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Design of a Testing Device for Cruciform Specimens Subjected to Planar Biaxial Tension

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Abstract. Multiaxial experiments are necessary to determine materials behavior subjected to complex stress state, corresponding to real operating conditions under complex loadings. Stresses applied in biaxial experiments are closely to the stresses that materials experience during their function life. Because of reduced acquisition cost, operation cost and maintenance costs, devices attached to the universal testing machine are beginning to be used in ever more applications. The present paper examines a new type of mechanism used to test biaxial cruciform specimens in order to investigate materials behavior in planar biaxial tensile conditions.

Introduction

Areas of applicability of a material require a comprehensive understanding of material behavior within a wide range of loading conditions. Engineering structures and components generally works in stress environments significantly more complicated than uniaxial tension or compression. Therefore, understanding materials failure under multiaxial stress conditions is very important. In order to answer to the different experimental aspects and questions, a wide variety of test configurations are used to study materials behavior in multiaxial stress states [1, 2]. To apply different loads to cruciform specimens can be used one or a combination of the following stresses: static-tension, compression, shear, bending or dynamic-fatigue. In case of multiaxial testing, mechanical characteristics values cannot be calculated directly, as it happens in uniaxial tensile test. The standard uniaxial test is used to obtain stress–strain curve of a material subjected to static stress.

To obtain multiaxial stress state can be used various testing methods. They can be classified according to several criteria. One criterion is the type of specimen used, which can be round bars, thin-walled tube or plates. After the mode of loadings, round bar can be tested under torsion-bending, thin walled tubes under tension- torsion, axial- internal pressure, axial- internal pressure-torsion, axial- internal pressure-external pressure-torsion. Testing methods for plates are cantilever bending, bulge test, anticlastic bending, disc-shaped specimen under equi-biaxial loading, cruciform specimen under static conditions [3] and fatigue tests [4]. To study biaxial stresss state of plates have been developed different multi-axial experiments, along the time: bulge pressure tests, hemi-spherical punch tests, cruciform tests , flat punch tests, multiaxial compression tests, electromagnetic forming tests [5].

Regarding types of machines used in multiaxial testing of materials can be made next classification: devices attachable to universal testing machine used to apply only biaxial static loads [6], independent machines used to apply biaxial static and dynamic loads [7] and independent machines used to apply biaxial and triaxial static loads [8, 9, 10]. Attachable apparatus can be found in several configurations for transforming vertical movement (tensile or compressive) of universal testing machine to stretch cruciform specimen (aligned vertically or horizontally to the ground): type pantograph, with sliding elements, with toothed rack-gear mechanism, inclined planes etc.

Loads can be applied independently or simultaneously to produce biaxial stress states. In service conditions, however, loads are simultaneously applied in several directions. The biaxial stress ratio depends on the specimen geometry or the loading fixture configuration, in the case of tests using a single loading system, while in the case of tests using two or more independent loading systems it is depending by the applied load magnitude. In this paper a preliminary study will be done for a device with inclined planes [11], which will be used for testing metallic materials and composites.

Configuration of Biaxial Tensile Testing

The biaxial testing allows making better predictions on the mechanical properties of composites, as well as on the mechanical behavior of rolled sheet metals during manufacturing processes. The mechanical properties of materials under uniaxial stress are used to estimate the failure of components in the design of a machine or structure. The experimental validation of material models used for simulations is mostly based on biaxial tests.

Different procedures have been developed for producing biaxial stress states in materials and they vary in design and complexity depending on the geometry of the used specimen. Biaxial tensile tests can be conducted with two categories of equipment: independent test machine and devices attached to the universal uniaxial testing machine. Biaxial testing of cruciform specimens using attached devices to the universal testing machine contains two main elements, sample and apparatus.

As no standard is available concerning the biaxial tension experiment in large deformation, and more particularly on the cruciform specimen special attention should be given to this aspect. In order to validate the specimen, numerical simulations of biaxial loading have also been carried out. A cruciform design sample was optimized in order to improve stress state distribution, were the highest stress level can be observed in the test section and it is there, where initial yielding occurs. [12]

In case of independent machines, three main types of static and fatigue rated actuators: electromechanical, electro-dynamic and servo-hydraulic can be used. Actuators may act all simultaneously or all individually, which means that the ratio of forces may be constant or may vary in any of direction. The main features to configure test equipment are force, stroke, speed, frequency and specimen material and dimensions.

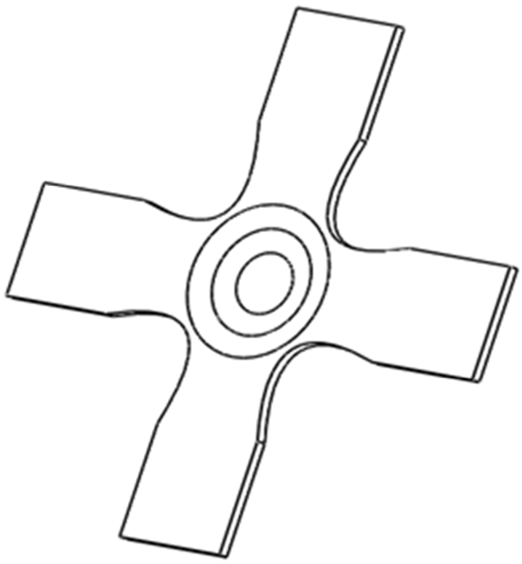


Fig. 1. Cruciform specimen - 3D view

Depending on the nature of the test (static or dynamic, tensile or compression) biaxial experiments must meet two main conditions. First is ensuring satisfactory dimensions of specimens, in order to obtain independent information on the particularities of different crystalline grains of the material and a high precision displacement measurement. Second is achieving a uniform biaxial stress state and high enough in specimen center. The most relevant promising method for conducting static and dynamic tests under biaxial tensile stress state, at this time, is testing cruciform specimen subjected to biaxial tensile loads.

Devices attached to universal testing machine from the point of view of minimizing the experimental configuration and the rationalization resources make this solution more practical, applicable and effective. Through this type of device, it is possible to convert the vertical movement of the crosshead into directional movement of the grippers. This mechanisms are adaptable to any uniaxial tension machine. A new type of attachable mechanism is proposed for in plane biaxial tensile testing of cruciform specimens to investigate mechanical behavior of different types of materials.

Description of Attachable Device Mechanisms

The idea behind this study is the type of device with inclined planes, which has been used by other researchers for biaxial tensile testing of thin films, showed in Fig. 2. This device is driven by tensile force of the universal testing machine, which turns to traction that pulls grips of the cruciform specimen arms. According to the mobility of vertical elements of the mechanism, the systems fall into two main categories: with bottom vertical element fixed and with bottom vertical element mobile.

The base of the device is fixed on the bottom of the tensile machine, while the upper half is fixed on the moving crosshead of the machine. When the crosshead of the tensile machine is moved, the higher vertical grip fixed on moves accordingly; whereas, the lower vertical grip fixed at the base of the tensile machine remains immobilized which is identical to any uniaxial testing.

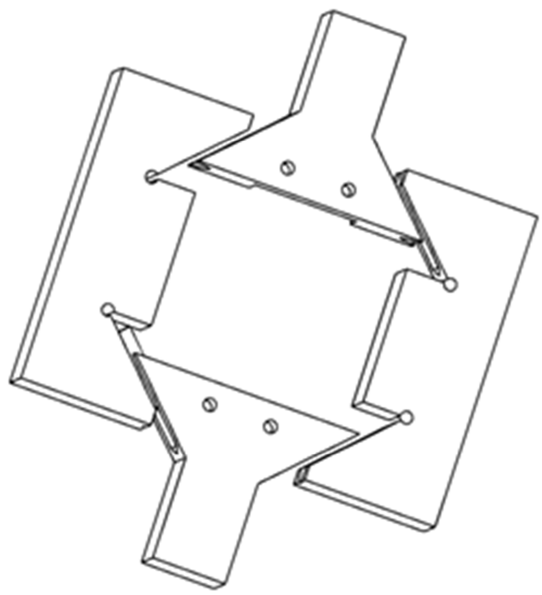
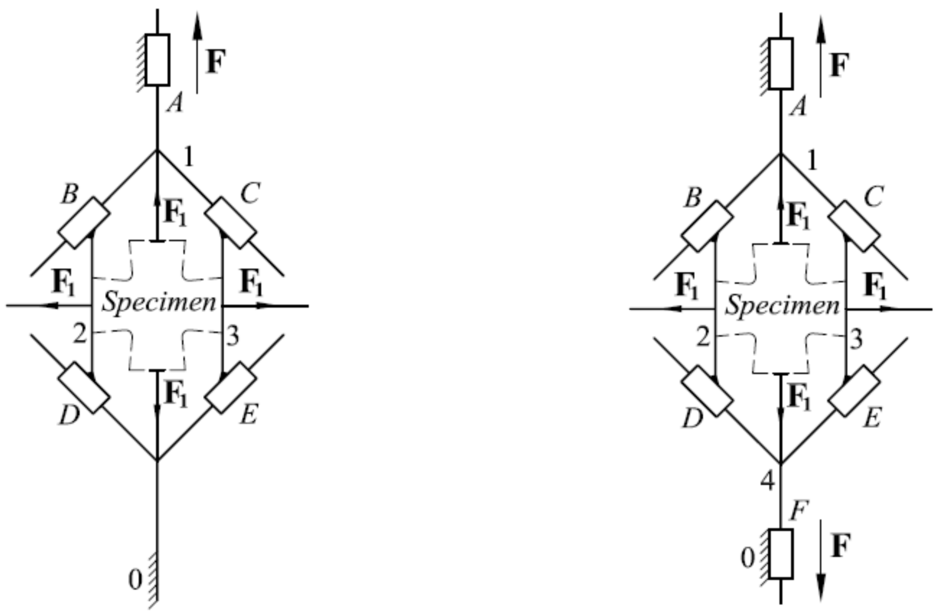


Fig. 2. Device 3D view

Stress measurement will be calculated in the following way. As the vertical top grip is fixed to the load cell through the vertical draw bar, the link between this grip and the load cell makes it possible to measure of the stress in the vertical direction, but affected by the friction. The cruciform specimen arms will be equipped with strain gages, in order to measure the strain. A strain rosette with three grids will be glued in the center of the specimen, in order to determine the principal stresses and their directions. Thus the strains in both arms of the cruciform specimen are thereby evaluated. From these strains, the stresses in arms of sample are computed. Two equivalent mechanisms of the test device studied are shown in Fig. 3.



a) b)

Fig. 3. Inclined planes mechanism: a) variant with bottom vertical element fixed; b) variant with bottom vertical element mobile

As we see in the figure, this mechanism contains only translational joints. It means, we only have two translational movements of the links, along x and y axis.
Not any rotational movement is possible. In this case, next equation may be used to compute the mobility of the mechanism:

$$M = 2(n-1) - C_5 = 2(4-1) - 5 = 1. \tag{1}$$

where n is the total number of links (including the referential one), C_5 is the number of joints (all of them with one degree of freedom). In Fig. 3.a, the actuator will drive A joint, acting with a F axial force. Thanks to the mechanism kinematics, on the central probe will act F_1 forces, as we see in the figure. If our device is designed as well as the force F may act biaxial, the equivalent mechanism will need two actuators (see Fig. 3.b) and it mobility will be computed as

$$M = 2(5-1) - 6 = 2. \tag{2}$$

To avoid a detachment of the lateral parts, 2 and 3, another equivalent mechanism is proposed, showed in Fig. 4. Based on this mechanism kinematics, in the future will be design the last version of our device.

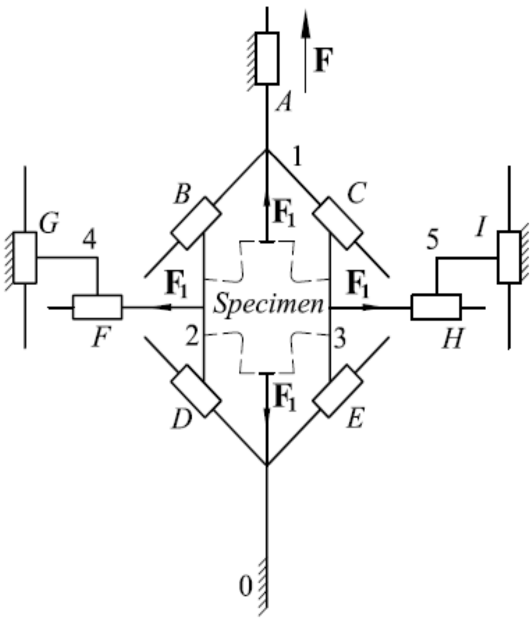
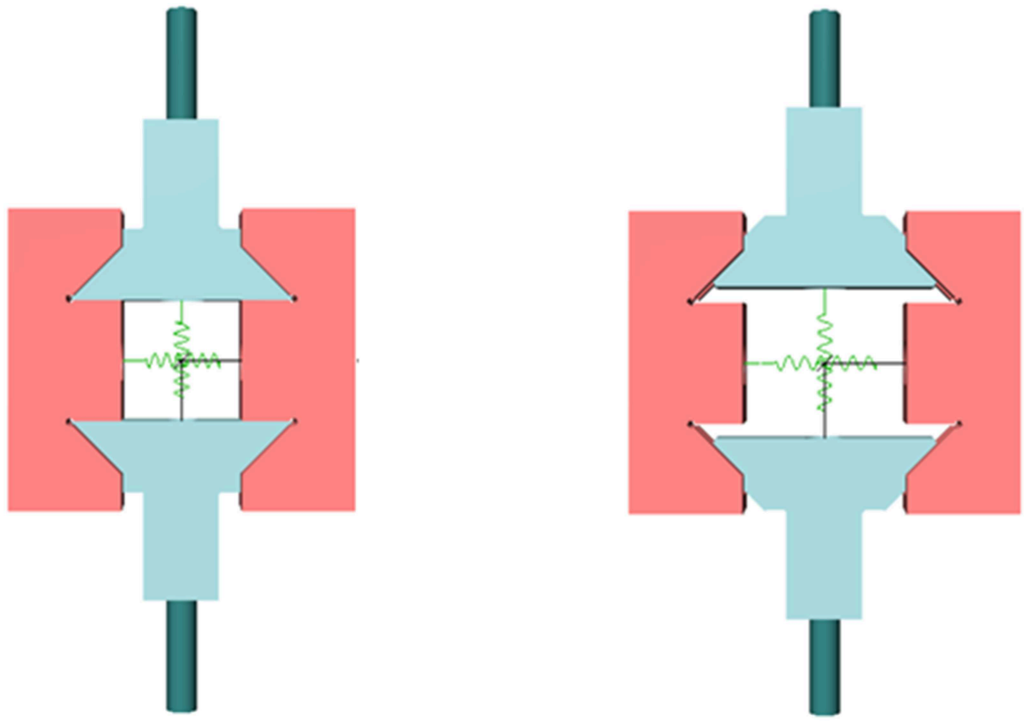


Fig. 4. Improved equivalent mechanism of the device

Discussions

Development of an attachable device for biaxial tensile testing of materials through cruciform specimens is a challenge to researchers. Over the past several decades, have been made considerable efforts to develop efficient experimental test methods to assess the behavior of materials under complex loading conditions. The minimum request for any procedure for in-situ mechanical characterization of multi-axial deformation is to produce the required level of load and displacement to reach material failure.

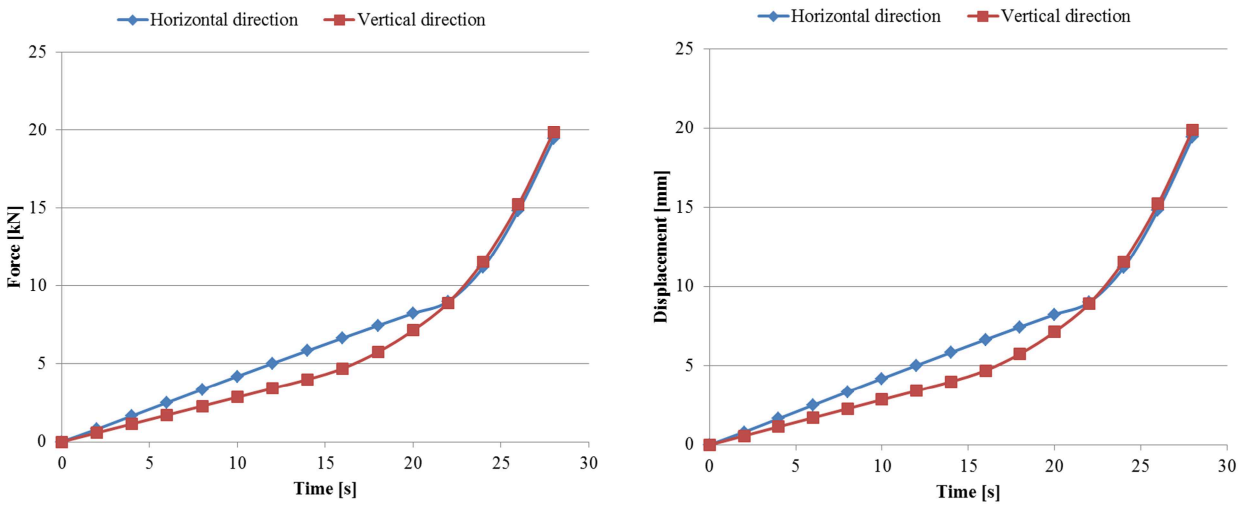
For modeling and simulation of dynamical system was used MSC Visual Nastran software. Input parameter for analysis was maximum allowable stroke for this type of device.
In order to run these simulations were used some simplifying hypotheses. Assumptions are based on the constraints of the forces applied by testing machine, displacements allowed by the device, the components material, and specimen material. The positions of the start and end of the system simulation are illustrated in Fig. 5. The results obtained from the analysis are showed in Fig. 6.



a) b)

Fig. 5. Model 3D simulation: a) initial position; b) final position;

Can be observed that variation of force during testing time is not equal in both directions, with very small differences (Fig. 6.a). Vertical displacements are also different from those horizontal regarding evolution in time (Fig. 6.b). Variation law of the load during the simulation of the mechanism was elliptic.



a) b)

Fig. 6. Evolution in time: a) forces b) displacements

Each of the two types of experimental procedures presented above has specific weaknesses and strengths. Equi-biaxiality of the specimen deformation is true under the assumption of negligible elastic deformation of the testing device. Another phenomenon that is present in attachable devices is friction, that should be assessed how influences outcomes. These devices can be implemented in various scientific and industrial applications due to their versatility, with minimal cost and good results. On the other hand, servo hydraulic testing facilities allows any stress ratio and strain rate and are used for simulating multiaxial stress states, but have the disadvantage of high costs of acquisition, use and maintenance.

Conclusions

The lack of standards and the fact that size and shape of cruciform specimens are related to material and testing equipment compels researchers to design some customized devices to examine the behavior of these materials. The development and design of those non-standard test systems is based on a close collaboration between industrial environments and scientific environment. A new attachable device for a biaxial test is designed for loading specimens in equi-biaxial tension. This mechanism can be adapted to any uniaxial tension test machine and thereby it reduces the cost of conducting tests compared to standalone expensive machines. A mechanical testing device has been designed to apply tensile loads according to two orthogonal axes on a cruciform specimen. This system is conceived to provide a uniform state of biaxial tension necessary to investigate behavior of various materials and particularly metals and composites. The main advantages of this new type of device are: it is simple and robust, it is ease of manufacture and assembly, minimizing test configuration, it has a low cost.

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