J. Cosmet. Sci., **60**, 135–141 (March/April 2009)

The Aqualon SLT: A novel device for measuring hair stiffness and lubricity

K. ABRAHAM VAYNBERG and M. NALL, *Ashland Inc.,*
500 Hercules Road, Wilmington DE 19804.

Synopsis

The ability to quantify hair property changes in response to treatment is essential to the successful development of new formulations and benefiting agents. In the attempt to expand the toolbox of hair tress testing tools, we developed a device that allows hair scientists to measure hair tress changes in stiffness and lubricity. The tool is based on a system of pins mounted on free rotating bearings and is operated in two modes: rotating and stationary. The hair attributes are measured by threading a hair tress through the pin assembly and measuring the total work of pulling through in rotational and stationary modes (the latter mode is obtained by immobilizing pins by a retaining plate). The data thus obtained is de-convoluted into the work of apparent stiffness (rotational mode) and the work of the friction-on-pins or lubricity (stationary mode minus the apparent stiffness). The data can be further reduced to produce an apparent friction coefficient defined as a ratio of the apparent lubricity to the apparent stiffness.

This work demonstrates the utility of the parameters measured by the Aqualon SLT and illustrates how the device can be used to predict and understand the impacts of various hair treatments.

INTRODUCTION

Consumer panel studies are the ultimate in decision making when it comes to personal care products. These studies, however, are expensive and time consuming to be suitable for day-to-day R&D activity and thus, not surprisingly, every application lab contains devices intended to quantify hair attributes to help streamline the development process.

The single most widely used test is based on measuring the combing forces in both the wet and dry state, first described by Newman *et al.* (1) and further improved by Kamath *et al.* (2). The test captures the effect of conditioning treatments and generally reflects the combined characteristics of comb-to-hair friction, hair-to-hair friction, hair entanglement, stiffness and volume (applicable in dry state).

Hair stiffness is an attribute recognized to be important to hair styling and relates to the body and volume of a hair assembly (3). Several methods exist to measure hair fiber stiffness. For example, hair fiber stiffness can be deduced from fiber bending characteristics (4) or through torsional rigidity (5). These methods provide fundamental mechanical information for individual hair fibers but the information can not be readily extended to the hair assembly stiffness due to the hair fiber variability and the fiber to fiber interaction.

A three-point bending experiment had been recently described to measure "hair suppleness." In this experiment, a tool imposing the three-point bend was slid along the tress length and the force measured. "Suppleness" thus combines attributes of the hair friction on the tool, fiber-fiber friction and the flexural stiffness of hair (6). Our own device, conceived and developed independently of this work, takes the approach a step further by allowing to separate the contributions of fiber-fiber friction and stiffness, referred to as *apparent stiffness* in this work, from the friction on the surface of the tool, defined as *apparent lubricity.* The design of the Aqualon SLT, measurement method, and the utility of stiffness and lubricity are described herein.

AQUALON SLT DESIGN AND MATERIALS

Figure 1 illustrates a prototype version of the Aqualon SLT* in the assembled state placed on a platform at the base of the Instron Tensile Tester. The plastic screw on the face of the device is used to switch between rotational (pins can freely rotate) and stationary (pins immobilized) modes of operation. The action of the screw is illustrated in Figure 2. The inside of the detached face plate shows attached rubber circles located, when assembled, opposite to the pins. When the face plate is engaged, the rubber circles push on the pins and immobilize them. Alternatively, when the screw is pulled out, the spring (also shown in the figure) acts to push the plate away from the pins thus allowing them to rotate freely. Pins are covered by tightly fitting replaceable Teflon sleeves.

Figure 3 shows how the hair tress is threaded through the tool. Testing was carried out with Caucasian virgin and bleached hair tresses from International Hair Importers weighing 3 grams and measuring 1″ × 12″. The Aqualon SLT, however, can be readily adjusted

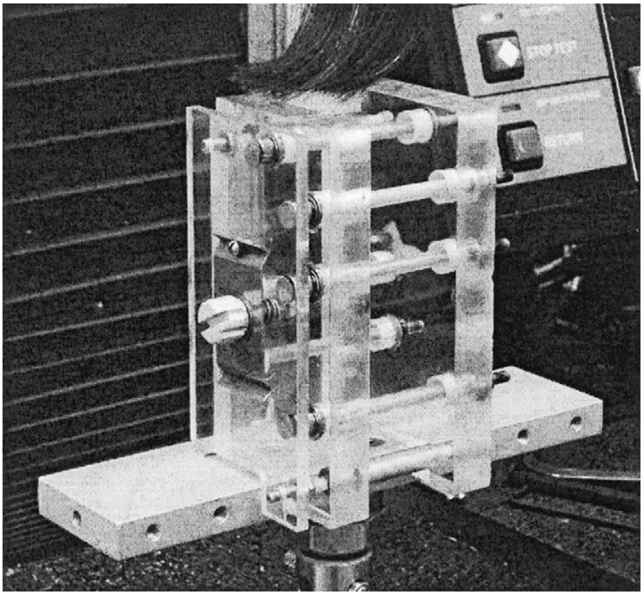

Figure 1. The Aqualon SLT placed on platform mounted on Instron Tensile Tester.

---

*Patent pending. The Aqualon SLT device in its improved form can be obtained from Ashland Aqualon Performance Materials by contacting Abe Vaynberg at kvaynberg@herc.com

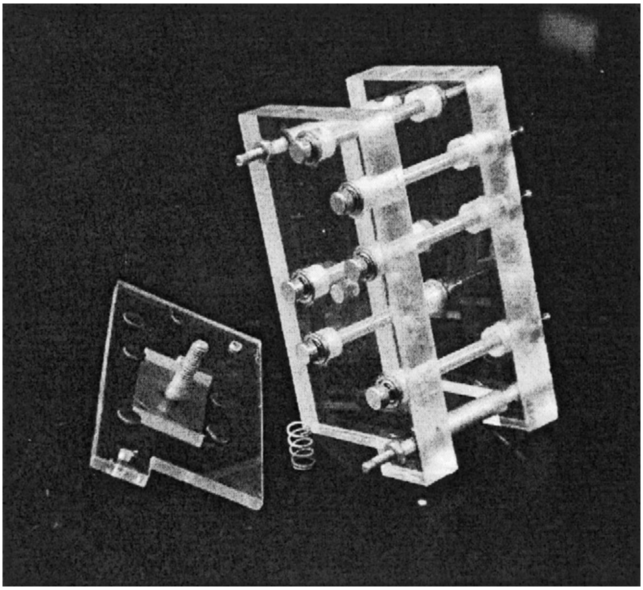

Figure 2. The Aqualon SLT with the face plate dismantled, illustrating the operation in rotational and stationary modes.

to accommodate different hair assembly configurations. Prior to each set of pulls hair tresses were combed, treated with an anti-static device (Zerostat) and the weight of the tress zeroed on Instron prior to the measurement. The pulling was carried out at the speed of 1000 mm/min and the experiment repeated 3–4 times in both rotational and stationary modes.

Hair tresses were washed by wetting with 40°C running tap water, applying the treatment, lathering the tresses for 30 seconds and rinsing in running 40°C tap water for 30 seconds. This was followed by a final rinse with room temperature DI water for 15 seconds. All hair tresses were blown dry using hand held hair dryer (Conair 1875) at warm heat and low air flow for ~3 minutes while combing, unless noted otherwise.

AQUALON SLT MEASURED PARAMETERS

The Aqualon SLT measures the rotational and stationary work of pulling. In the case of the rotational mode, the pins mounted on ball bearings are rotating freely. This eliminates the friction on the pins and the only contribution to the work of pulling (measured by Instron) is the resistance to deformation of an assembly of individual hair fibers, hair-to-hair friction and friction in the bearings that is assumed to be negligible. We define the combination of these two parameters as the *apparent stiffness*.

In the stationary mode, the tress is subjected to the same deformation with pins immobilized and, in addition to the apparent stiffness, the friction on pins contributes to the work of pulling.

Figure 4 shows force profiles produced by a Caucasian virgin hair tress in the two modes. The two profiles follow an identical pattern with the force profile in stationary mode shifted upward by a proportionality factor related to the hair tress friction on the pins.

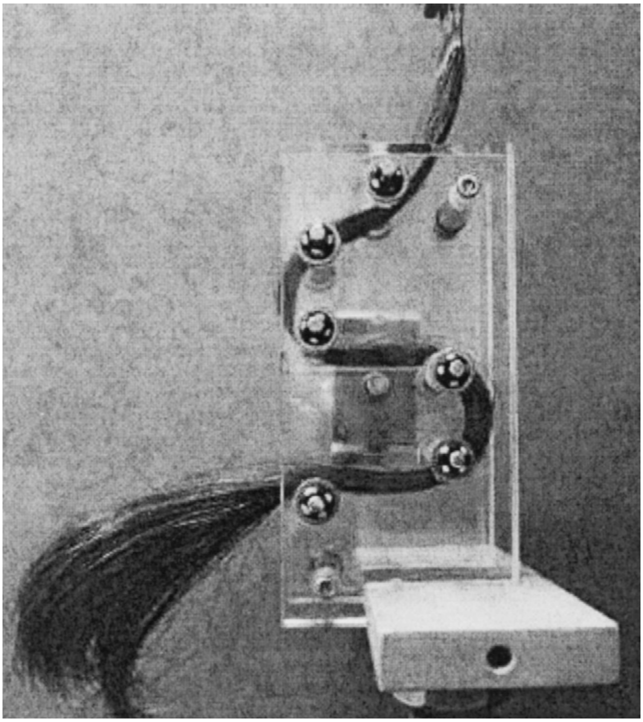

Figure 3. The Aqualon SLT with a hair tress threaded.

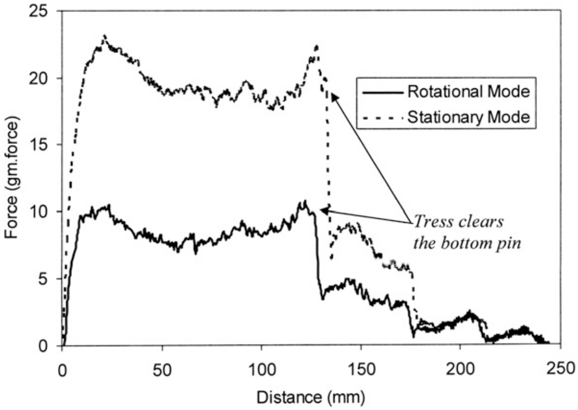

Figure 4. Force profile obtained by pulling a Caucasian virgin tress through the Aqualon SLT in stationary and rotational modes.

Note that the pulling force decreases in magnitude at around 130 mm, as noted in the figure, this corresponds to the point where a hair tress clears the bottom pin. The individual profile varies in from tress to tress. In order to eliminate the point to point variability in data we base the analysis on the total work of pulling.

The measured and calculated parameters are defined in equations 1 through 4. Equation 1 defines the work of pulling in the rotational mode as *apparent stiffness.* The description of the apparent stiffness excludes the contribution of hair assembly resistance to compression during the deformation process. This factor would be important in the cases of curly hair. In this work, however, since we are working with essentially straight hair, the parameter is omitted for simplicity.

Equation 2 describes the work of pulling in the stationary mode. The resistance to deformation in rotational mode is expected to be present in the stationary test as well. Thus, the work measured in the stationary experiment is the sum of the work of pulling in rotational mode and the work of friction of the hair tress on immobilized pins. Equation 3 describes the calculated work of friction on pins and defines this parameter as *apparent hair lubricity.*

$$W_{rotational} = W_{fiber\text{–}fiber\ friction} + W_{fiber\ stiffness} \equiv Apparent\ stiffness \qquad (1)$$

$$W_{stationary} = W_{rotational} + W_{friction\ on\ pins} \qquad (2)$$

$$W_{friction\ on\ pins} = W_{stationary} - W_{rotational} \equiv Apparent\ lubricity \qquad (3)$$

Finally, in the light of proportionality between forces in stationary and rotational modes we define an *apparent friction coefficient* as the ratio of apparent lubricity or friction on the pins to *apparent stiffness* as shown in equation 4.

$$Effective\ friction\ coefficient \equiv \frac{Apparent\ lubricity}{Apparent\ stiffness} = \frac{W_{stationary} - W_{rotational}}{W_{rotational}} \qquad (4)$$

VALIDATION

We offer a brief validation to the relevance of the measured parameters next. Table I shows the apparent stiffness, lubricity and the apparent friction coefficient of virgin and bleached Caucasian hair tresses. Bleached hair produces substantially less lubricity (i.e. larger work of friction on the pins), 2200 vs. 870 g-force mm than its virgin counterpart. The larger friction of bleached hair is an expected outcome attributed to the damage resulting from the bleaching process. Bleached hair also produces higher apparent stiffness, 1340 vs. 1050 g-force mm than virgin. Since the apparent stiffness includes a contribution from hair-hair friction it can not be conclusively stated if the difference is due to the changes in flexural stiffness or to the friction. Future communication will address the deconvolution between these two parameters. The confluence of these parameters, however, does not detract from the relevance of the apparent stiffness, as hair-to-hair friction is undoubtedly an important part to the perception of stiffness.

Table I also shows significantly different apparent friction coefficients. The coefficient is predictably lower on virgin hair then on bleached. To ascertain if the apparent friction

Table I

Comparison between Bleached and Virgin Hair Tress Attributes

	Stiffness (g-force mm)	Friction on pins (g-force mm)	Friction coefficient
Virgin	1050 ± 60	870 ± 70	0.8 ± 0.1
Bleached	1340 ± 100	2230 ± 200	1.7 ± 0.2
2 Bleached combined	3540 ± 270	5390 ± 380	1.5 ± 0.2
Bleached, thinned	1090 ± 40	1650 ± 80	1.5 ± 0.1

coefficient calculated by equation 4 is an intrinsic hair surface property devoid of particular hair configuration or mass we carried out the following two experiments. In the first experiment two hair tresses were combined and properties measured. In the second, a bleached hair tress was thinned by about ~15% of its original mass and tested. Table I shows that the described manipulations have not altered the value of the apparent friction coefficient. The latter observation has an important implication—the apparent friction coefficient is an intrinsic hair surface property that can serve as a basis for comparison of dissimilar hair tresses.

Next, we explore the effect of conditioner (Pantene PRO-V Daily Moisture Renewal) on bleached hair. Table II shows the changes to friction and stiffness in response to the treatment. As expected, we observe dramatic decrease to the work of friction on pins (i.e. increase in lubricity) that becomes comparable to the work of friction of virgin hair (see Table I). The apparent stiffness has decreased along with the apparent friction coefficient. Similar to the exercise described in Table I, we pair two conditioned bleached hair tresses to illustrate once again that the apparent friction coefficient described is indeed independent of the hair amount in the tress.

Finally, we illustrate the ability of the Aqualon SLT to detect changes in hair stiffness. In this experiment, washed hair tresses were treated with 0.25 gram of texturizing gel (DEP) followed by either air drying or blow drying while combing. Note that the amount and the mode of application of the gel was judicious in producing a realistic stiffening effect. Figure 5 shows images of both air and blow dried tresses.

In the case of the air dried sample (Figure 5A), the treatment 'glues' hair fibers together and repetitive deformation is expected to disrupt the fiber-to-fiber attachment points therefore decreasing the apparent stiffness of the hair tress. Table III illustrates how these changes can be quantified by the Aqualon SLT. Note that the measurements were

Table II
Impact of Conditioner Treatment on Bleached Hair

	Stiffness (g-force mm)	Friction on pins (g-force mm)	Friction coefficient
No conditioner	1340 ± 100	2230 ± 200	1.7 ± 0.2
Conditioner	1140 ± 110	960 ± 140	0.8 ± 0.1
2 Conditioned combined	2760 ± 170	2390 ± 170	0.9 ± 0.1

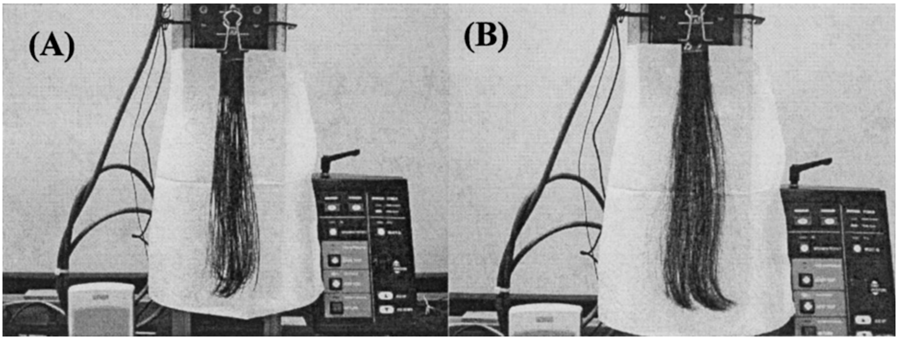

Figure 5. Virgin tress treated with texturizing gel. (A) air dried. (B) blow dried tresses.

Table III

The Effect of Texturizing Treatment on Apparent Stiffness of Air Dried Virgin Hair Tress

No. of passes	1	2	3	4	5
Apparent stiffness (g-force mm)	3300	2400	2100	1850	1790

Table IV

The Effect of Texturizing Treatment on Blow Dried Virgin Hair Tress

	Stiffness (g-force mm)	Friction coefficient
Control	1120 ± 30	1.5 ± 0.1
Texturizing treatment	1400 ± 100	1.4 ± 0.2

carried out only in the rotational mode. The first pass produces the highest apparent stiffness, which gradually decreases with each subsequent pass through the test assembly. Table III illustrates how one can quantify the effectiveness of texturizing treatment and its persistence.

Table IV shows the changes to hair stiffness and the apparent friction coefficient of blow dried hair samples treated with texturizing gel. The Aqualon SLT accurately detects the increase in hair stiffness. The treatment, however, did not affect the apparent friction coefficient. The difference in the apparent friction coefficients in Table I and Table IV is due to the difference in the batches of hair used. The results shown in Tables I and II were collected using "special quality" hair in which damaged hair is excluded. The tresses used in the subsequent work were regular quality hence the higher apparent surface roughness and the higher apparent friction coefficient.

CONCLUSIONS

Aqualon SLT measures apparent hair tress stiffness, friction and apparent friction coefficient. We demonstrated that the measured parameters correlate with changes expected from hair treatment—both chemical, i.e. bleached, and topical, i.e. treatment with conditioner or texturizing gel. The simplicity of the operation, efficiency and precision of the device make it a useful addition to any hair application laboratory.

REFERENCES

(1) W. Newman, G. L. Cohen, and C. Hayes, A quantitative characterization of combing force, *J. Soc. Cosmet. Chem.,* **24**, 773–782 (1973).

(2) Y. K. Kamath and H.-D. Weigmann, Measurement of combing forces, *J. Soc. Cosmet. Chem.,* **37**, 111–124 (1986).

(3) P. S. Hough, J. E. Huey, and W. S. Togyesi, Hair body, *J. Soc. Cosmet. Chem.,* **27**, 571–578 (1979).

(4) C. R. Robbins in *Chemical and Physical Behavior of Human Hair,* 4th ed., p. 413.

(5) L. J. Wolfram and L. J., Albrecht, *J. Soc. Cosmet. Chem.,* **36**, 87 (1985).

(6) U. Assmus, P. Augustin, H. Hensen, P. Hossel, G. Lang, H. Leidreiter, A. Markowetz, V. Martin, B. Noecker, E. Poppe, M. Pfaffernoschke, H. Schmidt-Lewerkuhne, E. Schulze-zur-Wiesche, A. Schwan-Jonczyk, J. Wood, and F.-J. Wortmann, Determination of the feel of hair after cosmetic treatment—Sensory and objective test methods, *IFSCC,* **11**, 121–128 (2008).