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Nanotensile Study of Single Human Hair Fiber

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A human hair has an outer layer of flat scales known as cuticle which protects the inner softer tissue called cortex. The cortex is where hair growth occurs. By examining hair fibers with microscopes, researchers discovered that ethnic differences in hair structure are apparent [1, 2]. Asian hair is seen to be more circular in shape and has a greater diameter than the other ethnic types. Caucasian hair has an intermediate cross-section between Asian and African hair. In longitudinal shape, Asian hair is straight with less irregularity, and Caucasian hair is usually straight with a few irregularities along the lengthwise. This investigation analyzes the difference in nanotensile mechanical properties between Asian hair and Caucasian hair.

Hair samples were collected from four volunteers who are Asian, Caucasian, at age of 20's or 40+. At least ten samples were obtained from each person. Each hair sample was labeled according to following scheme: A=Asian, C=Caucasian, F=female, 2=at age of 20's, 4=at age of 40+. A circular cross-section was assumed for all hair samples in nanotensile property calculation. The diameter was measured using an optical microscope (see Figure 1) at 3 different places along the length. The mean value was calculated for property determination.

To eliminate slippage during nanotensile testing, a winding grip has been designed and used to securely hold the hair sample (Figure 2).

nanoTensile tests were performed under displacement control at room temperature in ambient air on a newly developed nanoTensile™ 5000 automated system. All the samples were stretched to failure at a strain rate of 0.0017/s.

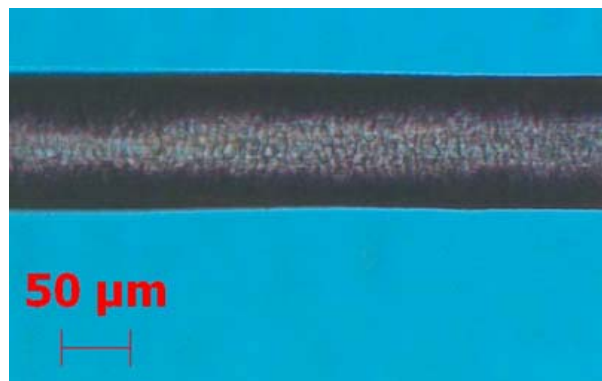


Figure 1. Optical micrograph of hair sample.

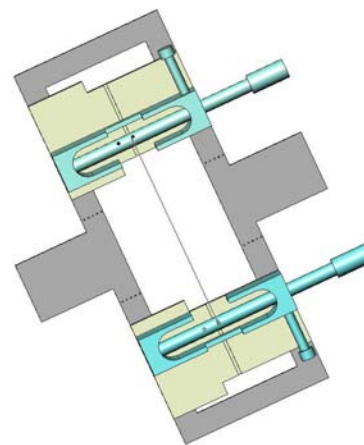


Figure 2. Winding grip.

The test results are reported in Table 1. It can be seen that Caucasian female hair attains significant higher Young's modulus, yield stress, and tensile strength, but has lower ultimate strain than Asian female hair. The Caucasian female hair possesses higher toughness than the Asian female hair, but to a lesser degree due to the smaller ultimate strain it sustains before break. Consistently, age plays a very important role in the hair property of both Caucasian and Asian females. The tensile properties measured for 20's group are higher than the 40+ group. An example of engineering stress vs. strain curves obtained for the above hair types is shown in Figure 3. It is noted that there are some small stress drops in the curves before failure.

Table 1. Tensile test results

	AF4	AF2	CF4	CF2
E(GPa)	4.18	4.23	5.15	5.41
σ_y (MPa)	69.72	71.70	87.47	93.33
σ_{ult} (MPa)	173.01	190.17	214.02	216.02
ϵ_{ult} (%)	49.51	50.16	42.18	46.11
u_f (J/m ³)	55.71	60.07	59.05	65.50

(E: Young's modulus, σ_y : yield stress, σ_{ult} : ultimate tensile strength, ϵ_{ult} : ultimate tensile strain, u_f : toughness)

Figure 4 is an optical image of ruptured hair. It seems that as hair is stretched, small strands of outer layer fail first while cortex remains intact. This may explain the small stress drops before failure in the tensile curves. When the stress continues to increase, it causes the hair fiber to fail completely in the end. AFM analysis of the fractured surface has been conducted (see Figure 5). Considerable z-height slope towards the fractured end indicates hair fracture has the characteristics of an angled fracture.

Reference:

- [1]. <http://www.ishrs.org/articles/hair-under-microscope.htm>.
 [2]. A. Franbourg, P. Hallegot, F. Baltenneck, C. Totain, and F. Leroy, "Current research on ethnic hair", J Am ACAD DERMATOL, June 2003.

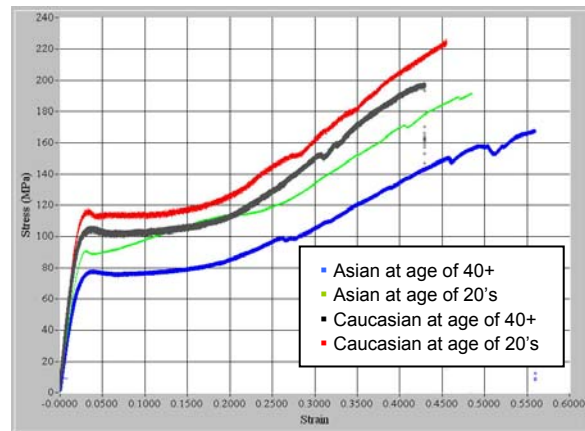


Figure 3. Engineering stress-strain curves of human hair samples.



Figure 4. Optical micrograph of ruptured hair showing the cross-section and broken loose strands of cuticle. Magnification: 1000X.

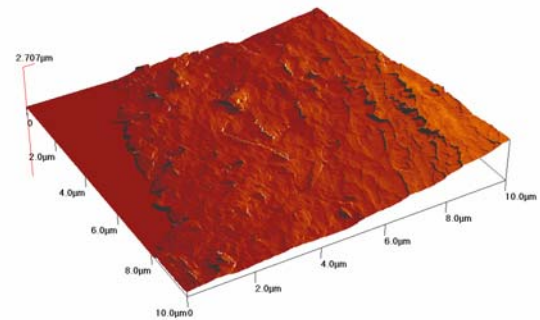


Figure 5. AFM image of fractured surface.



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