International Journal of Engineering & Technology, 7 (4.26) (2018) 180-184

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper



Dynamic Stress Analysis of Skin (Bovine) and Synthetic Skin (Silicone) under Low Impact Loading : a Review and Framework

Zurri Adam Mohd Adnan[1], Jamaluddin Mahmud*[2], Mohd Azman Yahaya[3]

Faculty of Mechanical Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia
**Corresponding author E-mail: jm@salam.uitm.edu.my*

Abstract

Skin performs multiple important functions for our body and that might be the main reason for it complex structure and unique mechanical behaviour. There have been a lot of studies about skin mechanical behaviour but skin deformation behaviour and its dynamic stress under low impact loading is still not well understood. This paper aims to review past research related to skin investigation, which ultimately leads to proposing a research framework in determining the dynamic stress of skin and synthetic skin under low impact loading. In the first stage, the literatures related to skin substitutes and skin hyperelastic properties were reviewed, summarised and reported. The past research related to numerical analysis using hyperelastic constitutive models such as Neo-Hookean, Mooney-Rivlin and Ogden model to quantify skin mechanical behaviour were discussed. Next, the literatures related to determining dynamic stress as well as the specimen specification were reviewed and reported. Finally, based on these reviews, a research framework to determine the dynamic stress of skin and synthetic skin under low impact loading is proposed. The information provided in this paper could contribute significant fundamental knowledge about skin behaviour and the preparation to perform experiments in understanding the dynamic stress of skin under low impact loading.

Keywords: *Skin, synthetic skin, hyperelastic, dynamic stress, low impact loading*

1. Introduction

Biologically, human tissues are complex layered natural part of our body which one of the part of it is skin. It provides insulation, regulates body temperature, offers a form of protection to inner organs and is therefore necessary for human existence and survival. Skin is one of the most important tissues since it accounts for about 15% of the body weight, averages 1.8 m^2 in surface, and has a thickness of 1.5–4 mm in the human body [1, 2]. It can be divided into three layered which are epidermis, dermis and hypodermis. These three layers have an extracellular proteinic matrix (ECM) in which it consists of three classes of biomolecules which are structural protein, specialized protein and proteoglycans and different cells apart of other structures such as blood vessels, glands, nerves and hair [3, 4].

The epidermis is an outer layer in which cover all layered of our skin. It consists of cell and cellular debris. The thickness of epidermis is about 0.05 mm (eyelids) to 0.8-1.5 mm (thicker in palms and soles) which consists of keratinocytes and 5% of other cells such as melanocytes, Merkel cells and Langerhans. The keratinocytes are cells that produce keratin which is cytoskeletal filament and also protective protein [3]. The epidermis which is the outermost layer is the dominant factor when determining the properties of the skin such as the tensile strength of skin, depending on the size and degree of crosslinking of the collagen framework [5]. The second layer of skin is dermis. This is the most important layer which consist of 90% the thickness of skin [3, 6]. The dermis thickness is about 0.6 mm to 3 mm. The dermis controls skin strength and flexibility which composed of collagen and elastin fibres [6, 7]. The basement membrane connects the dermis and epidermis in the dermo-epidermal junction with thickness of 65 mm -75 mm [3, 8]. The hypodermis which is the innermost layer of skin mechanically act as shock absorber [3, 9, 10]. It also known as “subcutis” or “subcutaneous fat” which mainly composed of areolar connective and adipose tissue that functions as energy storage and give thermal insulation to human body [3, 6].

Skin exhibits nonlinear, non-homogenous, viscoelastic and anisotropic behaviour [3, 4, 5], with the ability to endure large deformations. The mechanical properties of skin and behaviour are important for biomedical engineering, forensic, cosmetology and also plastic surgery [11]. Burn, damage and accident are the most complicated and leads to important study to determine the mechanical properties and behaviour of skin due to limited information and development of synthetic skin as skin substitute [5]

2. Skin Substitutes

Since then, the skin substitute variously tested to overcome the problem occur for skin injuries and it can be classified into three different group of clinical application purposes which are permanent, semi-permanent and temporary [12]. For temporary application the skin graft material will be used to cover and heal the wound. For semi-permanent, the material remaining attached to excised wound and eventually replace by autogenous skin grafts and permanent was incorporation of an epidermal analogue, dermal, analogue or both as permanent replacement. Apart from that, skin substitutes are categorized by the type of tissue for grafting which classified as three main types which are xenografts, allo-

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

grafts and autografts [12, 13]. Xenografts can be described as using tissue from living organisms to another in which to heal the wound. Meanwhile, allografts can be described as tissue of the same living organism that is human transplanted to another human and can be divided into three types in which epithelial or epidermal, dermal and composite. The different from two skin substitutes compared to autografts is it uses the same tissue from the living organism in which human to heal the wound [13, 14, 15]. The importance of design and fabrication skin substitute lead to studying the mechanical behaviour by Nadiah et. al [14] to investigate specific standard of measuring the properties of synthetic skin. The silicone rubber was used in determining two physical testing standards in which are ASTM D2209 and ASTM D412 [testing standard] involving uniaxial tensile testing and MATLAB programme to measure the material constant. Thus, the study of skin mechanical properties has been very important recently in which to determine the optimal skin substitute [15].

The understanding of the mechanical behaviour of skin and its properties is important in the design and fabrication of a compatible skin substitute, since up till now there are no models of bioengineered skin that can entirely replicate all the complicated nature of the uninjured skin [16]. This paper aims to review past research related to skin investigation, which ultimately leads to proposing a research framework in determining the dynamic stress of skin and synthetic skin under low impact loading.

3. Hyperelastic Materials

Skin has complex mechanical characteristics in which it is nonlinear and hyperelastic materials (17). Moreover, to date, there is no mathematical model that could predict accurately the dynamic stress of skin. However, the model is very crucial to aid in designing synthetic materials that could biomimic skin behaviour under low impact loading (a synthetic skin that could replicate skin mechanical behaviour and robust). Hence, the investigation using hyperelastic material model will be useful in determining the mechanical behaviour of skin which are originally developed for rubber materials such as Neo-Hookean, Mooney-Rivlin and Ogden models; are commonly adapted for soft tissues [18, 19, 20, 21, 22, 23, 25].

A parametric study has been constructed in determining the mechanical behaviour of material using Neo-Hookean's strain energy function [14]. In that study, the contributions of material constant C_1 were evaluated by varying its using Neo-Hookean constitutive equation. It has been observed using stress-stretch diagram that varying the value of material constant C_1 affected the behaviour of stress-stretch curve. Neo-Hookean material model has been used by Karimi et. al [25] to determine the anisotropic nonlinear mechanical properties of rat and mice skin tissue using the role of fiber orientations into that constitutive equation. Khajehsaeid et al [26] conducted a studied to determine the necessary properties to satisfy the efficient hyperelastic model. By comparing the experimental data and three hyperelastic material model which were AB model, Mooney-Rivlin model and Pucci−Saccomandi model, they found that the Mooney-Rivlin model is more accurate in terms of small extension and characteristic behaviour of the material in transition from extension to compression well predicted. Chen et. al 2013 [31], used three material model which were Neo-Hookean, Mooney-Rivlin and Yeoh to study the hyperelastic constitutive parameters from load-depth curves obtain from indentation test of silicone rubber. The Ogden model was recommended as the best hyperelastic material model in which to determine a large number of optimal sets of parameters [8,10]. Besides, this hyperelastic material model can be generally considered to be isotropic, incompressible and strain rate dependant [8]. The hyperelastic models are shown in Table 1 below with its Strain Energy functions.

Table 1: Hyperelastic models with Strain Energy Density Equations

Hyperelastic models	Strain Energy Density Function Equation
Neo-Hookean	$W = C_1(I_1 - 3)$
Mooney-Rivlin	$W = C_1 (I_1 - 3) + C_2 (I_2 - 3)$
Ogden	$W = \sum_{i=1}^{n} \frac{\mu_i}{\alpha_i}(\lambda_1^{\alpha_i}+\lambda_2^{\alpha_i}+\lambda_3^{\alpha_i}-3)$

4. Dynamic Stress Analysis under Low Impact Loading

The dynamic stress is often occurred to human body as an example, forces that applied to our body, in which cause the dynamic deformation to human skin [27, 28, 29, and 30]. The deformation of materials that are subjected to dynamic loading is defined by the strain rate, $\dot{\varepsilon}(t)$ in which can be defined as strain deformation with respect to time [18]. One of the most important key parameter in order to identify the dynamic stress behaviour is impact velocity or loading rate [19]. According to Shergold et. al [16], the importance of strain rate to determine the dynamic behaviour of soft solids such as skin and rubber range from the penetration pressure of skin by hypodermic needle, soft tissue damage and stabbing incidents. According to Zheng et. al [33], the important key parameters for dynamic loading experiment are size of specimens and impact velocity or loading rate. Table 2 below shows that the range of velocity under impact loading in determining the dynamic mechanical behaviour of material

Table 2: Classification of Impact Velocity Loading [35]

Impact Load	Range of Velocity
Low	<50 m/s
High	50 m/s – 1000 m/s
Hyper	>2-5 km/s

Besides, the strain rates or loading rates of material have been classified which are shown in Table 3 below.

Table 3: Classification of Strain rates [35]

Classification of Strain Rate	Range of Strain Rate
Quasi-Static Strain Rate	$<10^{-3}$ s^{-1}
High Strain Rate	$>10^{2}$ s^{-1}
Very High Strain Rate	$>10^{4}$ s^{-1}
Ultra-High Strain Rate	$>10^{6}$ s^{-1}

For dynamic stress analysis, one of the mechanical testing that commonly used is Split Hopkinson Pressure Bar (SHPB). The SHPB experiment have been widely used in many applications to determine the dynamic properties of materials such as metals, concrete, ceramics, composites and for soft material such as rubber [18, 30, 36]. This is due to the needs of critical understanding in determining the dynamic stress behaviour of materials as it always exposed to impact loading [23, 37].

The SHPB technique also have been introduced to analyze the dynamic rock test but have limitation and issues to ensure the dynamic rock strength value are valid [38, 39] which are the effect of friction between the sample and bars on the compressive strength of rocks, the choice of slenderness ratio of the compressive specimen, the necessity of dynamic force balance for the dynamic BD test, and the validity of using the standard BD equation in the data reduction in dynamic tests. The Split Hopkinson Pressure Bar (SHPB) will be used to study the dynamic stress of bovine skin and synthetic silicone under low impact loading. Referring to Figure 1, the deformation behaviour of material using Split Hopkinson Pressure Bar (Bar) test is investigated between two bars impact. The two bars name are incident and transmitter bar respectively. These two bars have dimension 12.7 mm diameter and length of 1000 mm. Then, there is another bar name as striker bar with diameter of 12.7 mm and length of 0.4 mm which is used air gun to give an axial impact to the specimen. The incident and transmitter bar made of aluminium alloy rods.

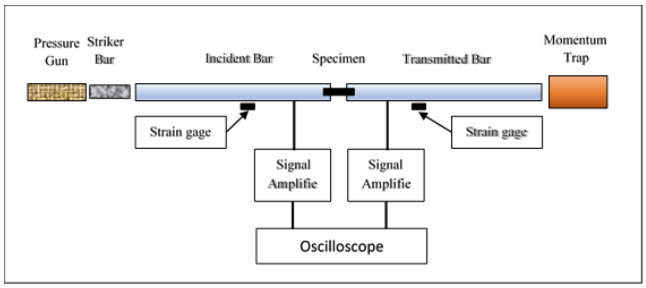

Fig. 1: Schematic diagram of SHPB set-up

The important parameter that can be analyze on dynamic properties of materials by employing the SHPB technique is that the stress-strain curves under large strain-rate deformation which ranging from 102 s-1 to 104 s-1 [25]. Soft material such as polymer, foam and biological tissues have low mechanical stiffness and strength that less understood in dynamic response due to limitation of understanding on dynamic experimental methods on high strain rates [40]. Lim et. al [18] modified the Split Hopkinson Pressure Bar (SHPB) technique into Split Hopkinson Tensile Bar (SHTB) in order to study the tensile behavior of pig skin at high strain rates and it shows that pig skin exhibits rate-sensitive, orthotropic, and non-linear behavior. Guo et. al [41] conducted the dynamic tensile using SHTB in order to analyze the effect of strain rate on the tension behavior of filled silicone rubber. The experiment shows that strain rate influences the dynamic tensile behaviour of silicone rubber. The increasing of strain rate leads to an increasing of stiffness and nominal stress value of silicone rubber.

As refer to the Figure 2 below, the pressure from pressure gun give an impact of striker bar on incident bar that generates the incident wave goes through the incident bar and transmitted to the material and transmitted bar then reflected back into the incident bar as tensile wave. According to Slighternhorst et. al [44], an increasing of striker impact velocity and decreasing the specimen gage length will increased the deformations rates of the materials.

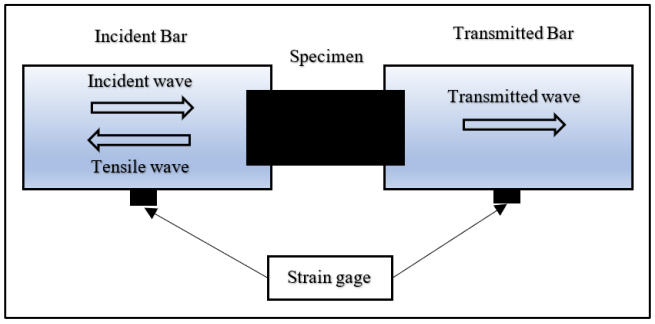

Fig. 2: SHPB test mechanism

Another important part in SHPB method is strain gage that are mounted on incident bar and transmitted bar to measure the incident, transmitted and reflected waves which gives results for dynamic stress-strain calculations of the materials. The incident strain, reflected strain and transmitted strain will be recorded as a function of time, t using strain gages that are attached to incident bar and transmitted bar. The equation below shows the engineering stress that will be obtained from the strain gage measurement [18].

$$\sigma_s(t) = \frac{A_t}{A_s} E_t \varepsilon_t(\mathrm{t}) \qquad \text{(Eq. 1)}$$

Where;

A_t = Cross-sectional of bar
A_s = Cross-sectional of specimen
E_t = Young's modulus of the bar
ε_t = Transmitted strain

The strain rate, $\dot{\varepsilon}(t)$ of the specimen will be calculated by using the Eq. 2 and Eq. 3 below.

$$\dot{\varepsilon}(t) = -\frac{2C_0}{l_s}\varepsilon_r(\mathrm{t}) \qquad \text{(Eq. 2)}$$

$$C_0 = \frac{E}{\rho} \qquad \text{(Eq. 3)}$$

Where;
$\dot{\varepsilon}$ = Strain rate of specimen
C_0 = Elastic bar wave speed in the rod
l_s = Initial gage length of the specimen
ε_r = The reflected strain
ρ = Density of the incident/transmitted bar

5. Specimen Preparation

For SHPB tests, specimens made of bovine skin and synthetic silicone have been selected. These specimens will be prepared in the Biomechanics Laboratory of Mechanical Engineering Faculty, Universiti Teknologi MARA (UiTM) Shah Alam. In the SHPB test, the specimens will be prepared with 10 mm diameter with length ranging from 1 mm to 5 mm [44]. The bovine skin that will be used is obtained from local butcher shop after slaughtering process. The criteria of bovine skin; such as species, age and weight as well as the location of specimen will be confirmed. The bovine skin will be immediately cut according to size of specimen. Then, in order to maintain the freshness bovine will be stored in airtight bag with temperature of 4°C. All of the fat layer and hairs will be removed from the specimens using a surgical scalpel.

The data obtained from SHPB test will be used to determine mechanical properties of bovine and silicone using Neo-Hookean, Mooney-Rivlin and Ogden material model. Then, the graph will be plotted to compare the experimental and numerical analysis and the mechanical behaviour of materials will be investigated using curve fitting technique. For synthetic silicone, the raw supersoft silicone rubber, Ecoflex 0030 was bought from Castmech Sdn Bhd (sole distributor for Smooth-On,Inc. in Malaysia) as shown in Figure 3 below. The silicone rubber has two combinations which were Part A and Part B. The mix ratio for both parts is 1:1 by volume.



Fig. 3: Silicone rubber Ecoflex 00-30 Part A and Part B

Steps that involve for mixing the part A and B of silicone rubber, Ecoflex 00-30 are as shown in Figure 4 below.





The silicone Ecoflex 00-30 Part A and Part B will be mixed for mix ratio volume of 1:1 using syringe.



The wood stick was used to stir the silicone mixture.



Then, the mixture of Part A and Part B of silicone were pour into aluminium mould and the specimens were allowed to cure for at least four hours

Fig. 4: Step for mixing the part A and B of silicone rubber

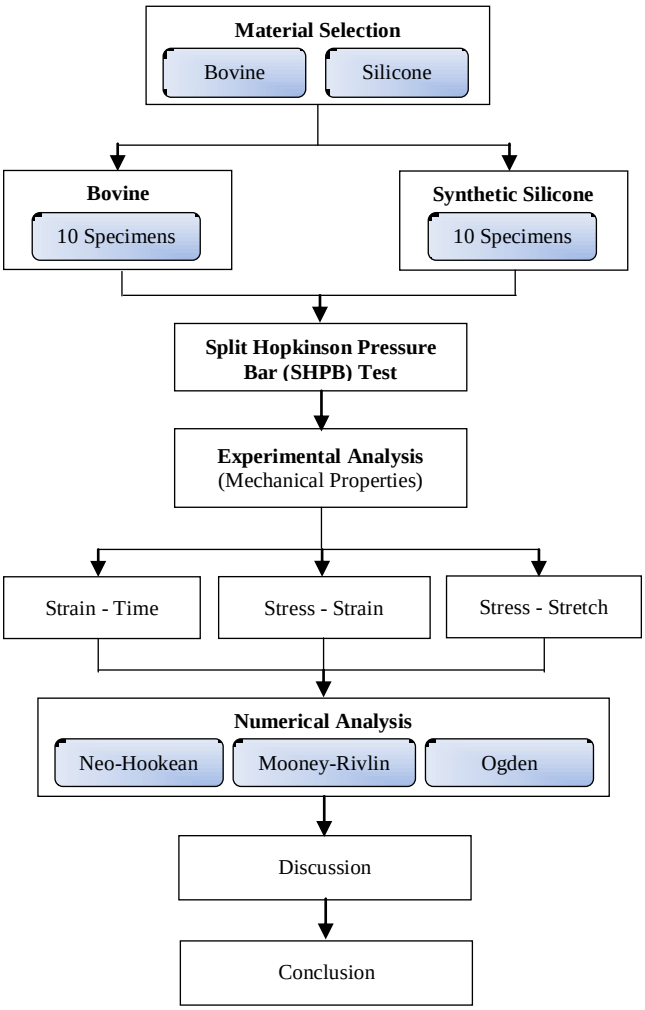

Fig. 5: A framework to determine the dynamic stress analysis of skin (bovine) and synthetic skin (silicone) under low impact loading.

6. Proposed Framework

In order to determine the dynamic stress analysis of skin (bovine) and synthetic skin (silicone) under low impact loading, a framework is proposed to display the process flow that will involve in this investigation. In this framework, two analyses will be implemented which are experimental and numerical analysis as shown in Figure 5 below. The data obtained from experimental analysis will be used to conduct the numerical analysis to acquire the material constant for hyperelastic constitutive model of Neo-Hookean, Mooney-Rivlin and Ogden. From the results of both materials through experimental and numerical analysis, the mechanical behaviour will be compared and discussed.

7. Conclusion

In conclusion, this paper aims to further understanding on dynamic stress analysis of skin deformation behaviour under low impact loading since the information is still very limited and not well defined. The knowledge from experimental and numerical analysis will enhance the research development to determine mechanical behaviour of skin. Furthermore, the study of hyperelastic constitutive model of skin through this research could contribute to better understanding of skin mechanical properties.

Acknowledgement

This research is sponsored by the Ministry of Education, Malaysia and Universiti Teknologi MARA (UiTM) Malaysia, under the Fundamental Research Grant Scheme, grant no. (UiTM File. No. 600-RMI/FRGS 5/3 (102/2017).

References

[1] Alrubaiy L and Al-Rubaiy K. K (2009), "Skin Substitutes: A Brief Review of Types and Clinical Applications," *Oman Med. J.*, vol. 24, no. 1, pp. 6–8.

[2] Annaidh AN, Bruyère K, Destrade M, Gilchrist M D, and Otténio M (2012), "Characterization of the anisotropic mechanical properties of excised human skin," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 5, no. 1, pp. 139–148.

[3] Benítez JM and Montáns FJ (2017), "The mechanical behavior of skin: Structures and models for the finite element analysis," *Comput. Struct.*, vol. 190, pp. 75–107.

[4] Foley E, Robinson A, and Maloney M (2013), "Skin Substitutes and Dermatology: A Review," *Current Dermatology Reports*, vol. 2, no. 2, pp. 101–112.

[5] Gallagher, A. J.; Ní Annaidh, Aisling; Bruyère (2012), "Dynamic Tensile Properties of Human Skin," *IRCOBI Conference*

[6] Mohd Noor SNA and Mahmud J (2014), "A Review on Synthetic Skin: Materials Investigation, Experimentation and Simulation," *Advanced Materials Research*, vol. 915–916, pp. 858–866.

[7] Pramudita JA, Shimizu Y, Tanabe Y, Ito M, and Watanabe R (2013), "Anisotropic Tensile Properties of Porcine Skin in Dorsal and Ventral Regions," *Journal of JSEM*, vol. 14, no. July, pp. 3–6.
[8] Ottenio M, Tran D, Annaidh AN, Gilchrist MD, and Bruyère K (2015), "Strain rate and anisotropy effects on the tensile failure characteristics of human skin," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 41, pp. 241–250.
[9] Moerman KM, Simms CK, and Nagel T (2016), "Control of tension-compression asymmetry in Ogden hyperelasticity with application to soft tissue modelling," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 56, pp. 218–228.
[10] Yilmazçoban NK and Yilmazçoban İK (2016), "Experimental and Computational Examination of the Bovine and Chicken Skins under Tensile Loading," *International Journal of Biological and Medical Science*, vol. 1, no. 2, pp. 16–20.
[11] Remache D, Caliez M, Gratton M, and Santos SD (2018), "The effects of cyclic tensile and stress-relaxation tests on porcine skin," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 77, no. August 2017, pp. 242–249.
[12] Mathew SAN, Nicholas N, Jeschke MG (2016), "Methodologies in Creating Skin Substitutes," *Cell Mol Life Sci*, vol. 73, no. 18, pp. 3453–3472.
[13] Halim A, Khoo T, and Shah JY (2010), "Biologic and synthetic skin substitutes: An overview," *Indian Journal of Plastic Surgery*, vol. 43, no. 3, p. 23.
[14] Azmi NN, Ab Patar MNA, Mohd Noor SNA, and Mahmud J (2014), "Testing standards assessment for silicone rubber," *ISTMET 2014 - 1st Int. Symp. Technol. Manag. Emerg. Technol. Proc.*, vol. 3, no. 600, pp. 332–336.
[15] Horch RE, Kopp J, Kneser U, Beier J, and Bach AD (2005), "Tissue engineering of cultured skin substitutes.," *J. Cell. Mol. Med.*, vol. 9, no. 3, pp. 592–608.
[16] Shergold OA, Fleck NA, and Radford D (2006), "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.
[17] Wang Y, Marshall KL, Baba Y, Gerling GJ, and Lumpkin EA (2013), "Hyperelastic Material Properties of Mouse Skin under Compression," *PLoS ONE*, vol. 8, no. 6.
[18] Lim J, Hong J, Chen WW, and Weerasooriya T (2011), "Mechanical response of pig skin under dynamic tensile loading," *Int. J. Impact Eng.*, vol. 38, no. 2–3, pp. 130–135.
[19] Manan NFA, Mahmud J, and Ismail MH (2013), "Quantifying the Biomechanical Properties of Bovine Skin under Uniaxial Tension," *J. Med. Bioeng.*, vol. 2, no. 1, pp. 45–48.
[20] Kim B *et al*(2012), "A comparison among Neo-Hookean model, Mooney-Rivlin model, and Ogden model for Chloroprene rubber," *International Journal of Precision Engineering and Manufacturing*, vol. 13, no. 5, pp. 759–764, 2012.
[21] Lateefi MM, Kumar D, and Sarangi S (2015), "A comparison of different material models for Elastomeric material under deformation," Indian Conference on Applied Mechanics (INCAM), no. July, pp. 13–15.
[22] Mohotti D, Ali M, Ngo T, Lu J, and Mendis P (2013), "Strain rate dependent constitutive model for predicting the material behaviour of polyurea under high strain rate tensile loading," Materials & Design, vol. 53, pp. 830–837.
[23] Faghihi S., Karimi A, Jamadi M, Imani R, and Salarian R (2014), "Graphene oxide / poly (acrylic acid)/ gelatin nanocomposite hydrogel : Experimental and numerical validation of hyperelastic model," *Materials Science & Engineering C*, vol. 38, pp. 299–305, 2014.
[24] Montella G, Calabrese A, and Serino G (2014), "Mechanical characterization of a Tire Derived Material: Experiments, hyperelastic modeling and numerical validation," *Construction and Building Materials*, vol. 66, pp. 336–347.
[25] Karimi A, Rahmati SM, and Navidbakhsh M (2015), "Mechanical characterization of the rat and mice skin tissues using histostructural and uniaxial data," *Bioengineered*, vol. 6, no. 3, pp. 153–160.
[26] Khajehsaeid H, Arghavani J, and Naghdabadi RB (2013), "A hyperelastic constitutive model for rubber-like materials," *Eur. J. Mech. A/Solids*, vol. 38, pp. 144–151.
[27] Shevchenko RV, James SL, and James SE (2010), "A review of tissue-engineered skin bioconstructs available for skin reconstruction," *J. R. Soc. Interface*, vol. 7, no. 43, pp. 229–258.
[28] Jakel R (2010),"Analysis Of Hyperelastic Materials With Mechanica-Theory And Application Examples", in 2nd Simulation Meeting SAXSIM (SAXon SImulation Meeting), T. U. Chemnitz, Ed., ed,.
[29] de Sousa Crespoa J (2009), "Human Tissue Hyperelastic Analysis," Instituto Superior Tecnico, Universidade Tecnica de Lisboa.
[30] Yusop M *et al* (2014), "A Parametric Investigation on the Neo-Hookean Material Constant," *Adv. Mater. Res.*, vol. 915, pp. 853–857.
[31] Chen Z, Scheffer T, Seibert H, and Diebels S (2013), "Macroindentation of a soft polymer: Identification of hyperelasticity and validation by uni/biaxial tensile tests," *Mech. Mater.*, vol. 64, pp. 111–127.
[32] Sen O (2010), "Analysis of the Study of Material Behaviour at Impact Strain," Michigan State University.
[33] Zheng Z, Wang C, Yu J, Reid SR, and Harrigan JJ (2014), "Dynamic stress-strain states for metal foams using a 3D cellular model," *J. Mech. Phys. Solids*, vol. 72, pp. 93–114.
[34] Vishwas M, Joladarashi S, and Kulkarni S (2018), "Modelling and Analysis of Material Behaviour under Normal and Oblique Low Velocity Impact," *Mater. Today Proc.*, vol. 5, no. 2, pp. 6635–6644.
[35] N. William and J. Sharpe (2008), *Springer Handbook of Experimental Solid Mechanics*.
[36] Xie Q, Zhu Z, and Kang G (2014), "Dynamic stress-strain behavior of frozen soil: Experiments and modeling," *Cold Regions Science and Technology*, vol. 106–107, pp. 153–160.
[37] Xia K and Yao W (2015), "Dynamic rock tests using split Hopkinson (Kolsky) bar system - A review," *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 7, no. 1, pp. 27–59.
[38] Dai F, Huang S, Xia K, and Tan Z (2010), "Some fundamental issues in dynamic compression and tension tests of rocks using split Hopkinson pressure bar," *Rock Mechanics and Rock Engineering*, vol. 43, no. 6, pp. 657–666.
[39] Meo M, Vignjevic R, and Marengo G (2005), "The response of honeycomb sandwich panels under low-velocity impact loading," *International Journal of Mechanical Sciences*, vol. 47, no. 9, pp. 1301–1325.
[40] Song B and Chen W (2004), "Dynamic stress equilibration in split Hopkinson pressure bar tests on soft materials," *Exp. Mech.*, vol. 44, no. 3, pp. 300–312.
[41] Guo H, Guo W, and Amirkhizi AV (2017), "Constitutive modeling of the tensile and compressive deformation behavior of polyurea over a wide range of strain rates," *Construction and Building Materials*, vol. 150, pp. 851–859.
[42] Miao YG. *et al* (2016), "Determination of dynamic elastic modulus of polymeric materials using vertical split Hopkinson pressure bar," *Int. J. Mech. Sci.*, vol. 108–109, pp. 188–196.
[43] Ramezani M and Ripin ZM (2010), "Combined experimental and numerical analysis of bulge test at high strain rates using split Hopkinson pressure bar apparatus," *J. Mater. Process. Technol.*, vol. 210, no. 8, pp. 1061–1069.
[44] Sligtenhorst CV, Cronin DS, and Brodland GW (2006), "High strain rate compressive properties of bovine muscle tissue determined using a split Hopkinson bar apparatus," *J. Biomech.*, vol. 39, no. 10, pp. 1852–1858.