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Observations on the Cutting of Beard Hair

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Synopsis: A device is described which permits measurement of the force required to CUT a BEARD HAIR FIBER under a variety of conditions. Studies with this device show that the force required to cut wet beard fibers with commercial razor blades is about 65 per cent less than that of dry fibers. Beard hair is almost completely hydrated by exposure to water for about 2 minutes at room temperature, and this hydration is accelerated by an increase in temperature. The force required to cut a beard hair increases with increasing fiber cross-sectional area, but this correlation is not perfect. The force required to cut beard hair is not lowered below that in water by the presence of a wetting agent, a shaving cream, or a soap solution. The force required to cut wet beard hair with a razor blade is lowered significantly by very severe attack on the fiber. On the other hand, the force required to cut beard hair increases as the rate of blade travel increases.

INTRODUCTION

Since the classical study by Hollander and Casselman (1) very few publications have dealt with the physics of shaving or the cutting of beard hair. Their study was based mainly on subjective evaluations by shaving panelists and included only minimal objective information obtained by mechanical testing (creep measurements) and microscopic examination.

The present study was designed to measure the force required to cut single beard fibers with commercial razor blades under conditions approximating the *in vivo* situation.

No attempt was made to analyze the problem of hair cutting mathematically. In accordance with the classical concepts of Dupré (2) one approach might be to equate the work-to-cut to the work to create two new cross-sectional hair surfaces plus frictional effects. Another approach would utilize a mathematical treatment of the elasticity of anisotropic materials, which according to Muskhelishoili (3) is extremely complex.

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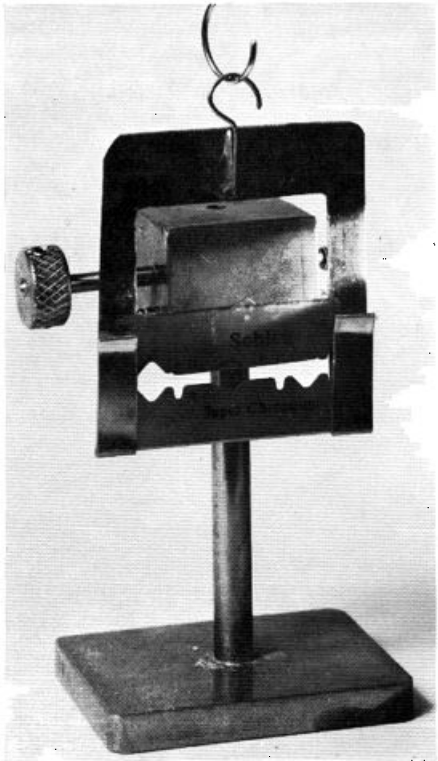
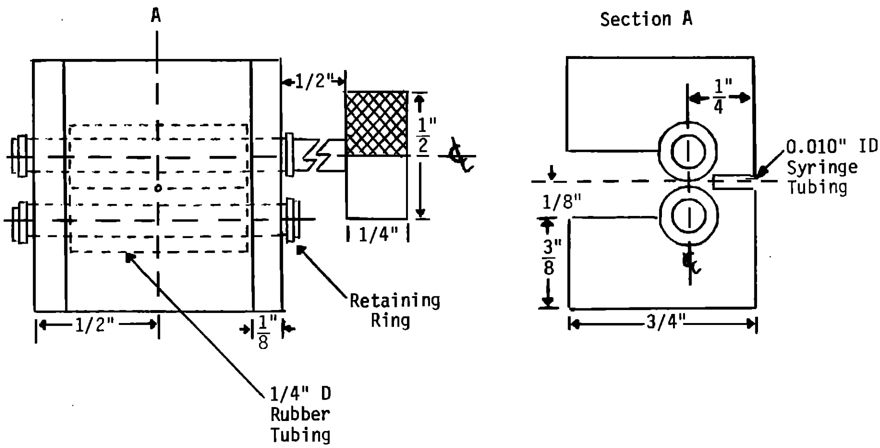


(a)



(b)

Figure 1. Beard Cutting Jig: (a) Overall view; (b) construction details. Jig is constructed of brass and supported with brass rod and base. Rollers are ⅛ in. i.d. rubber tubing with 1/16 in. walls. Syringe tubing is set into hole flush with front face

Experimental

Preliminary investigations involved selection of the most useful geometry for cutting fibers. Anvil cutting, i.e., forcing a blade through a fiber, placed on a compression cell of an Instron® tester,* was found to require very precise positioning of the blade to prevent premature contact of the blade with the cell. Catenary cutting, i.e., pulling a blade through a fiber held firmly at both ends, but without any tension, was found to produce scraping along the fiber before cutting unless the blade was centered exactly.

The method finally selected was cantilever cutting in which the beard fiber is allowed to protrude through a hole from the face of a brass jig (Fig. 1) placed on the crosshead of an Instron tester. The jig consists of a brass face, into which a 0.010-in. i.d. syringe tube bushing was inserted, and a set of rubber rollers to advance the fiber rapidly between cuts. The cutting blade was placed in a stirrup which was hung from the low range transducer (full scale 2 to 50 g) of a model TM Instron Tester. The fiber is cut by movement of the jig relative to the stationary blade. The angle between the blade and the face of the jig is approximately 3 degrees in order to prevent the blade from moving away from the face of the fixture. During and between cuts, the fibers were maintained "in" the solution of interest by pumping the solution from a constant temperature bath through a capillary pipette which directed the stream onto the fiber and into the syringe tubing in the face of the fixture.

The blades were randomly selected from one production lot of double edge

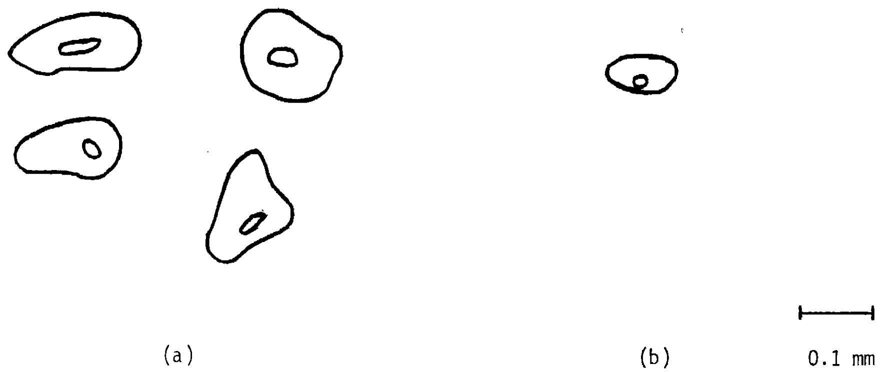


Figure 2. Typical cross sections of (a) beard and (b) head fibers

*Instron Corp., Canton, MA.

Schick blades coated with Vydax®* and were discarded after 5 to 10 cuts. No effort was made to examine or control variations in honing from blade to blade. Since only a few cuts of one fiber were made with each blade, and since these cuts occurred randomly over a distance of several millimeters along the blade edge, blade damage due to cutting was assumed to be minimal and neglected.

The TM Instron Tester recording system was used for measuring the cutting forces at speeds up to 5 in./min. A Tectronix®† storage oxcilloscope (Model RM564) fitted with a strain bridge was used to measure forces at cutting speeds up to 50 in./min. By combining both methods, cutting forces were measured at speeds ranging from 0.1 in./min to 50 in./min.

The use of scalp hair as a model for beard hair proved unacceptable, since the diameter of scalp hair is appreciably smaller and the cross-section much more regular than that of beard hair. Cutting force measurements in our laboratories demonstrated conclusively that scalp hair requires less force-to-cut (f-t-c) than beard hair. This may be merely a reflection of the fiber diameter or may be the result of the unexpected irregularity of beard hair cross-sections as shown in Fig. 2. Although Hollander and Casselman (1) reported that white beard fibers are more difficult to cut than dark fibers, it was found here that the presence or absence of melanin had no effect on the f-t-c.

The majority of the fibers used in this study were plucked from the beard of one subject. However, this was done only after comparing these fibers with those of four other volunteers and ascertaining that they were representative of beard fibers in general.

All chemicals used were analytical reagents except in the case of detergents, which were of commercial quality.

Results and Discussion

f-t-c versus Cross-sectional Area

Beard fibers removed by plucking from 5 subjects were completely hydrated and then cut 10 times at a rate of 0.5 in./min, while a stream of water at about 25°C was played on the fiber in the jig. The snippets created by the cuts were less than 1 mm long, and beard fibers as short as 3 cm suffice to yield statistically meaningful data. After each cut, the cross-section of the freshly cut surface was established by quickly photomicrographing the fiber in the jig and then determining the area with a planimeter. A plot of the f-t-c against the cross-sectional area is not very revealing (Fig. 3). Nevertheless, the slope for each fiber was determined by a linear regression analysis which forces the

*Vydax is a registered trademark of the E. I. du Pont Co., Wilmington, Del.
†Tectronix Inc., Beaverton, Oregon.

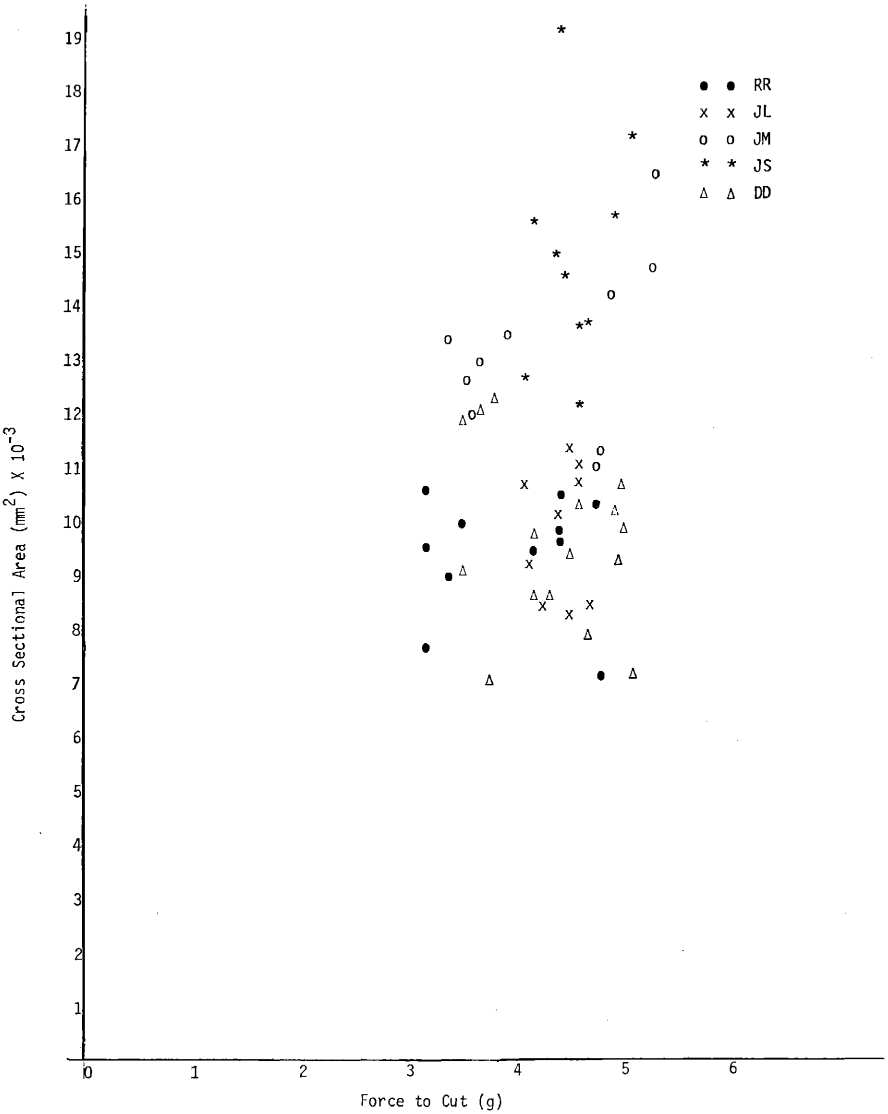


Figure 3. Cross-sectional area vs. cutting force

line through the origin (4), and the slope of this line is included in the tabulation of the data in Table I.

An examination of Fig. 3 and of the data in Table I suggests that there is some correlation between fiber diameter and f-t-c. The average standard error of the slope is about 5 per cent, while the average standard error of the

Table I
f-t-c of Beard Hair

Subject	Cross-Sectional Area mm^2 x 10^4 ± Std Error	Cutting Force in (g) ± Std Error	Slope (g/mm^2) ± Std Error
JM(a)	122 ± 3.9	3.93 ± 0.23	322 ± 27
(b)	147 ± 6.2	4.85 ± 0.33	332 ± 15
RR(a)	99 ± 2.1	4.43 ± 0.09	445 ± 7.7
(b)	94 ± 4.9	3.36 ± 0.07	358 ± 14
JL(a)	115 ± 5.3	4.49 ± 0.11	389 ± 15
(b)	89 ± 3.4	4.40 ± 0.10	494 ± 24
JS(a)	142 ± 9.3	4.52 ± 0.18	318 ± 17
(b)	160 ± 10.5	4.56 ± 0.11	285 ± 21
DD(a)	82 ± 5.8	4.50 ± 0.22	550 ± 45
(b)	121 ± 1.2	3.67 ± 0.09	303 ± 4.4
(c)	96 ± 2.3	4.68 ± 0.12	487 ± 11

f-t-c is about 4 per cent. Since the errors are of the same order of magnitude, there appears to be no need to utilize the time-consuming determination of the cross-sectional area. Instead, the f-t-c suffices for all practical purposes.

F-t-c versus Rate of Cutting

In order to determine how the speed of travel of the blade through the fiber affects the f-t-c, two fibers were cut at 5 different cutting rates varying between 0.1 in./min to 50 in./min. Although there is a spread in the data (Fig. 4), linearity is assumed over the range studied.

For practical purposes, it appears that the f-t-c increases significantly as the rate of cutting is increased. It is noted that a rate of cutting of 50 in./min approaches normal shaving conditions. Nevertheless, the much slower rate of 0.5 in./min was routinely used here in order to avoid the time-consuming complication of employing a storage oscilloscope.

Effect of Moisture on Cutting Force

It is an axiom of shaving tradition that the presence of water facilitates shaving and reduces discomfort. This tradition finds scientific support in the observations that the shear and tensile moduli of keratin fibers are functions of the relative humidity (5) and that hair is appreciably weakened by complete hydration.

The influence of relative humidity on the f-t-c was established by conditioning beard hairs at various humidities and cutting them at that humidity in an environmental chamber positioned on the Instron Tester. The cutting forces (normalized to the value at 0 per cent R.H.) are plotted in Fig. 5, which also includes curves for the shear and tensile moduli computed from

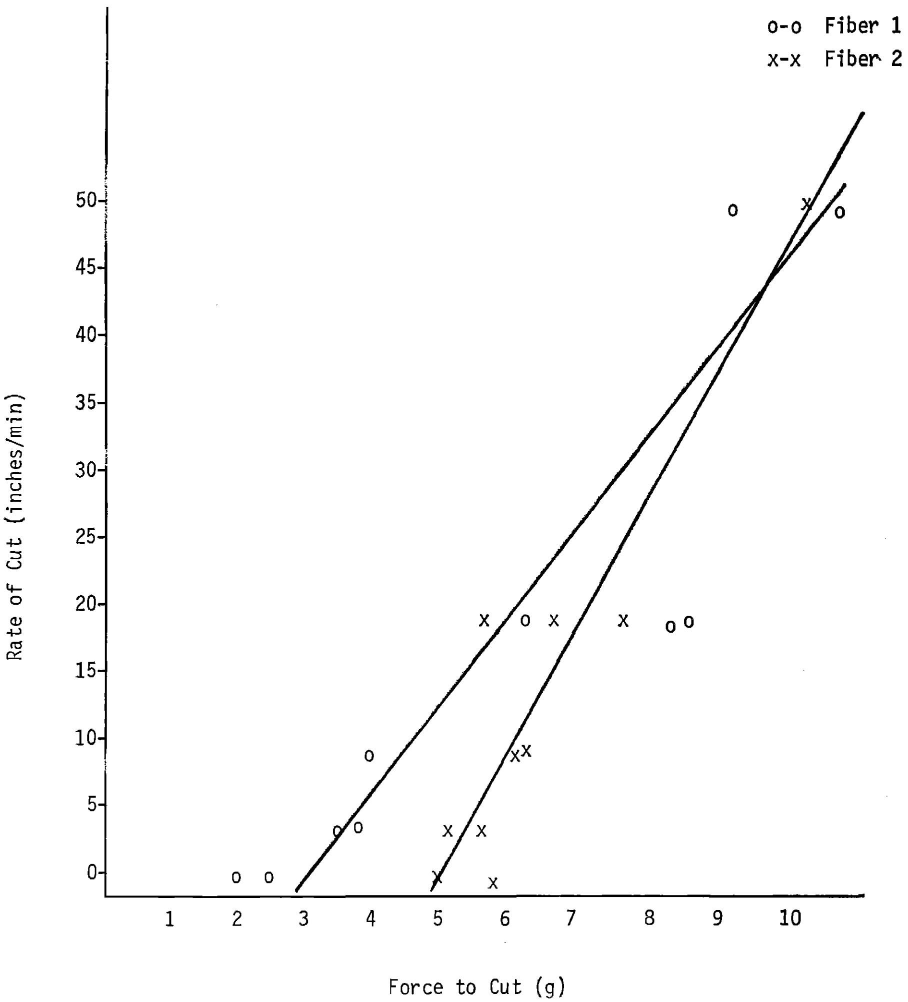


Figure 4. Cutting rate vs. cutting force (cantilever)

the data of Mitchell and Feughelman (5). The fact that the cutting force is less dependent on relative humidity than the shear or tensile modulus suggests that these moduli—even at a rate of 0.5 in./min—are not the predominant factors in beard hair cutting. Instead, the f-t-c might be more closely related to stress propagation or to the creation of new surface area, than to the viscoelastic properties of the fiber.

Hollander and Casselman (1) made creep measurements on scalp hair, which they then extrapolated to beard hair, to determine the rate of softening

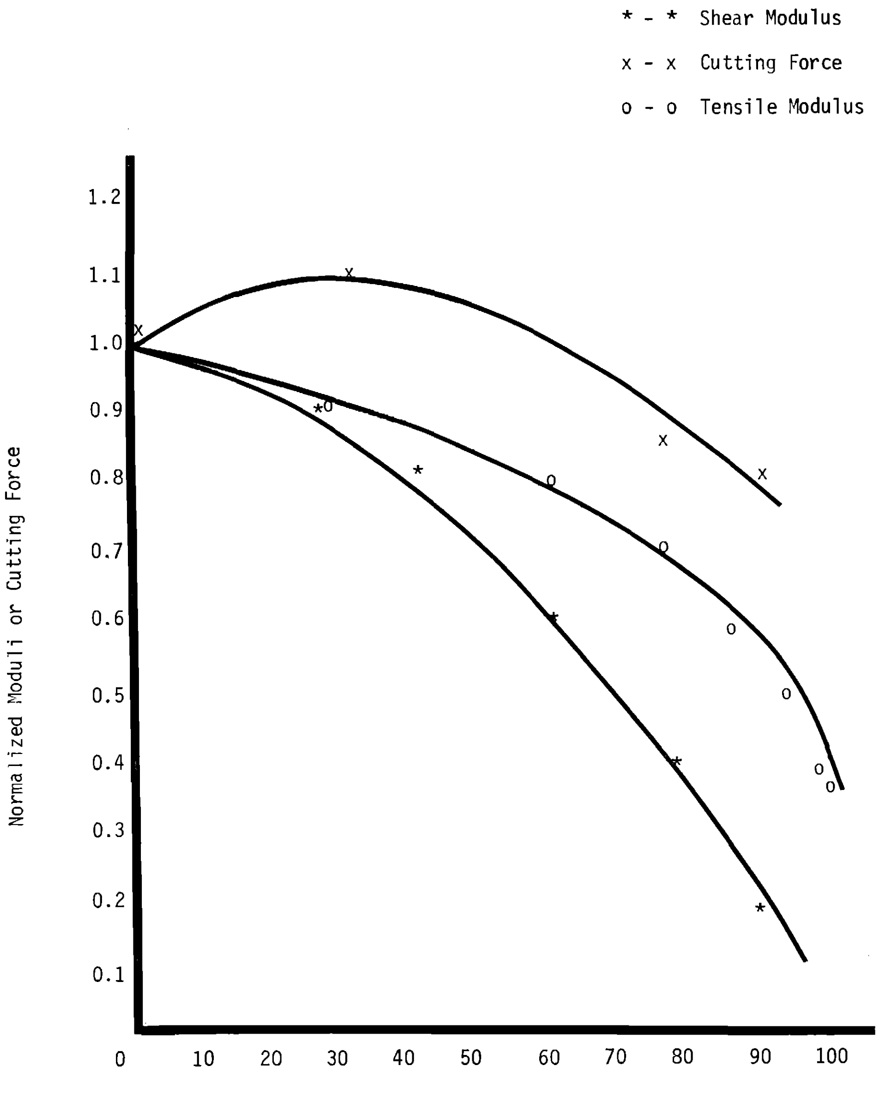


Figure 5. Normalized moduli or cutting force vs. per cent R.H.

of the hair with increased temperature. Their extrapolated value was 2½ to 3 min for complete hydration at 120°F.

The hydration studies reported below were performed as follows: (1) a fiber was cut 10 times at ambient humidity to determine an equilibrium dry

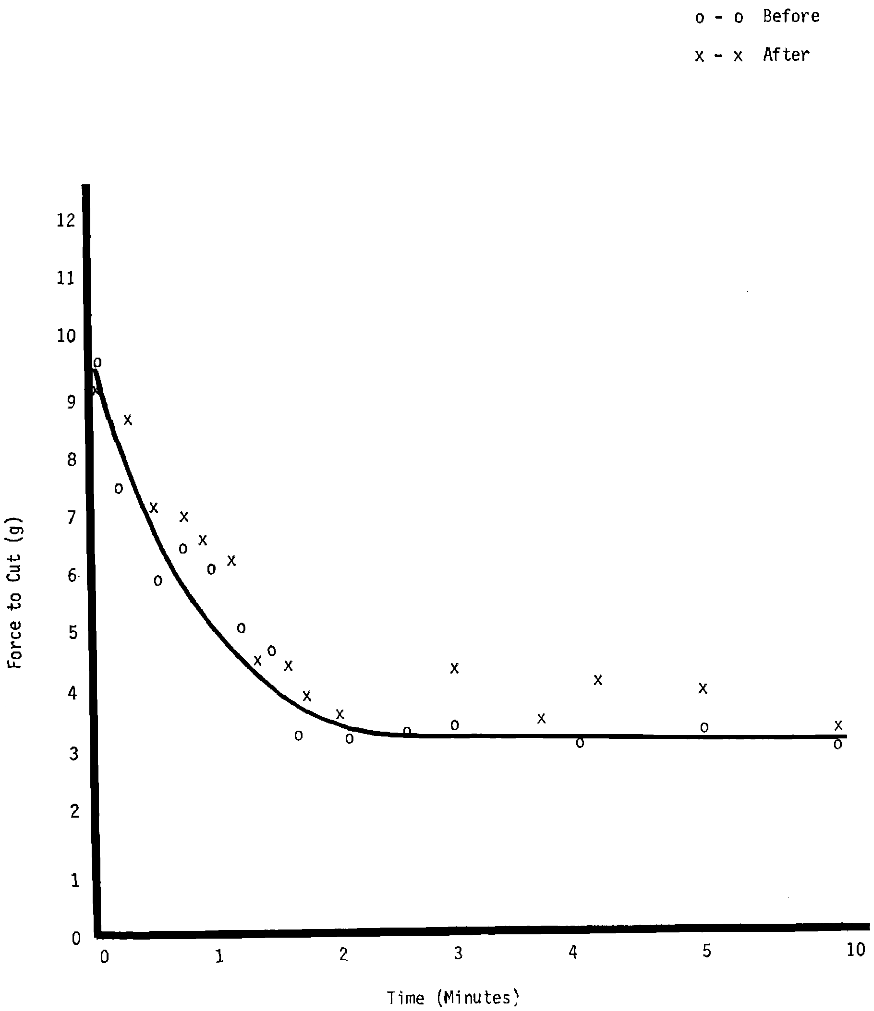


Figure 6. Hydration time before and after washing with sodium lauryl sulfate (0.5 per cent) at 23° C

value;* (2) a stream of water or of a test solution was directed at the fiber, and cutting forces were determined as rapidly as possible during the first 2 min; after this, cuts were made at 1 min intervals; (3) after 10 min a series of 10 cuts were made as a measure of the equilibrium cutting force in the wet state.

*Fig. 5 shows that the "dry" f-t-c is relatively insensitive to variations in the range of 10 to 60 per cent relative humidity.

Table II
Hydration Time and Cutting Force as a Function of pH

pH	9.1	6.84	4.01
Buffer	0.01 *M* borax	0.05 *M* phosphate	0.05 *M* phthalate
Hydration time (min) ± std dev.	2.60 ± 0.47	2.13 ± 0.26	2.16 ± 1.21
Force to cut wet (g) ± std dev.	4.01 ± 0.40	3.91 ± 0.39	4.31 ± 0.31
Ionic Strength of buffer	0.060	0.091	0.053

The results of a typical experiment are shown in Fig. 6. Following the determination of the initial hydration curve at 23°C (Fig. 6, before), the fiber was washed in 0.5 per cent aqueous sodium lauryl sulfate solution, rinsed with distilled water, and dried for 48 h in a desiccator over P_2O_5; a second hydration curve was then determined (Fig. 6, after). The absence of any significant difference suggests that the rate of hydration is not altered by the removal of surface lipids. Based on the f-t-c, beard hair fibers appear to have been completely hydrated by exposure to water at room temperature within about 2 to 3 min.

The rate of hydration of beard hair and the f-t-c could be expected to be dependent on the pH of the aqueous medium. Accordingly, cutting measurements were made in various buffer solutions, and the results are summarized in Table II.

Any differences between the hydration times or between the f-t-c are statistically insignificant. The ionic strengths and chemical composition of the buffers are different, but the variations are not likely to affect the results. These rather unexpected data indicate that the pH has little or no effect on the f-t-c or on the rate of hydration of beard hair.

Effect of Temperature on Cutting Force

It is part of shaving folklore that the use of cold water during shaving leads to an uncomfortable shave. It seemed important, therefore, to measure the effect of water temperature on the cutting force. Three types of experiments were performed on wet fibers and on dry fibers. For measurements on dry fibers, the fixture used for cutting beard fibers was fitted with a heating tape and a surface thermocouple. A single hair was cut (dry) 10 times at each of 4 temperatures. The average cutting forces and the standard deviations are tabulated in the chart below and indicate that the f-t-c of dry fibers is lowered by raising the temperature.

Temperature (°C)	23	56	65	75
f-t-c (g) ± std dev.	17.6 ± 1.5	14.5 ± 1.3	12.3 ± 0.80	13.1 ± 0.84

Significance (Values connected by underlining are significantly different)

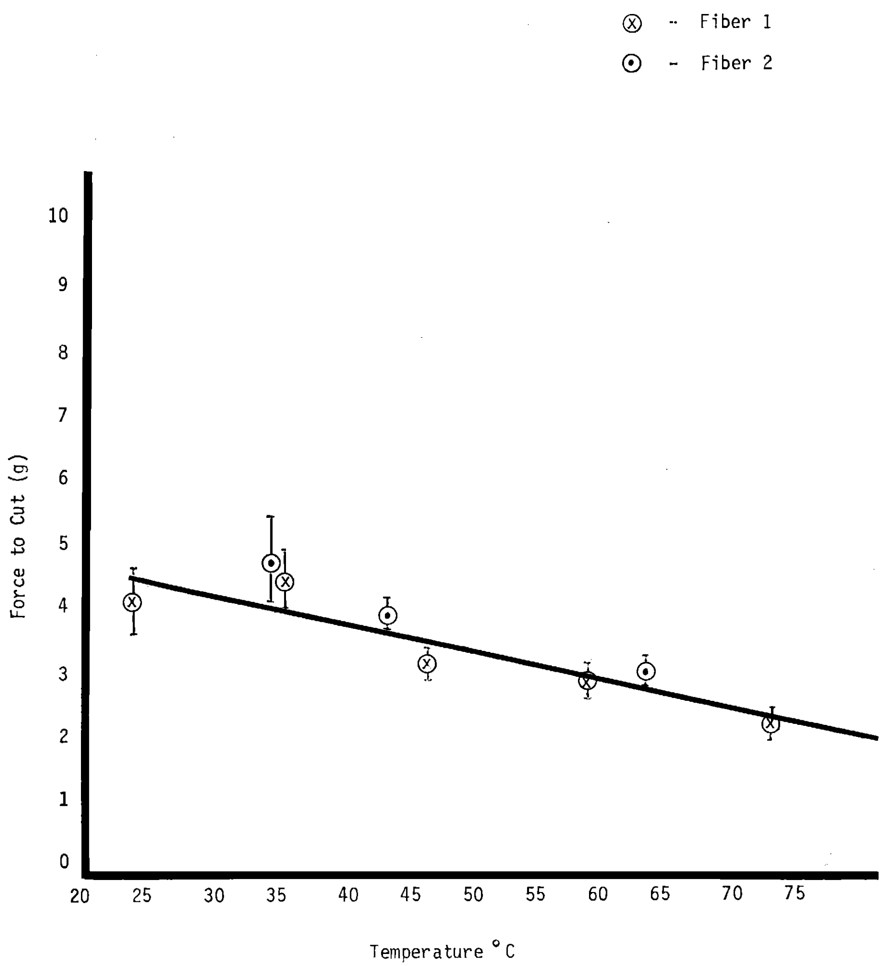


Figure 7. Temperature (°C) vs. force to cut (g) on same fiber (wet)

Similar studies of wet beard hair were conducted by measuring the cutting force of thoroughly hydrated fibers which were maintained at the desired temperature by playing a stream of warm water on the fiber positioned in the jig. Two fibers were each cut about 10 times at each of 4 or 5 temperatures, and the results are shown in Fig. 7. The computed least square slope indicates that the f-t-c is lowered by 0.051 g/°C. These data demonstrate that shaving should be easier at elevated temperatures.

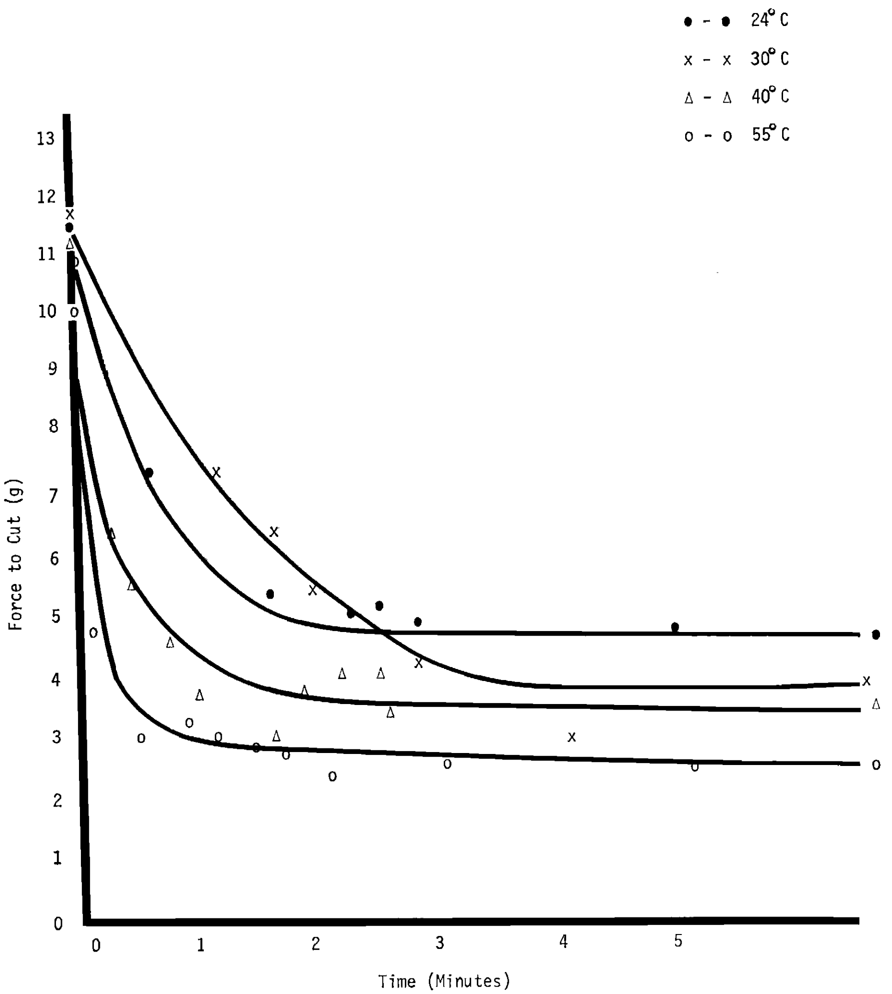


Figure 8. Force to cut as a function of time of hydration of beard hair in dilute (0.5 per cent) sodium lauryl sulfate at different temperatures

In a third study the influence of temperature on beard hair hydration time was determined in the presence of a wetting agent (0.5 per cent sodium lauryl sulfate). In view of the number of cuts required, it was necessary to use different hairs at different temperatures; the fibers were selected to exhibit the same dry cutting force at room temperature. Nevertheless, one anomaly occurred in the data at 30°C. All the data are summarized in Fig. 8. It is apparent that the time required for full hydration is shortened by increasing the temperature. Again (see Fig. 6), the f-t-c completely hydrated fibers decreases as the temperature is raised.

Effect of Chemical Treatments

The results of the studies reported so far indicate that the rate of hydration of beard hair is relatively fast and that softening—as measured by f-t-c—is not significantly altered by modest changes in pH or the presence of a wetting agent. In view of this, the effect of potassium stearate solution, aerosol shaving cream concentrates, and several finished commercial creams on the f-t-c hair was determined. None of these materials showed any reduction of the hydration time or of the f-t-c the fiber beyond that effected by water. Therefore, it was decided to utilize a few more drastic chemical treatments.

Since 1-propanol/water mixtures are known to make hair easier to extend (6) a 45:55 (w/w) 1-propanol/water mixture was directed on the fiber during cutting. The data given in the chart below show that the difference between the wet and dry cutting force (47 per cent lowering) is about the same as that of samples treated with distilled water (51 per cent lowering). The hydration time is comparable to that of water-treated fibers.

	Dry	Wet (propanol/water)
Average f-t-c (g) ± std dev.	6.20 ± 1.40	3.27 ± 0.82
Hydration times (min) ± std dev.	—	2.76 ± 1.44

In a more drastic procedure, beard fibers of known wet f-t-c were soaked in a commercial waving lotion (6.0 per cent thioglycolic acid, pH 9.3) for 5, 7, and 10 min, rinsed in several changes of distilled water, and then cut under a stream of water. The results tabulated in the chart below confirm again that significant chemical attack (7 min in waving lotion) on the fiber causes only a minor (13 per cent) reduction in the cutting force (98 per cent confidence level). Fibers exposed to the waving lotion for 10 min could not be cut because of excessive damage to the fiber, which allowed it to bend and to be split axially.

	f-t-c ± Std Dev. (in g)	
Time of Waving Lotion Treatment	Control	Treated
5 min	3.95 ± 1.06	4.20 ± 0.65
7 min	5.20 ± 0.57	4.51 ± 0.54

McLaren (7) has shown that wool is reduced more drastically in thioglycolic acid in aqueous 1-propanol (45:55 w/w) than aqueous thioglycolate. Therefore, it was decided to measure the cutting force of fibers soaked (for 2 or 5 min) in 1-propanol/water (45:55) containing either 0.5 per cent or

6.0 per cent thioglycolic acid adjusted to pH 9.2 with ammonia. In a separate set of experiments fibers were also treated with either 0.5 per cent or 6.0 per cent thioglycolic acid at pH 11.3 (with sodium hydroxide) for 2 or 5 min. Only exposure to 6 per cent thioglycolic acid at pH 11.3 for 5 min effected any lowering of the cutting force over that of water. The majority of the fibers with this treatment disintegrated before they could be cut, and the two fibers which could be cut bent during cutting.

The conclusions, which must be drawn from these studies, are that even the most severe chemical (covalent bond) damage, which is known to lower the tensile modulus drastically, has almost no effect on the force required to cut beard hair. In addition, rupture of hydrophobic bonds by 1-propanol/water also appears to have almost no effect on the f-t-c.

Conclusion

A device is described which permits measurement of the force required to cut a beard hair fiber under a variety of conditions. Studies with this device show that the force required to cut wet beard fibers with commercial razor blades is about 65 per cent less than that of dry fibers. Beard hair is almost completely hydrated by exposure to water for about 2 min at room temperature, and this hydration is accelerated by an increase in temperature. The force required to cut beard hair is not lowered below that of water by the presence of a wetting agent, shaving cream, or soap solution. The force required to cut wet beard hair with a razor blade is lowered significantly by very severe chemical attack on the fiber. On the other hand, the force required to cut beard hair increases as the rate of blade travel increases.

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