COMPUTERIZED DEVICE FOR DETERMINATION OF MECHANICAL PROPERTIES OF POLYMERS. SILK AS A PARADIGM

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Silk is widely utilized in various areas of industry that includes textile, medical, technological and etc. Mechanical properties of silk play an important role in many applications. In this work, we built a computerized device that can measure time-dependent mechanical properties of polymers. Silk was chosen as a paradigm. The device uses optical detection for mechanical deformation that increases sensitivity and precision of measurements compared to that of the previously used one. The pulleys with variable diameters act as an amplifier for deformation scale. Deformation of silk threats and time to rupture in constant stress conditions were monitored in real time using a home-built LabView program. Variable detection rates, which can be as low as data/1ms, can be used in the program. Mechanical properties of two kinds of silk samples were measured. The device clearly differentiates mechanical properties of the samples. The device can be used to study time-dependent mechanical properties of various types of polymers in fibrous as well as film forms.

Keywords: silk,mechanical strength,"LabView" programming, mechanical time-dependent instrument
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INTRODUCTION

Silk is a typical material produced by various insects, such as *bombyx mori*, *nelphia* and etc. Silk is being utilized as a textile and suture materials thousand years ago [1]. Silk consists of two parallel fibroin fibers and gummy part sericin that holds them together [2]. Sericin of silk has useful properties, such as resistant to oxidation, antibacterial, UV resistant and absorbing and releasing moisture easily [3,4].

Molecular organization of silk fibers determines their unique physical and chemical properties of fibroin, such as strength, toughness, stiffness and etc. [2].

Fibroin has a simple amino acid composition. Glycine (Gly), alanine (Ala) and serine (Ser) that have the smallest side chains, comprises about 82% of total amino acids.

Silk fibroin is used in diverse forms, such as gels, powder, membranes and fibers [1]. Silk fibroin shows very good biocompatibility, biodegradability and oxygen and water vapor permeability properties. Therefore, silk fibroin is very valuable material for biomedical, cosmetic and pharmaceutical industries.

Every kind of silk might have been evolved to perform the special task. Silk fibers from different insects show diverse physicochemical properties that can be attributed to their morphology [3].

One of the most important characteristics of silk is a mechanical strength, which is time-dependent by nature. Therefore, reliable measurements of time-dependent mechanical properties of polymers are very important.

Here we describe computerized device for such measurements. It can be used for various types of polymers in fibrous as well as film forms

MATERIAL AND METHOD

The experiments were carried out with two kinds of silk samples using home-built laboratory instrument that is described below. Two kinds of silk cocoons were tested. The samples with the 10 mm silk threads with the diameters of about 50-80 μm were used.

Computerized instrument to measure time-dependent deformation and time to rupture under constant mechanical stress conditions of polymers.

Schematic diagram of the device is shown in fig. 1.

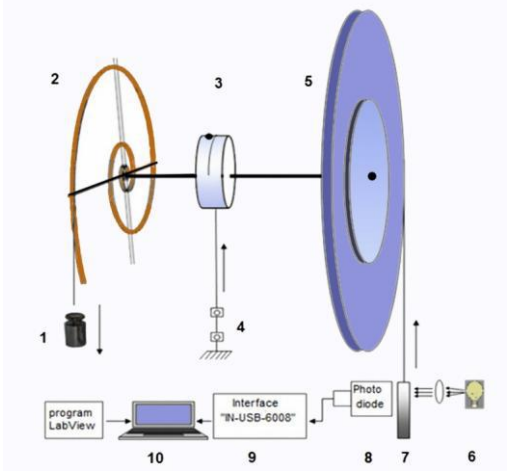

Fig. 1 The computerized device to measure the time-dependent mechanical properties of polymer under constant stress conditions. 1 is load, 2 is varying arm pulley, 3 is transmiting block, 4 is sample, 5 is two radii disc, 6 is light source, 7 is linearly variable neutral density filter, 8 is photo diode, 9 is interface, 10 is computer.

For each load (1), varying arm pulley (2) provides a constant mechanical stress. Disk with two radiuses (5) permits increase deformation scales by a ratio of radiuses of disks (5) and (3). Linearly variable neutral density filter (LVNDF) fastened to the disk (5) provides optical detection of the sample deformation. The filter is compensated with an appropriate extra load that is not shown in the figure for simplicity. The vertical position of LVNDF and, therefore, deformation of the sample are determined by light intensity on a photodiode. Thus, the sample fixed by clams undergoes deformation under

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constant mechanical stress condition. Deformation rotates the disk (5) counter clockwise that lifts up the LVDNF. Consequently, light intensity passed via LVDNF and, therefore, output voltage of the diode is decreased. The method provides an accurate measurement of the deformation of the samples during the load time and under constant stress condition. Deformation values at various times are monitored on computer using the home-built LabView program. Sudden increase of the deformation determines the time to rupture (or mechanical lifetime) at constant mechanical stress.

The output values of the photodiode at various positions of LVDNF were calibrated with deformation in mm (See below). Analytical formula that describes this dependence was used in the LabView program to get original value for mechanical deformation in mm.

RESULTS AND DISCUSSION

To determine time dependent deformation values, time to rupture of the samples under constant mechanical stress conditions, the output of photodiode depending on vertical position of LVDNF was calibrated. Because of optical linear density of LVDNF, this relation possesses exponential characteristic.

$$y = y_0 - A \cdot exp\left(-\frac{x}{t}\right)$$

Dependence of vertical position of on output voltage of photodiode is shown in the fig. 2.

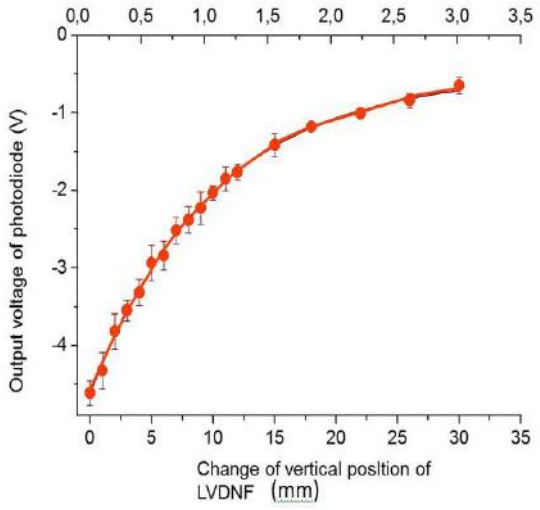

Fig. 2. Dependence of output voltage of photodiode on change vertical position of LVDNF. Solid circles are experimental data. Solid curve represents best fit of the experimental data to the exponential formula.

Data could be fit very well to the exponential formula with following parameters with, y_0 = -0.49, A = 4.12, and t = 10.07

This formula with the best fit parameters shown above was incorporated into the LabView program to show deformation in mm.

Dependences of the deformations of the silk threads on time at various constant mechanical stress values are shown in the fig. 3. Sudden increase in deformation indicates the rupture of the silk thread. The deformation values do not depend on mechanical stress values. Besides that, very little changes in deformation values were observed during the lifetime of the samples. However, it is clear that the time to the rupture increases significantly in decreased mechanical stress values.

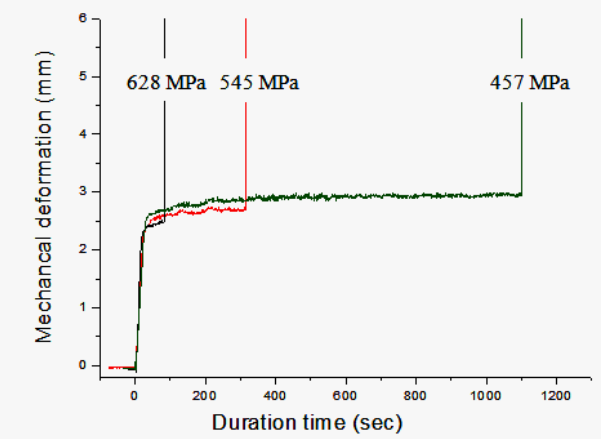

Fig. 3. Dependence of durability on mechanical stress for silk threads of 10 mm.

Consistent with other polymeric materials, logarithmic dependence is observed for the time to rupture and mechanical stress values (fig. 4).

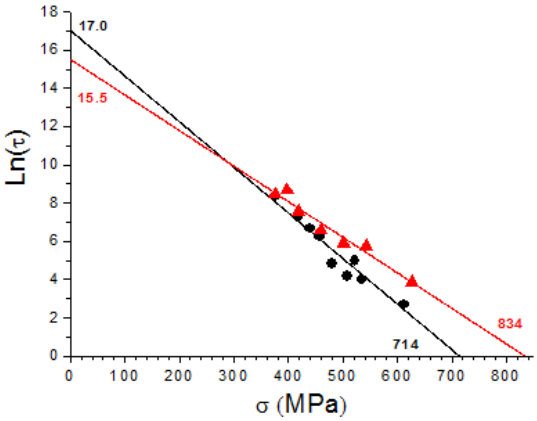

Fig. 4. Dependence of mechanical stress on durability (time to rupture).

This logarithmic dependence indicates that mechanical rupture is a process of Arrhenius type, goes through the energy of activation. This type of dependence observed for many polymeric materials has led to a formulation of thermo-fluctuation mechanism of destruction. At constant temperature, the dependence of time to rupture (τ) on applied constant mechanical stress (σ) is given as below [5] :

$$\tau = Ae^{-\alpha\sigma} \qquad (1)$$

where, A and α - constant parameters. The Arrhenius nature of the formula (1) can be understood by the following consideration. Dependence of time to rupture on temperature at a given constant mechanical stress value is described by following equation [5,6]:

$$\tau = \tau_0 exp\left(\frac{U_\sigma}{kT}\right) \quad (2)$$

U_σ is an activation energy at constant mechanical stress values that can be described as

$$U_\sigma = U_0 - \gamma\sigma \quad (3)$$

Thus, mechanical stress (σ) decreases the activation energy U_0. It follows that

$$\tau = \tau_0 exp\left(\frac{U_0 - \gamma\sigma}{kT}\right) \quad (4)$$

where, γ is coefficient that depends on identity of the sample, k is the Boltzmann constant.

It can be easily recognized that the formulas (1) and (4) are equivalent via following definitions [5]:

$$A = \tau_0 exp\frac{U_0}{kT} \quad (5)$$

$$\alpha = \frac{\gamma}{kT} \quad (6)$$

Thus mechanical rupture can be understood as thermal process. In thermal fluctuation, the molecules, the thermal energies of which are higher than (U_0-$\gamma\sigma$) will be ruptured. Mechanical stress (σ) just decreases the activation energy. The slop values of the graphs (fig. 4) indicate reveal structural information. Relatively higher value of 0.024 found for silk 1 (black data) compared to 0.019 of silk 2 (red data) indicates that mechanical stress more effectively decreases the energy of activation for mechanical rupture. The silk 2 can take higher stress value for one second 834 MPa versus 714 MPa, which indicates more mechanical strength (fig. 4). Thus, the device clearly can characterize mechanical-structural properties of various polymeric materials.

CONCLUSION

A computerized device described above is suitable to measure time-dependent mechanical properties of polymers. Optical detection used in the system significantly increases both precision and accuracy of the measurements. Data registration time can be as low as 1 millisecond.

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