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Design of a Cost Effective Biaxial Tensile Testing Device for Soft Tissues

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***Abstract* - This study focuses on the development of a specifically designed biaxial tensile device to characterize the mechanical properties of soft tissues. Soft tissues play an important role in medicine, biological research, and materials engineering projects. Therefore, a sensitive and customized testing device was needed to study the mechanical behavior of such tissues.**

Within the scope of the study, the design, production, assembly, and testing of the device were carried out. The device is optimized for performing biaxial tensile tests of soft tissues. These tests are used to understand the tension and deformation behavior of tissues, to determine their biomechanical properties, and to provide important data for medical applications.

Experiments show that the device operates with high precision and produces reliable results for characterizing the mechanical behavior of soft tissues. This biaxial tensile device could have a wide range of applications, from medical research to biomaterial development, contributing to progress in the field of soft tissue mechanics.

This study highlights the successful development and testing of a biaxial tensile device specifically designed to perform mechanical testing of soft tissues. This device can be used as an important tool in the characterization of soft tissues and biomedical research.

Keywords: Planar Biaxial Tensile Testing, Soft Tissues, Anisotropy.

I. INTRODUCTION

Biaxial devices are testing devices used to evaluate the materials' behavior under synchronous loading conditions in two orthogonal directions. As such devices (Electro Force, Texas Instruments) use high precision torque measurement systems for force or load controlled applications, they may not fit with small budget projects. A biaxial tensile testing device was designed to be used for soft tissues including cardiovascular, gastrointestinal, and skin tissues as only relatively small forces required to test such tissues under varying external loading conditions (Sigaeva, 2020). The mechanical behavior of soft biological structures considered as highly anisotropic due to their composite nature and undergo large displacements where the passive category components of strain energy function determines materials' elastic behavior.

Recent studies on constitutive modeling underlines the need for structure-based hyperelastic modeling approach when investigating the highly hyperelastic tissue response. Puertelos released a substantial review highlighting the anatomical variations along the colon by comparing different hyperelastic material models available in the literature (2020). The study of the mechanical behavior of soft materials therefore involves multiaxial tensile tests. On the other hand, some researchers, in their studies, have designed their own custom devices and achieved similar accuracies at a relatively lower cost while the validation and calibration of testing bench is essential topic (Hamada et al, 2023)

In this study, the "Dual Axis Tensile Testing Machine", a portable device to examine the mechanical properties of soft tissues, was designed and prototyped. The design and validation details of the device are presented. Finally, 10 cattle (bos-taurus) small intestine tissues tested at 1:1, 1:0.5, and 0.5:1 loading rates in circumferential and longitudinal directions respectively.

II. MATERIAL AND METHODS

Planar biaxial test is an experimental method used to characterize the behavior of materials, especially anisotropic behavior of composite structures. According to complex nature of biological structures, material response varies in different directions. These tests aim to examine the response of the material by applying a specific stress-strain condition to the material sample.

2.1 Equipment

The linear motor shown in Fig. 1 has been used for stretching the specimen. The Arduino Uno electronic card used to adjust the pulling speed of the linear motor as well as monitoring and recording of load cell data. Linear motor is selected within adjustable drive door opener commercial

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products. The maximum torque is 1500N and it runs on 12V DC electric motor with maximum stroke of 150 mm.

The reaction forces recorded by using 20 kg capacity Aluminum load cell which runs on 4.8 V and the refresh frequency rate is 80 Hz. Refresh frequency is important variable when running the test bench at different speeds. An Arduino Uno card used for collecting real-time load cell data and adjusting the speed of linear motors trough a computer interface.

In order to correlate displacement results from the experiments, a DIC camera used to collect real-time data from 5 nodes placed on the specimens. The center region of the specimen was recorded for further examination. Recorded videos and images then transferred to MATLAB for further image processing. The results were considered both from DIC displacement readings and load information from load cells.

2.2 Modeling and Analysis of Testing Bench

A chassis were designed to house linear motors as well as future developments such as adding a temperature controlled bath. The connection components then designed and printed to place linear motors on the chassis with high precision. The grip subassembly was created to allow quick replacement of specimens. In order to make sure of unwanted level of displacements on the measuring plane, a FEA study was conducted under varying loading conditions to determine maximum displacements occurring grip subassembly.

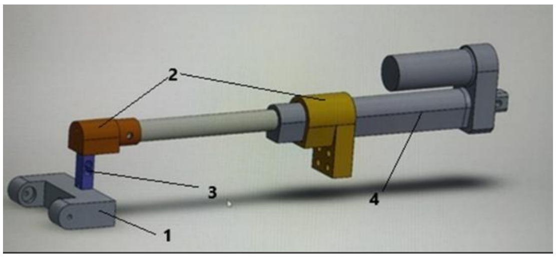

Figure 1: Fixtures components connected to the linear motor: 1.Specimen Grip, 2.Fixture components, 3.Load cell, and 4.Linear motor

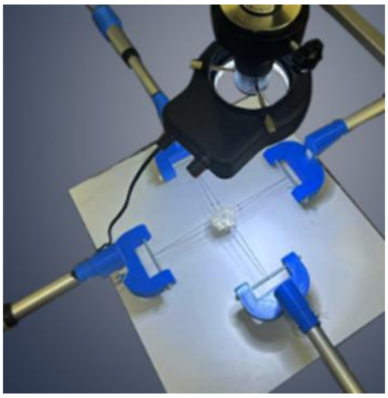

Figure 2: The Experimental Setup

Stress analysis of the specimen grip according to the 200 N and 1000 N were performed and the stress distribution was shown in Figure 4. Normally, there is no need for this analysis as a relatively small load is used for soft tissue. However, considering that the designed device will be used not only for soft tissue but also for different materials, it was necessary to know the stress distribution of the grip subassembly when the maximum force is applied.3D modeling of elements of grip is given in Figure 3.

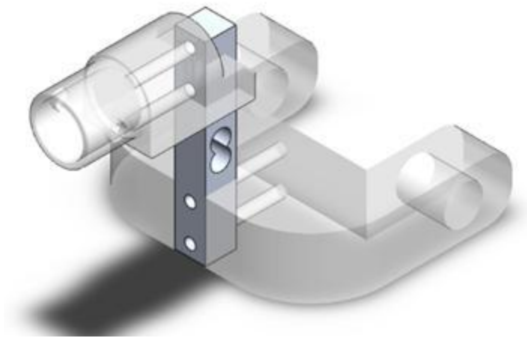

Figure 3: The isometric view of grip subassembly

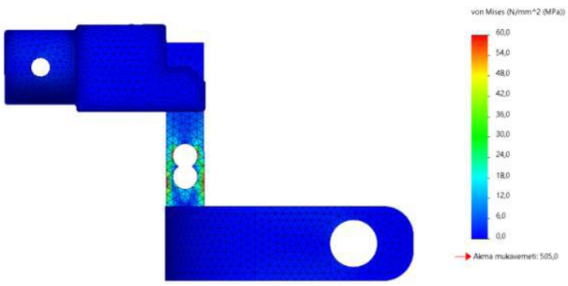

Figure 4: Von-Mises Stress under 200 N loading

One of the insights from design process was structural rigidity of the system where measurements directly rely on. When a force of 200N is applied, the maximum displacement of the grip is 0.353 mm. Therefore, it has been observed that the system designed for soft tissue is quite rigid and reliable. However, when we apply the force of 1000N, it is seen as shown in Fig. 4 that the displacement is 1.758 mm. So, it has been determined that the system is not rigid at greater forces. If this tester is intended to be used in material tests where larger forces will be used; materials of the grip should be made of materials such as steel, and aluminum.

2.3 Specimen Preparation

Soft tissues constitute an important component of biomedical and biomechanical research, and therefore sample preparation must be done carefully. Design and manufacturing of a biaxial tensile testing machine includes preliminary tissue stretch experiments. In this regard, freshly slaughtered cow small intestine was kept in the freezer until the experiment

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day. Frozen small intestine divided into 13X13 mm squared specimens of 10. The direction of cutting of soft tissues should be selected taking into account the anisotropic properties of the specimen. Therefore, a mark was placed on the axial direction of the small intestine by surgical skin marker. At the same time, each specimen's center was marked with 5 nodes in a cruciform shape using a biomarker. Marks in the specimen surfaces are important to keep track of the stress distribution, and these markings were analyzed using image processing software. Two fish–barbless hooks were used to hang the specimen on each edge. The cotton suture was chosen to decrease elongation under tension instead of nylon/absorbable sutures as shown in Figure 5.

2.4 Loading protocol

A 5 kN preload applied to achieve a zero-stress state. To investigate the anisotropic behavior of the tissue, loading protocol was carried out with 1:1, 1:0.5, and 0.5:1 on each axis respectively. At the same time, a speed control card was used to adjust the linear motor speed, and the speed was set to 1 mm/s.

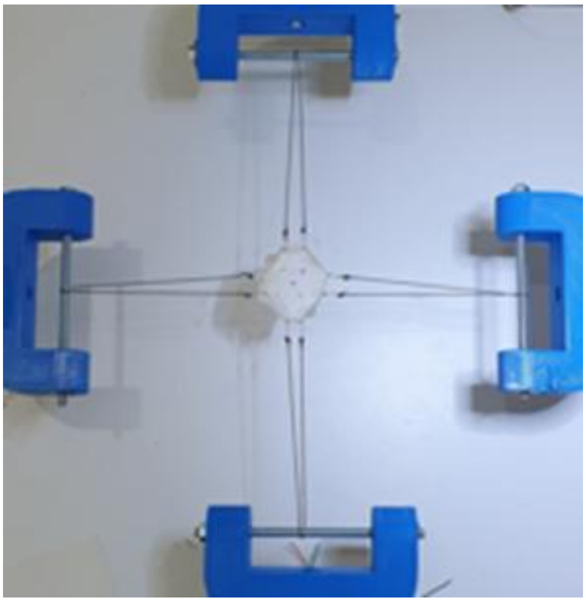

Figure 5: Experimental set up top view

III. RESULTS

A sample test was performed to test and validate the designed and manufactured biaxial tensile device and compared it with the literature. In the literature, three protocols were applied according to the sample withdrawal rates taken from porcine colon tissue, namely 1:1, 1:0.5, and 0.5:1 (14). In this study, the same protocol was applied (Figure6) and the graph in the literature (Figure7) was compared with the data obtained from the test device produced.

Similar results were obtained from the obtained graph to the literature. However, the difference between the numerical results of the graphs; is due to the difference in the tissue tested.

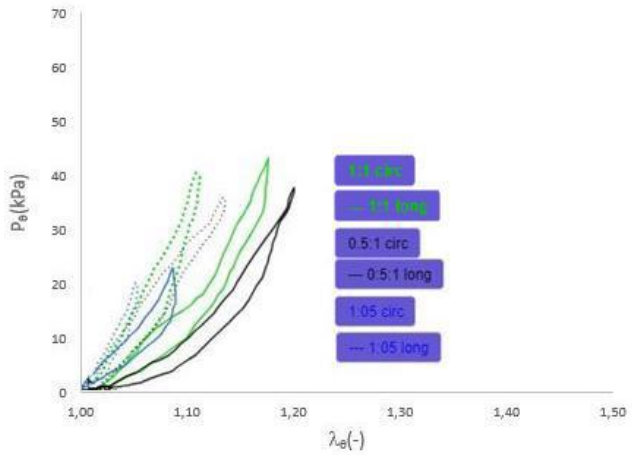

Figure 6: Biaxial experimental data behavior after preconditioning cycle at 1:1, 0.5:1, 1:0.5 ratios for small intestine tissue of a cow

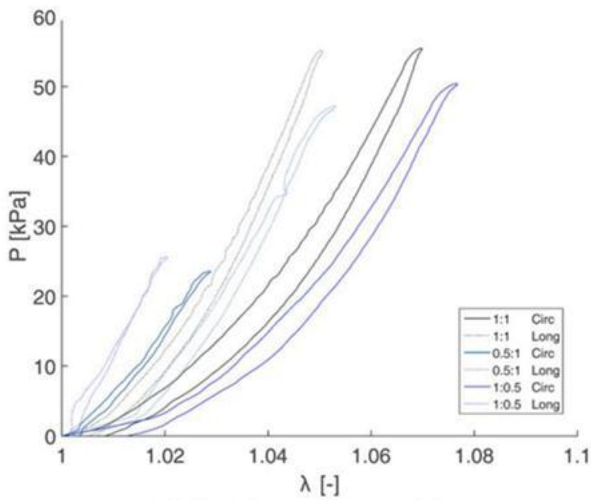

Figure 7: Biaxial experimental data behavior after preconditioning cycle at 1:1, 0.5:1, 1:0.5 ratios for pig colon tissue of pig (Ref : 14)

IV. CONCLUSION

In this study, the design and prototyping of an economical and need-based biaxial tensile device for soft tissue tests was carried out and its calibration was provided with accredited devices. The cost of the device was around 5 percent of conventional biaxial testing devices. In addition, with this study; for academicians who do not have biaxial tensile devices in their laboratories or who cannot access these devices, it has been shown that they can perform the device specific to their experiments at very small costs and with local facilities. The study also found that the device was accurate and reliable. The device was calibrated with accredited

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devices, and it was found to produce results that were consistent with those of conventional biaxial tensile devices.

As a result, the accuracy of the device; to test and confirm its accuracy with a sample study, the sample taken from the cow's small intestine was tested and the results were found to be by the literature.

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