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Nanotribological and nanomechanical characterization of human hair using a nanoscratch technique

Guohua Wei, Bharat Bhushan*

Nanotribology Laboratory for Information Storage and MEMS/NEMS, The Ohio State University, 650 Ackerman Road, Suite 255, Columbus, OH 43202, USA

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Abstract

Human hair (~50–100 μm in diameter) is a nanocomposite biological fiber with well-characterized microstructures, and is of great interest for both cosmetic science and materials science. Characterization of nanotribological and nanomechanical properties of human hair including the coefficient of friction and scratch resistance is essential to develop better shampoo and conditioner products and advance biological and cosmetic science. In this paper, the coefficient of friction and scratch resistance of Caucasian and Asian hair at virgin, chemo-mechanically damaged, and conditioner-treated conditions are measured using a nanoscratch technique with a Nano Indenter II system. The scratch tests were performed on both the single cuticle cell and multiple cuticle cells of each hair sample, and the scratch wear tracks were studied using scanning electron microscopy (SEM) after the scratch tests. The effect of soaking on the coefficient of friction, scratch resistance, hardness and Young's modulus of hair surface were also studied by performing experiments on hair samples which had been soaked in de-ionized water for 5 min. The nanotribological and nanomechanical properties of human hair as a function of hair structure (hair of different ethnicity), damage, treatment and soaking are discussed.

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Keywords: Nanoscratch; Nanoindentation; Nanotribology; Human hair; Scanning electron microscopy (SEM)

1. Introduction

Human hair (~50–100 μm in diameter) is a nanocomposite biological fiber with well-characterized microstructures, and is of great interest for both cosmetic science and materials science. The need for products that improve the look and feel of hair surface has created a huge industry for hair care. Hair care technology has advanced the cleaning, protection, and restoration of desirable hair properties by altering the chemical and physical properties of the hair surface. Shampoo is used to clean hair and conditioner is used to coat the hair with a thin film in order to protect it and provide desirable look and feel [1,2]. Conditioner consists of gel network chassis (cationic surfactant, fatty alcohols and water) for superior wet feel and combination of conditioning actives (silicones, fatty alcohols and cationic surfactant) for superior dry feel. 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 dry combing ease. Many other ingredients are added as well to meet the needs of consumers.

Characterization of nanotribological properties of human hair is essential to develop better shampoo and conditioner products and advance biological and cosmetic science. The conditioner coating plays an important role in protecting the hair surface from further physical damage like scratch during combing. In order to understand better the effect of conditioner on hair surface, it is important to study the nanotribological properties, especially the coefficient of friction and scratch resistance of hair surface. However, it is very challenging to perform nanotribological measurements on the surface of single hair fibers, which

*Corresponding author. Tel.: +1 614 292 0651; fax: +1 614 292 0325.
E-mail address: bhushan.2@osu.edu (B. Bhushan).

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has a shingle-like structure formed by a great number of 5–10 μm long (visible length), 0.3–0.5 μm thick cuticles cells. More details of the hair structure are discussed in the next section.

Nanoscratch technique can be used to characterize the nanotribological properties of human hair by scratching the hair surface using a conical diamond tip (radius about 1 μm) and recording the coefficient of friction, in situ scratch depth and residual depth. However, although nanoscratch technique has been widely used to evaluate the nanotribological properties of metallic, ceramic and polymeric thin film materials [3–6], little nanoscratch work has been done on biomaterials. In addition, since human hair is a nanocomposite biological fiber with well-characterized structures, it can be a good model to study the role of various structural and chemical components in providing mechanical strength for composite biological fibers. Therefore, the study of nanotribological and nanomechanical properties of human hair using a nanoscratch technique can expand the application of this technique to the field of nanobiotechnology and biomaterials research.

Many characteristics and properties of hair are uniquely related to one's ethnicity. Because of this, a growing number of hair care products specifically tailored for these distinct needs have recently entered the market. Thus, studying hair properties of various ethnicities, such as Caucasian, Asian and African hair, is of interest to cosmetic science. Since hair properties also range widely for treatments like conditioner treatment, coloring and permanent wave treatment, etc. there is still much to be learned about the nanotribology of hair as a function of all these considerations. During showering/bathing, our hair is soaked by water. It is necessary to study how the presence of water influences the nanotribological and nanomechanical properties of hair.

In this paper, systematic studies of nanotribological and nanomechanical properties of human hair are presented for the first time. The coefficient of friction and scratch resistance of human hair as a function of hair structure (hair of different ethnicity), damage, treatment and soaking are discussed.

2. Hair structure

Fig. 1 shows a schematic of a human hair fiber with its various layers of cellular structure, and the SEM and AFM images of the hair surface [1,2,7–9]. Hair fiber consists of cuticle and cortex, and in some cases medulla in the central region. All are composed of dead cells, which are mainly filled with keratin protein. Depending on its moisture content, human hair consists of approximately 65–95% proteins, which are condensation polymers of amino acids. The remaining constituents are water, lipids (structural and free), pigment, and trace elements. Among numerous amino acids in human hair, cystine is one of the most important amino acids. The distinct cystine content of various cellular structure of human hair results in a significant effect on their physical properties. Cystine has the capacity to cross-link the protein by its intermolecular

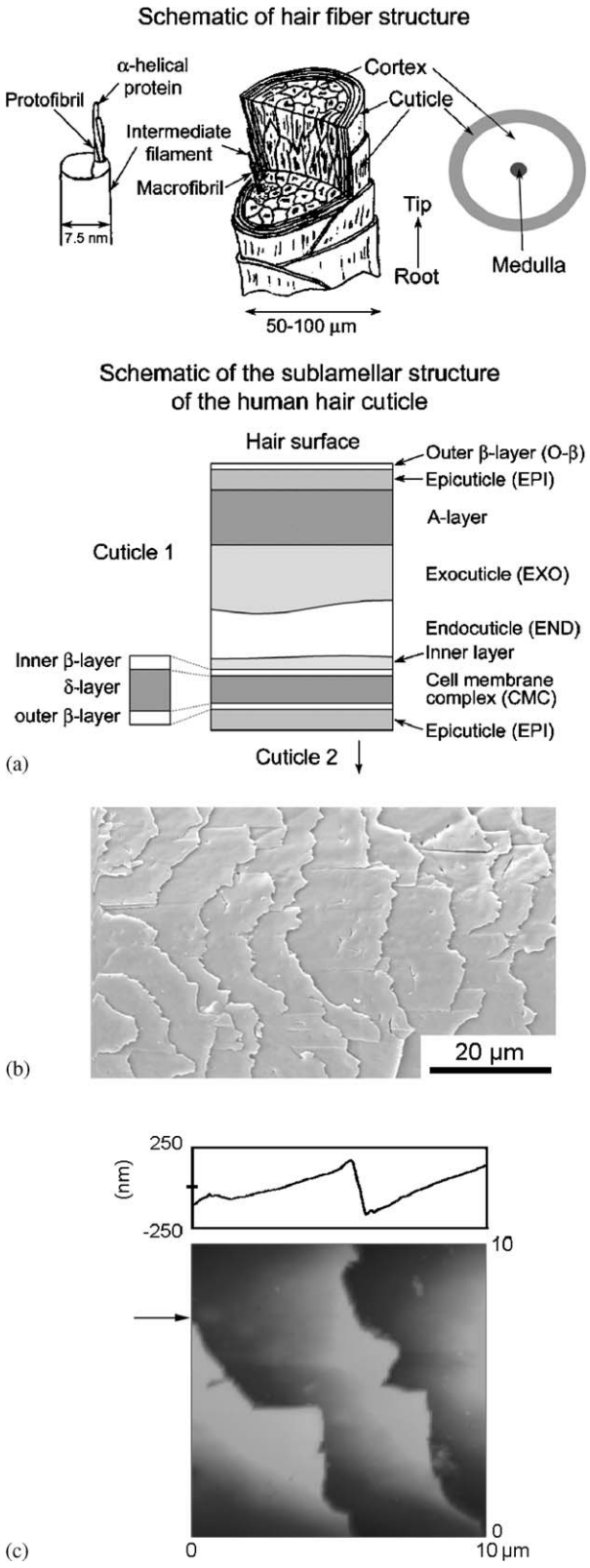

Fig. 1. Schematic of hair fiber structure and cuticle sublamellar structure (a), and SEM image (b) and AFM image (c) of hair surface.