Structural Differences of Human and Yak Hair

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Introduction

Yak belly hair has been proposed to replace human hair to study the effects of chemicals and hair dyes [1]. The particular advantage of Yak hair is the absence of the colouring molecule melanin, which is unfavorable e.g. in Raman spectroscopy. To replace human hair, one has to ensure that properties of Yak hair closely resemble those of human hair.
To compare these different hair types, we used various techniques such as small-angle X-ray scatting (SAXS) and scanning electron microscopy (SEM) to get information on the structures. Furthermore, we performed tensile tests of both types of hair to determine their mechanical properties.

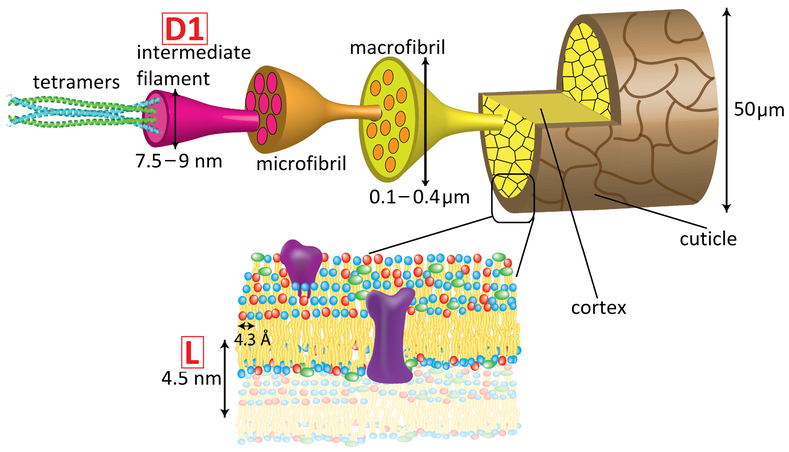

Fig. 1: Hierarchical structure of hair, adapted from [2]

As hair is also a hierarchically structured material, it has additional structural features at different length scales – from atomic to the nanoscale.
One important structural level is the intermediate filament formed by keratin coiled-coils with a diameter of ~7.5–9 nm.
At this size level, we investigated the different nanostructures of human hair and yak belly hair by small-angle X-ray scattering (SAXS) techniques.
SEM was used to characterize the microstructure, whereas the overall (macro-)structure is decisive for e.g. elastic properties and density.

Small Angle X-ray Scattering

Cu-K_α radiation with wavelength $\lambda = 0.1542$ nm was used for the X-ray scattering experiments with the setup in Fig. 2.
SAXS covers scattering angles of $2\theta \leq 4°$. Smaller scattering angles correspond to larger objects in real space.

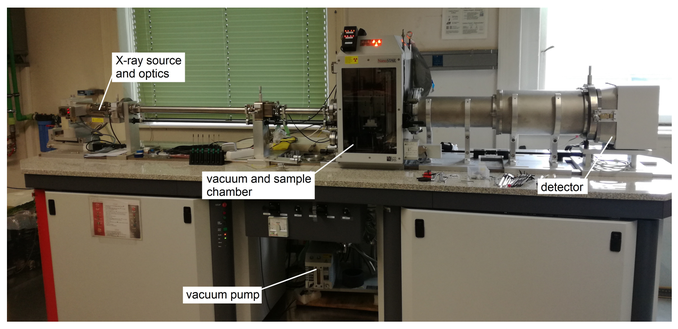

Fig. 2: SAXS-system of the Dynamics of Condensed Systems group

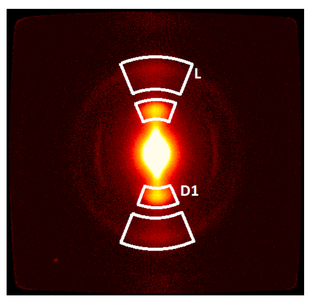

Fig. 3: SAXS pattern of a hair bundle

Fig. 3 depicts a typical 2D SAXS pattern of human hair oriented horizontally. The highlighted regions show peaks arising from different structural elements of the hair substance:
The peaks denoted as *D1* correspond to the radial distance of intermediate filaments, while *L* arises from the distance of lipid layers in the cuticle (see also Fig. 1).

Uniaxial Tensile Tests

A tensile testing machine was used to determine mechanical parameters of bundles of ~30 hairs with a gauge length of 10 mm.
Additional tensile tests on single hairs with a gauge length of 50 mm were performed using a smaller load cell.

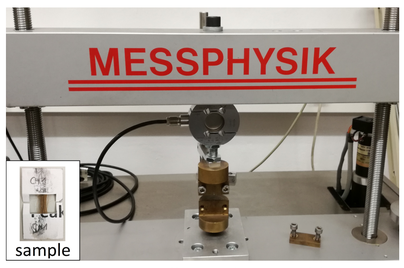

Fig. 4: Tensile testing machine

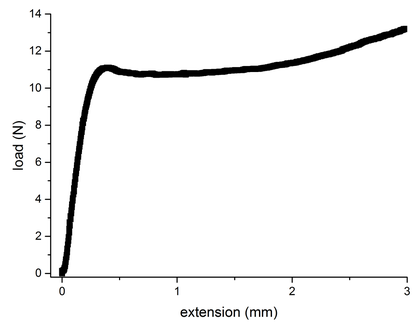

Fig. 5: Collected extension vs. load plot of a bundle of hair

Load and extension data were collected with load cells (1.2kN, 20N) and a linear variable differential transformer respectively.
Furthermore the area of the bundles' cross section was determined for stress calculation using a Zeiss Axioplan microscope (Fig. 6).

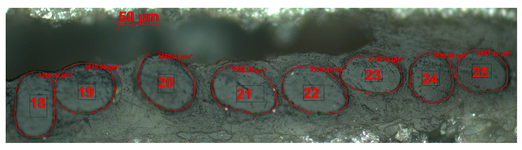

Fig. 6: Microscopical view - cross section of hairs

Nanostructure

Bundles of ~20 hairs were exposed to the X-ray beam for 7200 s. The scattered intensity was collected with a Vantec-2000 detector at a sample-to-detector distance of ~108 cm.

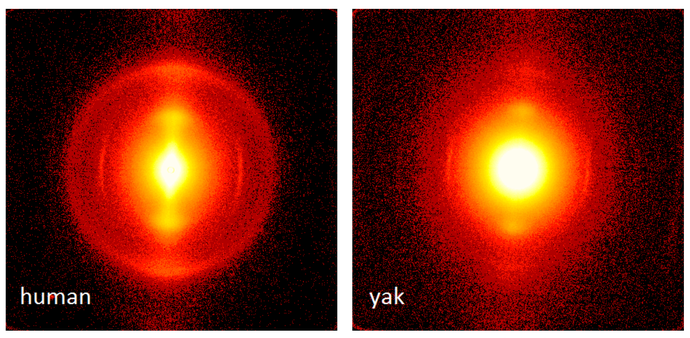

Fig. 7: SAXS-patterns of human and yak hair

Comparing the two patterns, one can see *D1* and *L* as well as a weak horizontal peak in both cases. An absence of the ring in size range of the *L* peak can be observed in the yak pattern while broad isotropic intensity in its center indicates the presence of very large pores.

Elastic Properties

Tensile tests show a larger Young's modulus and yield stress for human hair compared to yak belly hair.

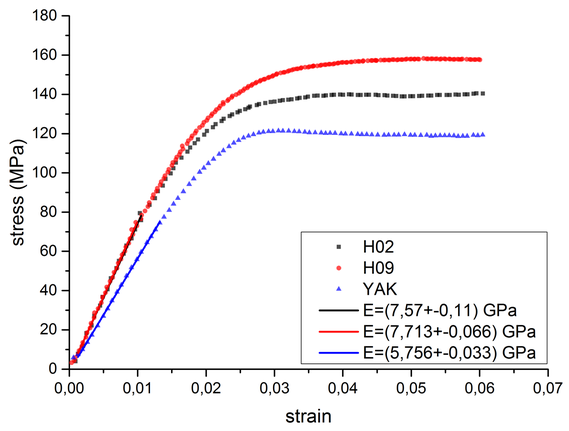

Fig. 8: Elastic properties of two human and one yak sample

Additional tensile tests on six single hair samples of yak hair resulted in a mean Young's modulus of (5.16 ± 0.17) GPa which is close to the result from bundle measurements

Porosity? - Density!

The density of human and yak hair was measured to substantiate the assumption (from SAXS), that yak hair is a porous material in contrast to human hair.

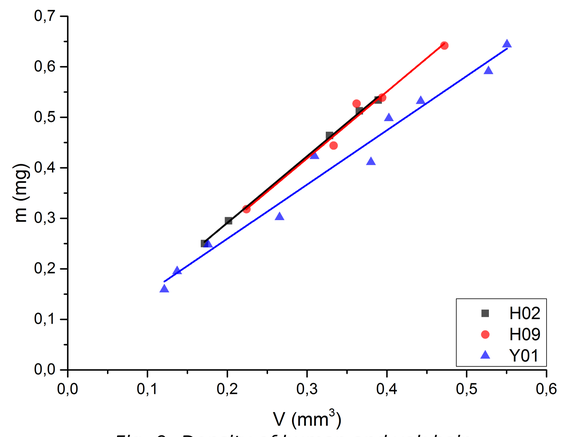

Fig. 9: Density of human and yak hair

The slope of the linear fit and thus its density is lower for yak hair compared to human hair.

$$\rho_{yak} = (1.074 \pm 0.060)\ \mathrm{g/cm^3}$$
$$\rho_{human} = (1.312 \pm 0.043)\ \mathrm{g/cm^3}$$

SEM-Assisted Interpretation

The scale-like structure of the cuticle is not visible for yak hair, which could be the reason for the missing ring in the SAXS pattern for yak hair.
"Cracks" visible in the cross section could indicate pores associated with the broad isotropic intensity in the center of the yak hair SAXS pattern.
The existence of pores in the nanostructure of yak hair in contrast to human hair explains the lower elastic properties and density of yak hair compared to human hair.

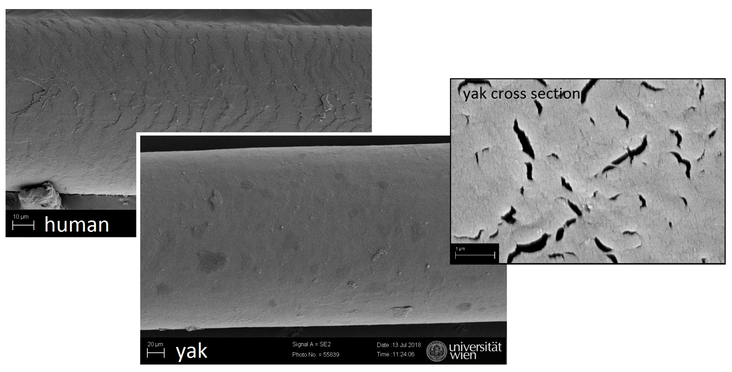

Fig. 10: SEM images of human and yak belly hair

Conclusion

Yak hair has the advantage of melanin absence, which makes it a material of choice for replacing human hair in Raman spectroscopy experiments. It can also be useful for developing and testing different hair treatments and dyes.
When replacing human hair with yak belly hair one has to consider structural and mechanical differences: Pores in yak hair could for example lead to an increased uptake of dye and thus affect the comparability with human hair.

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[1] P.D.A. Pudney, E.Y.M. Bonnist, K.J. Mutch, R. Nicholls, H. Rieley, S. Stanfield. "Confocal Raman Spectroscopy of Whole Hairs". Appl. Spectrosc. 2013. 67(12): 1408-1416
[2] Yang F., Zhang Y., Rheinstädter M.C. - https://upload.wikimedia.org/wikipedia/commons/5/55/Hierarchical_structure_of_hair_in_the_cortex_and_cuticle.png (08.03.2018)