# Influence of Deformation Speed and Humidity on Quasistatic Deformation Behavior of Vulcanized Fiber – Experiments with Different Load and Climate Profiles.*

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## ABSTRACT

The detailed knowledge of the material properties is the basic requirement for design and production engineers, to ensure safe and efficient operation conditions of structural components. The insufficiently studied construction material vulcanized fiber shall be investigated microstructure-based and evaluated, regarding the influence of deformation speed and relative humidity on the quasistatic properties. Besides materialographic and microscopic investigations, an ultra-micro hardness tester was used. The mechanical characterization was done with an electromechanical universal testing system, a clip-gage and a video extensometer, thermocouples and a thermography system and a high-speed camera to detect crack formation and propagation.


## 1. Introduction

In consequence of stagnating research activities only a few material properties of vulcanized fiber can be found. Technical vulcanized fiber consists of cotton linters and/or recycled rags. Its fibers are processed to make absorbent and unsized special papers, which are joined by a merging process into one homogenous material by adding a parchmentizing solution. After bonding, the parchmentizing solution is leached out in a multistage process by using osmotic forces. Finally, the vulcanized fiber is dried (Fig. 1). The material properties of technical vulcanized fiber are comparable to those of engineering plastics, but it is fully based on natural resources. This leads to a hygroscopic behavior, which has to be considered in the following investigations.

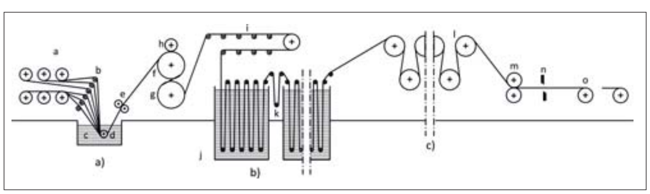

Fig. 1 Continuous production of vulcanized fiber

## 2. Experimental

### 2-1 setup and parameters

Specimens used in this investigation with the dimensions 140 mm x 15 mm were punched out of industrially manufactured vulcanized fiber with a thickness of 0.8 mm. From the wide field of influencing variables, deformation speed and relative humidity were chosen to determine their influence on the mechanical properties and the quantitative assessment. According to DIN 7738, the deformation speed has to be set to 10 % ± 2.5 % of the freely suspended length in mm/min. Speeds of 1, 5, 10, 100 and 1,000 mm/min were used in this investigation. The same DIN recommends climate conditions with 65 % relative humidity. In this case 25, 40 and 90 % relative humidity were taken into account. Therefore the specimens were conditioned in a climate chamber (Binder, Type KBF 240) at a temperature of 20° C. The tensile tests were performed directly after taking out the flat vulcanized fiber specimens of the climate chamber in a universal testing system (Shimadzu, Type AGS-X) with a maximum load of 5kN (Fig. 2).

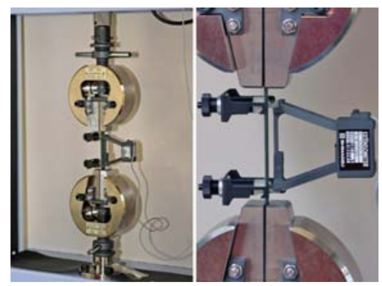

Fig. 2 Experimental set up for tensile tests

A precisely vertical clamping of the specimens with a freely suspended length of 70 mm excluded transverse forces. During the tests strain measurement was performed with an extensometer (Shimadzu, Type SSG25-50H) with a gage length of 50 mm.

### 2-2 results

*Material* - The aim of the production of vulcanized fiber is to dissolve the layer structure and merge the single fibers. This does not always succeed as Fig. 3 shows where the layers are differentiable from each other.

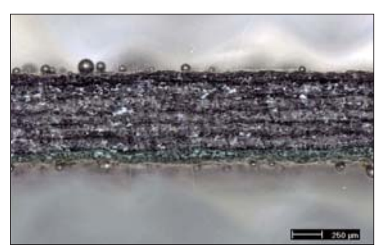

Fig. 3 Light micrograph, transversal cross-section

Scanning electron micrographs show the merging of the fibers in detail (Fig. 4).

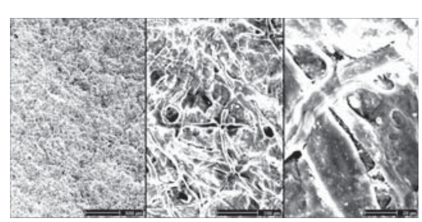

Fig. 4 Scanning electron micrographs (SEM)

Within the scope of the microstructural investigations, instrumented indentation tests according to DIN EN ISO 14577-1 were performed with an ultramicro hardness testing system (Shimadzu, Type DUH 211/S) as a load-unload-test. During the test the applied force in mN is logged as a function of the indentation depths in µm. The maximum force is held constant for a few seconds before relieving the load. After the test the elastic indentation modulus is measured by a tangent applied to the unloading curve and it corresponds to the E-modulus. For the tests a maximum force of 98 mN (10 P) was set according to HV 0.01.

*Influence of deformation speed* - For the investigations of the influence of deformation speed on the quasistatic material values, vulcanized fiber specimens were conditioned in 40 % relative humidity. Fig. 5 shows the strain hardening curves for 1mm/min and 1,000 mm/min deformation speed.

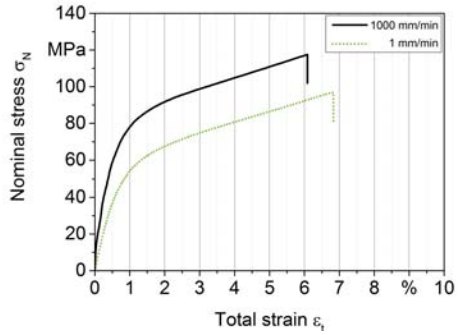


Fig. 5 Influence of the traverse speed on nominal stress-total strain-diagram

With an increase of the deformation speed from 1 to 1,000 mm/min, an increase of the E-modulus and the tensile strength and a decrease of the maximum strain can be seen. Fig. 6 shows the three material properties as a function of the deformation speed in linear or logarithmic scaling. At 1,000 mm/min the E-modulus reaches the highest value of nearly 16 GPa. In linear scaling the course of the curve indicates a saturation behavior so that deformation speeds > 1,000 mm/min are supposed to have only a small influence on this material property.

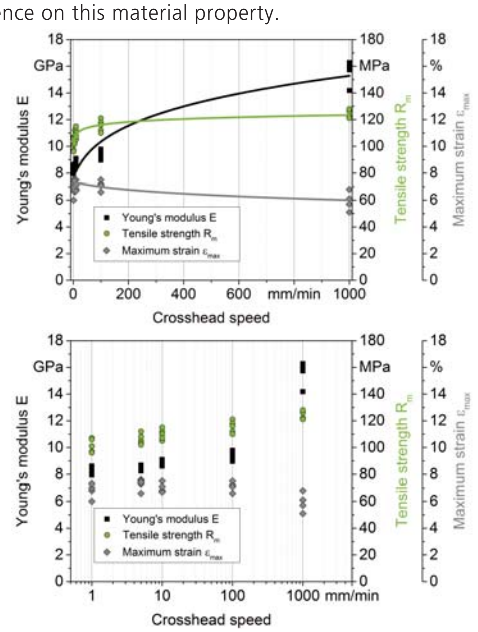


Fig. 6 Influence of traverse speed on E-modulus, tensile strength and maximum strain in linear and logarithmic illustration

*Influence of relative humidity* - Investigations have been performed at room temperature with a deformation speed of 10 mm/min. Fig. 7 shows the strain hardening curves for 25 % and 90 % relative humidity.

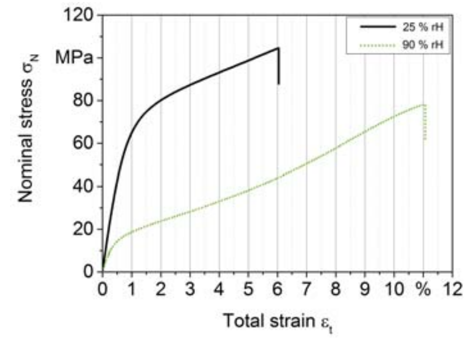


Fig. 7 Influence of the relative humidity on nominal stress-total strain-diagram

With rising relative humidity a decrease of the E-modulus and the tensile strength and an increase of the maximum strain can be seen. The countervailing effect of the curves is displayed in Fig. 8. As the abovementioned explanations show, both variables deformation speed and relative humidity have a strong influence on the material properties of vulcanized fiber.

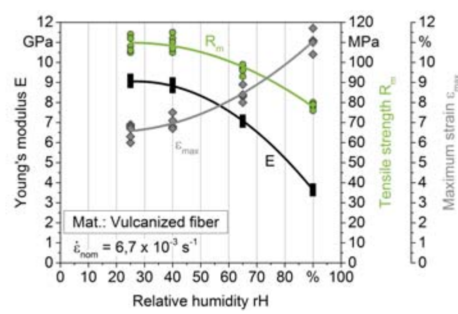


Fig. 8 Influence of relative humidity on E-modulus, tensile strength and maximum strain

*Additional measurements* - With the aim of a more detailed characterization of vulcanized fiber, further measurements have been used in the investigations. To exclude the damaging influence of the extensometer knifes a video extensometer (Shimadzu, Type TRViewX) has been used to measure the strain during the tests. Therefore reference marks have been attached to the specimen surface (Fig. 9). The results in strain measurement confirmed the measurements taken with the tactile extensometer.

Fig. 9 Experimental set up with video extensometer

Further information about the material behavior was provided by thermometric measurements and infrared thermography. At the beginning of the test in the area of elastic deformation, the flat vulcanized fiber specimen absorbed energy in the form of heat which leads to a decrease in temperature. At the transition between the elastic and the elastic-plastic area, the temperature increased till the fracture of the specimen (Fig. 10).

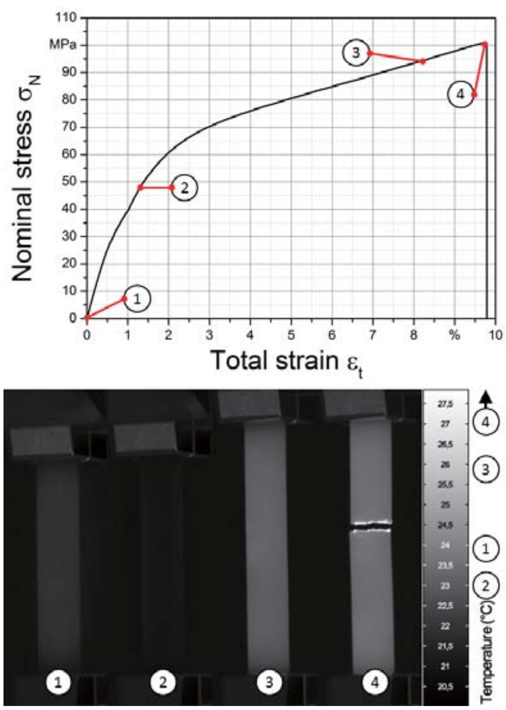


Fig. 10 Thermal images of different tensile test stages

Additionally the crack formation and the crack growth were analyzed. Thermography (Infra-Tec, Type IR8800) provided a reliable indicator of the starting point of cracks. A high-speed camera (Shimadzu, Type Hyper Vision II) was used for the investigation of the crack propagation (Fig. 11).

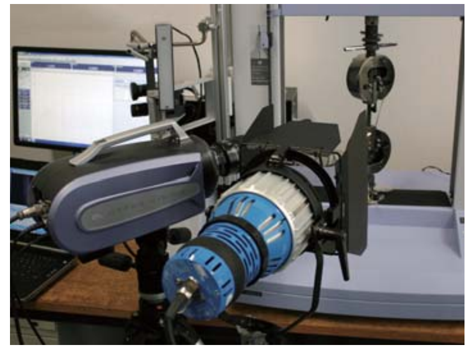

Fig. 11 Experimental set up with high-speed camera system

With a recording frequency of 500,000 frames per second, the time from crack formation to failure of the specimen could be determined with 3 x $10^{-4}$ seconds (Fig. 12).

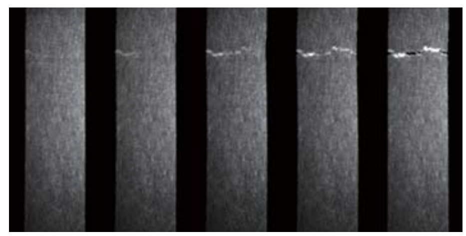

Fig. 12 Crack formation and propagation behavior in tensile test

## 3. Conclusions

For the characterization of technical vulcanized fiber with different load and climate profiles additional to conventional stress-strain-measurement, a video extensometer, a thermography system and a high-speed camera were used. Deformation speed and relative humidity have a significant influence on the quasistatic material properties. An increase in relative humidity leads to an increase in maximum strain and a decrease in E-modulus and the tensile strength. With an increasing deformation speed E-modulus increased too, but tensile strength and maximum strain showed a maximum value in the middle region. The use of additional measurement systems was well suitable for the detailed characterization of the deformation behavior of vulcanized fiber.

## 4. Outlook

This article provides quasistatic values of technical vulcanized fiber. The scope of a following article is the characterization of the fatigue behavior. On the basis of quasistatic and cyclic material values it is possible to optimize the process- and product-oriented material properties. This leads to various new fields of application.

## 5. Extended Abstract of:

Penning, B.; Walther, F.; Dumke, D.; Künne, B.: Einfluss der Verformungsgeschwindigkeit und des Feuchtegehaltes auf das quasistatische Verformungsverhalten technischer Vulkanfiber. **MP Materials Testing 55, 4 (2013) 276-284.**

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