BRIDGING THE GAP BETWEEN CONSUMER INSIGHT AND TECHNICAL PERFORMANCE

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<table>
<thead>
<tr>
<th>Anti-breakage</th>
<th>Longevity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-flyaway/static</td>
<td>Manageability</td>
</tr>
<tr>
<td>Anti-frizz</td>
<td>Moisturization</td>
</tr>
<tr>
<td>Body</td>
<td>Protection</td>
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<tr>
<td>Color Protection</td>
<td>Repair</td>
</tr>
<tr>
<td>Conditioning</td>
<td>Shine</td>
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<tr>
<td>Control</td>
<td>Strength</td>
</tr>
<tr>
<td>Damage</td>
<td>UV Protection</td>
</tr>
<tr>
<td>Hold</td>
<td>Volume</td>
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</table>
## Consumer language vs Scientific language

<table>
<thead>
<tr>
<th>Consumer language</th>
<th>Scientific language</th>
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<tbody>
<tr>
<td>Anti-flyaway/static</td>
<td>- electrostatic properties</td>
</tr>
<tr>
<td>Conditioning</td>
<td>- lubrication</td>
</tr>
<tr>
<td>Moisturization</td>
<td>- water content</td>
</tr>
<tr>
<td>Shine</td>
<td>- light scattering</td>
</tr>
<tr>
<td>Softness</td>
<td>- modulus</td>
</tr>
<tr>
<td>Strength</td>
<td>- tensile properties</td>
</tr>
<tr>
<td>Volume</td>
<td>- image analysis</td>
</tr>
<tr>
<td>Body</td>
<td>- ???</td>
</tr>
</tbody>
</table>

There is danger in taking consumers’ words literally.
Technical assessment of hair performance
An experiment you’ve all probably tried

Conditioner (master batch)

Conditioner (sub-batch #1)
Conditioner (sub-batch #2)
Conditioner (sub-batch #3)
Conditioner (sub-batch #4)
Consumer performance -vs- Technical performance

Technical performance gives loss
Consumer performance gives loss

Technical performance equivalent
Consumer performance gives loss

Technical performance win
Consumer performance gives loss/parity

Reformulate for improved performance
Reformulate for improved aesthetics?
Is the concept right?
Is the technical win off-set by poor aesthetics?
Is the technical parameter important?
The moisture content of hair
Dynamic Vapor Sorption (DVS)

Adsorption isotherm for hair and water

Weight increase and decrease as fn(humidity)

Speakman & Chamberlain - 1931
Evans - 2011
Chemically damaged hair will adsorb more water than healthy hair.

Technically, the term “dry damaged hair” is an oxymoron.

Hair contains highest levels of moisture at high humidity – a condition that is synonymous with “bad hair” days.
“It is concluded that human hair exhibits a rather robust static and dynamic water sorption performance that, against initial expectations, is not readily changed by cosmetic processes and ingredients”.

P&G Study – Presented by MG Davis at 2009 DWI Hair Conference

- 20g ponytail hair tresses were treated with a non-conditioning shampoo
- Tresses were equilibrated for 48 hrs at either 15%RH or 80%RH
- Tresses were transported in plastic containers to maintain RH until evaluated by panelists
- Blindfolded panelists were asked to feel tresses and answer a series of questions (n=50)
Thanks to P&G for access and permission to present this data.
Scanning electron microscopy pictures of hair
Scanning electron microscopy pictures of hair
Typical wet combing results

Effect of hair state on wet combing results

- Virgin hair
- Bleached hair
- Bleached & waved hair

Maximum combing force (gmf)
Lubrication is behind claims regarding –
Manageability
Conditioning
Protection
“Moisturization”
“Repair”
“Strengthening”
Strong, Healthy Hair
Constant rate extension experiments

Schematic of stress-strain curve for wet hair

% Extension

0 10 20 30 40 50 60

Force (g/m)

0 20 40 60 80 100

Break Extension

Break Force*

Elastic (linear) region

Modulus = slope of linear region

*Note: Break Stress = Force/Cross sectional area

Plateau Load

Break Stress for chemically treated hair

Wet Tensile Testing (N=40)

Treatment

Mean + SD
Mean - SD
Mean + SE
Mean - SE
Mean
Outliers
Extremes

Stress = force/unit area
Consumers do not assess the strength of hair by stretching at a constant rate and judging the force to break.

Brown & Swift (1975); Robbins (2006)

Hair fibers are plucked from the head upon application of forces considerably lower than the break force.


Consumer perception of “strength” is likely related to number of fibers in brush/comb after grooming; number of fibers in base of shower after washing; and/or visual observation of split ends.
Single fiber fatigue experiments


The S-N Curve

So hair fibers will break (and break in a predictable manner) upon repeated application of stresses considerably below the so-called "break stress."
Repeated grooming experiments

Cumulative breakage as fn of grooming strokes
Unconditioned virgin and bleached Caucasian hair at 60% RH

Virgin hair
Bleached hair
Repeated grooming experiments

Cumulative breakage as fn of grooming strokes
Unconditioned and conditioned bleached Caucasian hair at 60% RH
X times stronger claims
Fatigue leads to larger differences between samples

Average number of cycles-to-fail for Caucasian and Afro hair under repeated application of a 0.010 g/μm² stress at 60% RH

<table>
<thead>
<tr>
<th>Hair type</th>
<th>Average cycles-to-fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caucasian</td>
<td>≈ 37,000</td>
</tr>
<tr>
<td>Afro</td>
<td>≈ 5,500</td>
</tr>
</tbody>
</table>
Fatigue leads to larger differences between samples

Effect of RH on break stress

Failed cycles versus stress virgin hair
Caucasian hair as fn(RH)

Average # cycles-to-fail for Caucasian hair under repeated application of a 0.013 g/µm² stress as fn RH

<table>
<thead>
<tr>
<th>Relative Humidity</th>
<th>Average cycles-to-fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>≈ 24,800</td>
</tr>
<tr>
<td>60%</td>
<td>≈ 2,100</td>
</tr>
<tr>
<td>90%</td>
<td>≈ 100</td>
</tr>
</tbody>
</table>
Hot-off-the-presses” data

S-N Curve virgin and treated Caucasian hair

60% RH
3x bleached
Hot-off-the-presses data

S-N Curve virgin and treated Caucasian hair

Stress (g/um²)

Cycles to failure

Virgin 90% RH

60% RH

3x bleached

Virgin 90% RH
Hot-off-the-presses” data

Average number of cycles-to-fail under repeated application of a 0.011 g/μm² stress

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<tr>
<td>Virgin (60% RH)</td>
<td>≈ 37,000</td>
</tr>
<tr>
<td>Bleached (60% RH)</td>
<td>≈ 2,700</td>
</tr>
<tr>
<td>Virgin (90% RH)</td>
<td>≈ 2,400</td>
</tr>
<tr>
<td>Bleached (90% RH)</td>
<td>≈ 150</td>
</tr>
</tbody>
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Fatigue testing as fn of RH

Failure cycles versus Stress virgin hair

Caucasian hair as fn(RH)

Schematic of Young’s modulus as fn RH
Glycerol treatment

Average # cycles-to-fail for Caucasian hair under repeated application of a 0.011 g/μm² stress at 60% RH

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<td>Virgin</td>
<td>≈ 33,200</td>
</tr>
<tr>
<td>10% glycerol</td>
<td>≈ 7,600</td>
</tr>
<tr>
<td>20% glycerol</td>
<td>≈ 2,600</td>
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</table>

Repeated grooming data
Changing the water content of hair – carboxylic acids

Binding of phenols by hair, Parts I, II and III, M.M. Breuer, J. Phys. Chem., 68, p-2067-2084, (1964). – showed that water content is diminished by soaking hair in various phenolic solutions, with resorcinol showing the largest effect.
Changing the water content of hair – phenols

Reduction in water content of hair after treatment with phenols

Relative Humidity (%)

0 10 20 30 40 50 60 70 80 90 100

Amount adsorbed (%)

0
5
10
15
20
25

+ 5% Cl-resorcinol

Virgin Hair
Fatigue testing on resorcinol-treated hair

Failure cycles versus Stress virgin hair

Caucasian hair

Cycles to failure

Virgin hair
Resorcinol soaked hair

Stress (g/um$^2$)
The effects of acids on hair

- Some companies are including carboxylic acids as “actives”
- Kao’s “3 Days Straight” product uses lactic and malic acids as the active.
- Glyoxylic acid is being pushed as an alternative to formaldehyde-based BKT-type products.
- Olaplex uses maleic acid as an active
Resorcinol activity as a function of soak time

Reduction in water content for hair after soaking in 5% resorcinol

Time (minutes)
0 20 40 60 80 100 120
% Reduction in water content
0 5 10 15 20 25 30 35

% Reduction in water content for hair after soaking in 5% resorcinol

Time (minutes)
0 20 40 60 80 100 120

Resorcinol (HO-Ph-OH)

HO-Ph-OH
Citric acid activity as a function of temperature and soak time

Reduction in water content for virgin Caucasian hair after soaking in a 5% citric acid solution as a function of time and temperature.

Time (minutes)
0 50 100 150 200 250
% Reduction in water content
0 5 10 15 20 25

Temperature:
- 40°C
- 22°C

Graph showing the percentage reduction in water content over time at different temperatures.
Dynamic vapor sorption in Organics mode - adsorption rate for hair and ethanol

Adsorption of water, ethanol and propanol by hair

0-10% jump in relative vapor pressure

Time (minutes)

0 200 400 600 800 1000 1200 1400 1600

Amount adsorbed (%)

Water

Methanol

Ethanol
Propanol adsorption

Adsorption of methanol, ethanol and propanol by hair

0-90% jump in relative vapor pressure
Adsorption testing with decane

Adsorption of decane by hair after 0-90% jump in relative vapor pressure

- **Rapid surface adsorption**
- **Slow bulk adsorption**

![Graph showing rapid surface adsorption and slow bulk adsorption over time (minutes)]
Adsorption testing with cyclomethicone
Adsorption testing with amyl acetate

Adsorption of amyl acetate by hair after 0-90% jump in relative vapor pressure

Amount adsorbed (%) vs. Time (minutes)

- 0.0
- 0.2
- 0.4
- 0.6
- 0.8
- 1.0

Time (minutes)

Adsorption of amyl acetate by hair after 0-90% jump in relative vapor pressure

- Amyl acetate

<Chemical Structure>
The rigors of hair damage
The scope of the problem – what happens during bleaching with a simple hydrogen peroxide solution?

- Penetration of the solution between cuticle scales will weaken the inter-cuticular cement and leave this protective structure more susceptible to deterioration.

- Oxidative conditions, in combination with elevated pH, will irreversibly increase the swelling capacity of fibers – placing additional strain on the cuticle structure each time the hair is wetted.

- Degradation and dissolving of melanin pigment granules leads to lightening of the hair color while seemingly leaving behind microscopic voids.

- Oxidative side reactions with hair protein deplete strength-supporting cystine disulfide bonds by conversion to cysteic acid.

- Individual hair fibers become weaker and more prone to breakage.

- The dry state modulus increases – leaving individual fibers stiffer

- The lipid layer on the very outside surface of a hair fiber (the f-layer) is removed – changing its interaction with water and possibly leading to slower hair drying.

- Enhanced swelling in combination with a more-hydrophilic character can lead to increased fiber water content.

- Lipid structure becomes weakened and components are more easily removed.
What happens to hair during simple washing with a standard shampoo?

- Fibers swell - putting strain on the cuticle.
- Swollen fibers are subjected to inter-fiber abrasion and friction - likely causing cuticle wear.
- Bending and twisting of fibers could initiate localized cuticle uplift.
- Fibers encounter various tugging and fatiguing forces while in a decidedly weaker, plasticized state.
- Lipids and degraded protein may be leached from the hair.
Hair Damage - where does it occur?

Surface (cuticle)
(Tactile, manageability, shine)

Inside (cortex)
(Strength, breakage, stiffness)
Hair Damage - how does it occur?

Chemical impetus
Mechanical impetus
Thermal impetus
Photochemical impetus
Hair Damage - how does it manifest to the consumer

Manageability issues

Sensorial issues

Strength/breakage issues
Let’s combine the lot

Grooming-related surface damage

Sensorial-compromised hair due to grooming-related surface damage

- Repair
- Reduce
- Remove
Let’s combine the lot

Strength-compromised hair due to chemical-related internal protein damage

Repair  Reduce  Remove
Summary

• Hair care products are sold using “consumer language”. This is the language of our industry.

• We should not forget we are scientists. Scientists are very precise people who question everything.

• Upon doing this, it becomes apparent that “consumer language” and “scientific language” do not equate.

• This can severely muddle our industry and the product development process and often sends formulators off on wrong routes.
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