biological properties of chitosan films using Aloe vera and electrospun PVA nanofibers for wound dressing applications," *J. Ind. Text.*, vol. 50, no. 9, pp. 1456–1474, 2021.

[12] A. Vedadghavami *et al.*, "Manufacturing of hydrogel biomaterials with controlled mechanical properties for tissue engineering applications," *Acta Biomater.*, vol. 62, pp. 42–63, 2017.

[13] N. Aghamohamadi, N. S. Sanjani, R. F. Majidi, and S. A. Nasrollahi, "Preparation and characterization of Aloe vera acetate and electrospinning fibers as promising antibacterial properties materials," *Mater. Sci. Eng. C*, vol. 94, no. September 2018, pp. 445–452, 2019.

[14] I. Garcia-Orue *et al.*, "Novel nanofibrous dressings containing rhEGF and Aloe vera for wound healing applications," *Int. J. Pharm.*, vol. 523, no. 2, pp. 556–566, 2017.

[15] M. Arulmurugan, K. Prabu, G. Rajamurugan, and A. S. Selvakumar, "Viscoelastic behavior of aloevera/hemp/flax sandwich laminate composite reinforced with BaSO4: Dynamic mechanical analysis," *J. Ind. Text.*, vol. 50, no. 7, pp.1040-1064, 2019.

[16] A. R. Kakroodi, S. Cheng, M. Sain, and A. Asiri, "Mechanical, thermal, and morphological properties of nanocomposites based on polyvinyl alcohol and cellulose nanofiber from Aloe vera rind," *J. Nanomater.*, vol. 2014, pp. 12–18, 2014.

[17] H. Ezhilarasu *et al.*, "Biocompatible aloe vera and tetracycline hydrochloride loaded hybrid nanofibrous scaffolds for skin tissue engineering," *Int. J. Mol. Sci.*, vol. 20, no. 20, 2019.

[18] S. Chaitanya and I. Singh, "Novel Aloe Vera fiber reinforced biodegradable composites - Development and characterization," *J. Reinf. Plast. Compos.*, vol. 35, no. 19, pp. 1411–1423, 2016.
[19] S. Rahman, P. Carter, and N. Bhattarai, "Aloe Vera for Tissue Engineering Applications," *J. Funct. Biomater.*, vol. 8, no. 1, p. 6, 2017.
[20] S. Chaitanya and I. Singh, "Ecofriendly treatment of aloe vera fibers for PLA based green composites," *Int. J. Precis. Eng. Manuf. Technol.*, vol. 5, no. 1, pp. 143–150, 2018.
[21] R. Minjares-Fuentes *et al.*, "Effect of different drying procedures on physicochemical properties and flow behavior of Aloe vera (Aloe barbadensis Miller) gel," *LWT - Food Sci. Technol.*, vol. 74, pp. 378–386, 2016.
[22] M. Shahzad, A. Kamran, M. Z. Siddiqui, and M. Farhan, "Mechanical characterization and FE modelling of a hyperelastic material," *Mater. Res.*, vol. 18, no. 5, pp. 918–924, 2015.
[23] M. Czerner, J. Martucci, L. A. Fasce, R. Ruseckaite, and P. M. Frontini, "Mechanical and fracture behavior of gelatin gels," *13th Int. Conf. Fract.*, vol. 16, no. 21, pp. 4439–4448, 2013.
[24] S. L. Evans, "On the implementation of a wrinkling, hyperelastic membrane model for skin and other materials," *Comput. Methods Biomech. Biomed. Engin.*, vol. 12, no. 3, pp. 319–332, 2009.
[25] S. D. Łagan and A. Liber-Kneć, "Experimental testing and constitutive modeling of the mechanical properties of the swine skin tissue," *Acta Bioeng. Biomech.*, vol. 19, no. 2, pp. 93–102, 2017.
[26] Y. Zhang, B. Zhichao, X. Ye, and Z. Xie, "Chemical Investigation of Major Constituents in Aloe vera Leaves and Several Commercial Aloe Juice Powders," *J. AOAC Int.*, vol. 101, no. 6, pp. 1741–1751, 2018.