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MEASURING OF MECHANICAL PROPERTIES OF FLEXIBLE CONTAINER FABRIC

MĚŘENÍ MECHANICKÝCH VLASTNOSTNÍ LÁTEK PRUŽNÝCH NÁDRŽÍ

Abstract

This work is focused on measuring mechanical properties of a fabric used in flexible intermediate bulk containers. Firstly, the methods of measuring are analyzed and discussed. Then a method of measuring is chosen with the devices needed to accomplish it. The results of the actual experiment are presented in form of pictures and charts. At last conclusions of the measured data are presented.

Abstrakt

Tato práce se zaměřuje na měření mechanických vlastností textilií používaných v tzv. pružných nádržích nebo také žocích. Nejprve jsou vyhodnoceny a diskutovány metody měření. Po zvolení metody jsou také zvážena nutná zařízení pro tyto experimenty. Výsledky provedených experimentů jsou prezentovány pomocí obrázků a grafů. Nakonec jsou tato změřená data shodnocena do závěrů.

Keywords

Tensile testing, fabric, flexible intermediate bulk container, Hooke's law, orthotropic material

1 INTRODUCTION

The constitutive model is essential in solid mechanics modelling. It is by far the most basic and most important information in case of displacement prediction. The definition of any constitutive relation is not limited and it can be considered as any measured physical property. The goal of a good constitutive relation is to be as universal as possible, so they can be applied for any situations and keep the variables of it as few as possible. Therefore, most constitutive models have been developed so that they are invariant to the geometry. Such invariance is particularly useful because it allows to use the same equations for different materials.

In bulk materials such as metals, the concepts of strain and stress allowed the constitutive relation proposed by Robert Hooke for the springs to be independent of geometry. Therefore instead of stiffness of each spring the coefficient was abstracted to materials by their elastic moduli. The definition of stress is similar to the definition of pressure which is force scaled by the area it is acting on. The difference is that the pressure is a scalar and the stress is a tensor, but in case of a uniaxial load, they are identical in their magnitude and differ only in the orientation. For thin materials, where the thickness is not uniform or it cannot be measured correctly, it can be quite difficult to apply the concept of stress, since the cross-sectional area is not uniform.

The fabric is a material which precisely follows this description. Since it is made of fibers which can are quite large when compared to the size of the parts made from it, the surface can be

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quite rough or uneven so the thickness is very hard to measure or to be stated precisely so that it can be used for computation. If the fabric is additionally coated by some polymer the surface may be smooth, but the material is now a laminate or a composite and the thickness measured cannot be accounted as a thickness of a layer.

One possibility of treating this is to disassembly the fabric into fibers and measure the properties of the fibers for purposes like in work [1] and verify the data by measuring the fabric properties. In such case, the data are not usually abstracted to variables as young's modulus, since the geometry of the fibers is still uncertain, but the data can be expressed as stiffness in terms of force per length instead of stress per elongation or strength in force, not stress. These data can be theoretically used for coated fabrics with linear superposition of layers properties. The structure of the coating is small and can be considered isotropic in many cases. Such measuring was done in work [2].

The other way of treating the uncertain thickness is to measure simply a specimen and express the stiffness or strength in units such as forces per length for stiffness or force per width for the strength. Such quantities are very useful for analytic computations such as using the Laplace's membrane equation or other situations where analytical solutions are known. The limitations of such quantities is using them in approximation methods such as finite element analysis. Most finite elements software are not ready for quantities independent of thickness.

This insufficiency can be treated by modelling the fabric as a continuous medium with uniform thickness being equal to 1. Therefore or the constants are either multiplied or divided by 1 and the quantities do not change. Such model can be then subjected to boundary conditions simulating the experiment and the constitutive model can be adjusted so that same results are observed from both modelling and experiment.

At the same time, constitutive models account for the hypothesis of a continuum. The continuum can be explained as the opposite of the atomic theory, which specifies that the matter consists of smaller undividable pieces. The continuum hypothesis however ignores the inner structure and assumes that the inner structures repeat so much that in a macroscopic view, the structure acts as one homogenous continuous piece. In case of metallic materials, the structure of dislocations and grains is very small in comparison to the pieces made of the metal. However in such materials as fabrics, the structure is very distinguishable and obvious. Still the continuous assumption is very useful and still well accurate to be used.

Another special property of a fabric that needs to be understood prior to testing is the crimp interchange phenomenon. Other authors such as [3] are measuring its impacts more thoroughly. This phenomenon is characterized by the deformation of the fibers perpendicular to the pull direction. For example, if the fabric is pulled in the weft direction, as the weft fiber stretch from their original shape, warp fibers need to bend around them in a way they haven't been manufactured in which results in sudden unexpected changes in the force-displacement relationship.

This goes hand in hand with the orthotropy that is naturally present in the fabric from manufacture. Not all fabrics are woven, but especially woven fabrics have usually two perpendicular directions called warp and weft. Even in cases when fibers forming warp and weft are the same, the orthotropic property can be caused by the weave itself. Such orthotropic property requires more than one direction of testing [4].

2 TESTING

In order to be able to produce some constitutive model of a fabric behavior, a method of measuring any quantities has to be specified. First of all, fabrics cannot be considered automatically linear. One remark on that is that the linearity does not need to be satisfied as a whole. Following the Hooke's Law, a constitutive relationship may be sufficient if it is linear only to some extent. That means if the scope is only within the margins of linearity, this hypothesis may be used.

Using such assumptions, a standard tensile testing device may be used to measure the force-displacement relationship. Although the standard procedure is to assume uniaxial tension in the body, in fabrics this can be difficult to achieve. Clearly a fabric with fibers woven two directions, this can be partially achieved if the pull direction is same as the warp or weft direction. However if the direction is not collinear, the observed behavior can be hardly described as uniaxial.

According to the orthotropy that is naturally present in 2 direction woven fabric, it may seem reasonable to measure the properties in these two directions. Because the data in other directions cannot be safely superposed from these two direction it is a good practice to measure the properties in tilted directions such as 30 or 45 degrees. This study uses specimen for the two fabric principal direction as well as the 45 degrees angle study. The dominant dimension of the specimen is the length in which the pulling happens.

Another issue to consider is how the specimen is attached to the tensile testing device. During this testing a device was manufactured to be able to attach the fabric by pure friction, so that the attachment would assure an uniaxial load. However, this device proved itself improper for such tests, since the fabric always sled out. Instead, an ordinary clamp was used as a connection. The speed of testing was 10mm/min. The testing temperature was 22°C degrees.

Fig. 1 A specimen clamped in the tensile testing device

3 SPECIMEN

The material is a fabric used to make bulk bags or more precisely flexible intermediate bulk containers. The fabric is made from woven uncoated polypropylene strands, with their width varying from 1 to 4 mm. The thickness is however uncertain and quite hard to measure due to the crimp from weaving.

The specimen dimensions are limited from both sides to maximal length of 250mm and width of 40mm, because they need to fit in the testing clamps, however they need to be as large as possible to minimize the influence of the pattern in the textile structure. This makes the field of choices quite narrow. In tensile testing, it is a custom to make the specimen narrower in the center in order to prevent the maximal stresses to occur in the clamps. It can be done similarly with the fabric, however the shear strength is so low, that the stresses at the clamps are only indistinguishably higher.

Fig. 2 Example of a specimen geometry, this particular piece is cut in the warp direction

There were total 9 pieces of specimens fabricated for the experiment. Since the fabric which were specimens made from is a plane weave, 3 directions have been taken into account. The Warp direction, the weft (filling) direction and the bias direction which is tilted by 45 degrees from both warp and weft.

4 RESULTS

Both the warp and weft direction specimen showed slightly different breaks. From fig 3 it can be observed that the breaks are not always symmetrical, which can be accounted to the variance of the strand geometry.

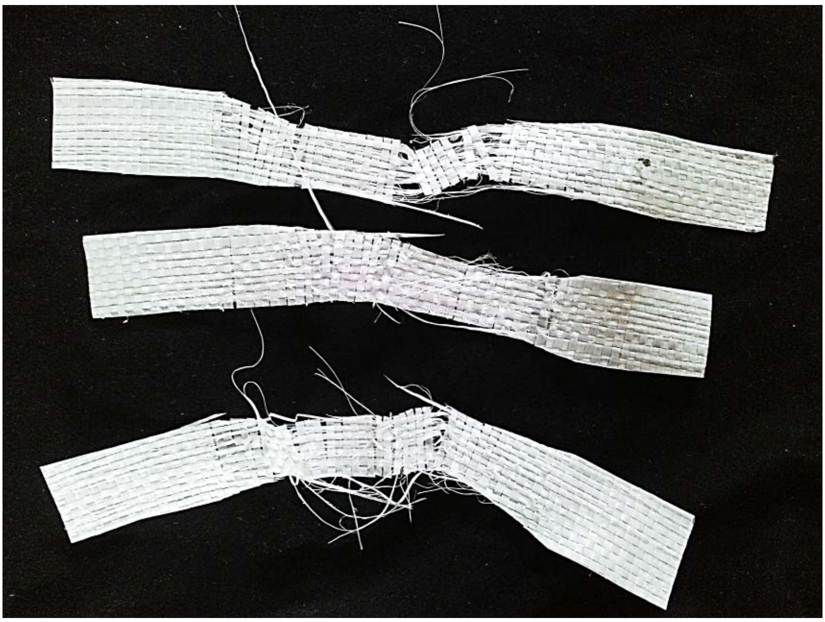

Fig. 3 Example of different types of breaks happening in the weft direction testing

The bias direction shows completely different type of failure, where the strands are pulled out of the weave. One can observe in the figure 4 that the failure of the weave happens in random spots.

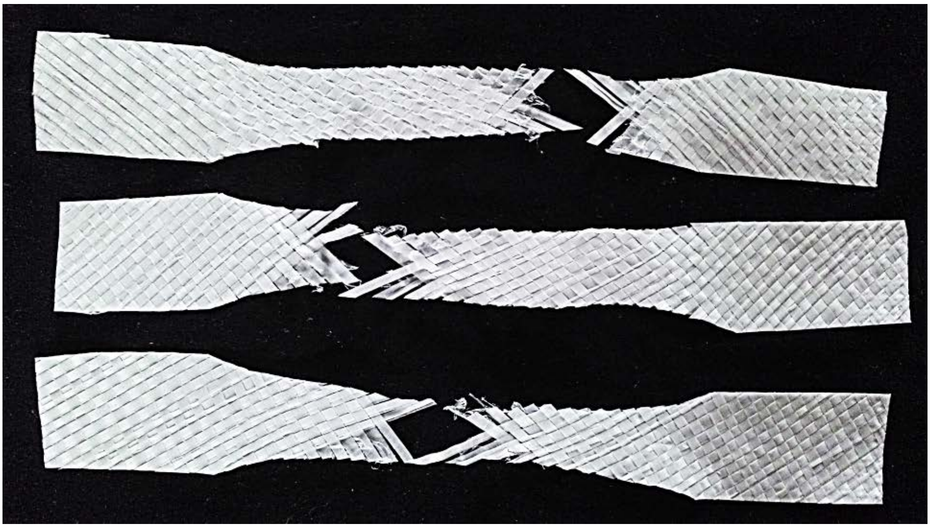

Fig 4. Example of the breaks in the specimen cut on the bias.

Since the tensile testing device used for this experiment measures the force-deflection relationship, it is the primary observed variable. These relationships can be used to deduce the apparent Young's modulus. Due to the unknown or uncertain thickness, the Young's modulus cannot be stated exactly from the tests. Therefore, it can be only stated as an elastic modulus per unit thickness.

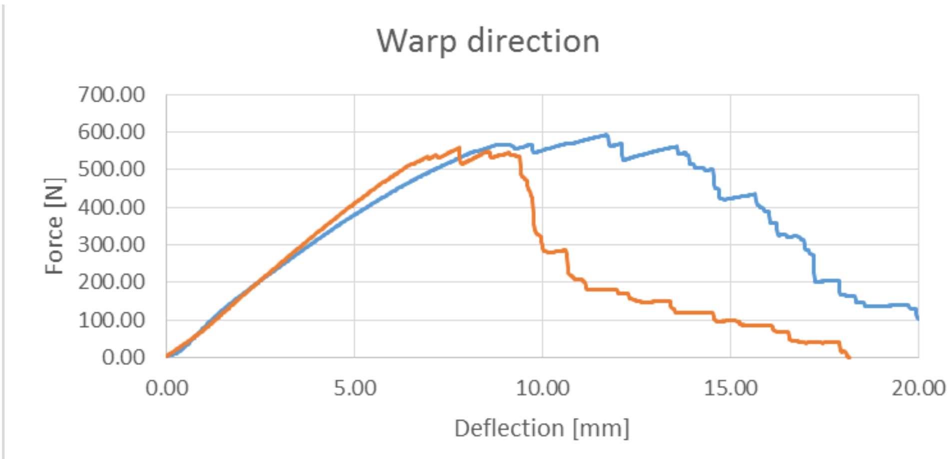

Chart 1 The force-displacement relationship in the warp direction.

The results also provide the comparison of strength in the measured directions and the variation in the strength. Also, it is a good point to observe the location of the breaks to be able to tell whether the tests meet the initial criteria. The charts 1 and 2 show relatively similar strengths for both warp and weft directions unlike the bias direction which is much lower (see chart 3).

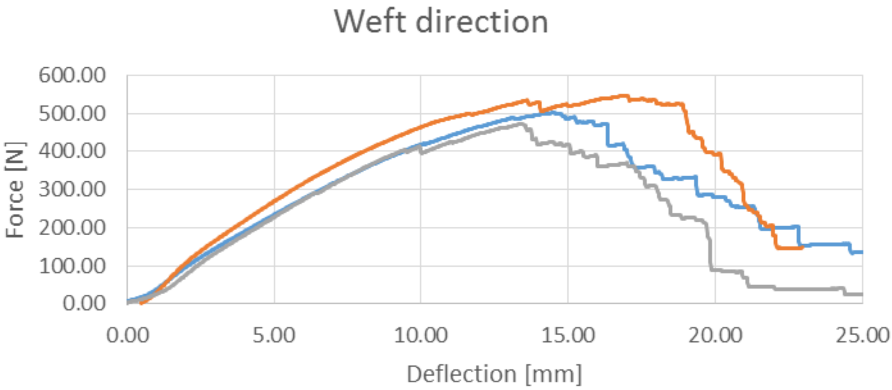

Chart 2. The force displacement relationship in the weft direction.

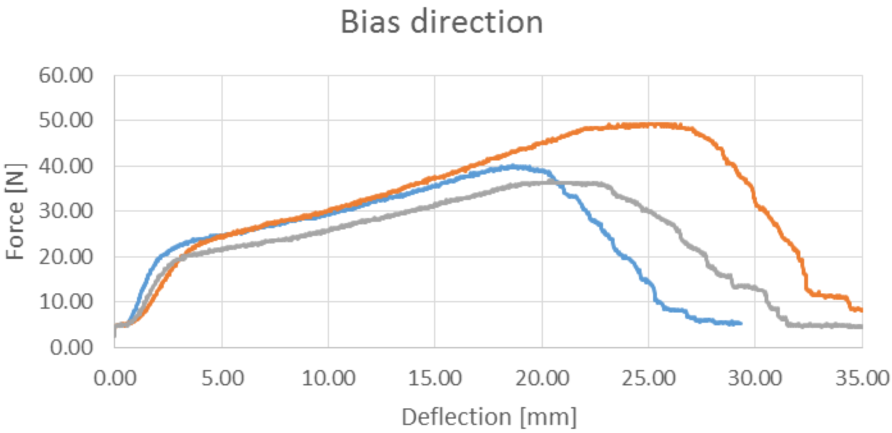

Chart 3. The force displacement relationship in the bias direction.

5 CONCLUSIONS

The experiments are characterized by gradual breaking of the strands rather than a sudden crack or any plastic stiffness drop occurring. However all the specimens broke in the center rather than in the mid. The difference in warp and weft directions is quite low for both warp and weft direction.

It can be seen that the bias direction is characterized by a very low stiffness as well as very low strength when comparing to the warp or weft direction. There is also a sudden stiffness change point at the start. The variation in the strength of the bias direction is quite high though when observing the plot 3.

In every plot curve, small sudden drops can be observed which correspond to the breaking of the strands which is the fabric formed of. Any contraction in the perpendicular direction of the tests is unnoticeable.

For all directions it can be seen that the variation of the slope is very low which can be used for a consistent estimate of the Elastic modulus per unit thickness.

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