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Investigation of scale effects and directionality dependence on friction and adhesion of human hair using AFM and macroscale friction test apparatus

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Abstract

Macroscale testing of human hair tribological properties has been widely used to aid in the development of better shampoos and conditioners. Recently, literature has focused on using the atomic force microscope (AFM) to study surface roughness, coefficient of friction, adhesive force, and wear (tribological properties) on the nanoscale in order to increase understanding about how shampoos and conditioners interact with the hair cuticle. Since there are both similarities and differences when comparing the tribological trends at both scales, it is thus recognized that scale effects are an important aspect of studying the tribology of hair. However, no microscale tribological data for hair exists in literature. This is unfortunate because many interactions between hair–skin, hair–comb, and hair–hair contact takes place at microasperities ranging from a few μm to hundreds of μm. Thus, to bridge the gap between the macro- and nanoscale data, as well as to gain a full understanding of the mechanisms behind the trends, it is now worthwhile to look at hair tribology on the microscale. Presented in this paper are coefficient of friction and adhesive force data on various scales for virgin and chemically damaged hair, both with and without conditioner treatment. Macroscale coefficient of friction was determined using a traditional friction test apparatus. Microscale and nanoscale tribological characterization was performed with AFM tips of various radii. The nano-, micro-, and macroscale trends are compared and the mechanisms behind the scale effects are discussed. Since the coefficient of friction changes drastically (on any scale) depending on whether the direction of motion is along or against the cuticle scales, the directionality dependence and responsible mechanisms are discussed.

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1. Introduction

Everybody wants beautiful, healthy hair and skin. For most people, grooming and maintenance of hair and skin is a daily process. The demand for products that improve the look and feel of these surfaces has created a huge industry for hair and skin care. Beauty care technology has advanced the cleaning, protection, and restoration of desirable hair and skin properties by altering the hair surface.

Fig. 1 shows a schematic of a human hair fiber with its various layers of cellular structure [1–4]. Of most importance to tribologists is the cuticle, the outermost region that protects the cortex. The cuticle is composed of keratin and consists of an A-layer, exocuticle, endocuticle, and cell membrane complex. Attached to the surface of the cuticle scale is a saturated fatty acid called 18-methyleicosanoic acid (18-MEA), a lipid layer, which strongly contributes to the lubricity of the hair. The multi-layered cuticle region is important to the hair's frictional characteristics because it is this structure, which comes in contact with skin, combing devices, and other hair fibers. The cuticle consists of flat, overlapping cells (scales). Each cuticle cell is approximately

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0.3–0.5 μm thick and the visible length is approximately 5–10 μm. A summary of dimensions and geometrical properties of various hairs are listed in Table 1.

The hair surface is negatively charged and can be damaged by a variety of chemical (permanent hair waving, chemical relaxation, coloring, bleaching) and mechanical (combing, blowdrying) factors [2,5,6]. With continual damage, the negative charge of the hair increases, making it harder to control so-called static electricity "fly away". The friction and adhesion of the hair increases as well, so that the hair becomes harder to comb and entanglement occurs more readily. These issues are considered to be harmful to the tribological requirements for healthy and desirable hair. Friction is the most relevant parameter to hair care. Our perception of a soft, silky feel comes from our ability to glide a comb or skin over the hair fibers. For a smooth wet and dry feel, friction between hair and skin should be minimized in wet and dry environments, respectively. For a good feel with respect to bouncing and shaking of the hair during walking or running, friction between hair fibers and groups of hair fibers should be low.

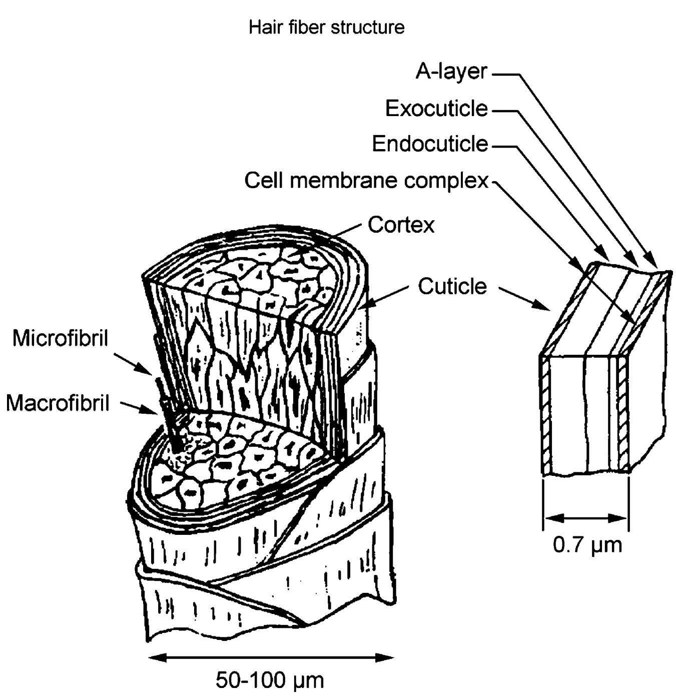

Fig. 1. Schematic of hair fiber [2].

The friction one feels during combing is a result of interactions between hair and the comb material (generally a plastic), and this too needs to be low to easily maintain, sculpt, and comb the hair. Adhesion is also important. To minimize entanglement, adhesive force (the force required to separate the hair fibers) needs to be low. In other cases, a certain level of adhesion may be acceptable and is often a function of the hairstyle. For individuals seeking "hair alignment", where hair fibers lay flat and parallel to each other, a small amount of adhesive force between fibers may be desired. For more complex and curly styles, even higher adhesion between fibers may be optimal.

The main objectives of hair care science, then, are to inhibit the damage caused by the factors described previously and to create an improved feel of the hair. The use of conditioners on hair can cause drastic changes in the surface properties of hair, both quantitatively (such as in decreased coefficient of friction [COF]) and by human perception of feel. Conditioner thinly coats the hair primarily by Van der Waals attractions. Thus, lubrication of the hair fibers ensues to create a softer, smoother change in feel for the consumer. This layer of lubrication also provides a protective coating to the hair surface for prevention of future damage. The uniformity of this layer over the hair surface is a very important feature, namely how and where it is localized.

Conditioner consists of a gel network chassis (cationic surfactants, fatty alcohols, and water) for superior wet feel and combination of conditioning actives (cationic surfactants, fatty alcohols, and silicones) for superior dry feel. The benefits of the conditioner are shown in Table 2. The wet feel benefits are creamy texture, ease of spreading, slippery feel while applying, and soft rinsing feel. The dry feel benefits are moistness, softness, and easier dry combing. Each of the primary conditioner ingredients also has specific functions and roles that affect performance of the entire product. Cationic surfactants are critical to the forming of the lamellar gel network in conditioner, and also act as a lubricant and static control agent, since their positive charge aids in counteracting the negative charge of the hair fibers. Fatty alcohols are used to lubricate and moisturize the hair surface, along with forming the gel network. Finally, silicones are the main source of lubrication in the conditioner formulation.

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Table 1
Dimensional and geometrical properties of hair

	Shape	Maximum diameter (D_1) (μm)	Minimum diameter (D_2) (μm)	Ratio D_1/D_2	Number of cuticle scales	Cuticle scale thickness (μm)
Caucasian	Nearly oval	74	47	1.6	6–7	0.3–0.5
Asian	Nearly round	92	71	1.3	5–6	0.3–0.5
African	Oval-flat	89	44	2.0	6–7	0.3–0.5

Average length of visible cuticle scale: about 5–10 μm.