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ANALYSIS OF THE MECHANICAL BEHAVIOR OF LATEX RESISTANCE BANDS AS SUBSTITUTES OF HUMAN SKIN IN MECHANICALS TESTS

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ABSTRACT

The skin is a highly anisotropic multilayer tissue, and the analysis of its characteristics has been studied for decades without finding a definitive model. Nowadays, both models and skin substitutes are needed to supply the necessities in surgery simulators, video games, and animation industry. In this study pig skin samples from a local store were used due to the similarities between the pig and human skin. The hypodermis was removed, and the skin was dissected in specimens of approximately 6 mm x 12 mm. The specimens were tested in a Shimadzu AG-X universal testing machine with three replicates. Having as a reference the tests performed to pig skin, latex resistance bands are proposed as mechanical substitute for human skin and its viability is evaluated in this study. Uniaxial tensile tests were carried out to C-type dumbbell specimens according to ASTM D412 standard using seven latex resistance bands (their rigidity are differenced by colors). The constants for Veronda Westman hyperelastic model for both materials were obtained by an optimization process carried out in FEBio Suite. Using the deformation energy as comparative factor, this kind of band could not replace mechanically human skin in assessing scenarios and applications described above.

Keywords: Human skin, pig skin, latex resistance bands, tension test, hyperelasticity.

ANÁLISIS DEL COMPORTAMIENTO MECÁNICO DE BANDAS DE RESISTENCIA COMO SUSTITUTO DE LA PIEL HUMAN EN ENSAYOS MECÁNICOS

RESUMEN

La piel humana es un tejido multicapa altamente anisotrópico, el análisis de sus características ha sido estudiando por años con el fin de encontrar un modelo definitivo que describa su comportamiento. Actualmente se necesitan modelos y sustitutos para suplir las necesidades de simuladores quirúrgicos y en industrias como los video juegos y la animación. En este estudio se usaron muestras de piel de cerdo adquiridas en una tienda local debido a las similitudes entre la piel de cerdo y la piel humana. Se seccionaron tres muestras de 60 mm x 120 mm a las que se le removió la hipodermis y fueron evaluadas en una máquina universal Shimadzu AG-X. Teniendo como referencia los ensayos realizados en la piel de cerdo, se estima la viabilidad de las bandas de resistencia elaboradas de látex como sustituto mecánico de la piel humana. Se realizaron ensayos de tracción en siete diferentes bandas de resistencia (su rigidez está definida por el color) utilizando un perfil C de acuerdo con la norma ASTM D412. Tanto para las muestras de piel de cerdo como para las bandas de resistencia se obtienen las constantes para el modelo hiperelástico de *Veronda*

Westman usando la *Suite FEBio.* Empleando la energía de deformación como factor comparativo, se determinó que las bandas de resistencia elaboradas de látex no podrían reemplazar la piel humana en los escenarios y aplicaciones descritas anteriormente.

Palabras clave: Piel humana, piel de cerdo, Bandas de resistencia, ensayo uniaxial, hiperelasticidad

1. INTRODUCTION

The human skin is the interface of the human body in the communication with the environment, this helps to understand all our surroundings [1–3]. In these interactions the human skin is under pressuring, stretching, scratching among other [4], and including to those factors the changes in the temperature and humidity in the environment could generate some issues in the skin. Irritation, blisters, red skin, deep tissue injure, and wounds are some of these possible issues [5–8]. To avoid those kind of problems numerical and experimental studies have been carried out to understand the behavior of the human skin. These studies led to develop accurate models to evaluate solutions to issues by the skin interactions and supply the necessities in surgery simulators, video games, and animation industry [5, 7, 9,10]. This kind of models give supports to find substitutes for the human skin, that reproduce its mechanical behavior to calibrate machines for testing before to assess contacts with new surfaces and devices onto human skin or to teach sutures and surgical procedures in medical schools [11–14]. Latex resistance bands are proposed as mechanical substitute for human skin and its viability is assessed in this study, and it is compared its behavior in Uniaxial tensile tests with pig skin due to the similarities between the pig and human skin [15–17]. The constants for Veronda Westman hyperelastic model for both materials were obtained by numerical methods.

This article is organized as follows, in Section 2 the experimental and numerical setup is described, the viability of the latex resistance bands as mechanical substitute of human skin is discussed in Section 3 and the conclusion of this work are presented in the Section 4.

2. METHODS

To assess the viability of the latex resistance bands as mechanical substitute of human skin the following procedures were carried out

2.1. Experimental setup

Tensile tests were performed in pig skin and latex resistance bands specimens, and their behavior were compared to assess the viability of the latex resistance bands as mechanical substitute for human skin, the methodology used is described below.

2.1.1 Pig skin samples

Due to the similarities between pig and human skin was used as reference, it was bought from a local store. The hypodermis was removed, and the skin was dissected in specimens of approximately 60 mm x 12 mm. Uniaxial tension test were carried out in these samples using a Shimadzu AG-X Series universal testing machine with a 50 kN load cell exceeding a strain of 100%. A deformation rate of 10 mm/s was selected for this test as previous studies performed in human skin by Lapper et al [11].

2.1.2 Latex Resistance bands specimens

Latex resistance bands of seven colors (yellow, red, green, blue, black, gray, and mustard) were cut in dumbbell Type C specimens according ASTM D412, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension [18]. All tests were done using a Shimadzu AG-X Series universal testing machine in a random sequence previous prepared in R 3.6.1 (R Foundation) using maximum strain of 100% under 10 mm/s of deformation rate.

2.2. Numerical analysis

To have a quantitative reference in the comparison between Pig skin and Latex Resistance Bands, the constants of Veronda – Westmann hyperelastic model are assessed by numerical analysis. The Hyperelastic model is described by the equation **¡Error! No se encuentra el origen de la referencia.** [19]:

$$w = C_1\left(e^{C_2(I_1-3)} - 1\right) - \frac{C_1 C_2}{2}\,(I_2 - 3) + g(I_3) \tag{1}$$

Where C1 and C2 are parameter determined from experimental studies, I_1, I_2 and I_3 are the invariants of the Cauchy – Green deformation tensor **C**, and Finally g is a function of incompressibility that depends on Bulk modulus k. This analysis was performed in FeBio Suite (MRL The University of Utah, MBL Columbia University) [20].

2.2.1 Pig model

The Pig skin model is created on preview 2.1 (MRL The University of Utah, MBL Columbia University). This monolayer specimen of 10 mm x 6 mm x 2.5 mm was discretized using FEBio Hex8 elements, described by 2223 nodes and 1728 Elements. In one end of the sample was established fixed Displacement, and the opposite side a Prescribe displacement in x axis was imposed (Figure 1a).

2.2.2 Latex Resistance Bands specimens numerical model

The geometrical representation with FEBio Hex8 of the latex resistance bands was created with a custom Python script (Python software Foundation). The script generates a monolayer with the specific thickness for each color. The mesh has 854 nodes and 852 Elements, and as the case of pig skin hyperelastic behavior using Veronda – Westmann model was chosen. Fixed Displacement on the left zone were the grips are in contact with the specimen, in the right zone a Prescribe displacement in x axis rig (Figure 1b).

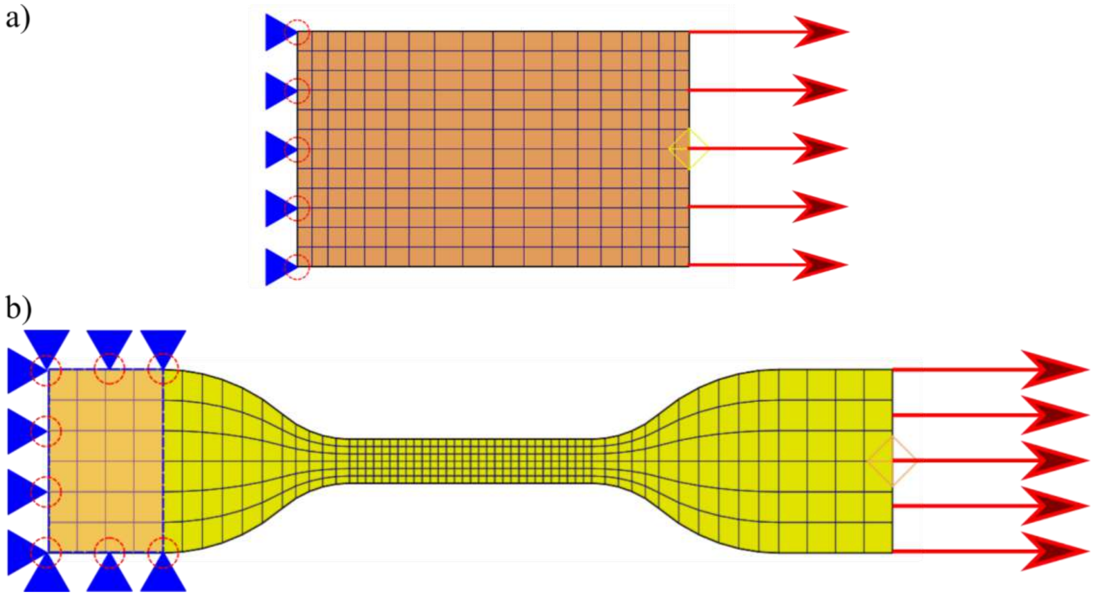

Figure 1. *Boundary conditions in the numerical studies: a) Pig Skin and b) Latex Resistance Bands.*

3. RESULTS AND DISCUSSION

The strain stress curve for both Pig Skin and the Latex Resistance Band are presented in the Figure 2 , According with this figure, the resistance bands have different trend than the pig skin, being the pig skin more rigid than the bands.

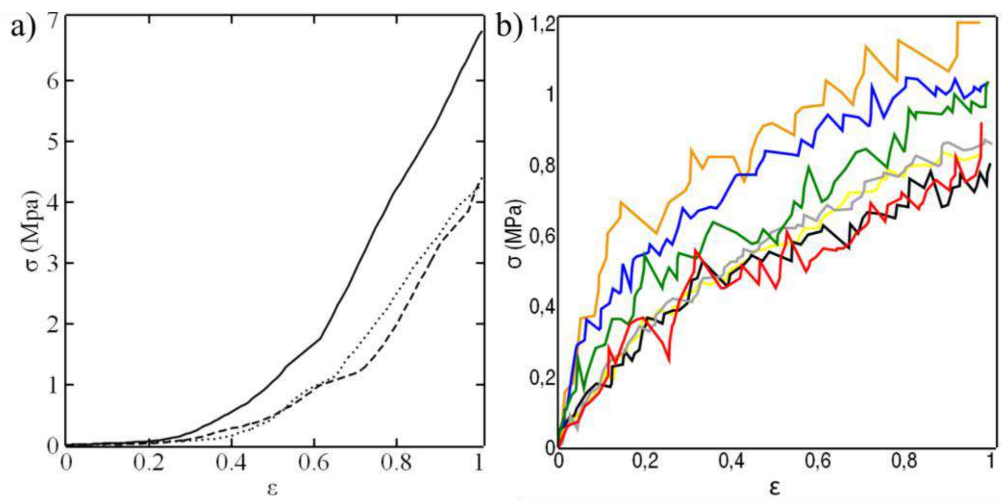

Figure 2. *The strain stress curves: a) Pig Skin specimens and b) Latex Resistance Band specimens.*

The constants for Veronda Westman hyperelastic model for both materials Pig and Latex resistance band obtained by an optimization process in FEBio Suite are shown in the Table 1. Using those parameters as comparative factor, any of the bands evaluated have similarities in the magnitudes in the reaction forces with skin.

Table 1. *Parameters for pig skin and latex resistance bands for Veronda Westman.*

Code Color	Thickness (μm)	C1	C2	K
Pig	2350	0.01	1.95	100
Yellow	150	1.01	0.55	2
Red	220	1.01	0.58	2
Green	250	1.1	0.77	2
Blue	315	1.2	0.7	2
Black	380	1.1	0.4	2
Gray	540	1.2	0.56	2
Mustard	650	1.2	0.51	2

4. CONCLUSIONS

There are no differences in the deformation energy among deformation rates latex resistance bands, there are significant statistic differences among colors in the deformation energy being this factor who influence the most in the model. The interaction between both factors Color and deformation rates has no influence. It is necessary to continue looking for a material to replace the human skin in assessing scenarios and applications, a candidate for this task could be the polyurethane, due the characteristic of its structure and the way how could distribute the energy.

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6. REFERENCES

[1] Derler, S. and Gerhardt, L. C., “Tribology of Skin: Review and Analysis of Experimental Results for the Friction Coefficient of Human Skin,” *Tribol Lett*, vol. 45, no. 1, pp. 1–27, Jan. 2012.

[2] Limbert, G. *et al.*, “Biotribology of the ageing skin—Why we should care,” *Biotribology*, vol. 17, pp. 75–90, Mar. 2019.

[3] Limbert, G., “Mathematical and computational modelling of skin biophysics: a review,” *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 473, no. 2203, p. 20170257, Jul. 2017.

[4] Leyva-Mendivil, M. F., Lengiewicz, J., Page, A., Bressloff, N. W. and Limbert, G., “Skin Microstructure is a Key Contributor to Its Friction Behaviour,” *Tribol Lett*, vol. 65, no. 1, p. 12, Jan. 2017.

[5] Zhong, W., Xing, M. M. Q., Pan, N.,and Maibach, H. I.,“Textiles and human skin, microclimate, cutaneous reactions: An overview,” *Cutaneous and Ocular Toxicology*, vol. 25, no. 1, pp. 23–39, 2006.

[6] Schwartz, D., Magen, Y. K., Levy, A., and Gefen, A., “Effects of humidity on skin friction against medical textiles as related to prevention of pressure injuries,” *Int Wound J*, vol. 15, no. 6, pp. 866–874, Dec. 2018.

[7] Carlson, J. M., “Functional limitations from pain caused by repetitive loading on the skin: A review and discussion for practitioners, with new data for limiting friction loads,” *JPO: Journal of Prosthetics and Orthotics*, vol. 18, no. 4, pp. 93–103, 2006.

[8] Sopher, R. and Gefen, A. “Effects of skin wrinkles, age and wetness on mechanical loads in the stratum corneum as related to skin lesions,” *Med Biol Eng Comput*, vol. 49, no. 1, pp. 97–105, Jan. 2011.

[9] Tran, H. V., Charleux, F., Rachik, M., Ehrlacher, A., and Tho, M. C. Ho Ba, “In vivo characterization of the mechanical properties of human skin derived from MRI and indentation techniques,” *Computer Methods in Biomechanics and Biomedical Engineering*, vol. 10, no. 6, pp. 401–407, 2007.

[10] Gerhardt, L.-C., Strässle, V., Lenz, A., Spencer, N. D., and Derler, S., “Influence of epidermal hydration on the friction of human skin against textiles,” *Journal of the Royal Society Interface*, vol. 5, no. 28, pp. 1317–1328, 2008.

[11] Lapeer, R. J., Gasson, P. D., and Karri, V., “A hyperelastic finite-element model of human skin for interactive real-time surgical simulation,” *IEEE Transactions on Biomedical Engineering*, vol. 58, no. 4, pp. 1013–1022, 2011.

[12] Lapeer, R. J., Gasson, P. D., and Karri, V., “Simulating plastic surgery: From human skin tensile tests, through hyperelastic finite element models to real-time haptics,” *Progress in Biophysics and Molecular Biology*, vol. 103, no. 2–3, pp. 208–216, 2010.

[13] Renvoise, J., Burlot, D., Marin, G., and Derail, C., “Adherence performances of pressure sensitive adhesives on a model viscoelastic synthetic film: A tool for the understanding of adhesion on the human skin,” *International Journal of Pharmaceutics*, vol. 368, no. 1–2, pp. 83–88, 2009.

[14] Derler, S., Schrade, U. and Gerhardt, L.-C. “Tribology of human skin and mechanical skin equivalents in contact with textiles,” *Wear*, vol. 263, no. 7–12, pp. 1112–1116, Sep. 2007.

[15] Lim K. H., *et al.*, “New extensometer to measure in vivo uniaxial mechanical properties of human skin,” *Journal of Biomechanics*, vol. 41, no. 5, pp. 931–936, 2008.

[16] Shergold, O. A., Fleck, N. A., and Radford, D., “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, no. 9, pp. 1384–1402, Sep. 2006.

[17] Martins, P., Natal Jorge, R. M., and Ferreira, A. J. M., “A Comparative Study of Several Material Models for Prediction of Hyperelastic Properties: Application to Silicone-Rubber and Soft Tissues,” *Strain*, vol. 42, no. 3, pp. 135–147, 2006.

[18] ASTM, *ASTM D412-06a(2013), Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension*. West Conshohocken, PA,: ASTM International, 2013.

[19] Veronda, D. R., and Westmann, R. A., “Mechanical characterization of skin—Finite deformations,” *Journal of Biomechanics*, vol. 3, no. 1, pp. 111–124, Jan. 1970.

[20] Maas, S. A., Ellis, B. J., Ateshian, G. A., and Weiss, J. A., “FEBio: Finite Elements for Biomechanics,” *J Biomech Eng*, vol. 134, no. 1, pp. 011005-011005–10, Feb. 2012.