Development of bench top biaxial tensile testing machine

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Abstract. Development of new biaxial testing apparatus is carried out to study and evaluate the mechanical properties of different materials. Novel materials like biological tissue, soft plastics, fibers, wires, carbon nanotubes, smart materials, textiles, ceramics, composites etc. can be tested to evaluate its mechanical properties on the developed apparatus. The developed apparatus will be used to evaluate mechanical properties. This apparatus will be used to characterize a material’s properties as a function of strain frequency, stress or a combination of these parameters. The equipment can be used to apply sinusoidal oscillating stress (load) which is applied to the specimen by actuators with the help of a servo controlled electric motors. The equipment has basic capabilities to produce static and cyclic multiaxial loading system. Generally, the test facility requires cruciform(Cross Shape) specimens which will be loaded orthogonal direction. Stress-controlled and strain controlled are two main techniques that are employed to test the specimen. As the stress-controlled analyzers are cheaper to manufacture (1) this technique will be adopted in the test rig. The test rig will be equipped with two mutually perpendicular actuators capable of incremental motions of as small as few microns. Each actuator will be equipped with a load cell to measure both tension and compression loads. The servo-electric actuators will be programmed to move independently or in a coordinated motion. Camera will be used to record and measure the strain produced in the specimen. Real world loading system can be created within the device to tests material capability in more realistic manner.

1. Introduction

During the last few decades, newer materials like smart materials, composites, ceramics etc. have become an integral part of everyday life. Their excellent mechanical performance together with their low specific weight explain why these materials, are popular for applications in various industries from aeronautics, aerospace and transportation to sports, construction and health care. Although these materials have many benefits over traditional materials such as metals, there are also some drawbacks or limitations in using them. The cost of fabrication is generally higher, repair of most materials is rather difficult and its mechanical characterization is more complex (2). The latter drawback is a result of the complexity of the material, for example in the case of composites specifically continuous fiber consisting micromechanically out of two phases (fibers and matrix) and macro-mechanically out of several lamina stacked in a certain direction. This makes the computation and testing of composite materials difficult. The equipment is designed to study and evaluate these materials in a more realistic manner.

(1) The stress-controlled analyzers are cheaper to manufacture.

(2) The mechanical characterization is more complex due to the complexity of the material.
structures not straightforward (3). Uni-axial tensile tests like tension test, compression test, 4-point bend test etc. results are insufficient to predict and evaluate the mechanical behavior of composites materials subjected to biaxial stress-strain states. Many of the service application of composites, fabric soft plastic or rubber involve in multi-axial loads so these materials need to be tested in several directions. Different test like tabular inflation test, planar biaxial test ,bulge test are required to measure mechanical properties of materials which are independent of the way materials are modeled (isotropic or anisotropic) (4). A biaxial testing involves many difficulties like the design of a suitable specimen, the correct analysis of the results and the purchase or development of expensive testing equipment. The micromechanical behavior of materials which we have understood is based on uniaxial testing techniques. This deformation test gives the strain path in 180° i.e. loading and unloading. It is now broadly accepted that mechanical properties of materials under multi-axial loading conditions are different than those anticipated on the basis of test results from uniaxial tests. A planar biaxial test rig applies the stress in planar orthogonal direction with the help of actuators. This test gives the better result as compared to other bulge and inflation test as the different stress can be applied in two directions. Cyclic load can also be applied to the specimen. The test can be performed on materials like biological material, smart materials, engineering textiles, membrane, carbon nano-tube, plastic, polymer, and ceramics. If we consider a membrane in a fuel cell, it is a thin sheet which is constrained in a 2D plane and not in the thickness plane. So the study of the mechanical behavior in plane becomes important to enhance the life and performance of these membranes. Meredith N. Silberstein el. al. investigated the elastic-viscoplastic behavior of Nafion (polymer electrolyte membrane) in biaxial loading condition (5). Biaxial testing rig are extremely useful in medical and aeronautical industries.

Types of multi axial testing (6)

1. Tubular Inflation Test

This is a hydrostatic test. A specimen of tubular shape is clamped on circular jaw. The jaw must be rigid. The hydrostatic pressure created using air or water. The pressure created inside the tube generates peripheral stress. Along with this axial load can be applied at the end of the cylindrical specimen. Permeable materials like clothing fabric cannot be tested as due to permeable nature the pressure changes along the fabric so it behaves differently (7)

2. Planar Biaxial Tension test

In this test, force are applied to the cruciform shape specimen in orthogonal directions. Stress and Strain are continuously recorded during the test. Stress strain curve for materials are developed. U.S. Lindholm et. al. developed a dynamic biaxial testing machine for generating the generalized constitutive equations for materials in 1966 (8). Both the actuators are independently control.

3. Bulge Test

The material is inflated until bursting by the pressure of air or water changing the shape to sphere. The test shows bursting strength and stress strain relationship. Instant pressure and radius of curvature is measured using optical method. The bulge test has as main drawbacks that only the tension-tension quadrant can be investigated, that only thin specimens can be tested to avoid the stress gradient through the thickness and that due to the gripping, non-homogeneous stress fields could be introduced.

2. Design and Construction
Development The apparatus modeled in Solidwork 2016 SP 02 version. The 3D Model of the test instrument developed is shown below

![3D Model of Biaxial tensile testing machine (left) and complete assembly with camera (right)](image)

**Figure 1**: 3D Model of Biaxial tensile testing machine (left) and complete assembly with camera (right)

The testing equipment includes four stepper motors NEMA 17 2.2 Kg-cm. These will be used for applying loads in tension and compression mode. Motors are mounted in orthogonal direction as can be seen in the model. The Motors are attached to the head with the help of square threaded rod. Two guide rods are attached to the head with linear bearing for the desired motion. The assembly is mounted on the acrylic sheet of 10mm thick.

The components of the apparatus are manufactured using 3D printer. The moveable head is manufactured using Ultimaker 2 extended. The equipment can apply a load of 5 kg on one axis

![Biaxial tensile testing machine (left) and complete assembly with camera (right)](image)

**Figure 2** Biaxial tensile testing machine (left) and complete assembly with camera (right)
The cutting on acrylic sheet was done using laser cutting machine. This ensured the proper alignment of the holes with the precision of 0.1mm. The load cell of FUTEK was used for measuring stress. The NI DAQ is used to collect the data for the analysis. The Shape of the specimen to be used us cruciform.

3. Cruciform specimen design and geometry

The in-plane loading of cruciform specimens is a technique which was used for the first time in the late 60’s to investigate the biaxial behavior of metals. Mönch et. al. started with the application of two perpendicular inplane loads on a rectangular plate to create a biaxial stress state in the centre of the specimen. (9) The shape of the specimen was adjusted quite quickly to a cruciform to avoid damage near the clamps and to lead failure to the center.

There are at least two principles of designing biaxial tension specimen (10):
1. Stress-strain homogeneity within the center section so that we can calculate the stress with deviations as less as possible.
2. Yield has to occur in the test section and stress concentrations to avoid fracturing in arms.

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