FAST TESTING OF HYDROSTATIC RESISTANCE OF SEMI-PERMEABLE LAMINATED FABRICS

[1]L. Hes*, [2]M. Boguslawska – Baczek, [1]J. Lecbychova
Faculty of Textile Engineering, Technical University of Liberec, Czech Republic,
[1] University of Bielsko – Biala, Institute of Textile Engineering and Polymers Materials, Poland
corresponding author: Lubos Hes (lubos.hes@gmail.com)

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1. Introduction

Semi-permeable fabrics became standard component of outdoor and protective clothing in recent decades. Their most important parameters are water vapor permeability and resistance against leakage under increased pressure called hydrostatic resistance. The quality outdoor garments exhibit up to 20 m hydrostatic resistance, which present sufficient protection against leakage when wearing the backpack on the outdoor jacket under heavy rain.

The critical hydrostatic pressure in then recorded when the operator observes 3 drops on the reverse surface of the tested fabric, and it is currently tested according to the standard ISO 811. Due to the rheological behavior of the used semi-permeable synthetic membranes, the authors of this standard require slow increase of the testing pressure, generally 60 cm H_2O per minute, which often results in very long testing time resulting in high laboratory expenses. The objective of this study is to develop a new, more economical method and instrument for the determination of hydrostatic resistance of semi-permeable fabrics and laminates.

In this study, we have examined the effect of the velocity of the pressure increase on the visually detected critical pressure. Besides that, also water vapor resistance of the investigated samples was determined, as there can be certain correlation between the hydrostatic resistance of the studied semi-permeable fabrics and their water vapor resistance.

2. Viscoelastic properties of materials [1]

Viscoelastic materials exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials, like honey, resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain instantaneously when stretched and just as quickly return to their original state once the stress is removed. Viscoelastic materials have elements of both of these properties and, as such, exhibit time dependent strain.

In reality all materials deviate from Hooke's law in various ways, for example by exhibiting viscous-like as well as elastic characteristics. Viscoelastic materials are those for which the relationship between stress and strain depends on time.

Some phenomena in viscoelastic materials are:

- if the stress is held constant, the strain increases with time (creep);
- if the strain is held constant, the stress decreases with time (relaxation);
- the effective stiffness depends on the rate of application of the load;

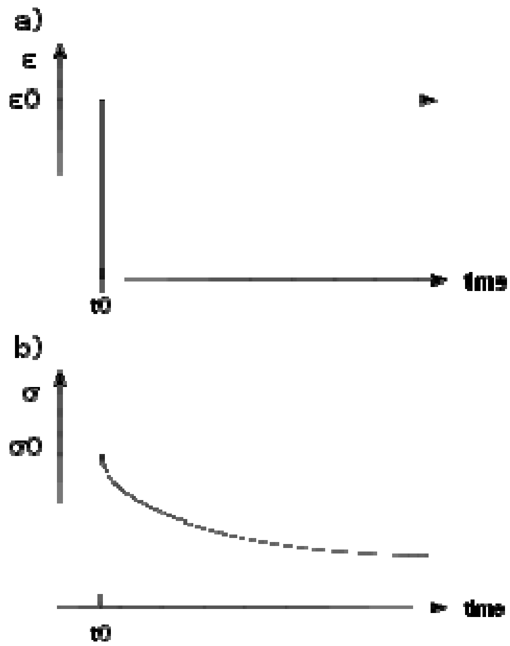

Fig. 1 a) Applied strain and b) induced stress as functions of time for a viscoelastic material.

All materials exhibit some viscoelastic response. In common metals at room temperature and at small strain, the behavior does not deviate much from linear elasticity. Synthetic polymers display significant viscoelastic effects. A viscoelastic material has the following properties:

- stress relaxation occurs: step constant strain causes decreasing stress
- creep occurs: step constant stress causes increasing strain

3. Constitutive models of linear viscoelasticity

Viscoelastic materials, such as amorphous and semi-crystalline polymers can be modeled in order to determine their stress or strain interactions and their temporal dependencies. These models, which include the Maxwell model, the Kelvin-Voigt model, and the Standard Linear Solid Model, are used to predict a material's response under different loading conditions. Viscoelastic behavior has elastic and viscous components modeled as linear combinations of springs and dashpots, respectively. Each model differs in the arrangement of these elements. The elastic components, as previously mentioned, can be modeled as springs of elastic constant E, given the formula:

$$\sigma = E\varepsilon \qquad (1)$$

where σ is the stress, E is the elastic modulus of the material, and ε is the strain that occurs under the given stress, similar to Hooke's Law. The viscous components can be modeled as dashpots such that the stress-strain rate relationship can be given as

$$\sigma = \eta \frac{d\varepsilon}{dt} \qquad (2)$$

where σ is the stress, η is the viscosity of the material, and dε/dt is the time derivative of strain.

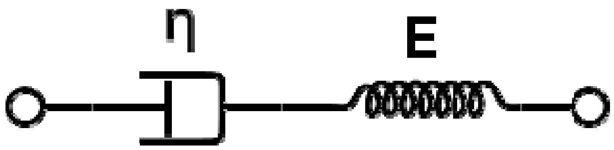

Fig. 2 The Maxwell model

The Maxwell model can be represented by a purely viscous damper and a purely elastic spring connected in series, as shown in the diagram. Under this model, if the material is put under a constant strain, the stresses gradually relax, When a material is put under a constant stress, the strain has two components. First, an elastic component occurs instantaneously, corresponding to the spring, and relaxes immediately upon release of the stress. The second is a viscous component that grows with time as long as the stress is applied. The Maxwell model predicts that stress decays exponentially with time, which is accurate for most polymers.

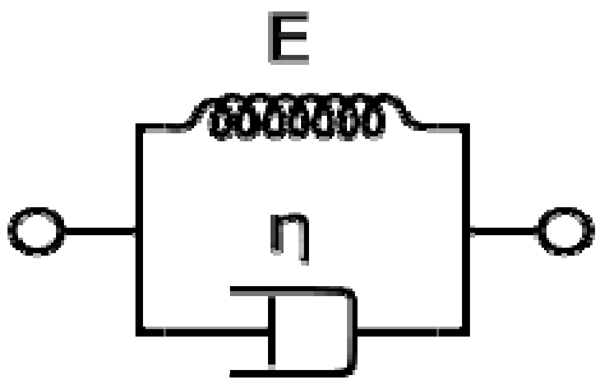

Fig. 3 The Kelvin–Voigt model.

The Kelvin–Voigt model consists of a Newtonian damper and Hookean elastic spring connected in parallel, as shown in the picture. It is used to explain the creep behavior of polymers. The constitutive relation is expressed as a linear first-order differential equation:

$$\sigma(t) = E\varepsilon(t) + \eta \frac{d\varepsilon(t)}{dt} \qquad (3)$$

This model represents a solid undergoing reversible, visco-elastic strain. Upon application of a constant stress, the material deforms at a decreasing rate, asymptotically approaching the steady-state strain. When the stress is released, the material gradually relaxes to its un-deformed state. At constant stress (creep), the Model is quite realistic as it predicts strain to tend to σ/E as time continues to infinity.

This last model effectively combines the Maxwell Model and a Hookean spring in parallel.

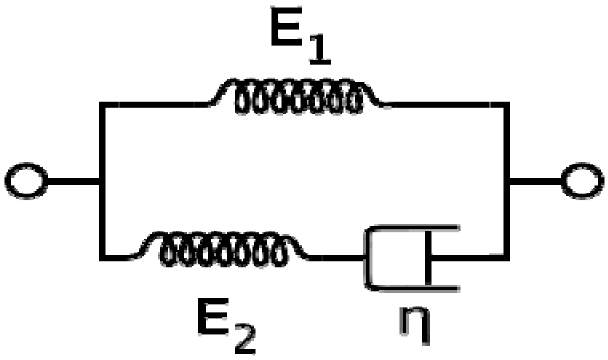

Fig. 4 The Standard Linear Solid model

A viscous material is modeled as a spring and a dashpot in series with each other, both of which are in parallel with a lone spring. The governing relation is:

$$\frac{d\varepsilon}{dt} = \frac{\frac{E_2}{\eta}\left(\frac{\eta}{E_2}\frac{d\sigma}{dt} + \sigma - E_1\varepsilon\right)}{E_1 - E_2} \qquad (4)$$

Under a constant stress, the modeled material will instantaneously deform to some strain, and after that it will continue to deform and asymptotically approach a steady-state strain.

This model is considered the most suitable for the testing of semi-permeable laminates. The parallel spring simulates the laminated compact fabric, whereas the serial combination of the spring and a dashpot should describe the behavior of the un-drawn, plastic membrane. If the pressure in-creases slowly, there is enough time to deform the membrane, porosity of which increases, thus reducing the hydrostatic resistance.

4. Characteristics of the analyzed textile fabrics and laminates

Three basic semi-permeable fabrics were investigated: micro-porous low elasticity PTFE foil laminated to the outer polyester fabric (85 g/m^2), non-porous (or nano-porous) elastic polyurethane foil laminated to the outer polyamide fabrics (156 g/m^2) and an outer fabric coated by elastic polyurethane nano-porous (hydrophilic) layer (130 g/m^2). All these fabrics are successfully used by the some manufacturers of leisure, sport and outdoor clothing manufacturers in Czech Republic.

5. Experimental equipment

5.1. Testing of hydrostatic resistance

The studied effect of the velocity of the pressure increase on the visually detected critical pressure was determined by means of the SDLATLAS Hydrostatic Head Tester M018.

Fig. 5 The M018 Hydrostatic Head Tester

This compact instrument with reliable clamping of the tested sample enables determination of the critical hydrostatic pressure at pressure increase velocity ranging from 1 cm H_2O/min. to 500 cm H_2O/min. We have chosen the pressure rate from 10 cm H_2O/min to 500 cm H_2O/min (16,5 Pa/s to 822 Pa/s).

5. 2. Testing of water vapor resistance

The used PERMETEST instrument in the Fig. 6 (by Czech manufacturer SENSORA) enables the non-destructive determination of both thermal and water vapour resistances of dry and wet fabrics within 3 -5 minutes. Measuring head of this small Skin Model is covered by a semi-permeable foil, which avoids the liquid water transport from the measuring system into the sample. Cooling flow caused by water evaporation from the thin porous layer is recorded by a special sensing system and evaluated by the computer. Given by a new concept of double calibration, very good measurement repeatability was achieved, with CV often under 3%. Moreover, this instrument, which can be used in non-air-conditioned space also, provides all kinds of measurements very similar to the ISO Standard 11092. The results are treated statistically, displayed and recorded [2]. According to the ISO 11092 Standard, the measured water vapour resistance R_{et} is expressed in [m^2Pa/W], given by the relationship

$$R_{et} = (p_{wsat} - p_{wo}) \, (1/q_o - 1/q_s) \qquad (5)$$

Here, $\mathbf{q_s}$ and $\mathbf{q_o}$ mean heat loses of moist measuring head in the free state and covered by a sample. The values of water vapour partial pressures $\mathbf{p_{w\ sat}}$ and $\mathbf{p_{wo}}$ in Pascals represent the water vapour saturate partial pressure valid for the temperature of the air in the measuring laboratory $\mathbf{t_o}$ (22-25^oC), and the partial water vapour pressure in the outside air.

Fig.6 The PERMETEST Fast Skin Model

6. Experimental results and conclusions

Tab. 1 Correlation between hydrostatic and water vapor (evaporation) resistances

Average values for the fabrics and laminates as characterized below	Hydrostatic resistance in m H_2O at pressure rate 60 cm H_2O/min	Evaporation resistance in $Pa.m^2/W$ ac-according to the modified ISO 11092
1. porous	19, 23	5,23
2. non-porous	21,94	8,73
3. coated	9, 71	9,70

As follows from the presented results, the non-porous laminate fabric exhibits the highest hydrostatic resistance, but its evaporation resistance is quite high, due to the more compact structure. Therefore, the semi-permeable laminate fabrics containing porous PTFE membrane achieve the highest market value, due to their lowest evaporation resistance and still very high hydrostatic resistance.

The main results of this study are displayed in the next Fig. 3.

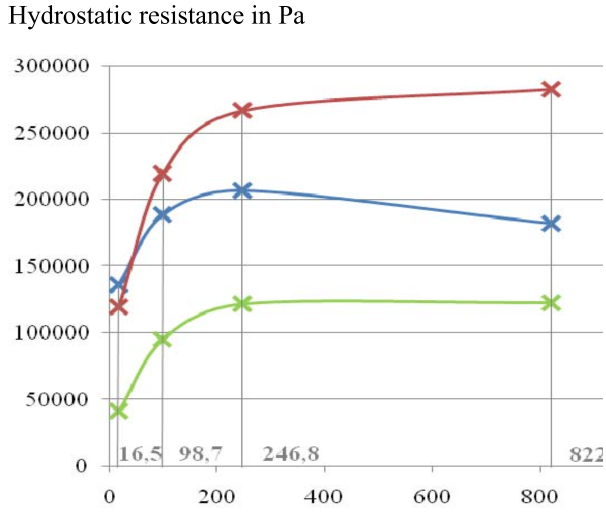

Fig. 7 Rate of the testing pressure increase in Pa/s

Here, the highest hydrostatic resistance exhibit the non-porous laminates, (upper line), the porous laminates (medium line) are a bit worse and the coated fabrics (bottom line) are characterized by the lowest (worst) hydrostatic resistance.

From the results follows, that the hydrostatic resistance, when tested at the standard pressure rate approx. 100 Pa/s, is in the average just by approx. 20% higher then in case when the pressure rate was approx. 250 or 822 Pa/s. Moreover, the testing time was shortened from 42-122 min. to 17-37 min. It was observed, that at the pressure rate higher then 250 Pa/s, the hydrostatic resistance practically does not depend on the velocity of the pressure increase [2]. This finding might in the future enable the design of a simple and fast measuring hydrostatic resistance tester. This operation advantage would be important when testing performance semi-permeable fabrics with hydrostatic resistance over 30 m H_2O.

7. References

[1] http://en.wikipedia.org/wiki/, rheological models created by Pekaje

1. [2] L. Hes, M. Araujo: Simulation of the Effect of Air Gaps between the Skin and a Wet Fabric on Resulting Cooling Flow. Textile Res. J., Vol 80(14), pp. 1488–1497, 2010

[3] J. Lecbychova: BSc Thesis, TU Liberec 2011