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DETERMINATION OF VISCOELASTIC PROPERTIES OF HUMAN HAIR BY DAMPED TORSION OSCILATION METHOD

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SUMMARY

By means of torsion pendulum oscillation measurement, one can establish the shear elasticity modulus and the viscosity of human hair, and enrich the number of material parameters determined for this material that way. While from the tensile curve the tensile elasticity modulus of the hair is commonly determined and the Poisson ratio can be evaluated by optical methods while tearing, by measuring of the self-sustained oscillations one can effectively determine also their shear elasticity modulus and solid-state dynamic viscosity. This all, in accordance with other authors, assuming homogeneity and isotropy of the hair fibre. Although, from the dependence of the elasticity modulus on the hair diameter, reasonable estimate about the cortex thickness can be done and unravel the knowledge of its modulus and the one of the cuticula. It's necessary though to measure sufficient number of hairs from one head for that purpose. The measurement of dumped torsion oscillations takes place in a linear arrangement hair-detector-laser. The hair is placed in a pair of fixed jaws and pre-strained with a weight. In its centre, the hair carries a special mirror; its inertial mass acts as the fly. A laser beam is directed onto the mirror. Its reflection is scanned by a photodetector. Output signal is recorded as . wav by a digital recorder. Two positions near the zero deflection of the mirror are scanned. From the period and from the changing velocity of passing the equilibrium position, shear elasticity modulus and the viscosity are determined.

Keywords: shear elasticity modulus of hair, hair viscosity, torsion pendulum, damping action, oscillation period, zero passing velocity

INTRODUCTION

Some reports from measuring objectifying properties of fur or hair exist. Authors either measure physical dimensions and forces necessary to break fibres and they determine yield limit, or they determine the failure strength, tensile elasticity modulus, elastic limit. They determine material parameters of the hair from the tensile deformation (fig. 1). This paper enriches the repertoire of the methods of objectification with the possibility of direct determination of shear elasticity modulus and viscosity for single fibres.

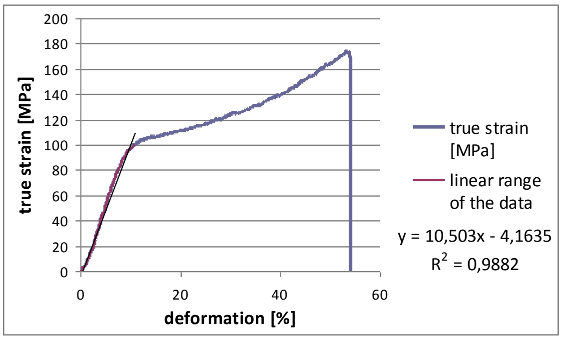

Figure 1. Tensile test of the hair

MATERIAL AND METHODS

For our testing, Caucasian women's hair cut near the head surface, 100 mm in length, has been always used. A total of 200 hairs from 40 women have been measured. The measuring equipment is shown in fig. 2 with its cover removed. Using this equipment, passing of the fly through two points close to the equilibrium point has been detected.

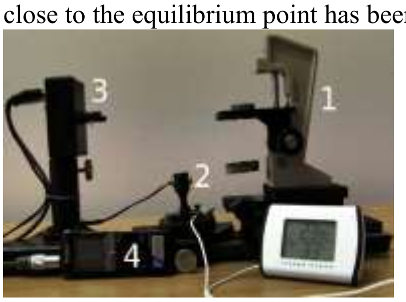

Figure 2. Dismantled measuring apparatus.

1-preparation fir fixing the hair with the fly, 2-laser, 3-phototransistor and gate, 4-recording device.

An example of detected fly speeds while passing the vicinity of zero position can be seen in Fig. 3, together with an approximation of this damping curve with an exponential with coefficient β. The period T of oscillation is found as an average of all registered swing time periods within a given measurement. From these T and β values and from the hair diameter d = 2R determined in five points by an optical method, we can provide effective shear elasticity modulus G with formula (1) and effective dynamic viscosity with formula (2).

$$G = \frac{4LJ}{\pi^2 R^4}\omega^2 \text{ [Pa]} \qquad (1)$$

$$\mu = \frac{4\sqrt{2}LJ}{\pi^2 R^4}\beta \text{ [Pa·s]} \qquad (2)$$

Description in the text.

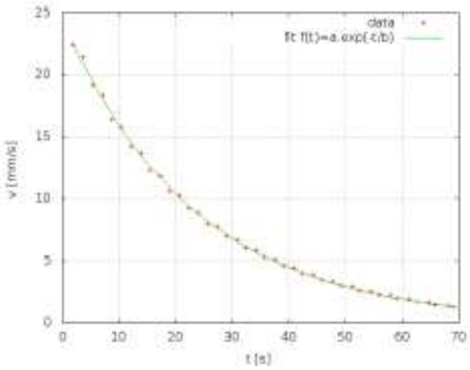

Figure 3. Measured zero passing speed data with fitted dependence v(t)=A.exp(-t/β).

v - the velocity [mm/s] motion velocity traces; t - the time [s]; A - the amplitude of the initial velocity [mm/s]; exp - the exponential; β - relaxation time in seconds.

RESULTS

As an example of the results we will mention the dependence of hair viscosity on their diameter, Fig. 4. This dependence gives us the possibility to estimate the thickness of the cortex, on the assumption that its thickness is equal for all hair diameters. It comes out at 11 µm. There's a question though whether the thickness is equal in all women investigated. To answer this question, it would be necessary to take more than five measurements from each woman, or use another method.

DISCUSSION

When determining of the viscosity from the damping of the torion pendulum, a question arises of the fly bar damping by air friction. Vacuum measurements are out of the question for biological hydrophilous composites as the hair, so we have at least tried to minimize this friction by the spherical shape of the fly. With respect to the planeness of the mirror, the fly is prepared from a clear material, and the mirror is cast in it. Prestraining of the specimen before measurement is albeit necessary, however with the used force of 1.2 mN it lies deep in the Hookean area of deformation for all specimens yet measured. The flies used have their moment of inertia about J = 0.5 kgm^2 and the ratio of the major axis and the minor axes of inertia about 1:3. This ratio proved to be important, as with lower ratios spurious oscillations along other axes happen to occur. Reproducibility of the oscillation period determination is 0.1 %, reproducibility of the determination of the damping about 1 %. No other direct method of determining (even only effective) viscosity and elasticity modulus of the hair than this one is not known to us.

CONCLUSION

From the results of the experiment follows that the viscosity in particular, but also the elasticity modulus both depend significantly on the hair diameter and thus they differ at least for the cortex and the cuticula. The viscosity, in addition, describes the damping behaviour only from 90 %, as with small velocities and amplitudes additional bindings build up and the damping increases. Also with regard to these shortcomings, it is possible to obtain the value of shear modulus with the precision of about 3 % and the value of the viscosity with the precision of about 5 % for a particular hair fibre. As with other methods, the main problem stays primarily with the determinativ of the hair diameter, that changes furthermore significantly along the neceséry 100 mm length and is therefore the main cause of the emergence of the errors of determination of these material parameters. Despite of these imperfections, we find the submitted method viable and standardly usable and enriching for the objectifying of the viscoelastic properties of the hairs.

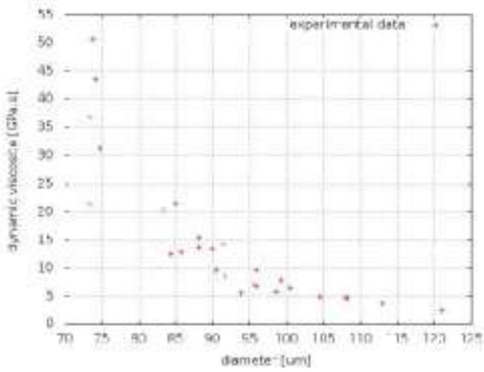

Figure 4. Dependence of effective viscosity of Caucasian woman's hair on its diameter.

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