

Preliminary Research Proposal

Investigating the Microscopic Mechanics of Hair-Hydrometer via Atomic Force Microscopy

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Abstract

1 The Problem

- What's the microscopic mechanism of the Hair-Hydrometer?
- How a normal keratin in human hair change in morphology and its Young's Modulus with the change of environment humidity and temperature?
- What's the relationship between the keratin's mechanical properties and the macroscopic mechanical properties of human hair?

2 Background

A simple hygrometer can be built stretching a bunch of degreased human hair, invented in 1800 by a swiss physicist and the founder of mountaineering, de Saussure. Even now the hair-hydrometer is still playing an important role in meteorological oservatories all over the world because its high precision.

The stiffness of the hair will change with the humidity, temperature and other factors of the environment and thus the hair length will change under a fixed tension applied at two endings of the hair. The previous work done by our team found out the rough relation between hair length and environment factors in a macroscopic view, and we hypothesised a physical model to explain the phenomenon using estimated density of Hydrogen bonds between kerotins, which is the core compounds consisting human hair and the chemical equilibrium of Hydrogen bond breaking under different humidity and temperature (hydrogen bonds provide a part of the hair's stiffness), but the microscopic mechanics is still under debating.

Enlightened by the Atomic Force Microscopic(AFM) imaging for Young's Modulus(YM) of amyloid fibrils [2](they used an advanced AFM mode, Peak

Force Quantitative Nanomechanics Measurement (Peak Force QNM) mode, to get the **radial** YM data of amyloid fibrils under different conditions (e.g., in different environment, after different incubation time) by nano-indentation), we came up an idea that to make kerotins fibrils as the specimen instead of amyloid fibrils.

We can control the environment easily by setting up the whole instrument in a artificial box allowing us to adjust the humidity and the temperature.

2.1 Literature review

At beginning (1921), people thought it was humidity that changes the curvature of water menisci in the hair cell pores and then strain or loosen the cell walls. The mechanical properties of hair follows Hooke's law[3].

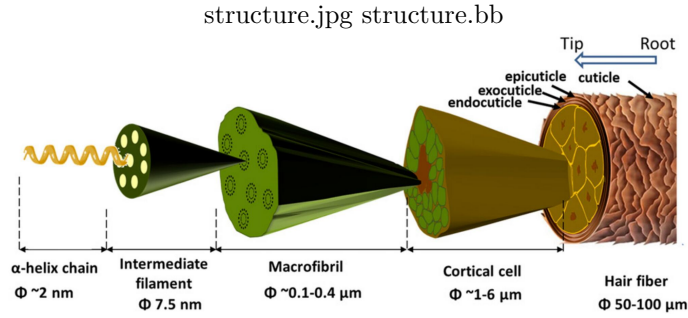


Figure 1: hair structure[4]

Human Hair is mainly consisted by curtail, cortex, and medulla from outside to the center. In one paper, they used α and β kerotin model (examined by X-ray scattering) to explain the elasticity of human hair:

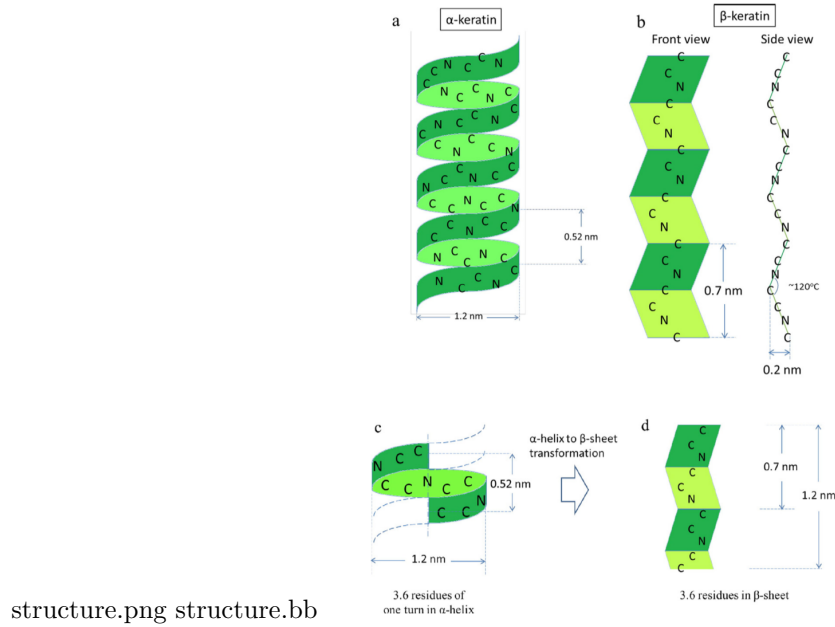


Figure 2: protein structure[4]

but they didn't consider the humidity acting on the chemical bond inside keratin.

Many AFM studies on nanomechanical properties of human hair(mainly on cellular structure) was done by Bhushan in Ohio State University[1]. But this work is not about the keratin and they mapped only lateral not longitudinal.

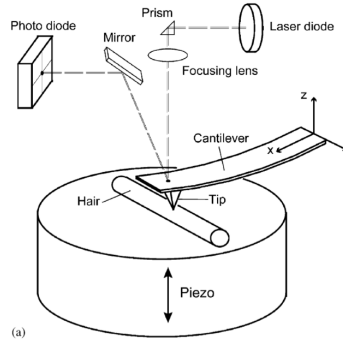


Figure 3: Bhushan's method

Simulation and mesoscopic experiments are done in []

Since there are numerous physical models and explanations, the first thing to do is focusing on the second problem. Then we can develop the solution to

the third and the first, which is the core.

3 Design

3.1 Modeling

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3.2 Instrumentation

Specimen: different keratin fibrils, hairs

AFM: AFM, T-shaped cantilever with normal tip, oblong cantilever

Environment control: Humidity&Temperature control box (using raspberry and electronic hydrometer&thermometer to feedback), covering the whole AFM head.

3.3 Method

First, we measure the keratin protein's YM under different humidity and temperature. Second, measure how keratin effect hair's YM (i.e. by control variables only related to keratin inside hair, like using special enzyme(keratinase[?])) solution which can influent keratin to process the hair). Third, set up the mechanical model and do the simulation.

Notice: we need to bias the humidity influence on adhesion between tip and specimen.

3.4 Difficulties

- How to measure the axial Young's modulus of a nano fiber? and How to fix an end of keratin fibrils?
- How to develop a better hair mechanical model? There must be other relevant factors.
- How to control variates? like How to only destroying the protein fibrils inside the hair?

4 Expected Result

Expected to have

- a decreased keratin YM with increasing humidity and temperature.
- a proportional relationship between keratin fibrils YM and hair YM (longitudinal).

4.1 Expected Finishing Time

References

- [1] Bharat Bhushan and Nianhuan Chen. Afm studies of environmental effects on nanomechanical properties and cellular structure of human hair. *Ultra-microscopy*, 106(8-9):755–764, 2006.
- [2] Wonseok Lee, Hyungbeen Lee, Gyudo Lee, and Dae Sung Yoon. Advances in afm imaging applications for characterizing the biophysical properties of amyloid fibrils. *Exploring new findings on amyloidosis*, 2016.
- [3] F J W Whipple. The theory of the hair hygrometer. *Proceedings of the Physical Society of London*, 34(1):i–v, dec 1921.
- [4] Yang Yu, Wen Yang, Bin Wang, and Marc André Meyers. Structure and mechanical behavior of human hair. *Materials Science and Engineering: C*, 73:152–163, 2017.