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ALTERNATIVE POSSIBILITIES OF BIAXIAL TESTING OF FIBER AND FABRIC MATERIALS IN NONSTANDARD CONDITIONS

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Abstract: *The commonly used static uniaxial tensile tests don't describe the properties of materials based on fibers sufficiently therefore a biaxial test has been utilized. An important requirement is to conduct the test also at significantly higher speeds and under various climatic conditions; due to sensitivity of fibrous materials to climatic influences, in particular temperature and humidity. This is for existing testing devices point where we encounter two significant insufficiencies. Firstly they have limited speed and maximal loading force. Secondly, their use for testing under extreme climatic conditions is almost impossible due to their usually electronic control. The aim of this work was to propose appropriate experimental facilities using only two engines instead of the usually required four that would be able to work at higher speed, under climatic loading and in limited space. Based on these findings a testing mechanism that can be placed in an external box of climate chambers connected to a laboratory hydrodynamic-circuit has been created. This method utilizes a sliding displacement of the jaws controlled with inner forces in a tested sample and four springs. Increased sensitivity of fibrous materials to the speed of strain and climatic conditions were detected during following experiments. Compared with other used tests, the concept seems to be sufficiently precise.*

Keywords: Fibers, Biaxial loading, Multiaxial stress, Ortotropic materials, Climatic loading.

1. Introduction

The basic requirement for a successfull design of a final product is the perfect knowledge of mechanical properties of used materials with under real conditions. For textile materials which show considerable anisotropy or orthotropy it is generally not sufficient to perform tests in one axis, it is necessary to load in two axes simultaneously. Because of the small thickness of fabrics the component of the stress in thickness direction of the material could be usually neglected, see Quaglini (2008), Seibert (2014). Technical textiles are typically subjected to plane stress conditions. For industrial materials containing fibres it is especially important to take into account the real ambient conditions occurring in real operations. In an effort be as close as possible to real condition in vehicle, with a significant climatic influence, it was necessary to do test in a climatic chamber with variable temperature and humidity. The climate changes in the textile material with significant sorption process, affecting their properties. For testing textiles the conditions are given in the standard. For orthotropic materials, which are loaded plane state of stress, it's possible to use following relationship:

$$\begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ 2\varepsilon_{12} \end{bmatrix} = \begin{bmatrix} \frac{1}{E_{11}} & -\frac{\mu_{21}}{E_{22}} & 0 \\ -\frac{\mu_{12}}{E_{11}} & \frac{1}{E_{22}} & 0 \\ 0 & 0 & \frac{1}{G_{12}} \end{bmatrix} \begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{12} \end{bmatrix} \tag{1}$$

Where *Eij* are moduli of elasticity in the main directions of the material, *Gij* are moduli of elasticity in shear and μ is Poisson's ratio taking into account transverse contraction.

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The conditions for testing textile materials are given in the standard. The air temperature must be 20 ºC and humidity of 65 ± 2 %. The fabric should be dried before the test and then placed in a precisely air conditioned environment for 12 – 24 hours.

2. Biaxial testing

As Reinhardt (1976) and Kawabata (1984) historically pointed at their works aimed to testing methods, textile materials are almost always burdened biaxially. In one axis tensile test in a longitudinal direction, there are typically main stress concentrators with a subsequent rupture formed at the site near the clamping jaws. In contrast, in transverse direction the stress is concentrated more equally in the centre of the sample. According to Escárpita (2012), for testing of biaxially loaded samples it is necessary to ensure that the test device meets the basic requirements. There must be strictly a tension or compression, avoiding spurious shear or bending loads. The orthogonality between the loading axis must be guaranteed throughout the entire test. Generally it is recommended to use hydraulic devices or mechanical system with linear motors, system of cables, pulleys and bearings.

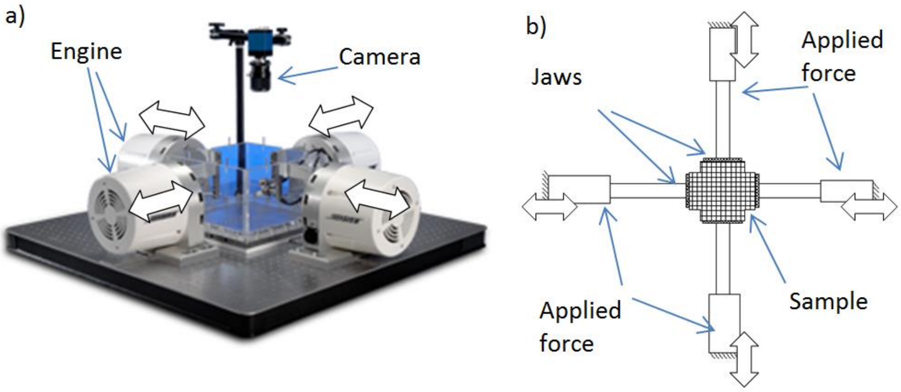

Fig. 1: Ideal and common case of static - biaxial testing device.

Fig. 1. shows the ideal and desired state simultaneous tension in all directions. To perform multiaxial tests in a climatic chamber, with significantly limited space, it is not possible to use any electric propulsion. With electric linear motors it is not possible to achieve the required strength and speed for dynamic testing. Use of the hydrodynamic circuit is a solution to the problem. Hydrodynamic parts are not so sensitive to ambient conditions and compared to pneumatic parts we obtain a more fluent running without steps, caused by compressibility of inner medium. When studying the literature, it is possible to find concepts that are incorrect as pointed e.g. Quagliny (2008), Kulhavy (2014) and Srb (2014) see (Fig. 2). In these cases the arising stress in the sample depends on increasing displacement and significantly changes the nature and distribution of forces.

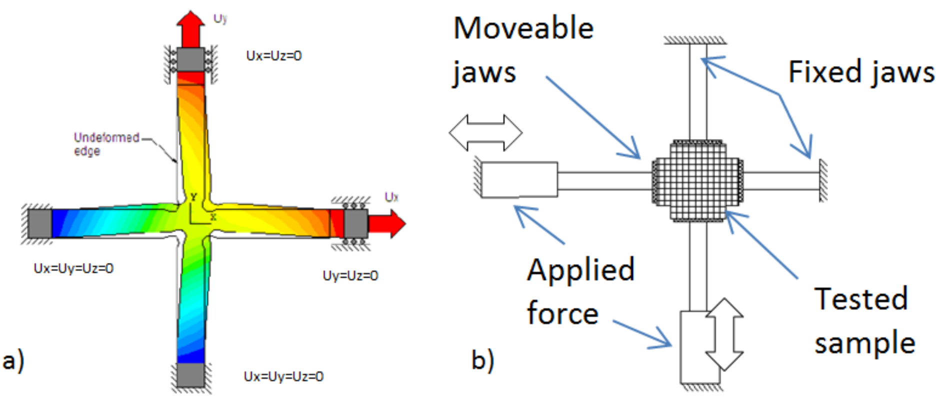

Fig. 2: Wrong simplified version of the test - an uneven loading.

3. Clamping device

A problem with using hydrodynamic devices in the climate box is the necessity to use simultaneously 4 horizontal engines. For this reason a concept that could have only two engines, but able to fulfill all the prerequisites of biaxial testing, where the centre point of jaws connecting lines is still coincident, was sought.

A suitable variant may use sliding jaws with movement normal to the direction of the applied loading force (Fig. 3a), so that the required position is still adjusted. The results of this process are considerably better than in the variant of Fig. 2. Due to friction in the sliding bearing arising in the sample some shearing forces and as could be seen from the simulation, the stress distribution is not entirely appropriate. Design modification that can eliminate all these problems seems to be a mutual connection of the sliding jaws with springs (Fig. 3b). Due to constant rigidity of used springs, the forces ensure an almost ideal position during the entire course of the test. The Fig. 4a shows simulation for a case when the shear stress is transmitted through the textile sample. The situation when the "unwanted" force is transmitted by springs could be seen in the Fig. 4b. It is possible to see (Fig. 4) that the stress distribution is for the second concept better.

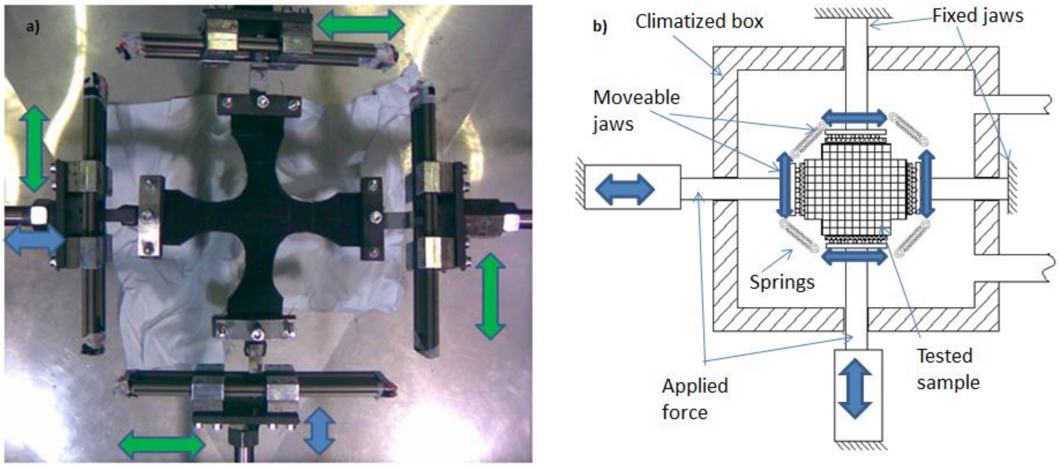

Fig. 3: Sliding jaws concepts: a) First - force transmission via textiles; b) Second –springs.

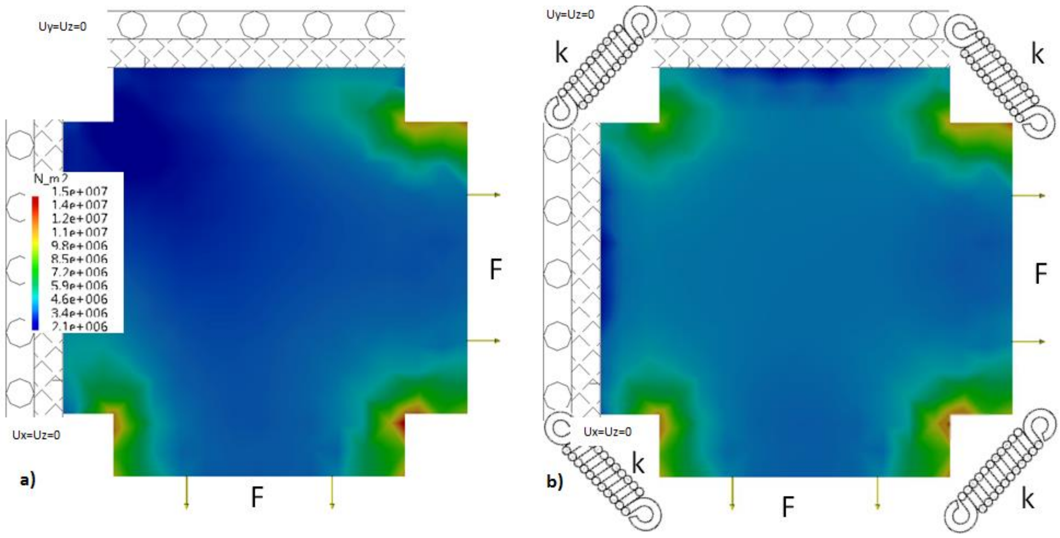

Fig. 4: Equivalent stress in the simulated models: a) Frictional variant; b) Variant with springs (displayed with a common scale).

4. Experimental comparison

The graphs in Fig. 5 show the arithmetic average (5 pieces of samples for each of the three devices - ideal, shear sliding and springs) of individual measurements for the warp and weft directions. As can be seen, the "ideal" variant and concept with springs has a quite similar course. In the variant 2 where the symmetrical loading could not be guaranteed, the maximal force values are slightly lower. This is caused probably due to stress unilateral concentrations in the edges of fabric.

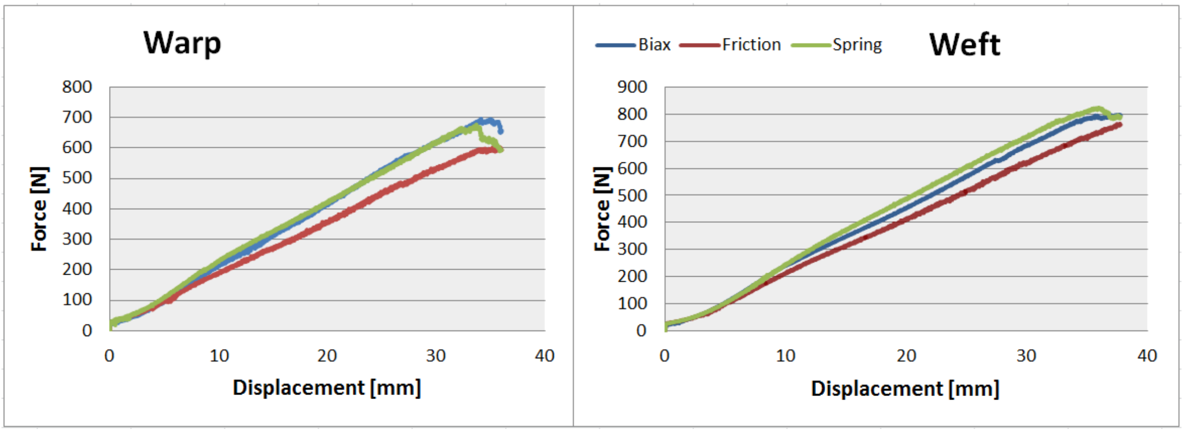

Fig. 5: Biaxial tension diagram of a tested fabric for the three tested concepts.

5. Conclusions

The presented work aimed to an alternative biaxial testing method, used primarily for fabrics and textile reinforcement materials such as composites and rubber. As has been mentioned in the introduction, are the common testing devices suitable mainly for static loads. For possibilities of dynamic testing also in a climatic chamber it was necessary to find a new design solution. It is suitable to use hydraulic motors, but an installation of four engines in a climatic chamber is technically very complicated. Some authors therefore solved this problem incorrectly by simultaneous two axial tension, when however as could be seen above, results may significantly vary. Therefore the mechanism with movable jaws, whose mutually position is adjusted by springs has been designed. This concept has been verified on some testing fabrics and compared with the other devices.

The tensile curve of the fabric has an almost linear character. The difference in the shape of the curves is because of different yarn density. The density of warp is usually higher and that is why the fabric in weft direction shows less tensile strength compared to warp direction. Strength of the fabric generally decreases, when humidity increases. This is because of the moisture absorption by the fibres and also by changing the value of friction between the fibres.

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