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NUMERICAL INVESTIGATION OF OGDEN AND MOONEY-RIVLIN MATERIAL PARAMETERS

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ABSTRACT

Soft tissues, skin and rubber-like material research has gained considerable attention over the last few years. Most related research have adopted hyperelastic material models namely Mooney-Rivlin, Neo-Hookean and Ogden models. The complex behaviour (highly non-linear) makes it challenging to be analysed. Nevertheless, the fundamental understanding of a particular hyperelastic model could assist researchers to have a better judgement on their findings. Therefore, performing a parametric study is vital especially at the beginning of such numerical analysis. This study aims to investigate numerically, the contribution of material parameters of two hyperelastic constitutive models viz. Ogden and Mooney-Rivlin. This study is divided into three stages, i.e. the derivation and simplification of the hyperelastic equations, the parametric analysis of the hyperelastic models and the demonstration of the hyperelastic material parameters with respect to stress and stretch. The second stage consists of the following investigations (1. The influence of the first material parameter Constant 1, C_1 and Ogden Exponent, α for Mooney-Rivlin and Ogden Model respectively; 2. The influence of the second material parameter Constant 2, C_2 and Ogden Coefficient, μ for Mooney-Rivlin and Ogden Model correspondingly and 3. The influence and sensitivity of the stress levels with different stretch, λ. on the three-dimensional stress-stretch curve). From this parametric study, the Mooney-Rivlin Model indicates that an incompressible, isotropic Mooney-Rivlin Model is more sensitive to C_1 variations as compared to C_2 variations. Nevertheless, the Ogden model shows results that the higher Ogden exponent influence the stress level as well as the stress-stretch curve with an accelerated stress increment at the beginning of deformation. It is also evident from the stress-stretch curves illustrated in each investigation, the hyperelastic models are sensitive towards different material coefficients.

Keywords: ogden, mooney-rivlin, hyperelastic, non-linear behaviour, parametric study.

INTRODUCTION

Skin is a nonhomogeneous, viscoelastic and relatively incompressible material (Jijun *et al.* 2009), (Wan Abas and Barbenel, 1982) that protects the body from hazardous environment. Available information on skin properties is still limited, and there is no sole standard that has been established in determining skin's behaviour. Researchers have identified a number of parameters that ought to be considered in the determination of skin properties, where this in turn demonstrates its complexity (Delalleau *et al.* 2008). The understanding of skin properties is non-trivial in the development of synthetic skin, as it will significantly attribute towards the production of an ideal skin substitute either for medical or cosmetic purpose. Presently in the medical field, synthetic skin has been utilised to substitute burnt skin in burn wound recovery (Föhn and Bannasch, 2007), (Halim *et al.* 2010). Producing a temporary or permanent skin substitutes that possess similar properties of real skin and compatible with the human body are some of the many reasons why research on skin properties has gained due attention. Owing to the significant applications of synthetic skin, skin behaviour and its mechanical properties has been explored (Mahmud *et al.* 2013a). Human skin is often modelled as a hyperelastic membrane (Gallagher *et al.* 2012), (Mahmud *et al.* 2013b) whilst disregarding its viscoelastic characteristics. Therefore, plenty effort have been put actively to improve existing constitutive models as well as to formulate new constitutive models for skin.

Hyperelastic models have been employed skin, soft tissues and rubber-like materials (rubber, silicone and synthetic material) analysis due to the elastic behaviour of the material. Existing established models such as Mooney-Rivlin, Neo-Hookean, Ogden, Boyce-Arruda, and Veronda-Westman amongst others are commonly used as the main constitutive models for such analysis. Furthermore, such models have been incorporated in current commercial software finite element analysis (FEA) software package. In essence, the rapid development signifies the importance of hyperelastic models. Nevertheless, advanced numerical studies necessitate the fundamental understanding behind the computational process. Notwithstanding, parametric study plays an important role to know how a particular model behaves. In line with this, Mooney-Rivlin model parametric study was performed to investigate the prestretch influence to the strain energy function (Mohd Noor and Mahmud, 2015). The study also highlights the sensitivity of the Mooney-Rivlin material constants C_1 and C_2 with respect to prestretch conditions. Delalleu *et al.* also carried out a parametric study with a different approach and focused on FEA (Delalleau *et al.* 2006). Mahmud et. al. also demonstrated a parametric study in determining the human skin parameter by means of FEA (Mahmud *et al.* 2012).

As mentioned earlier, hyperelastic models demonstrate adequate skin behaviour. The Ogden model has been adopted in many skin studies (Shergold *et al.* 2006), (Manickam *et al.* 2014), (Cooney *et al.* 2015). The model was used to quantify animal skin (pigskin and linea alba),

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silicone and agar phantom material parameters. A variety of skin sample has been extensively analysed in skin research namely bovine skin (Adull Manan *et al.* 2013), (Adull Manan *et al.* 2014), canine skin (Bismuth et.al, 2014), murine skin (Groves *et al.* 2013) and human skin (Mahmud *et al.* 2010), (Ní Annaidh *et al.* 2012). Nonetheless, only specified quantification value of skin material properties have been reported. Due to that reason this study aims to investigate numerically the contribution of material parameters on two hyperelastic constitutive models (Ogden and Mooney-Rivlin). This study focuses on Ogden model that has been simplified as shown in Equation (1) that is derived from the strain energy equation, W (Ogden *et al.* 2004).

$$W(\lambda_{1,2,3}) = \sum_{i=1}^{N} \frac{\mu}{\alpha_i}(\lambda_1^{\alpha} + \lambda_2^{\alpha} + \lambda_3^{\alpha}) \quad (1)$$

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

Where σ_E, is the engineering stress (MPa), λ is stretch and hyperelastic material properties μ and α also known as Ogden Coefficient (MPa) and Ogden Exponent respectively.

Shergold *et al.* (2006) stated that rubber-like behaviour can be characterised by Mooney-Rivlin model implementation. Mooney-Rivlin was initially formulated by Melvin Mooney and Ronald Rivlin in 1952, and it is inherently an extension of the Neo - Hookean material model (Groves, 2012), (Kim *et al.* 2012). The strain energy density function W, is proposed for Mooney-Rivlin model as shown in Equation (3) below is generated from a linear combination of two invariants of left Cauchy-Green tensor B (Holzapfel and Ogden, 2006), (Kim *et al.* 2012) to cater hyperelastic, incompressible, isotropy and nonlinear behaviour of soft tissue and rubber-like material (e.g. human skin).

$$W = C_1(I_1 - 3) + C_2(I_2 - 3) \quad (3)$$

C_1 and C_2 are the material constants; meanwhile I_1 and I_2 are the first and the second invariant element of left Cauchy-Green deformation tensor's unimodular component. The engineering stress σ_E and principal stretches λ relationship can be expressed as in Equation (4) as follows.

$$\sigma_E = \frac{1}{\lambda}\left[\left(2C_1 + \frac{2C_2}{\lambda}\right)\left(\lambda^2 - \frac{1}{\lambda}\right)\right] \quad (4)$$

METHODOLOGY

This study consists of three main stages to facilitate the numerical investigation of the contribution of material parameters of two hyperelastic constitutive models (Ogden and Mooney-Rivlin) accordingly.

Stage 1: Simplification of hyperelastic model
Stage 2: Investigation of material parameter
Stage 3: Numerical assessment

Figure-1 illustrates the overall methodology that is employed in this study.

The first stage is the simplification of hyperelastic model that is derived from Strain Energy Function as in Eq. 1 to Eq. 2 and Eq. 3 to Eq. 4 for Ogden and Mooney-Rivlin models, respectively. Next, the equation will be input into Microsoft Excel before the second stage is commenced to detail the parametric study and investigate the influence of the hyperelastic material parameter thoroughly.

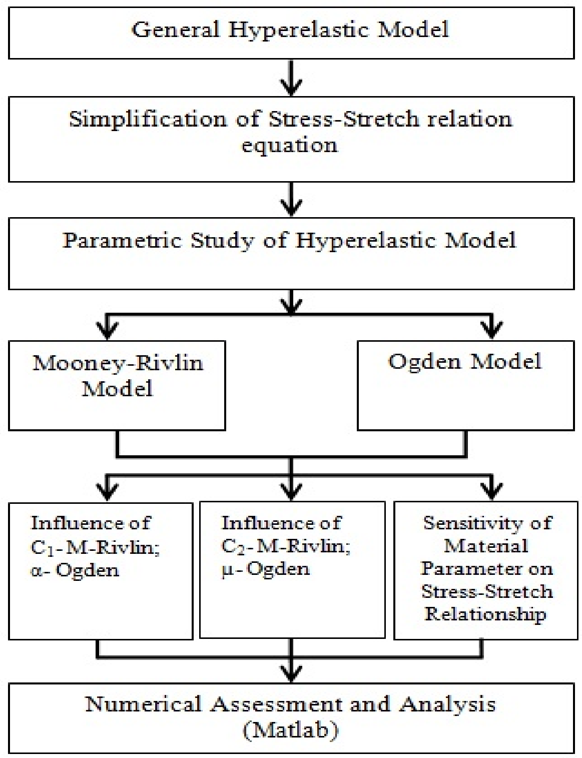

Figure-1. Overall Process Flow.

The second stage is the parametric study that scrutinises the influence of material parameters to the stress-stretch curve. It this study, three main case studies or analysis was planned systematically to investigate the relationship of Mooney-Rivlin constants (C_1 and C_2) and Ogden Coefficient (μ and α) with stress and stretch, respectively. The three main study cases or analysis are the investigations of:

- Case 1: the influence of Mooney-Rivlin constant, C_1 and Ogden Exponent, α,
- Case 2: the influence of Mooney-Rivlin constant, C_2 and Ogden Coefficient, μ
- Case 3: the influence of (C_1 and C_2) and (μ and α) on stress level with different stretch, λ.

Constitutive Modelling- Ogden Model

Case 1: The influence of Ogden Exponent, α with fixed μ,

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In this stage, the analysis begins with constant Ogden Coefficient μ at 0.4MPa. This value was used by Shergold *et al.* (2006) as the initial value. Several set of stress-stretch curves are observed on the influence of the Ogden exponent, α on the Ogden Model by varying the values from -3, 0.12, 1.2 and 3 accordingly.

Case 2: the influence of Ogden Coefficient, μ with fixed α,

The influence of Ogden Coefficient μ on Ogden model is examined by varying the Ogden Exponent α on the second stage. Now, the Ogden Exponent, α is fixed at 12, as also reported by Shergold.

Case 3: the influence of μ and α on stress level with different stretch, λ.

This work concludes with an innovative analysis by investigating the μ and α response at multiple stress levels. Several graphs were produced to indicate the variety of stretch, λ. This, in effect, highlights the latest finding of hyperelastic model material coefficient determination that adopts the Ogden Model.

Constitutive Modelling- Mooney-Rivlin Model

In assessing the Mooney-Rivlin model constants, Equation (4) has been employed in this parametric study with the variation in C_1 and C_2 value. The process flow of this parametric study was illustrated in Figure 1.

By using Equation (4) which has been re-derived from Equation (3), three sets of constants variation have been performed which are:

- Case 1: Influence of C_1 comparing to known constant value by Shergold *et al.* (2006).
- Case 2: Influence of C_2 comparing to known constant value by Shergold *et al.* (2006).
- Case 3: Influence of C_1 and C_2 value to investigate the sensitivity of Equation 2 at certain magnitude of constants.

This parametric study was designed to measure the constitutive response of incompressible, isotropic Mooney-Rivlin model at different constant values as well as comparing with known human skin Mooney-Rivlin constant values by Shergold (Shergold *et al.* 2006) valued 0.3 MPa for C_1 and 0 MPa for C_2 as a reference.

In stage three, a systematic numerical analysis of hyperelastic material parameters that represents the relationship between material parameters with stress and stretch are presented graphically. Furthermore, for Ogden Model results a Three-Dimensional Stress-Stretch curve that indicates the influence of material parameter on different stress level was plotted.

RESULTS AND DISCUSSIONS

Result and discussion of the analysis will be elaborated according to the Ogden and Mooney-Rivlin constitutive models, respectively.

Ogden Model

Case 1: influence of exponential parameter, α with fixed μ.

The results obtained for case 1 set (a) as depicted in Figure-2 to 4 shows three different findings. First, the curves in Figure-2 show almost linear dispersion on the stress-stretch curve. Also the positive and negative sign of α reflects the same pattern for stress-stress curve as illustrated by a=-3 (orange curve). In this case study, the linear increment of α from 0.12 and 1.2 was also observed. These four curves as in Figure-2 may results a linear dispersion curve with a small value of α. In addition, the negative stress result indicates negative Ogden Exponent, α. From the Eq. 1 the material parameter of stress functions corresponds proportionally with Ogden Exponent parameter and this response accordingly with curves as in case 1 set (a).

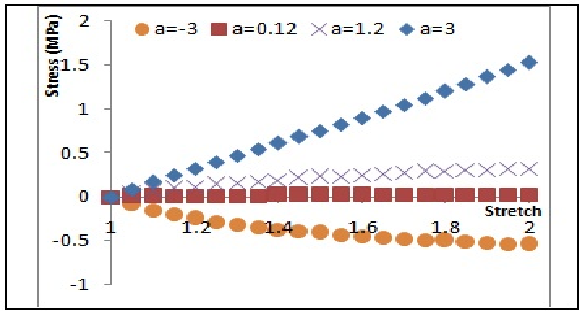

Figure-2. Case 1 Set (a)- Linear dispersion of Ogden Model.

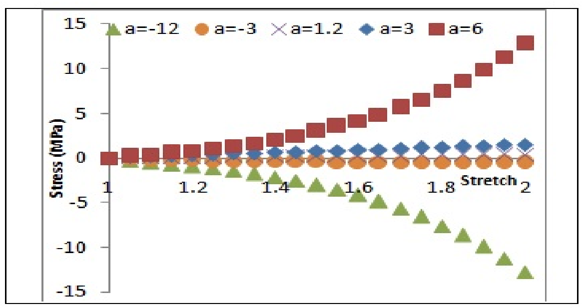

Figure-3. Case 1 Set (b)- Exponential of hyperelastic behaviour.

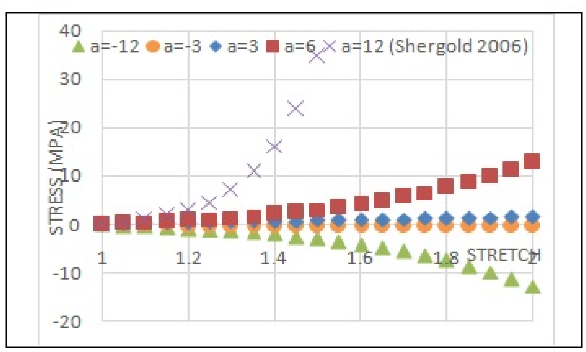

Figure-4. Case 1 Set (c)- Rapid stress level.

In set (b) in Figure-3 indicates smoothens exponential curves on the stress-stretch curve with α equal to -12 and 6. It is evident that from set (c) in Figure-4, the higher

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value of α influence the stress level as well as the exponential curve with rapid stress increment at the beginning of deformation. This phenomenon signifies the real stretching behaviour of material, in which as the stress is increased, the more will the material stretch. Furthermore, it demonstrates the function of the strain energy on the stretch behaviour.

Case 2: influence of Ogden Coefficient, μ with fixed α,

Stress-stretch curve in Figure-5 also shows the exponential curves with respect to a variety of Ogden Coefficient, μ. In this second stage, we fixed the exponential parameter α at 12 with as reported by Shergold (Shergold *et al.* 2006). The legend 'm' in the figure 5 represents the Ogden Coefficient of μ. By varying the μ between positive-negative values, it can be observed that the stress-stretch curve behaves (pattern) accordingly through the positive-negative exponential curves. This behaviour indicates that the constitutive parameter of μ reacts proportionally to the Ogden Model equation. Through this analysis, it is apparent that μ will influence the stress-stretch curve linearly where by increasing the values will cause the curves to behave highly non-linear.

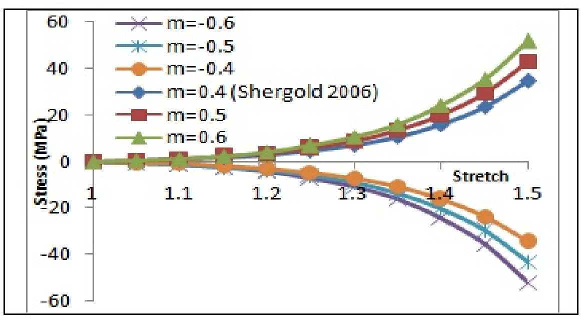

Figure-5. Stress-stretch curve with fixed α.

Case 3: influence of μ and α on stress level with different stretch,λ.

In general, Figure-6(a) and 6(b) illustrates the 3-dimensional graphs of the relationship between Ogden material parameter μ and α with stress levels. The x-axis represents the Ogden Exponent, α and denoted as 'Alpha'. The value varies from -12 to 12 as minimum and maximum limits respectively. On the other hand, the y-axis indicates the Ogden Coefficient, μ between -0.6 MPa to 0.6 MPa. Figure-6 shows the relationship between μ and α with different stretch values by varying from 1.1 until 1.8 with an interval of 0.3.

The 3D graph shown in Figure-6, indicates the position of the main reference (Shergold *et al.* 2006) results with μ and α are 0.4 MPa and 12 respectively at stretch 1.1. The graph shows stress level between 0 MPa to 0.5MPa that is represented by the colour purple. By increasing the stretch value, the stress level also rise gradually until at the maximum of 200 MPa at stretch 1.8 graphs.

This study provides a guide on the study of hyperelastic material model especially on Ogden model that is widely used in skin, soft tissues, and rubber-like material. This further suggest the influence of specific values viz. the positive-negative values, small and big integer number and also the response to the stress level.

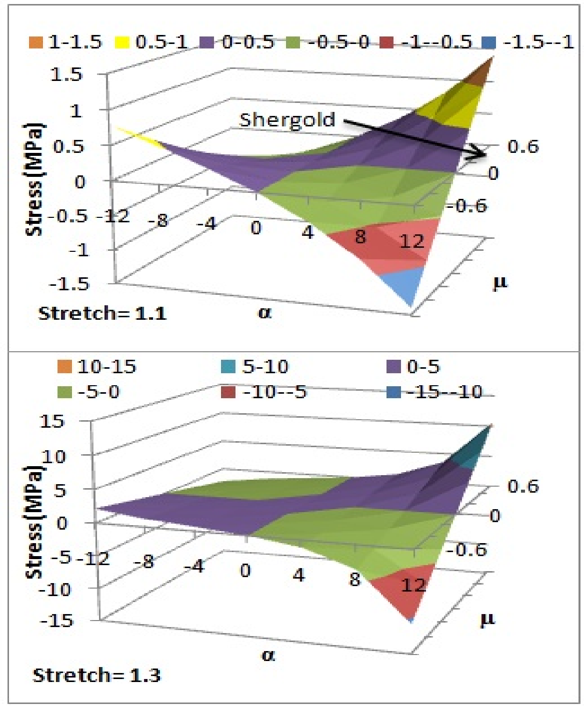

Figure-6(a). Relation between μ and α on stress level for Stretch1.1 and 1.3.

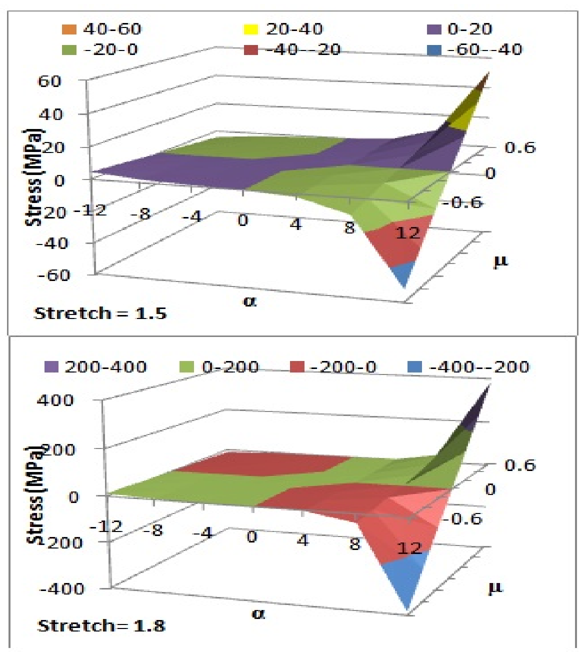

Figure-6(b). Relation between μ and α on stress level for stretch 1.5 and 1.8.

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Mooney-Rivlin Model

Case 1: Variation in C_2 with Fixed C_1

For the first set of assessment, the value of C_1 was fixed at 0.3 MPa as reported by Shergold *et al.* (2006). The objective of Set 1 was to observe the effects of variations in C_2 value. Figure-7 illustrates a stress-stretch diagram showing the sensitivity of the Equation (2) at several C_2 values range from negative to positive. Four stress-stretch curves were plotted with C_2 value varies from -0.1 to 0.5 MPa whilst keeping C_1 constant at 0.3 MPa and comparing to Shergold *et al.* constants. The horizontal axis represents the stretch value whilst stress values appear on the vertical axis. It is observed that three values of C_2 (-0.1, 0.1 and 0.5) represent similar curve trend as per Shergold *et al.* constants (C_1 = 0.3 MPa, C_2 = 0 MPa) in contrast with the curve for C_2 value at -0.5 MPa which shows a nonlinear elastic plot. This indicates that even a slight difference by 0.4 unit in C_2 (ΔC_2) is able to change the graph behaviour as illustrated in Figure-7.

Case 2: Variation in C_1 with Fixed C_2

Figure-8 represents four graph results from the variation in C_1 value (-0.1, 0.1, -0.5 and 0.5 MPa) with fixed value of C_2 compared to Shergold *et al.* graph. Equivalent to Set 1, four stress-stretch curves were plotted with C_1 value varies from -0.1 to 0.5 MPa whilst again keeping C_2 fixed at 0 MPa. The horizontal axis represents stretch value whilst stress values are located on the vertical axis. The objective of Set 2 was to observe the effects of variations in C_1 value. Variation in C_1 value indicates significant differences between each curve plotted. It is apparent Therefore, that Equation (2) is more sensitive to the change in C_1 value with only two graphs merely follow the Shergold curve trend constants (C_1 = 0.3 MPa, C2 = 0 MPa) as compared to the change in C_2 observed in Figure 2. Positive C_1 values construct the same curve trend as Shergold *et al.* curve meanwhile negative C_1 values shows otherwise. The large negative values of C_1 shifts the curve plot away from the reference curve plot.

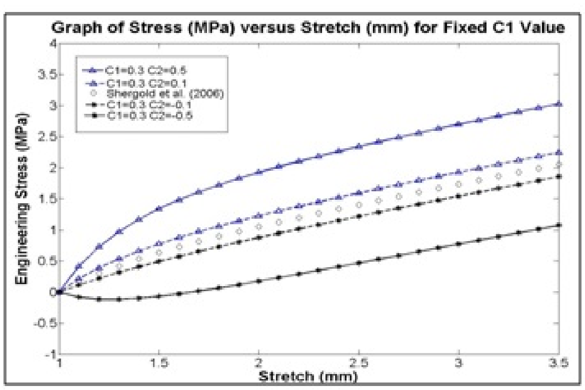

Figure-7. Variations in C_2 with fixed C_1 value of 0.3 MPa.

Case 3: Variation in C_1 and C_2

By changing both values of C_1 and C_2, five stress-stretch curves plotted in Figure-9. The objective of Set 3 was to observe the sensitivity of the constant itself, C_1 and C_2. The first curve plotted with the same positive value of C_1 and C_2 (0.1MPa). The second curve was plotted with C_1 equal to 0.1 MPa and -0.1 MPa for C_2 value. Then the third curve plotted with 0 MPa for C_1 and C_2. As for the fourth curve, C_1 value is equal to -0.1 MPa and 0.1 MPa for C_2 value. Lastly, fifth curve plotted with same negative C_1 and C_2 (-0.1MPa). It is worth noting that the third and fifth curve was totally identical although different values of C_1 and C_2 were used. As for C_1 and C_2 equal to 0 MPa, a straight line was produced with stress value of 0 MPa.

The variation of C_1 and C_2 value affects the curve plotted suggests that these constants do influence skin properties and behaviour for different subjects. Evaluating Case 1 and Case 2 with fixed C_1 and C_2 respectively, the stress-stretch diagram is appears to be sensitive to the change in C_1 value. However, as stated earlier in Case 1, change in C_2 value could shift the graph behaviour as depicted in Figure-7. Therefore, several sets of Mooney-Rivlin possible constants (C_1 and C_2) could produce equivalent skin deformations.

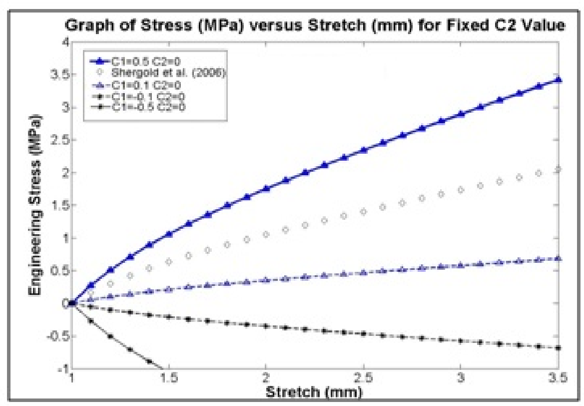

Figure-8. Variations in C_2 with fixed C_1 value of 0 MPa.

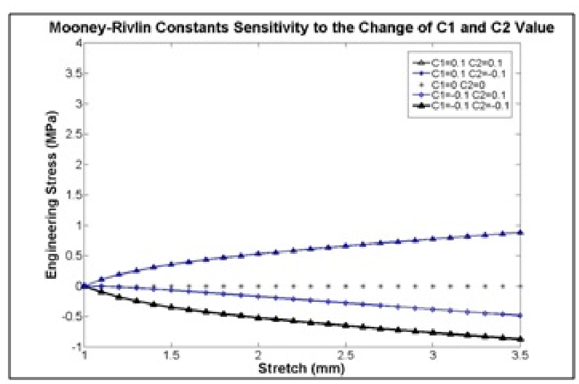

Figure-9. Mooney-Rivlin constants sensitivity to the change of C_1 and C_2 value.

CONCLUSIONS

This study highlights the findings of a series of parametric studies on hyperelastic material properties. The influence and response of Ogden material parameters on stress-stretch curves were analysed by means of several case studies. This study is significant for numerical works on hyperelastic models as it provides a general insight of hyperelastic behaviour of materials. In addition, this paper also highlights the success of assessing hyperelastic materials constitutive equation, on Mooney-Rivlin constants using numerical approach. The strain energy density function formulated by Melvin Mooney and Ronald Rivlin, Mooney-Rivlin constants have been investigated through a stress-stretch correlation with three proposed sets of constants variation.

This parametric study demonstrates interesting findings on the influence of Mooney-Rivlin constants value to the stress-stretch graph that can represent skin behaviour and properties. The results from this study could enhance the development of a hyperelastic constitutive model of skin in the near future. Further investigation will be carried out to examine the effect of skin pre-stretch parameters embedded into the Mooney-Rivlin constitutive equation and the results will be reported in the near future.

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REFERENCES

[1] Adull Manan, N. F., Mahmud J. and Ismail M. H. 2013. Quantifying the Biomechanical Properties of Bovine Skin under Uniaxial Tension. Journal of Medical and Bioengineering, Vol. 2, pp 45-48.

[2] Adull Manan, N. F., Mahmud J. and Ismail M. H. 2014. Biomechanical testing of bovine skin using various sample specifications. Materials Research Innovations, Vol. 18, (S6), pp. S6-389-S6-394.

[3] Bismuth C., Gerin C., Viguier E., Fau D., Dupasquier F., Cavetier L., David L. and Carozzo C. 2014. The biomechanical properties of canine skin measured in situ by uniaxial extension. Journal of Biomechanics, Vol. 47, pp. 1067-1073.

[4] Cooney G. M., Moerman K. M., Takaza M., Winter D. C. and Simms C. K. 2015. Uniaxial and biaxial mechanical properties of porcine linea alba. Journal of the Mechanical Behavior of Biomedical Materials, Vol. 41, pp. 68-82.

[5] Delalleau A., Josse G., George J. and Lagarde J. M. 2008. Skin mechanical properties analyse through ultrasound imaging and inverse identification. 2008 SEM XI International Congress & Exposition on Experimental & Applied Mechanics, Orlando, FL. pp.1534-1545.

[6] Delalleau A., Josse G., Lagarde J.-M., Zahouani H. and Bergheau J.-M. 2006. Characterization of the mechanical properties of skin by inverse analysis combined with the indentation test. Journal of Biomechanics, Vol. 39, pp. 1603-1610.

[7] Föhn M. and Bannasch H. 2007. Artificial Skin. In: HAUSER, H. & FUSSENEGGER, M. (eds.) Tissue Engineering. Humana Press.

[8] Gallagher A., Ní Annaidh A. and Bruyère K. Dynamic tensile properties of human skin (2012). 2012 International Research Council on the Biomechanics of Injury Conference, pp. 494-502.

[9] Groves R. 2012. Quantifying the mechanical properties of skin in vivo and ex vivo to optimise microneedle device design. PhD Thesis. Cardiff University.

[10] Groves R. B., Coulman S. A., Birchall J. C. and Evans S. L. 2013. An anisotropic, hyperelastic model for skin: Experimental measurements, finite element modelling and identification of parameters for human and murine skin. Journal of the Mechanical Behavior of Biomedical Materials, Vol. 18, pp. 167-180.

[11] Halim A. S., Khoo T. L. and Mohd. Yussof S. J. 2010. Biologic and synthetic skin substitutes: An overview. Indian Journal of Plastic Surgery, Vol. 43, pp. S23-S28.

[12] Holzapfel G. A. and Ogden R. W. 2006. On experimental testing methods for characterizing the mechanical properties of soft biological materials such as arterial tissues. Journal of Biomechanics, Vol. 39, Supplement 1, S324.

[13] Jijun S., Haitian Z. and Tongtong G. 2009. The Study of Mechanical Properties on Soft Tissue of Human Forearm in Vivo. International Conference of Bioinformatics and Biomedical Engineering, Vol. 11-13 June 2009. pp. 1-4.

[14] Kim B., Lee S., Lee J., Cho S., Park H., Yeom S. and Park S. 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, pp. 759-764.

[15] Mahmud J., Holt C., Evans S., Adull Manan N. F. and Chizari M. 2012. A Parametric Study and Simulations

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in Quantifying Human Skin Hyperelastic Parameters. Procedia Engineering, Vol. 41, pp. 1580-1586.

[16] Mahmud J., Holt C. A. and Evans S. L. 2010. An innovative application of a small-scale motion analysis technique to quantify human skin deformation in vivo. Journal of Biomechanics, Vol. 43, pp. 1002-1006.

[17] Mahmud J., Holt C. A., Evans S. L. and Adull Manan N. F. 2013a. Quantifying Skin Properties Using a Novel Integration Experiment-Finite Element Simulation and Skin Pre-Stretch Model. Advanced Science Letters, Vol. 19, pp. 3155-3160.

[18] Mahmud L., Ismail M. H., Adull Manan N. F. and Mahmud J. 2013b. Characterisation of soft tissues biomechanical properties using 3D Numerical Approach. 2013 Business Engineering and Industrial Applications Colloquium IEEE, 7-9 April 2013, pp. 801-806.

[19] Manickam K., Machireddy R. R. and Seshadri S. 2014. Characterization of biomechanical properties of agar based tissue mimicking phantoms for ultrasound stiffness imaging techniques. Journal of the Mechanical Behavior of Biomedical Materials, Vol.35, pp. 132-143.

[20] Mohd Noor, S. N. A. and Mahmud J. 2015. Skin Prestretch Evaluation Adapting Mooney-Rivlin Model. Journal of Medical and Bioengineering, Vol. 4, No. 1, pp. 31-35.

[21] Ní Annaidh A., 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, pp. 139-148.

[22] Ogden R. W., Saccomandi G. and Sgura I. 2004. Fitting hyperelastic models to experimental data. Computational Mechanics, Vol. 34, pp. 484-502.

[23] Shergold O. A., Fleck N. A. and Radford D. 2006. The uniaxial stress versus strain response of pig skin and silicone rubber at low and high strain rates. International Journal of Impact Engineering, Vol. 32, pp. 1384-1402.

[24] Wan Abas W. a. B. and Barbenel J. C. 1982. Uniaxial tension test of human skin in vivo. Journal of Biomedical Engineering, Vol. 4, pp. 65-71.