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Fractography of human hair

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Synopsis

Scanning electron microscopy and optical microscopy show that when HUMAN HAIR is extended in water the cuticle usually suffers multiple circumferential FRACTURE with local separation from the cortex before the latter fractures. The cortex fracture is typically smooth and perpendicular to the fiber axis. In the dry state the fracture is more irregular indicating axial splitting of the cortex before or during fracture without prior failure of the cuticle. Except for the cuticle–cortex separation which occurs in wet extension, fracture surfaces do not show a strong tendency to follow cell boundaries.

INTRODUCTION

Scanning electron microscopy has been applied extensively to the study of human hair topography. Applications have ranged from studies of pathological conditions (1–3) to assessment of the effects of normal weathering and grooming (4) and of cosmetic treatments (5, 6). More recently there have been reports of direct observation of the response of hair to mechanical stresses applied by means of apparatus specially designed to manipulate hair in the specimen chamber of the microscope in modes simulating a variety of grooming operations such as brushing and backcombing (7, 8).

In this paper we report results of a more conventional study of the topography of hair after tensile strain in different environments and after different pretreatments. We discuss our observations with reference to the known histology and chemistry of hair and the expected response to factors such as hydration and age.

MATERIALS AND METHODS

Natural brown European hair was obtained from DeMeo Brothers, New York, New York. With the single exception of the study of fracture type versus age, this hair was used throughout. For the latter study, hair samples were obtained from a young woman with long (approximately 50 cm), light brown virgin hair. The hairs were plucked or snipped at a distance not exceeding 1 cm from the scalp.

Bleaching with potassium persulfate/hydrogen peroxide was done in alternating 1- and 2-hr intervals to give 3- and 6-hr bleached hair. Fresh solution was introduced at the end of each interval. Hairs fractured in solvents were soaked a minimum of 16 hr before Instron testing. Variation in pH was accomplished by addition of acetic acid or ammonium hydroxide. It was noted after 16 hr that the pH of these systems was not affected by the hair. Relative humidities other than 50 ± 1% (room condition) were obtained for 20, 71, 79 and 90% by using saturated salt systems (9) in capped jars containing sample hanging racks and a fixed post. Samples to be fractured were equilibrated for a minimum of three days at 21 ± 1°C in these chambers. A glycerin/water mixture equivalent to a water activity of 50% RH was prepared using 22.5% water and 77.5% anhydrous glycerin by weight.

Stress/strain measurements on hairs were made on a Model TT-B Instron Tester. Hairs were mounted in special holders of stainless steel with chamfered holes and secured with tapered Teflon plugs. The working length was 12.7 mm and most experiments were done at a constant rate of extension of 200%/min. Some determinations were made at one-tenth this speed (20%/min).

Hairs run in the humidity chambers were fixed between small screw clamps to provide the desired working length and suspended between a hook on the Instron and the fixed post in the chamber. The hook extended down through a small hole in the cover. The screw clamp subjected the hair to a 2- to 3-g stress during the conditioning period which was ignored since the resulting extension is negligibly small.

The hairs were viewed in a Coates and Welter Cwik Scan Model 100-2 Field Emission Scanning Electron Microscope. Prior to viewing, the hairs were sputter coated with gold/palladium in a Denton DV-515 Evaporator equipped with a Model DSM-1 Sputtering Module. The sputtering was done at 10 mA and 150 millitorr for 1.5 min in intervals of 30 sec.

For SEM viewing the hairs were mounted perpendicular to the surface of a standard Coates and Welter specimen stub. The length of hair exposed below the fracture varied but was generally of the order of 1 mm. Both sides of the fracture were examined in all cases.

The optical microscopy was carried out on hairs immersed in a dish of water on the stage of a Zeiss Universal Photomicroscope. The hairs were mounted on a Hoffmann hose clamp modified to permit use of the screw-driven bearings to stretch the specimen.

RESULTS

WET FRACTURE

The fracture surfaces of virgin hairs broken under water are often quite flat as shown in Figure 1. Here it appears that the fracture started at a small zone on the edge of the fiber and radiated from there in a plane perpendicular to the axis. Such detailed evidence of fracture propagation is seldom seen but, in general, the new surface is remarkably devoid of evidence of the cellular and subcellular fibrous structure of hair; the fracture pattern is much more similar to the brittle fractures of glass or carbon (10) than to the fracture patterns of other natural fibers such as cotton (11).

The cuticle fracture is also planar and perpendicular to the fiber axis and again evidence of cellular structure is lacking; there is little sign of delamination or axial slippage of the

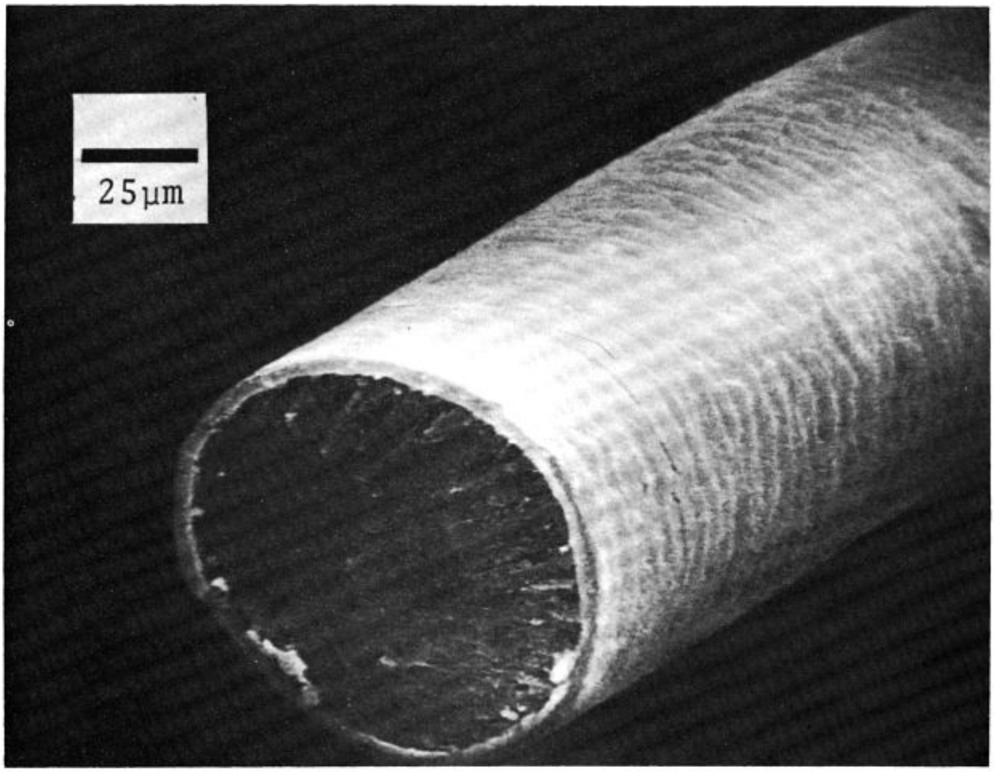
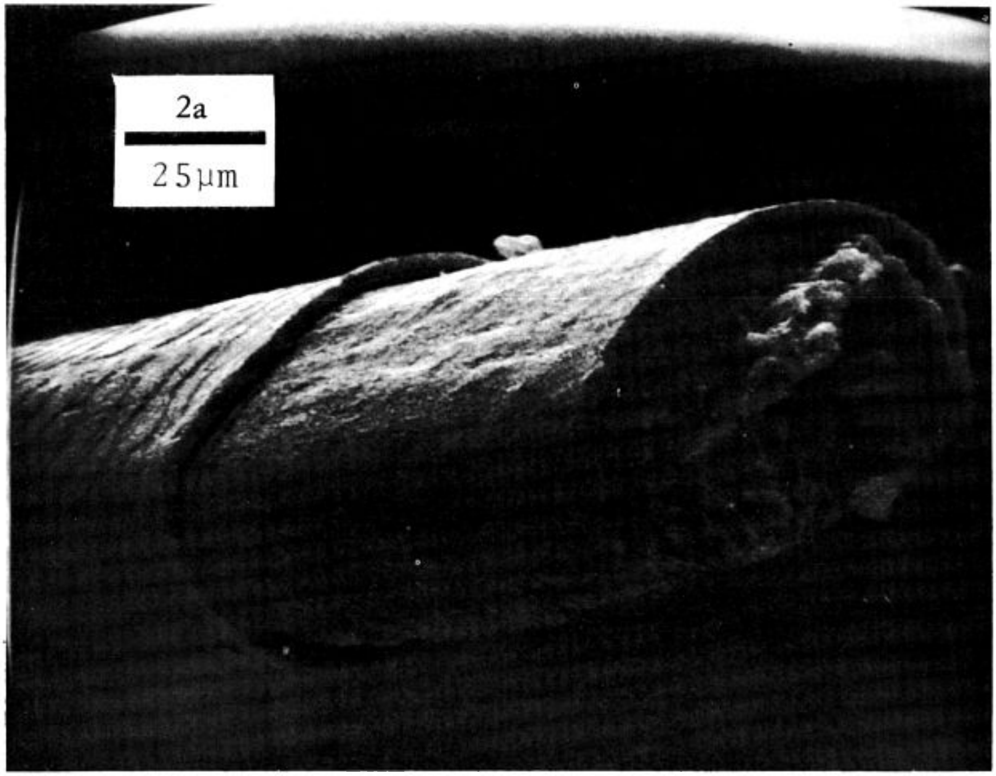


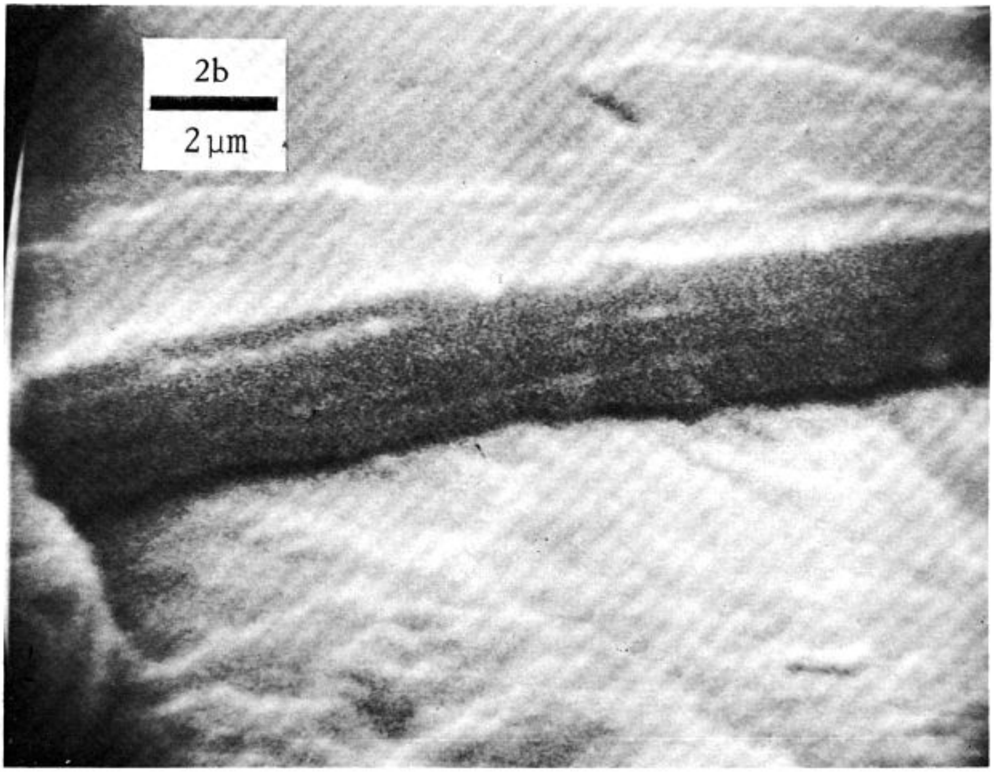
Figure 1. Fracture of natural brown hair in water

cuticle cells. At about a quarter of the fiber diameter from the fracture plane it can be seen that the cuticle has cracked circumferentially; this too is typical of the wet fracture pattern.

In Figure 1 the break fits Brown and Swift's description (7) "almost as if cut with a knife." In a few cases, however, we observed wet fractures like that in Figure 2a where there is a gross mismatch of the fracture planes of the cuticle and cortex. A gap between cuticle and cortex can be seen in Figure 2b. Figure 2c is the opposing fracture surface which is complementary to the first. Here there is much clearer evidence of another circumferential failure of the cuticle far from the fracture surface. Such fractures of the cuticle were frequently observed several diameters from the fracture surface, as seen in Figure 3.

Although such cuticle fractures might have occurred at the instant of failure, the more intriguing possibility is that the cuticle fails well before the cortex. Two types of experiment proved that this is indeed the case. First, hairs that were extended in water to just short of failure, relaxed in water and then dried and examined in the SEM showed many cracks like those in Figure 3. Second, when hairs were extended incrementally in water and examined in the polarizing microscope it was evident in some cases, as shown in Figure 4, that at least part of the cuticle had ruptured. In Figure 4a the rupture lines are clearly seen in top focus against the bright corticle matter between slightly uncrossed polars. In Figure 4b at edge focus in the same view it can be seen that


2a
25µm


2b
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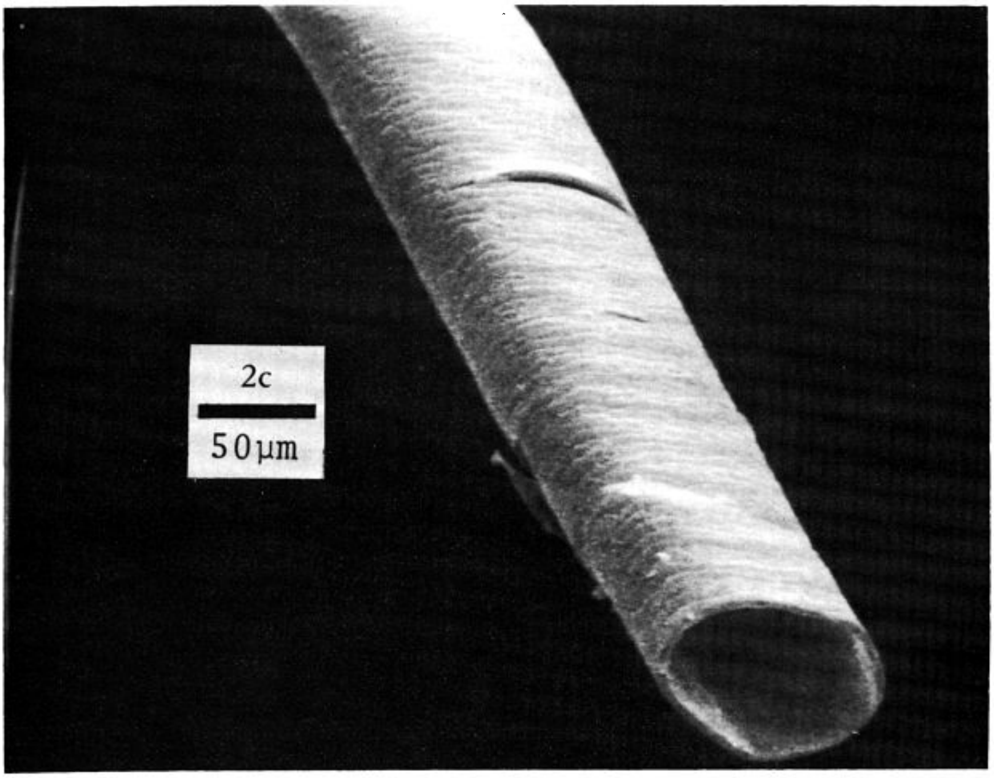

Figure 2. Sleeve-type break of natural brown hair in water showing (a) cortical plug, (b) cuticle fracture on plug showing separation from cortex and (c) cuticle sleeve

near the fracture lines the broken cuticle is flaring away from the fiber; this is seen more clearly in Figure 4c.[1]

Figure 5a is an electron micrograph of the hair in Figure 4c after drying in the extended state. The cuticle flaring is seen again as well as grossly degenerated subcellular cuticle fragments which seem to be barely attached to their substrate. Figure 5b at higher magnification shows that the cortex is exposed between the flares and it also shows details of the spongy surface of the disrupted scales lying on what would seem to be an otherwise normal cuticle surface.

DRY FRACTURE

The fracture surfaces of hairs broken in air at 50% RH are generally more ragged than those of hairs broken in water. Figures 6a and 6b show two of the many types of breaks

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[1] Although the lower extensibility of cuticular tissue was reported in Alexander and Hudson, "Wool, Its Chemistry and Physics," Chapman & Hall, London, 1954, pp 7 and 12 with prior reference to Reumuth, Klepzig, *Textil-Z.*, 45, 288 (1942), we find that Reumuth in turn cites E. Lehmann, *Melliand Textilber.*, **22**, 145 (1941). The Lehmann paper, however, does not contain the attributed illustration contained in Reumuth as well as in Alexander and Hudson. Two other Lehmann papers (in 1943 and 1944) likewise do not. Therefore, we cannot authenticate either the illustration or the experimental conditions under which it was obtained.

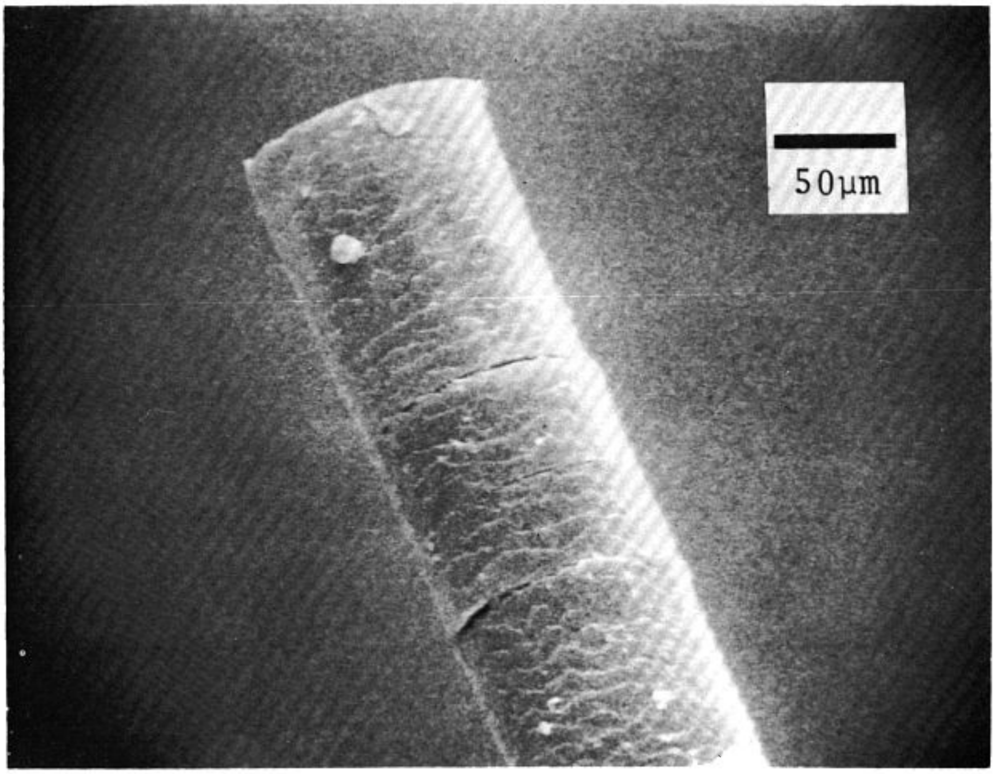
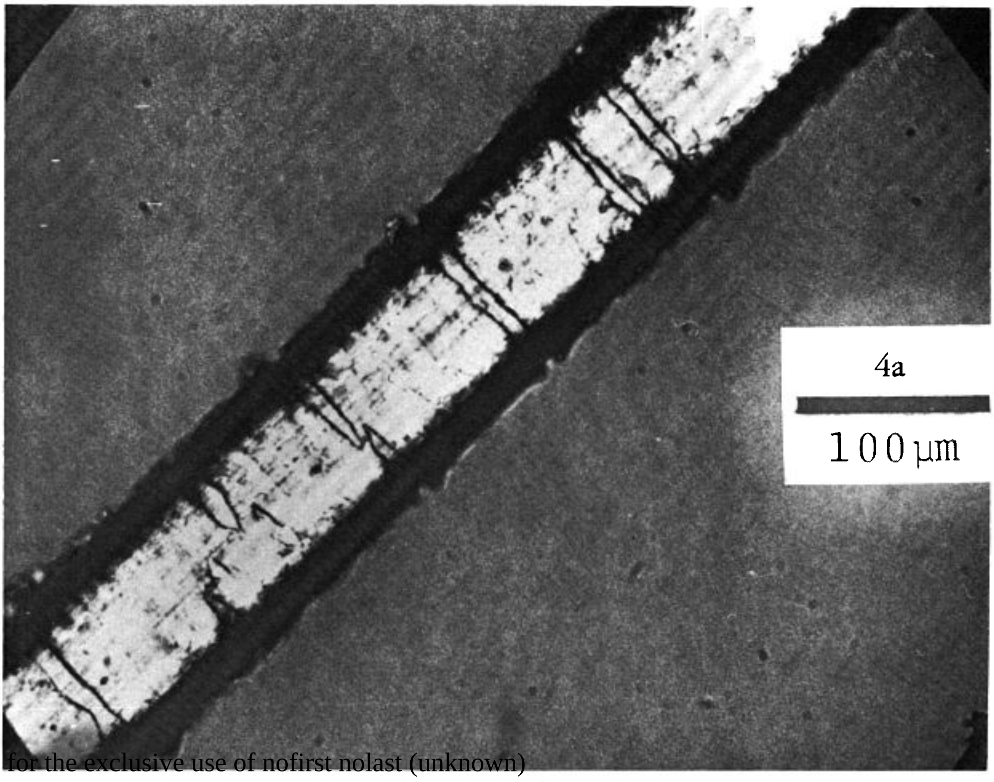


Figure 3. Cracking and buckling of cuticle on natural brown hair broken in water



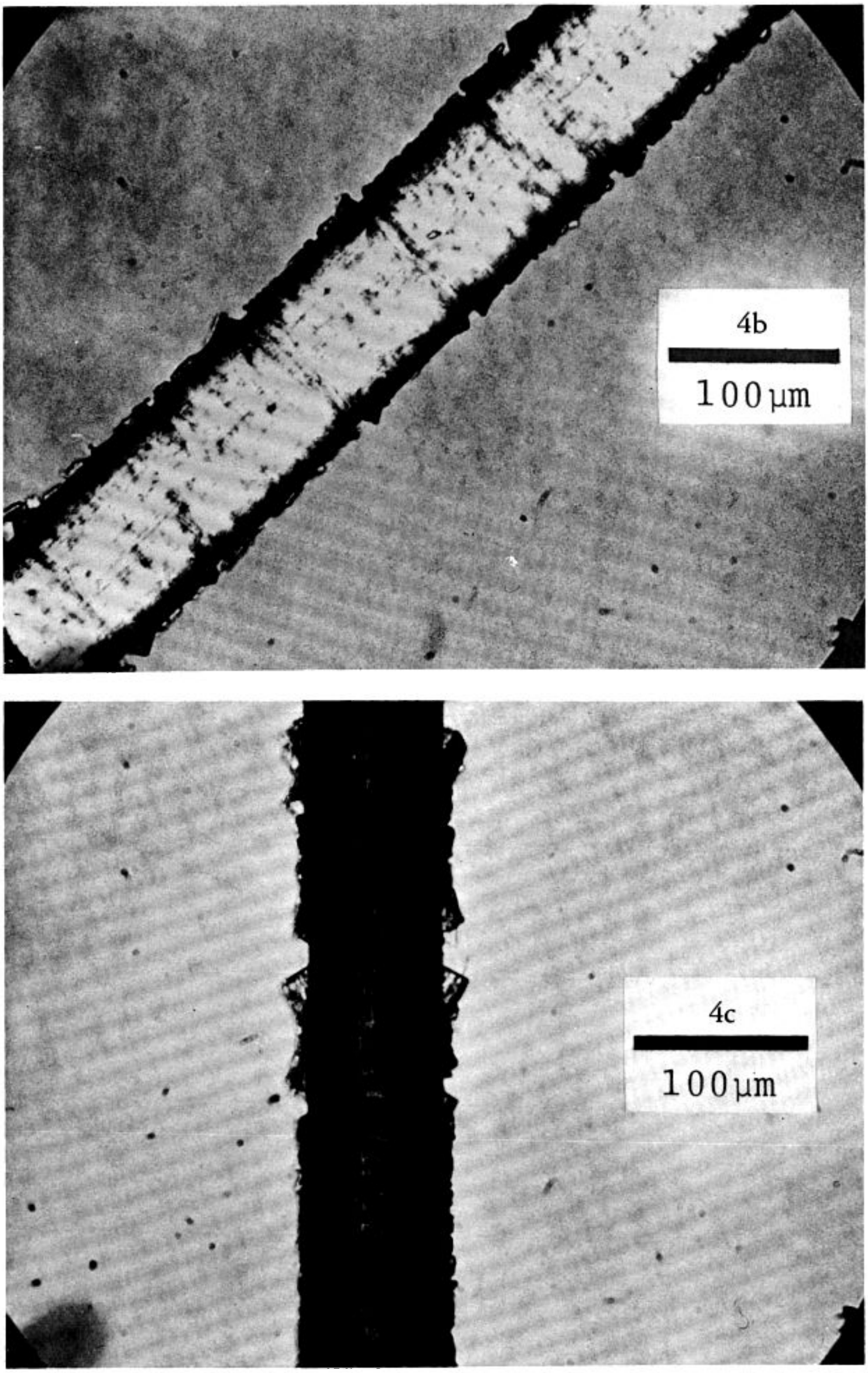


Figure 4. Optical micrographs of natural brown hair at high extension in water, (a) top focus showing cuticle cracks, (b) edge focus showing flaring and (c) extreme flaring at higher extension

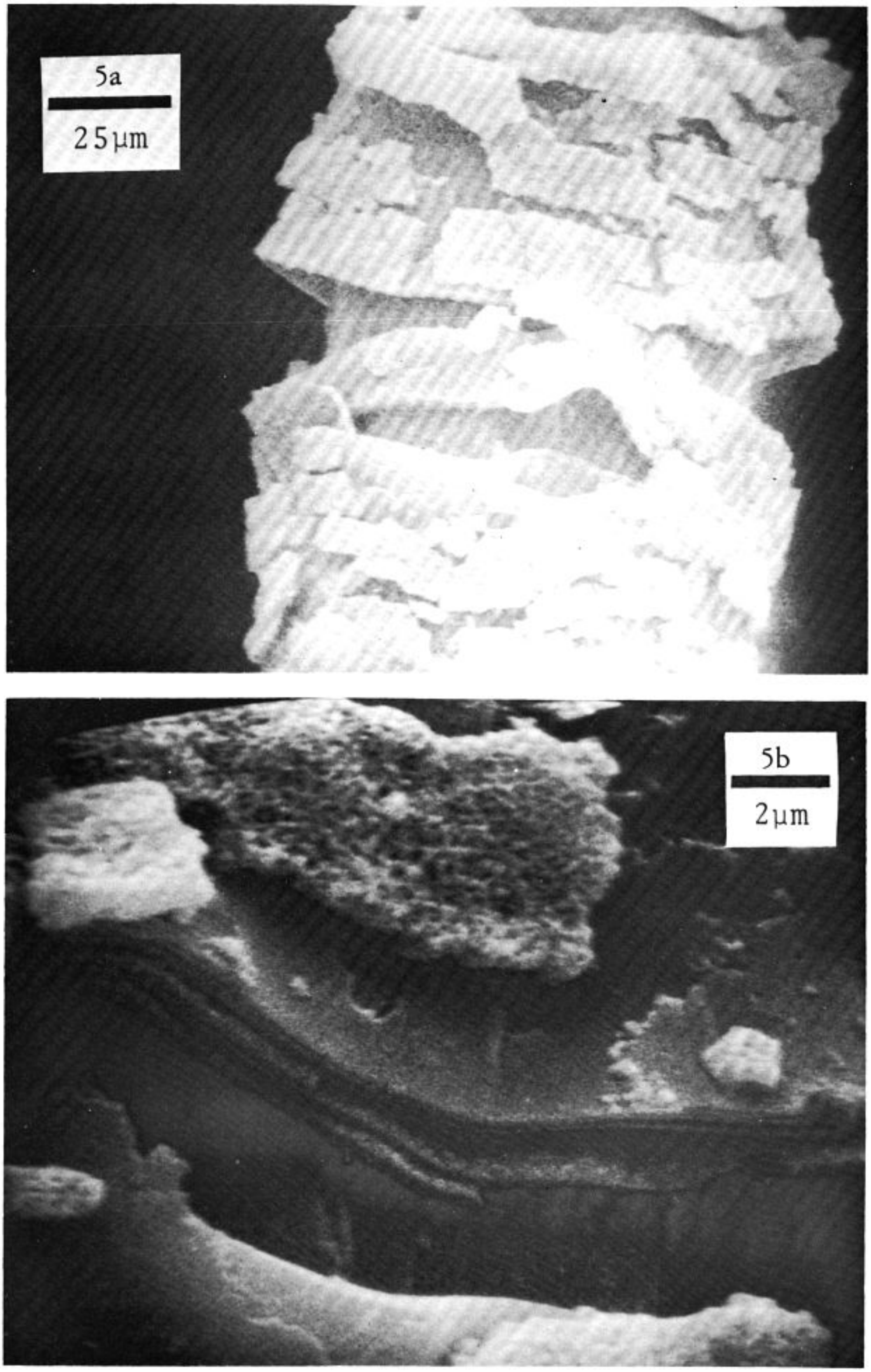


Figure 5. Scanning electron micrograph of natural brown hair extended in water and dried in air at fixed extension showing (a) cuticle flaring and loose scales and (b) cortex visible in cuticle gap

observed with virgin hair under these conditions. A feature common to most dry breaks is that the corticle fracture surfaces are of two kinds: first, flat, smooth surfaces perpendicular to the fiber axis just as in the wet breaks; and second, very rough surfaces in the axial direction revealing details of fibrillation finer than the lateral dimensions of individual corticle cells. Because of the step-like arrangement of the flat radial surfaces these are referred to as step fractures.

In Figure 6b there is an axial crack in the cuticle and more extreme examples of this are shown in Figures 7a and 7b. In dry breaks there is no evidence that the cuticle behaves as a mechanically independent entity; in particular, the cuticle does not split circumferentially as it does in a wet break. Optical examination of a few hairs extended in air revealed no change in the cuticle except possibly a slight uplifting of the distal edges of the scales as the breaking strain was approached.

AGE OF HAIR

Hairs 45 to 50 cm in length, taken from the crown of the scalp of a young woman who had not bleached, dyed or chemically waved her hair, were sampled near the root, the middle and the tip. As expected from observations such as those of Bottoms, Wyatt and Comaish (4), many of the tip sections were found to be partially or totally devoid of cuticle while the mid- and root-section specimens were covered with cuticle and resembled the commercial virgin hair.

Specimens from each section were broken in air at 50% RH and in water. The root- and mid-hair specimens of these hairs behaved very much like the commercial virgin hair; flat breaks with circumferential cuticle cracks were obtained in water, step fractures in air at 50% RH.

The tip sections broke more irregularly under both conditions. In air at 50% RH two out of five specimens were fibrillated completely at the cellular level, the flat step feature being absent altogether as shown in Figure 8. In water, seven out of ten fractures were flat, but three were more like the step fractures typical of dry air breaks.

Although the number of observations is too small to establish a correlation at a high level of confidence, it appears that hairs with more extensively damaged cuticle yield more jagged breaks.

PRE-STRESSED HAIRS

To further study the role of the cuticle in determining fracture type, five virgin hairs that had been hydrated and stretched in water almost to fracture were dried under tension in air and fractured at 50% RH. All five fractures were flat and typical in all respects of a wet break. Hairs pre-stressed almost to break at 50% RH and then broken in water also gave flat fractures.

ENVIRONMENTAL EFFECTS

Virgin hairs conditioned and broken in air at 20, 71 and 79% RH yielded step fractures similar to those obtained at 50% RH, as described above. At 90% RH in air there was a transition to the flat-break pattern obtained in water although circumferential cuticle cracking was absent.

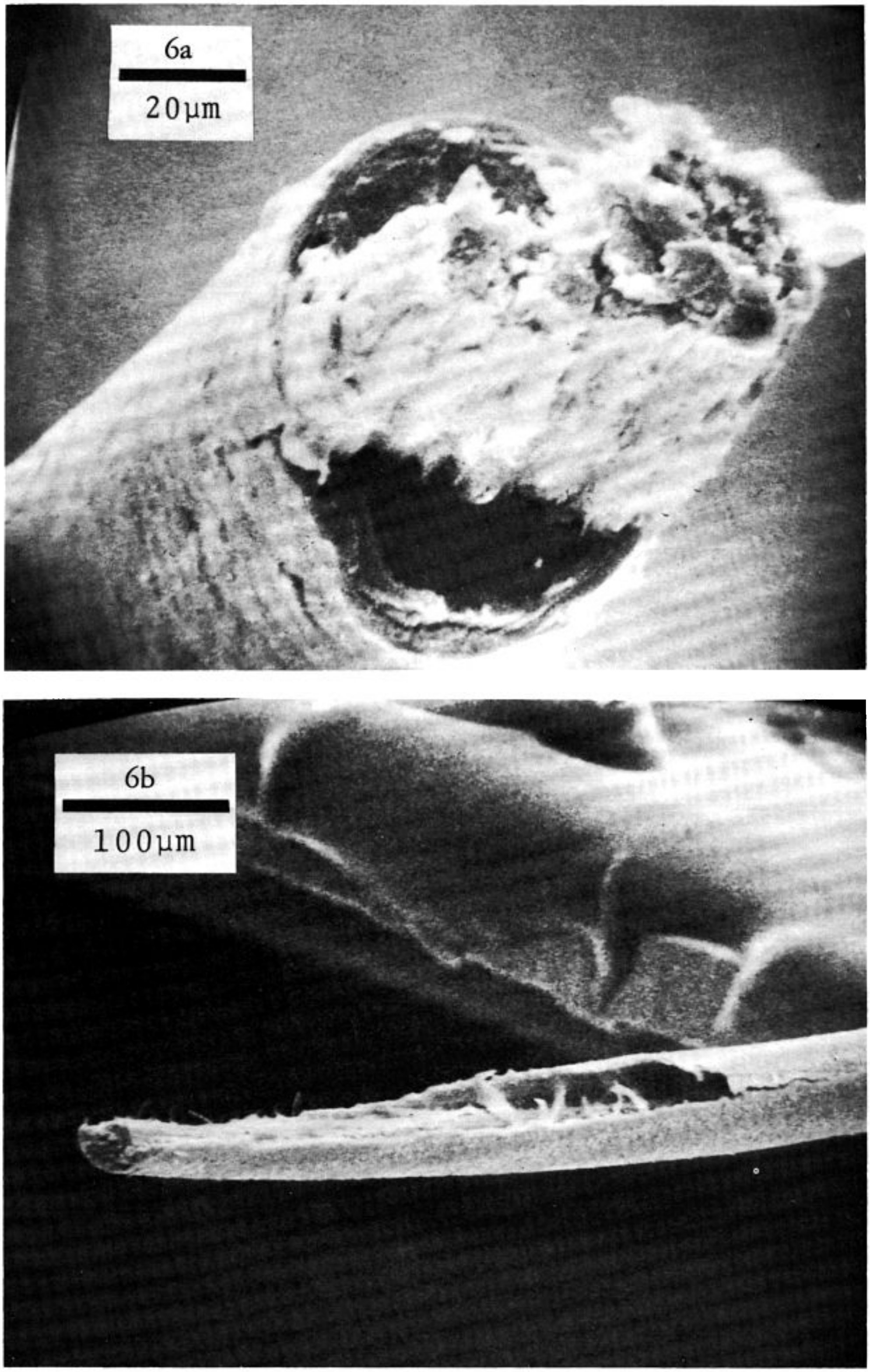


Figure 6. Fractures of natural brown hair at 50% RH in air

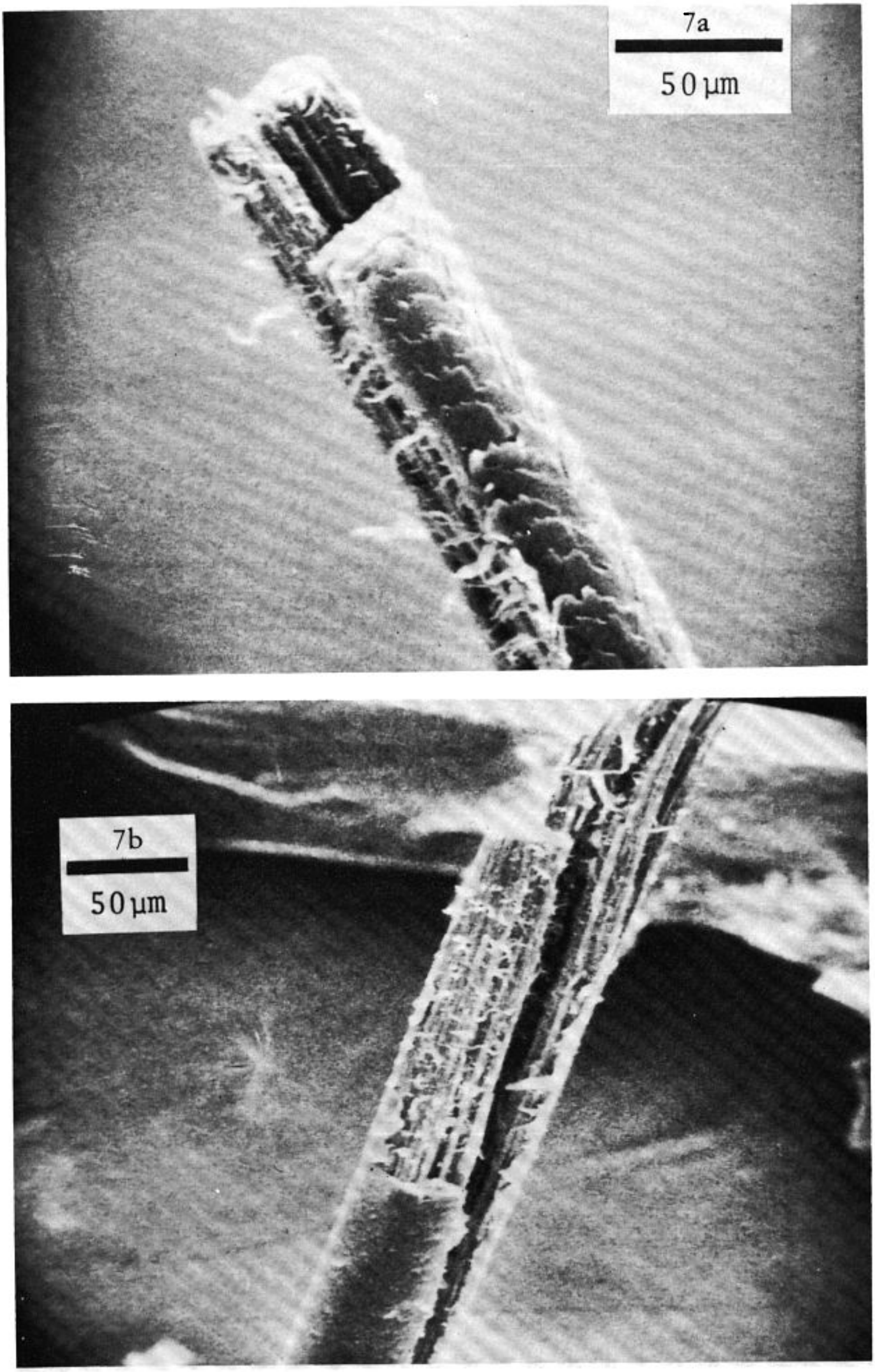


Figure 7. Fractures of natural brown hair at 50% RH in air showing lateral shredding of cortex and axial splits through cuticle

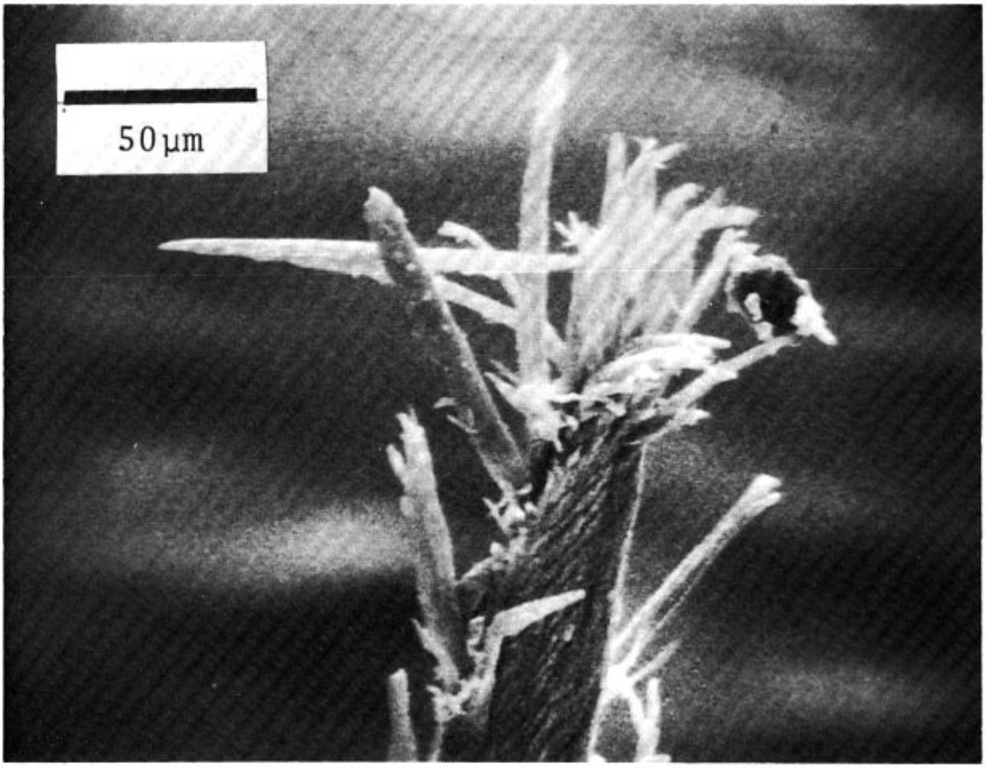


Figure 8. Fracture of aged hair at 50% RH in air illustrating tip-end cortical fibrillation

Hair broken in a water/glycerin mixture equivalent to 50% RH gave flat breaks and this pattern was also obtained in anhydrous glycerin. In anhydrous ethanol and in ethyl acetate the fracture pattern was also more like that obtained in water than in air at 20 to 79% RH in spite of the fact that the hair was not hydrated and gave, as expected, a stress-strain curve like that of dry hair. The sleeve-type break, somewhat like that shown in Figure 2, occurred more frequently than in water but with the significant difference that the annular fracture surface (the surface seen on the protruding plug) was within the cortex, not at the cuticle–cortex junction; this is shown in Figure 9 where it can be seen that the plug tapers into the cortex. The fracture patterns obtained in solvents also differ from those in water in the fact that circumferential cracks in the cuticle do not occur. Although they are superficially similar to breaks in water, breaks in solvents are qualitatively different in detail.

Sodium lauryl sulfate at 3% had no noticeable effect on the fracture pattern relative to that in water, nor did adjustment of pH to 3, 9 and 11.

PRETREATMENTS

Fractographs of hairs bleached for 3 hr and broken in water are shown in Figure 10. The flat-fracture surface of the cortex is like that of virgin hair in water, but the cuticle disruption is much more extensive. Similar results were obtained with hair bleached for 6 hr. At 50% RH in air bleached hair yields step fractures not noticeably

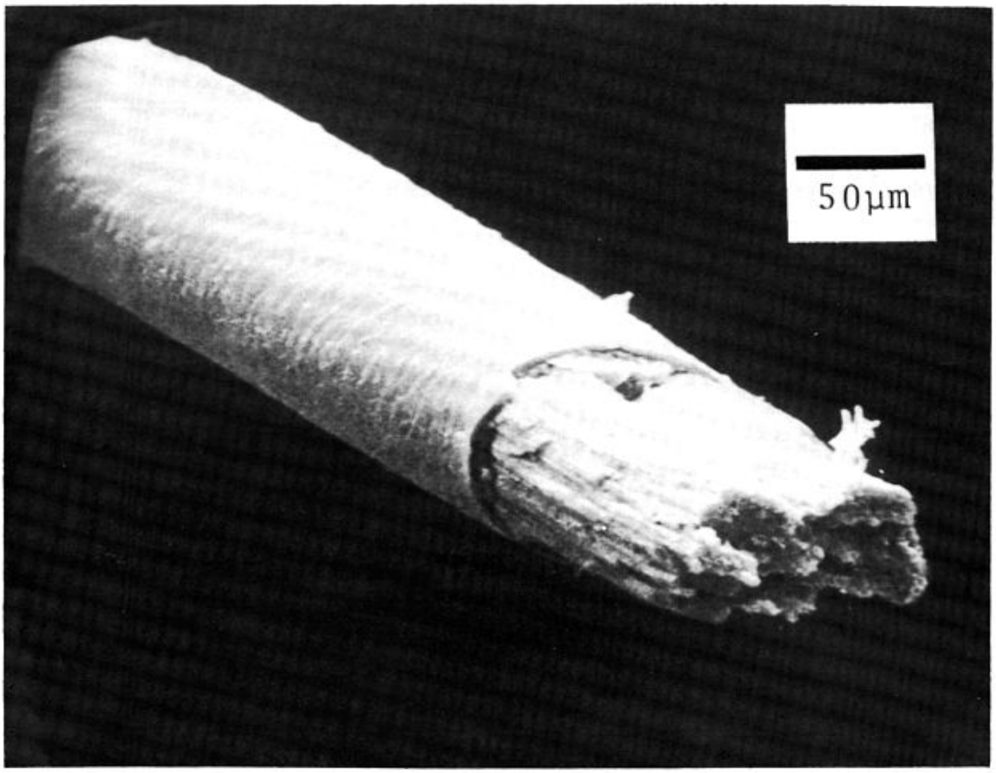


Figure 9. Fracture of natural brown hair in ethyl acetate

different from those of virgin hair. Defatting virgin hair by soaking overnight in 2:1 chloroform/methanol had little or no effect on the fracture pattern in either water or air at 50% RH.

STRESS/STRAIN BEHAVIOR VS. RELATIVE HUMIDITY

Force and elongation measurements were made on natural brown hairs at several relative humidities from 20 to 90%, and also immersed in water. To avoid introducing the variable of hair diameter, the dimensionless ratio of the force at the end of the Hookean region (plateau force) to the break force has been used for comparison of behavior at different relative humidities. This ratio was found to decrease continuously as relative humidity increased, as shown in Figure 11. Also shown is the increase in percentage of elongation at break. The trend is opposite that of the plateau force/break force ratio. Instead of the steady decline exhibited by the ratio data, the percentage-of-elongation trend indicates a change in fracture mechanism above about 80% RH, where a sharp increase in extensibility begins.

DISCUSSION

These studies indicate that there are qualitatively distinct mechanisms involved in the tensile fracture of wet and dry virgin hair. In wet fracture we have observed the cuticle

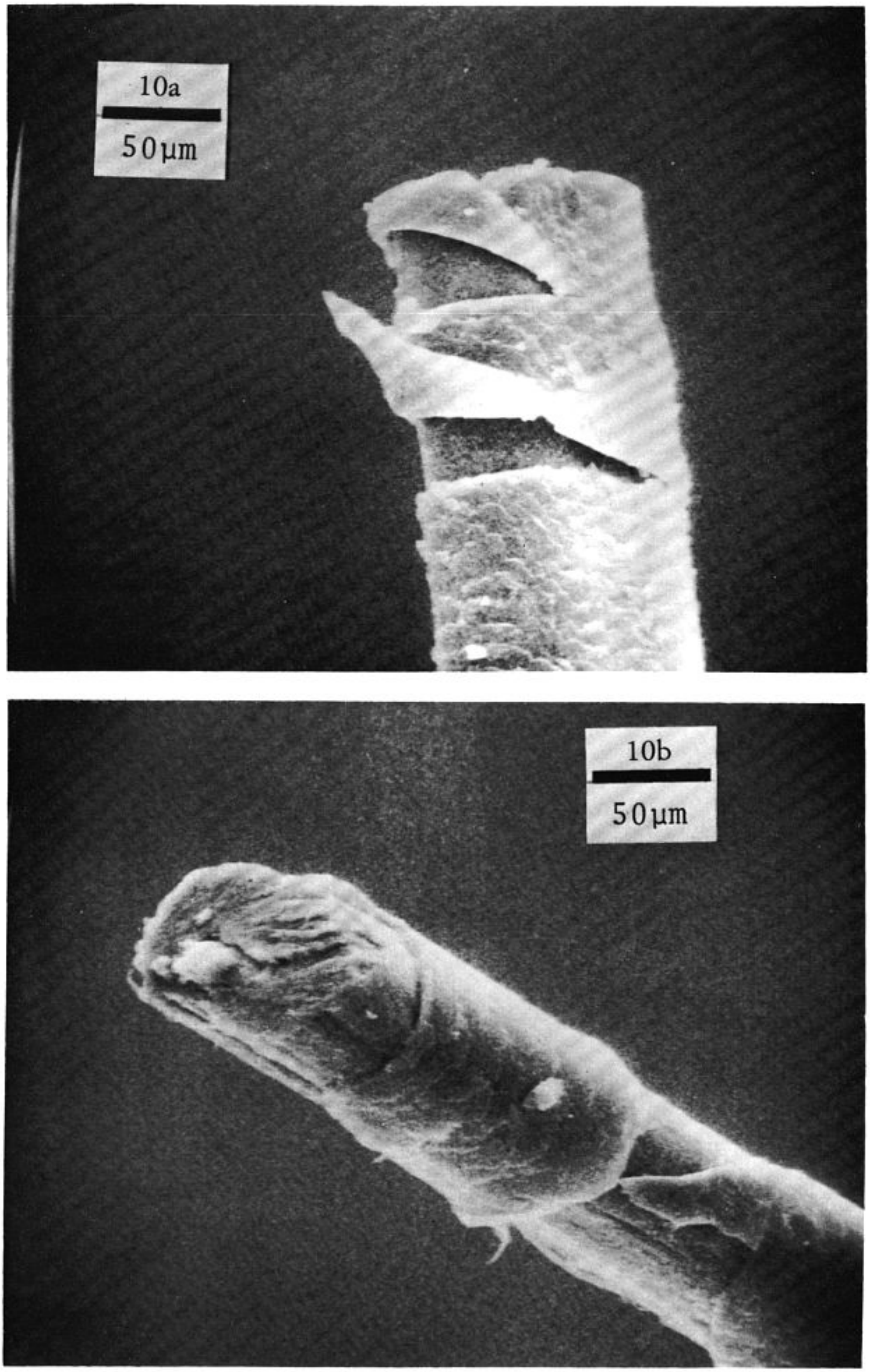


Figure 10. Fractures of 3-hr bleached hair in water showing cuticle peeling

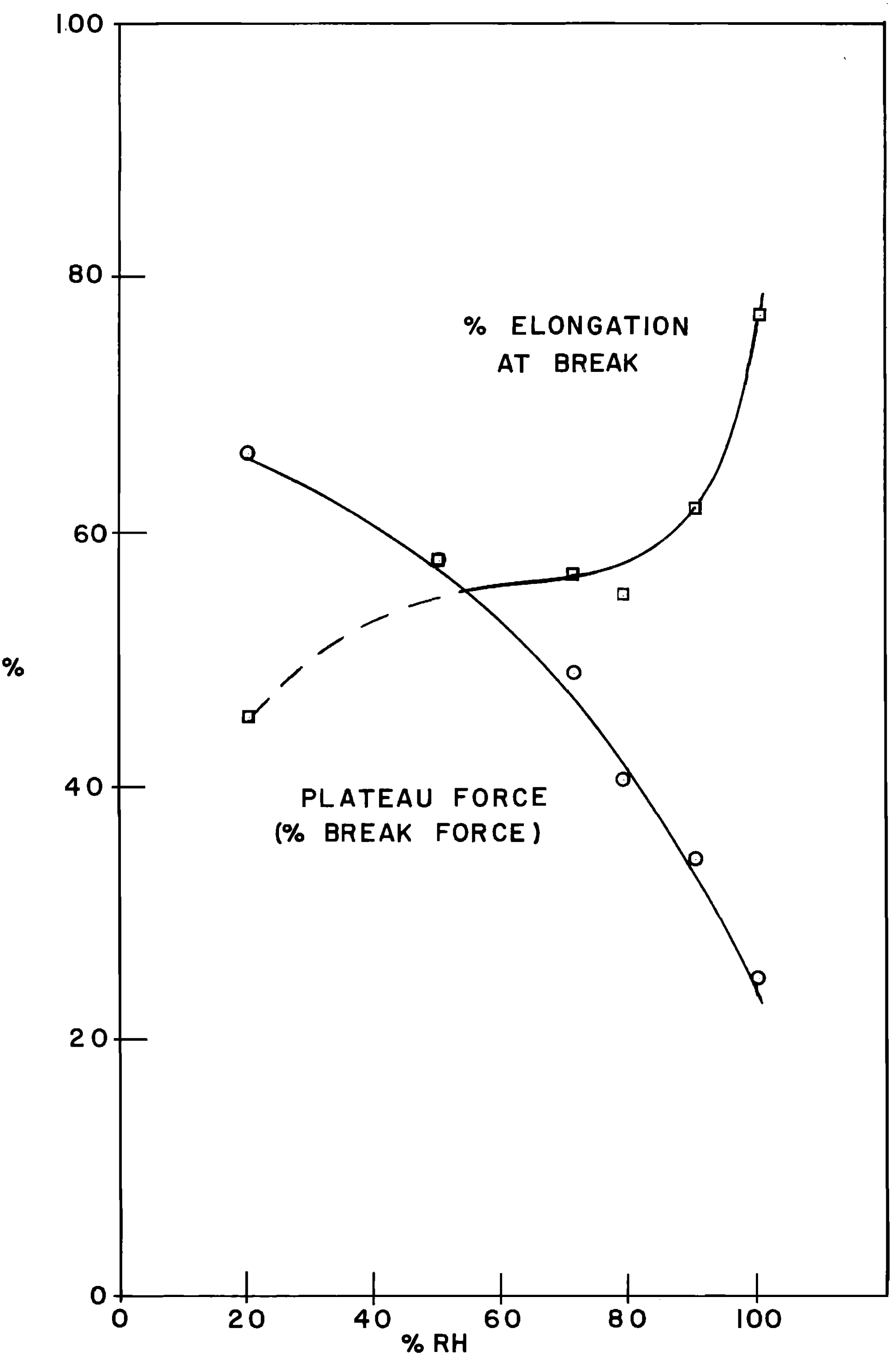


Figure 11. Stress/strain parameters vs. relative humidity

being gradually torn apart circumferentially before the catastrophic failure of the cortex. In air at relative humidities of 80% or less the cortex appears to have split axially into two or more mechanically independent subunits which failed in different radial planes, probably in rapid sequence, yielding a step fracture; in this case it appears that the cuticle fails in a pattern largely determined by that of the underlying corticle elements to which it remains firmly attached.

At 90% RH in air the cuticle and cortex fracture planes coincide as though the fiber were homogeneous. There is no evidence of prior failure of the cuticle as invariably occurs in wet breaks.

From these observations we infer that in the wet state the cortex is more extensible than the cuticle as has been reported on the basis of swelling experiments on animal hair (12, 13), but that in air at less than 90% RH the opposite is true; dry cortex is less extensible than dry cuticle. At 90% RH the extensibilities appear to be equal. Although at 50% RH the cuticle fracture seems to follow that of the cortex, its role may not be entirely passive. The fact that prior wet fracture of the cuticle leads to flat fracture of the cortex at 50% RH indicates that the cuticle is involved in the generation of the compressive or shear forces that crack the cortex axially, producing step fractures.

It is known that if hairs are stressed in water to an extension greater than their elongation at break in 50% RH air and allowed to dry under tension, they do not break until more stress is applied.

As stated above, when they are then broken, flat breaks are obtained as though the fracture had occurred in water. On the other hand, if hairs are extended almost to break at 50% RH, then hydrated and broken in water, flat breaks are also obtained. Apparently the hairs "remember" the pre-stress in water, but not the pre-stress at 50% RH. We interpret this as confirmation of the proposed mechanism, i.e. during the pre-stress in water, the cuticle fails and subsequently the cotex therefore breaks flat even in 50% RH air. The pre-stress in air did not cause failure of either the cuticle or the cortex, and the hairs therefore exhibit the normal flat break when subsequently hydrated and broken. Jagged breaks, then, are the product of failure of the cortex under conditions of intact and attached cuticle, which leads to the tearing and shredding observed.

The experiments in which hairs were pre-stressed at 50% RH, then hydrated and broken in water, provide a confirmation that wet hair is weaker than dry hair. When hairs were extended to 58% elongation (which at 50% RH is virtually the breaking point) and then hydrated, the break force is at least 15% lower than the force required during the pre-stress in air. Experimentally, this is almost equivalent to breaking the same hair segment twice—once at 50% RH and once in water, thereby eliminating sample variation.

It is remarkable how little evidence of the cellular structure of hair is revealed in its fractography. The fibrous structure of the cortex is clearly seen only on the lateral surfaces of dry step fractures. The cuticle cleaves as though it were a homogeneous sleeve; its imbricated cells do not slide over each other nor is delamination detectable except in high magnification views of some wet fractures.

This is in marked contrast to the behavior of cotton as reported by Hearle and Sparrow (11). Dry fractures of cotton are complex and elongated; wet fractures are even more elongated and their resemblance to the fracture of a yarn was taken as an indication that water weakens the interfibrillar matter.

A similar weakening might have been expected in the case of hair in view of its pronounced swelling in water, but from our data it would appear that the intercellular and interfibrillar material in both wet and dry hair is as strong as the keratinous matter in both the cortex and the cuticle. The cuticle–cortex boundary, however, is a zone of intercellular weakness in the wet state and this weakness is markedly aggravated by oxidative bleaching, as shown in Figure 10; cylindrical segments of the entire cuticle have been lost in the process of tensile fracture. This is the only evidence of bleach damage; dry breaks of bleached hair appear to be quite similar to those of virgin hair.

The weakness of this boundary is also revealed in virgin hair in sleeve fractures (Figure 2) and in the related flaring of the cuticle after its tensile failure, as seen in Figure 4. The multiplicity of the cuticle cracks on wet extension indicates that the junction with the cortex fails only locally, probably as a result of the combined forces of axial shear and radial tension generated by the elastic relaxation of torn cuticle to its unstressed length and radius. The flaring in Figure 4c is about 30% of the fiber diameter as would be expected for relaxation from 70% extension at constant volume (assuming a Poisson ratio of 0.5 throughout).

The effect of age on hair fracture is quite different from that of bleach. Where cuticle is present its bond with the cortex seems unchanged, but the cortex in old hair splits and fibrillates much more than in young hair. With reference to virgin hair, we argued above that intact cuticle is involved in the generation of splitting forces; on the same argument we would expect that loss of cuticle on old hair should lead to less, not more, splitting on tensile fracture. From the fact that the contrary is observed we conclude that the major effect of aging in the cortex as revealed in fractography is a significant decrease in the inherent cohesiveness of this tissue at the intercellular level. Loss of cuticle in vivo, however, leaves the cortex much more vulnerable to other modes of stress and we do not wish to imply that such loss is of no consequence cosmetically; on the contrary, we propose that even in young hair cuticle rupture in the wet state may have significant cosmetic consequences. The evidence of multiple fracture of the cuticle on wet extension (Figures 3 and 4) suggests a mechanism for producing "frizzies" in midshaft. If the detached cuticle were subsequently eroded away from such fracture sites the cortex would be locally exposed to mechanical and chemical attack. In extreme cases this might lead to a condition dermatologists would diagnose as acquired trichorrhexis nodosa (14).

The spongy scales seen in hairs dried in the extended state after wet stretching to cuticle rupture (Figure 4b) are thought to be the remains of cells which have split through the endocuticle layer as proposed by Swift and Bews (15) in reference to similar features on hair which had been subjected to prolonged agitation in water in their cuticle isolation procedure. It seems plausible that if the hair shown in Figure 4 were even mildly scoured in the wet state the scales would slough off and the end result would be a normal-looking hair. This is supported by our observation that after a hair has been broken in water under the optical microscope a considerable amount of scaly, isotropic matter is seen in the bath. It seems reasonable to postulate that such cracking of the swollen endocuticle will occur in hairs under tension since the inclination of the stacked cuticle cells to the fiber axis should give rise to a component of force normal to their surfaces.

This sloughing phenomenon should be studied further, especially with reference to the question of whether it occurs at the much lower extensions involved in ordinary grooming operations (such as setting wet hair on rollers) and also whether it occurs when the entire cycle of extension and relaxation occurs in water. In either case it may make a significant contribution to the gradual loss of cuticle associated with aging.

Hair fractures in dry solvents (glycerin, ethanol and ethyl acetate) look like wet fractures on cursory examination, but the absence of cuticle cracks and the location of sleeve fracture surfaces in the cortex rather than at the base of the cuticle suggest a sequence of events different from those of both wet and dry breaks.

The absence of noticeable response to pH variation and addition of surfactant indicates that the wet fracture dynamics are not very sensitive to either the charge state of the protein or to reduction of interfacial tension with the environment at the fracture site. Removal of accessible lipids with chloroform/methanol was also without noticeable effect on dry or wet fractures.

With reference to Figure 11, the shape of the curves shows that there is not a direct relationship between the plateau-force/break-force ratio and percentage of elongation at break. Nevertheless some interesting features are noted. Compared with the reported decrease in plateau force vs. relative humidity for keratin fibers (16), we find that the plateau-force/break-force ratio decreases more slowly, indicating that a decrease in the break force also occurs with increasing relative humidity. This provides a second, indirect confirmation that wet hair is weaker than dry hair.

The percentage of elongation at break is almost constant at 55 to 60% in the 50 to 79% RH range in which jagged fractures are almost invariably obtained in air. We conclude that, except for highly hydrated hairs, this is the limiting extensibility of the cortex.

It is interesting to note in connection with the difference in hair fracture at intermediate vs. very high humidities that over 60% of the observed radial swelling of wool by water occurs above 70% RH (17), indicating a change in the effect of water at high humidities. Based on our results, we propose that a similar change in hair properties occurs at high humidities. Over 60% of the change in relative rigidity of wool occurs above 65% relative humidity (18). From our data and that on wool it appears that hydration is the dominant variable affecting both the stress/strain behavior and the fracture mechanics, and that the two are interrelated. It seems appropriate to point out that our data on percentage of elongation at high relative humidities follows a trend very similar to the uptake of water by wool in the same range (19). Based on our own data, hair shows the same behavior up to 90% RH, the highest humidity at which water uptake was determined.

SUMMARY

Fracture pattern and stress/strain behavior of hair are interrelated through degree of hydration. The different fracture patterns obtained for wet and dry hair are attributed to an inversion in the relative extensibilities of the cuticle and cortex. The boundary of these two tissues is weak in the wet state and this weakness is aggravated by oxidative bleaching. Aging causes a reduction of cohesiveness in the cortex as well as a loss of cuticle; a new mechanism, not necessarily involving abrasion, is proposed for cuticle loss. Finally, a new demonstration of the lower tensile strength of wet, relative to dry, hair is presented.

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REFERENCES

(1) R. Caputo and B. Ceccarelli, Study of normal hair and of some malformation with a scanning electron microscope, *Arch. Klin. Exp. Derm.,* **234,** 242 (1969).

(2) A. Tosti, S. Villardita, M. L. Fazzini and R. Scalici, Contribution to the knowledge of dermatophytic invasion of hair, *J. Invest. Dermatol.,* **55,** 123 (1970).

(3) E. Wyatt, E. Bottoms and S. Comaish, Abnormal hair shafts in psoriasis on scanning electron microscopy, *Brit. J. Dermatol.,* **87,** 368 (1972).

(4) E. Bottoms, E. Wyatt and S. Comaish, Progressive changes in cuticular pattern along the shafts of human hair as seen by scanning electron microscopy, *Brit. J. Dermatol.,* **86,** 379 (1972).

(5) R. P. Ayer and J. A. Thompson, Scanning electron microscopy and other new approaches to hair spray evaluation, *J. Soc. Cosmet. Chem.,* **23,** 617 (1972).

(6) S. P. DiBianca, Innovative scanning electron microscopic techniques for evaluating hair care products, *J. Soc. Cosmet. Chem.,* **24,** 609 (1973).

(7) A. C. Brown and J. A. Swift, Hair breakage: the scanning electron microscope as a diagnostic tool, *J. Soc. Cosmet. Chem.,* **26,** 289 (1975).

(8) E. Bernstein, *Dynamic Experiments on Hair in the Scanning Electron Microscope,* in "The First Human Hair Symposium," A. C. Brown, Medcom Press, New York, New York, 1974, pp 317–331.

(9) N. A. Lange, "Handbook of Chemistry," 10th ed, McGraw-Hill Publishing Company, New York, New York, 1956, pp 1420–1421.

(10) J. W. S. Hearle and S. C. Simmens, Electron microscope studies of textile fibres and materials, *Polymer,* **14,** 273 (1973).

(11) J. W. S. Hearle and J. T. Sparrow, The fractography of cotton fibers, *Text. Res. J.,* **41,** 736 (1971).

(12) E. Lehmann, Mikroskopische untersuchungen über chemische und physikalische vorgänge an Pelztierhaaren, *Melliand Textilber.,* **22,** 145 (1941).

(13) J. H. Bradbury and G. V. Chapman, An investigation by light microscopy of the swelling of wool fibers, *Text. Res. J.,* **33,** 666 (1963).

(14) M. E. Chernosky, *Acquired Trichorrhexis nodosa,* in "The First Human Hair Symposium," A. C. Brown, Medcom Press, New York, New York, 1974, pp 36–49.

(15) J. A. Swift and B. Bews, The chemistry of human hair cuticle-I: a new method for the physical isolation of cuticle, *J. Soc. Cosmet. Chem.,* **25,** 13 (1974).

(16) Encyclopedia of Polymer Science & Technology, Wiley, New York, New York, **8** (1968), p 22.

(17) Ibid., p 30.

(18) Ibid., p 28.

(19) Ibid., p 37.