J. Cosmet. Sci., **68**, 137–140 (January/February 2017)

A unifying theory for visualizing the causes of hair breakage and subsequent strategies for mitigation

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INTRODUCTION

The performing of constant rate extension experiments to generate stress–strain curves represents one of the most fundamental tests within the hair care industry, and is most commonly used in assessing structural damage imparted by various hair insults. Yet this must be considered a *characterization* technique, as this one-time catastrophic deformation of samples is not especially representative of real-life habits and practices. The repetitive nature of grooming practices begs an analogy to materials failing under fatiguing conditions and this presentation compares and contrasts hair breakage results from these two types of mechanical test. It becomes apparent that extensively different conclusions can arise from performing these two testing approaches on common sets of samples. This forces us to rethink the reasons and causes for hair breakage, and, in doing so, a new approach for conceptualizing this occurrence is proposed.

METHODS

Both single-fiber stress–strain and fatiguing experiments on hair were performed using commercially available automated mechanical testing equipment (Dia-Stron Ltd, Andover, UK). These methodologies have been described previously (1–4). All testing was performed with equipment housed in benchtop environmental chambers to ensure controlled climatic conditions. In certain instances, single-fiber fatigue experiments were supplemented by automated repeated grooming experiments that were performed on a custom-built device (2,5).

RESULTS

Figures 1 and 2 show results obtained from testing virgin Caucasian hair under differing climatic conditions. Figure 1 shows the break strength of hair decreasing significantly with increasing relative humidity; yet, the S-N curves in Figure 2 show a dramatically larger effect.

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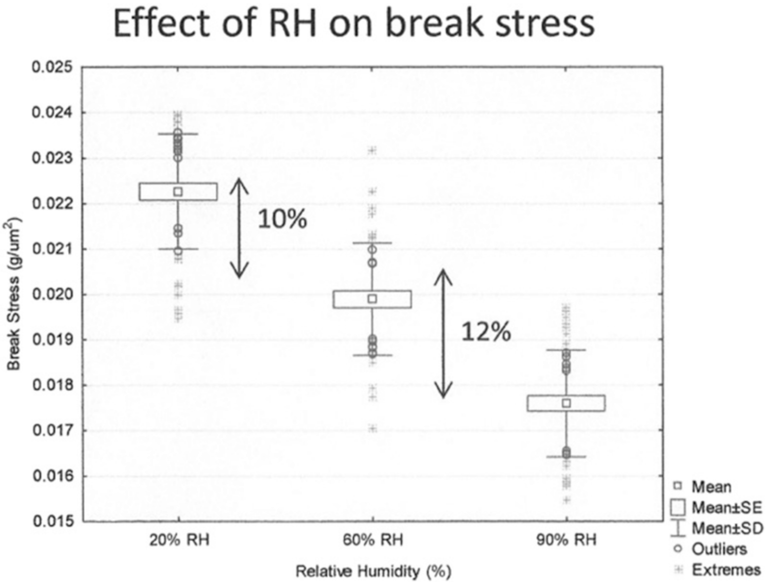

Figure 1. Decrease in break strength of hair with increasing relative humidity.

This is a common finding, with single-fiber fatigue experiments frequently showing much larger differences among test samples, and potentially suggesting that traditional stress–strain curves have been providing underestimates as to the effects of various insults on hair breakage. In the above example, it is hypothesized that increased plasticization of hair at elevated humidity results in a common force inducing greater deformation of the sample, and repeated application of this increased strain leads to faster breakage. Corroboration for this postulate has been obtained by determining that other treatments/conditions that plasticize hair also give rise to similar effects.

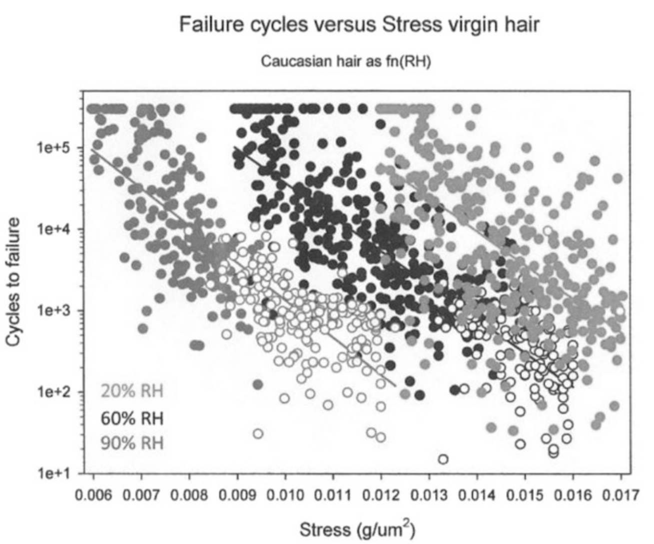

Figure 2. Cycles-to-break for single hair fibers as a function of applied stress and relative humidity.

DISCUSSION

The traditional stress–strain approach for assessing hair strength probes the underlying tensile properties of hair fibers, including average one-time stresses and strains to induce breakage. However, materials break at their weakest point, and the presence of any flaw represents a nucleation site that can be propagated to failure by repeating deformations. Therefore, by fatigue theory the tendency for failure lies with both the presence and propagation rate of flaws within a sample.

A variety of parameters can be conceptualized as contributors to the presence of flaws in hair: condition of the hair; exposure to chemical treatments, UV, etc.; mechanical flaws caused by ponytails, braids, etc.; hair type; hair length; etc. Similarly, factors can be identified that are expected to influence flaw propagation rates. Figure 2 shows how application of higher stresses produces an exponential increase in the tendency for hair breakage. Therefore, repeated applications of higher (grooming) forces or application of comparable forces to thinner fibers should quicken flaw propagation. The effect of the hair's mechanical properties on propagation rates has already been discussed. Factors outlined earlier relating to the presence of flaws are those traditionally cited when discussing reasons for increased hair breakage, whereas those associated with propagation rates have not traditionally been considered. Yet, modeling work based around extensive experimental data suggests that factors associated with propagation rate of flaws have a markedly stronger influence on the tendency for breakage.

To this end, our industry already possesses the means for slowing flaw propagation, namely, surface lubrication provided by traditional conditioning products lowers grooming forces, which reduces the magnitude of fatiguing forces and results in an exponentially slower tendency for fiber breakage (see Figure 2). This occurrence can be demonstrated in a more consumer-relevant manner by performing repeated grooming experiments, where hair tresses are continuously brushed with periodic counting of broken fibers. Figure 3 shows

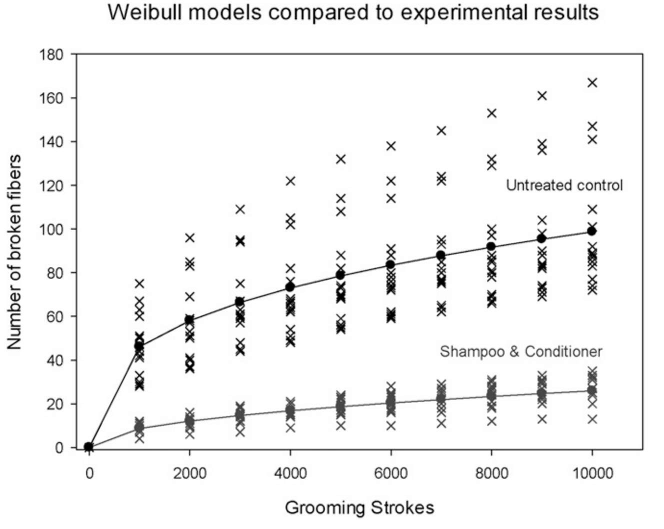

Figure 3. Decreased hair breakage as a result of applying traditional products in a repeated grooming experiment.

the sizable benefits of a typical commercial shampoo and conditioner regimen on the tendency for hair breakage in such an experiment.

CONCLUSIONS

Conceptualization of hair breakage in terms of fatigue testing principles (i.e., the presence and propagation rate of flaws) leads to a simple and succinct underlying theory that explains the tendency for this occurrence under a range of conditions. In accordance with scientific principles, this theory explains the effect of customary insults, while also making predictions by which the model can be tested and refined. To date, experimental findings are in good agreement with such predictions, and, in some cases, demonstrate considerable impact from previously unrecognized factors.

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