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Mechanism of split-end formation in human head hair

J. ALAN SWIFT, *Department of Textiles and Fashion, De Montfort University, Leicester LE1 9BH, England.*

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Synopsis

The satisfactory prevention or repair of "split ends" in long-hair styles continues to present a significant challenge to the toiletries industry. The mechanics by which they form has not been clarified previously. Combing is a common requirement, without which few split ends are formed (1,2). Splitting always occurs in the plane containing the hair's major elliptic diameter. A theoretical analysis supports the notion that during the combing of tangled hairs, high shear stresses are developed about the major elliptic diameters of the fibers. Shear fracture about this diameter and the further propagation of the fracture front towards the hair tip adequately explain the characteristic primary morphology of this cosmetically undesirable terminal bifurcation of the hair. Amongst the various factors that influence split-end formation, two are highlighted in that they offer prospects for simple modification to the cosmetic advantage of reducing the incidence of split ends. One is about reducing frictional interactions between hairs by lubrication and the other concerns improvements in the longitudinal shear plasticity within the hair's bulk.

Of frequent concern among those with long-hair styles are "split ends." The satisfactory elimination of this cosmetically undesirable manifestation of hair damage remains a major challenge for the toiletries industry. Split ends form more readily in hair that has been treated with harsh chemical agents (as in bleaching or permanent waving or oxidative dyeing) or that has been exposed to excessive sunlight. They do not form spontaneously but require the input of mechanical energy most commonly thought to be associated with brushing and combing (1).

Many of the factors that exacerbate the formation of split ends are known (1,2), but yet the sequence of mechanical events underlying their generation has not been described previously. In his extensive investigations of human head hairs with the scanning electron microscope (SEM) the author has noted that terminal splits involve a primary bifurcation extending away from the hair's extremity in a longitudinal plane invariably through the fiber's diameter. Moreover, given that most hairs are elliptical in section, this initial split without exception occurs through the major elliptic diameter. It is this form that provides the clue to the mechanical events that were involved in the hair's longitudinal fracture.

During regular combing of hair, "snagging" often occurs as the comb approaches the ends of the hair, an effect that increases in severity with the natural length of the hair (3). Such high terminal comb forces are encountered during the first passage of the comb through the hair, but this force diminishes with successive passages of the comb and as parallel alignment of the hairs is gained. These high forces, which are greater than those encountered for the majority of the comb's traverse, are due to entanglement of the hairs (3). The tangles are drawn to the ends of the hairs, where they "stick," probably as a consequence of localized increases in surface friction brought about by the cumulative effects of natural weathering and of other insults to which the hair has subjected during its lifetime (3). In the "teasing" process (known as "backcombing" in some other countries), tangles are deliberately induced by using a comb to draw the ends of the fibers for a short distance into the hair bulk. Considerable combing force is then required to disentangle this hair, the overall procedure being commonly used to increase the volume of a hair style.

Over 20 years ago the comb-out of uncoated hair tangles was examined dynamically using a low-voltage SEM (4). This work revealed that the tangle could involve intimate contact of as many as 30 individual hairs, each seemingly moving independently of the others and, at moderate magnifications, looking to some extent like a seething sea of snakes. At initial low comb force some of the contacting hairs would slide over each other in the acute angular presentation of their longitudinal axes. With increasing force, such sliding resulted in the disengagement of some of hairs, but in many other instances adjacent hairs were drawn to perpendicular presentation of their long axes. In these cases the hairs became increasingly bent around each other so that the radius of curvature of a given hair would approach the radius of the contacted hair and would be wrapped around it, often through 90° and even sometimes by as much as 360°. Each hair moved axially within the tightening array until finally its end was released from the tangle. In doing so, it was being rapidly bent about its minor axial diameter and then straightened at all points along its length of contact. While, of necessity, the speed of combing was slowed down for the SEM work, it is estimated that in the real combing of hair tangles, the time constant for such bending and straightening events is between 100 μs and 1 ms.

It is now proposed that the mechanics of hair bending during the comb-out of a tangle can be treated by analogy with that of a solid rod of elliptical cross section (5). There will be an overwhelming preference for this rod to bend by the application of forces in a direction parallel to its minor axial diameter than about any other axis, i.e., involving preferential bending of the longitudinal plane containing the major axial diameter (6). Towards the outside of the bend, the rod will be under tensile stress and the inner portions will be under compression. The longitudinal plane of the original rod containing the major axial diameter will be under zero tensile stress; this is known as the neutral (tensile) stress plane. In its bent configuration the rod will also experience longitudinal shear stresses at the point where it enters and then where it leaves the bending support (7). The magnitude of these shear stresses will be parabolically distributed across the minor axial diameter of the elliptical section, with zero shear stress at each end of the minor axial diameter and with maximum shear stress about the plane containing the major axial diameter (5). This shear stress maximum will be 133% of the average shear stress in rods of circular section, tending to a limiting value of 150% of the average in rods of elliptical section as the ratio of major to minor diameters increases to infinity (5). Where other factors are kept constant, the magnitude of shear stress about the major axial diameter will increase with increasing minor axial diameter, with decreasing radius of curvature of the bend, and with an increasing angular sweep of the bend (i.e., of wrap).

In the light of the foregoing analysis, it seems likely that where hairs are being bent acutely during combing, localized longitudinal shear fracture may occur within the fibers and this will be favored to take place about the major axial diameter of each hair. An initial fracture once formed will tend to be propagated towards the hair tip by the continuous bending and straightening process experienced during the release of the hair from its entrapment. Such a fracture in the plane of the hair's major axial diameter would be entirely consistent with the microscopic form of the primary bifurcation of the split end. It is worth adding that a given combing operation may not give rise to a split end in a particular hair, but it is likely that repetitive combing of tangled hair eventually will cause shear stress fatigue and the amalgamation of localized fractures to generate a macroscopic split end.

For a given person, several factors such as the length of hair, the speed of combing, the degree of tangling, and the hair's cross-sectional size and shape will influence the facility with which split ends are formed. There are two further important factors that will influence the propensity towards split ends and that are amenable to modification by the suitable application of hair toiletry products. The first of these is the frictional coefficient of the fiber surfaces. With increasing friction one expects higher forces to be applied in the comb-out of hair tangles and for this to be accompanied by the tighter bending of the hairs over each other and by greater longitudinal shear forces being generated within the individual fibers. Any hair toiletry product that culminates in lubricating the frictional interactions between hairs will serve of necessity to reduce the shear stresses and reduce the incidence of split ends. The second factor concerns the hair's internal plasticity, particularly in relation to the shear stresses imposed on the hair's longitudinal elements and also in relation to the time constants for the bending and straightening processes noted previously. If the components of the hair shaft (they are mainly proteinaceous) do not respond plastically to the imposed shear stresses, then shear fatigue and shear fracture will ensue. Such loss of response is likely to occur in hairs that have been exposed to sunlight, where the protein crosslinking networks have been modified by free-radical attack (8). This would account for why the hairs of persons indulging in excessive exposure to sunlight are particularly susceptible to splitting. Note also that the total radiation dose in given segments will be temporally cumulative with increasing distance along the hair towards the tip. Agents that help plasticize the hair's proteins to stresses of short time constant should reduce the incidence of split ends. It is the author's observation that fewer split ends are formed when hair is combed at high rather than at low relative humidity, indicating that water itself is one such plasticizing agent. As judged by its effect in reducing the brittleness of cold-waved hair (9), glycerol is another plasticizing agent that seemingly also reduces the incidence of split ends.

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