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MECHANICAL BEHAVIOR OF FIBROUS SOFT TISSUE UNDER SIMPLE SHEAR

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Abstract. *The study of biological soft tissues has a great importance for understanding tissue injury and, consequently, some diseases. Simple shear deformation is important to illustrate crucial characteristics of non-linear elasticity theory and is induced in soft tissues in numerous configurations. Most of previous research in this field has concentrated on very small samples to take into account the properties of all parts they are made of. Moreover, these researches have been neglected standard procedures so that the data could be compared with others easily. The purpose of this work is to study the mechanical behavior of a bovine fibrous soft tissue under simple shear. This paper suggests a more standardize approach for specimen dimensions, following the International Standard ISO 1827. In addition, the tests were made in samples with muscle fibers positioned in different directions and with different thickness. It could be seen that the resistance in simple shear of the material increases with the angle of the fibers.*

Keywords: *fibrous soft tissue, simple shear, biologic tissue, digital image correlation*

1. INTRODUCTION

Recently, there has been growing interest in the mechanical behavior of biological tissues. This knowledge has great importance for understanding tissue injury and, consequently, some diseases and its causes and treatments. For instance, knee osteoarthritis is related to the tension acting in the cartilage (Deneweth *et al*., 2015). Another example is chronic damages and pain in tendons, which is caused by repetitive loads (Khayyeri *et al.*, 2016). In addition, the study of these tissues improves the models of the interactions between soft tissues and medical devices (Leibinger *et al*., 2015).

In the non-linear elasticity, simple shear deformation illustrates important characteristics of the theory. Moreover, shear is induced in soft tissues in numerous configurations (Horgan and Murphy, 2010). For instance, invertebral disc (annulus) failure happens in regions of maximum shear (Hollingsworth and Wagner, 2011). Changes in the shear properties of plantar soft tissue may contribute to ulceration in diabetic patients (Pai and Leudox, 2011).

The mechanical behavior of biological soft tissues under simple shear has been widely investigated. Porcine brain (Budday *et al.* ,2017), human aortic tissues (Sommer *et al.*, 2016 and Haslach Jr. *et al.*, 2018), human ventricular myocardium (Sommer *et al.*, 2015), neonatal porcine ventricles (Ahmad *et al.*, 2018) have been tested in simple shear. However, most of previous researches in this field considered very small specimens to take into account the properties of all parts they are made of. Furthermore, they do not follow standard procedures so that the results could be easily compared among them.

Destrade *et al.* (2015) suggested that the specimen dimensions must follow the International Standard ISO 1827. The size seems to be enough to considerer the characteristics of all components of the tissue, as collagen and elastin fibers. In addition, this standard is the one used for rubber characterization in shear. Therefore, the aim of this work is to study the mechanical behavior of a bovine fibrous soft tissue under simple shear. The dimensions for the experimental procedure also followed the International Standard ISO 1827. Moreover, the tests were made in samples with muscle fibers positioned in different directions.

2. MATERIAL AND METHODS

An eye round meat was acquired from a local slaughter house. It is a bovine muscle that is located near the ox tail. This tissue was chosen because it is made of aligned and strength muscle fibers. The eye round was cut into specimens of 25 mm x 20 mm x 4 mm dimensions, following the International Standard ISO 1827, with muscle fibers positioned in different directions. The angles of the fibers in relation to the applied force in the test were 0 and 45 degrees. The tissue was kept refrigerated at about 5 °C. All samples were prepared and tested at a nominal room temperature of 23 °C and they were tested within 72 hours after subject aquisition. The surfaces (25 mm x 20 mm) of the specimens were glued with cyanoacrylate glue into the experimental arrangement. Thirty minutes settling time were sufficient to ensure proper adhesion of the sample to the platens. The specimen surface (25 mm x 4 mm) was painted white, with a thin paint coat, and after with a black spray, making a speckle pattern. This pattern is crucial for Digital Image Correlation method, which was used to assess displacement fields.

Figure 1 shows the experimental arrangement, that was composed of a tensile testing machine, a simple shear special apparatus (in detail in Fig. 2), a 5 kgf load cell and a high resolution CCD camera (1280 x 960 pixels) Sony model XCD-SX900. Images of the specimen's surface were acquired before and during loading at each 0.4 s, using the camera. A light source was used to homogenize the sample surface so that no external light would interfere in correlation. The results of the tests were processed in a correlation program.

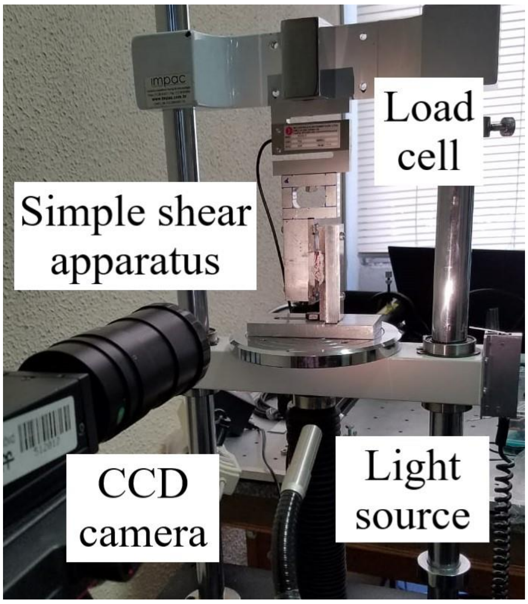

Figure 1. Experimental arrangement.

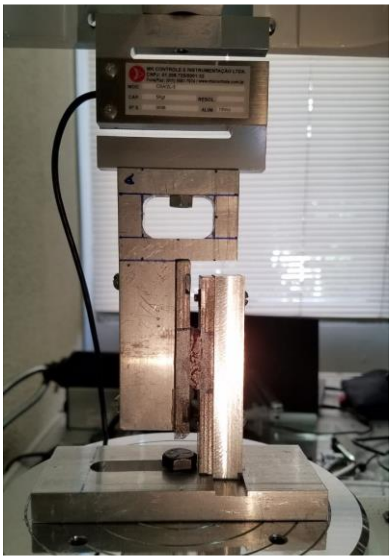

Figure 2. Simple shear special apparatus.

3. RESULTS AND DISCUSSION

Figure 3 shows the specimen surface pattern during the shear tests. It can be seen that the sample’s left side do not move, but the right side moves down with the applied shear force. This behavior can be also seen in the Fig. 4, which shows the displacement field of the specimen in vertical direction during a simple shear test.

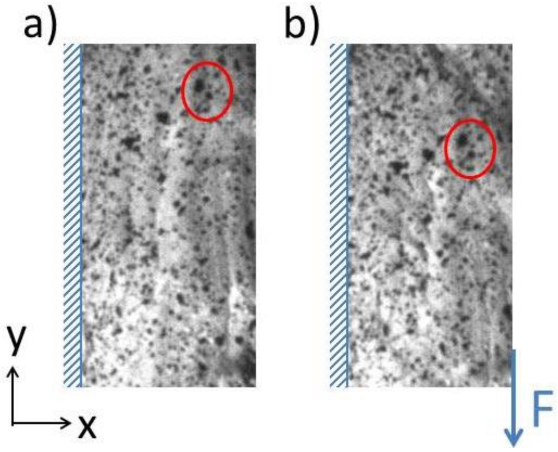

Figure 3. Images of the specimen a) before the test begin and b) after some applied force.

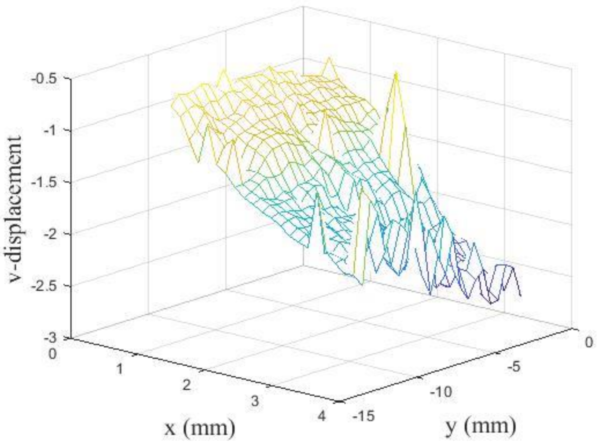

Figure 4. Displacement field of the specimen during a simple shear test.

Figure 5 shows the results of the shear stress versus the amount of shear of the specimens with fiber angles 0° and 45°. It can be seen that the mechanical behavior of the material in simple shear is non-linear, which is similar to the behavior of hyperelastic materials. The maximum stress supported by this biological material in simple shear is about 25 kPa. Moreover, the resistance of this material increases with the angle of its fibers.

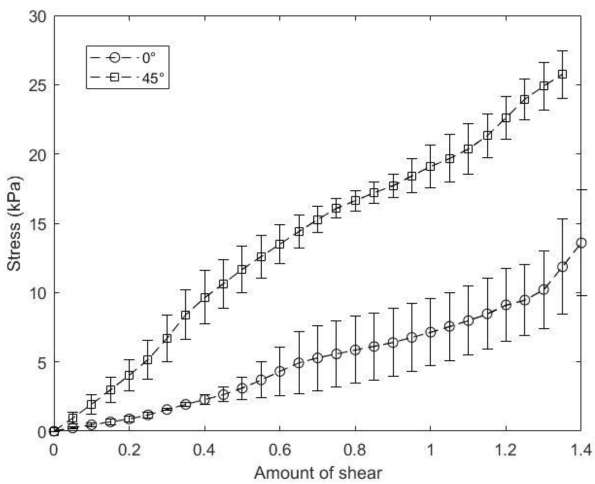

Figure 5. The shear stress versus the amount of shear of specimens of thickness of 4 mm and fibers angles of 0° and 45°.

4. CONCLUSIONS

In the present paper, a bovine fibrous soft tissue was tested under simple shear. The sample dimensions followed the International Standard ISO 1827 and, as a consequence, the results can be easily compared with others. The results showed that this is a non-linear material, with simple shear stress in the order of kPa. Moreover, the resistance of this material increases with the angle of its fibers. This paper contributes to the study of the mechanical behavior of fibrous biological soft tissues.

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