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Study of hair shine and hair surface smoothness

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Synopsis

A new hair visual appearance measurement system called SAMBA from Bossa Nova Technologies (Venice, CA) has been employed to measure effects of cosmetic treatments on hair shine and surface smoothness of different types of hair samples. Experimental procedures for evaluations of shine value and surface cuticle angle of hair samples treated with rinse-off products (shampoo or/and conditioner) have been successfully established and applied. We demonstrated that hair spray and conditioner formulas containing PPG-3 benzyl ether myristate (PBEM) (1) showed great performance on shine enhancement for hairs with light and medium colors. Instrumental measurement of shine values was also conducted to compare different commercial shampoo and conditioner products. This study showed reliable utility of SAMBA system and demonstrated the shine enhancement of PBEM in hair care.

INTRODUCTION

Hair luster (gloss, shine) is an important feature of hair appearance, and this attractive visual effect is a key consumer objective in the hair care market. However, the perception of hair shine is affected by many factors such as lighting environment, hair color, surface smoothness, hair morphology, hair mass density on scalp, and hair fiber alignment. These factors make it difficult to conduct meaningful shine measurements. SAMBA, a hair luster evaluation apparatus, has been recently applied to study effects of cosmetic treatment on hair shine and surface smoothness (2,3). In a SAMBA measurement, a hair tress is illuminated and the different types of light reflected are collected. Using polarized illumination coupled to polarization analysis, SAMBA is able to differentiate the specular and diffusive reflection. The specular reflection gives information about hair gloss and roughness, while the diffused light gives information about the hair color. By acquiring two states of polarization at video rate, SAMBA can be used to determine changes in hair shine indexes and surface cuticle angles of hair samples before and after cosmetic treatment. In this study, we established experimental procedures for hair treatment with rinse-off products and demonstrated that PBEM, an emollient ester used in many hair care formulations, improved hair shine. Effects of treatments with commercial shampoo and conditioner products on hair shine were also quantitatively measured by employing SAMBA as the polarimetric imaging system.

EXPERIMENTAL

MATERIALS

- PPG-3 benzyl ether myristate (Trade name: Crodamol STS, Croda Inc., Edison, NJ)
- Quaternium-91 conditioners (compositions listed in Table IV), Croda Inc., Edison, NJ
- Commercial shine shampoos and conditioners
- Blond, medium brown, dark brown, Asian black, and light bleached hair (International Hair Importers, Inc, New York)

HAIR SAMPLE PREPARATION

Hair cleaning. Hair tresses, about eight inches in length, one inch in width and approximately 7.5 grams in weight, were washed and air-dried overnight as follows:

- Immerse the hair tress into 200 ml isopropyl alcohol (IPA) for 10 minutes keeping the wax strip out of solvent.
- Soak hair tress in 1.6% sodium laureth sulfate (SLES) warm solution (50°C) for 30 minutes keeping wax strip out of soak solution while getting as much hair as possible in solution.
- Rinse each tress with tap water to fully remove previously used washing solutions.
- Wash hair tress with 1 ml of 16% SLES solution for 1 minute then rinse under running water for 30 seconds. Repeat this step 2 times.
- Rinse each hair tress in tap water to remove remaining SLES.
- Air-dry at room temperature (25°C) overnight.

Hair treatment. Shampoo and/or conditioner treatment procedures were conducted as follows under strictly controlled conditions:

- Weigh and record weight of each tested hair tress (including the glue wax).
- Calculate the weight of applied product to each single hair tress using the weight ration of 7.5 to 2 (2.0 grams of product applied to 7.5 grams of hair).
- Wet the hair tresses and massage the product through the hair tress (both sides) using fingers (with a latex glove) and leave the product on the hair surface for 3 minutes.
- Prepare 2000 ml of deionized water in a glass beaker; dip the treated hair tress into the water for 5 cycles. Squeezing out extra water using fingers before dipping in the water for the next cycle (5 cycles of dipping and squeezing). Repeat this step 2 times.
- Allow hair tresses to dry overnight at room temperature (25°C).

HAIR SHINE MEASUREMENTS

Luster values have been characterized by hair care scientists using classical gloss meter, shine box, goniophotometers, and other instruments to tentatively quantify human perception of hair shine (4–6). SAMBA software calculated different luster formulas such as Reich-Robbins, TRI, Stamm, Guiolet and Bossa Nova Technologies (BNT) simultaneously. In this paper, we used BNT luster (L_{BNT}) formula for data analysis, which is a Reich-Robbins formula adapted to polarization measurement. L_{BNT} is defined as:

$$L_{BNT} = 100 * \frac{S_{in}}{(D + S_{out})} * \frac{1}{W_{visual}}$$

S_{in} = Integral inside the specular peak in the specular profile

S_{out} = Integral in the wings of the peak in the specular profile

D = Integral in the diffused profile

W_{visual} = Mean value of the band width along the region of interest (ROI) from the real image

Figure 1 explains how to decompose a specular spectrum into S_{in} and S_{out} by using selection functions. The selection function to isolate S_{in} in the specular light is a Super Gaussian function, which is defined by its width and its position. The FWHM (full width at half maximum) of the selection function is twice the FWHM of the measured specular profile. The position of the selection function is centered on the same point as the specular light distribution. Then the selection function and measured profile are multiplied together to give the S_{in} signal. The selection function to isolate S_{out} is of the form K*(1-Super Gaussian function), where K is a constant to keep the ratio observed in the wings. Otherwise, the influence of S_{out} would be underestimated compared to the influence of integral in the diffused profile. The super Gaussian function used in S_{out} depends on the position only, and FWHM is fixed and was optimized experimentally.

Hair luster was measured with SAMBA in a dark box before and after treatment. Since the measurement results rely on a good positioning and combing of the hair tresses, we aligned the hair tresses uniformly in the same direction with a comb to ensure reliable results. To prevent flyaway of hair fibers on the sample holder due to static build up, we always wear cotton gloves when handling and combing the hair. The hair cleaning and treatment processes were strictly followed to apply shampoo or conditioner to the sample. Regarding the hair spray product, each hair tress was treated with 50 µl of product per gram of hair. The tress was permitted to air dry for 4 hours at room temperature. All luster data represents an average of the results obtained on 3 hair tresses, and each tress was measured twice. In each measurement, we determined 4 hair shine values: both sides at two orientations (root-to-tip and tip-to-root). Therefore, each luster value represented an average of 24 measurements.

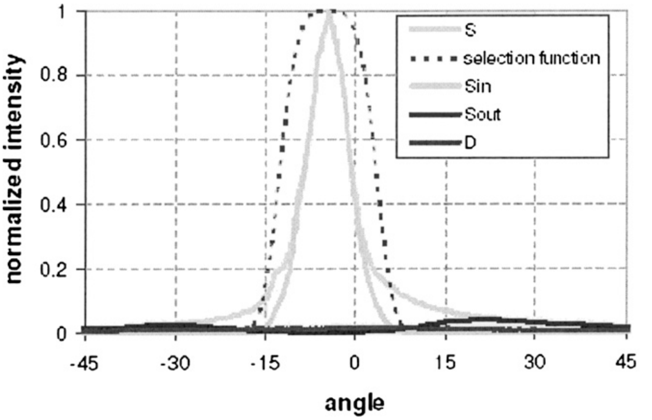

Figure 1. Decomposition of specular distribution.

APPARENT CUTICLE ANGLE MEASUREMENTS

The apparent cuticle angle can be deduced from the angle difference between the maximums of the specular profiles in tip-to-root and root-to-tip positions. To avoid the dependency on the origin and lower measurement uncertainty, instead of rotating hair samples, the sample holder is rotated to change the orientation from root-to-tip to tip-to-root. Figure 2 shows the two parallel polarization images taken with the same exposure time for two orientations of the hair. The distributions of specular light in tip-to-root and root-to-tip positions are plotted in Figure 3. For the perfectly aligned hair, the angle deviations of the reflected light in root-to-tip and tip-to-root positions are 2α and -2α, where α is the apparent cuticle angle which is explained in Figure 4. So the angle difference (β) between the maximum angles at the root-to-tip and tip-to-root orientations in the specular profiles is equal to four times of the apparent cuticle angle value. Therefore, we can deduce the apparent cuticle angle from the specular light distribution. For the light hair, of which the specular band contains both shine and chroma profiles, we found in the experiments that the data reproducibility is generally better to use the shine band only for

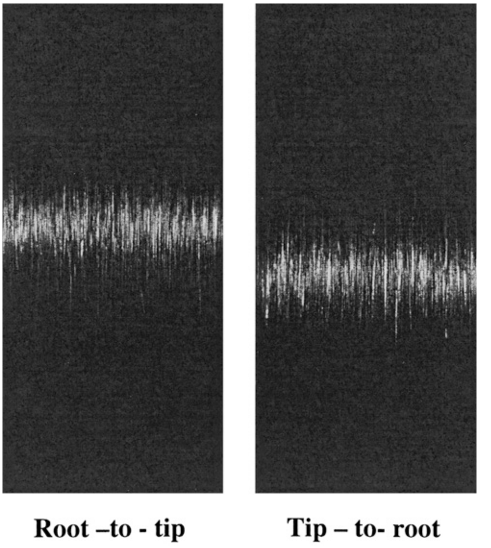

Figure 2. Effect of hair sample orientation on shine images.

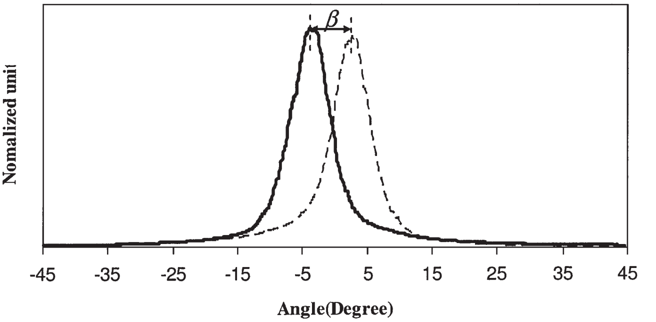

Figure 3. Distribution of specular light at tip-to-root and root-to-tip orientations.

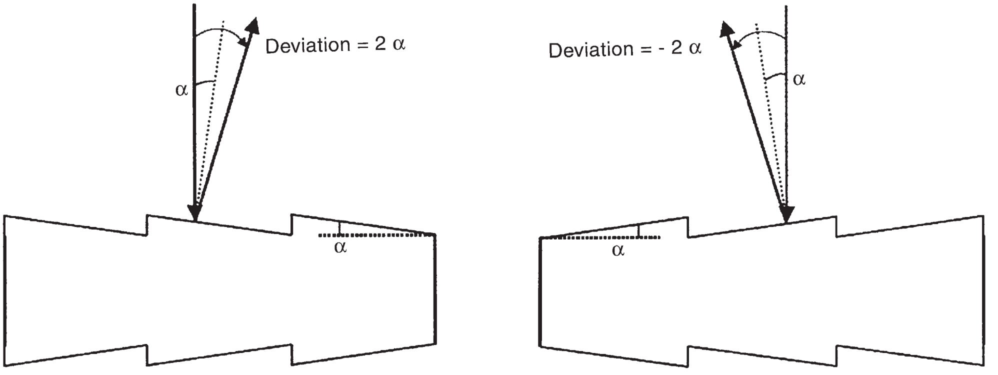

Figure 4. Deviation of the reflected light at root-to-tip and tip-to-root orientations.

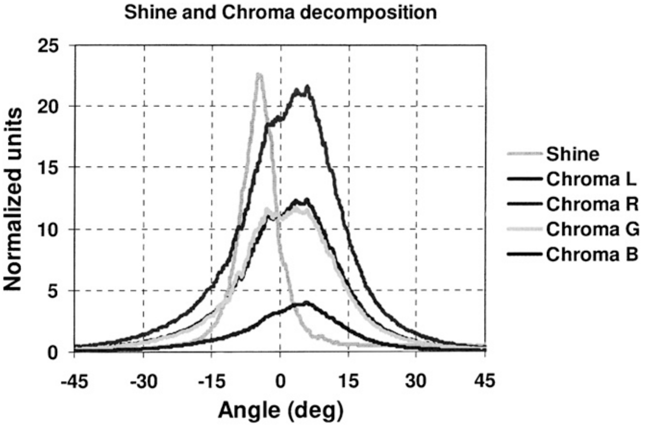

Figure 5. Extraction of the shine and chroma bands from the specular profile.

the light hair to calculate apparent cuticle angle. Based on the fact that the shine band is white while the chroma band is colored, the processing on the specular profiles using RGB information allows separate the shine band from the chroma band (Figure 5).

RESULTS AND DISCUSSION

DATA REPRODUCIBILITY

In order to examine the data reproducibility, we measured the hair shine values before and after treatments with a commercial shine shampoo for three blond hair tresses (Table I), dark brown hair tresses (Table II), and Asian black hair tresses (Table III). All these changes were significant with 95% confidence. Experimental results in Tables I–III demonstrate excellent data reproducibility and validate our test methodology.

HAIR SHINE ENHANCEMENT BY COMMERCIAL PRODUCTS

To determine hair shine enhancement by selected shine shampoo and conditioner, we carried out experiments using bleached, medium brown, dark brown, and Asian black

Table I
Shine Values and Changes of Blond Hair after Commercial Shine Shampoo Treatment

Hair sample	Shine value		Change (%)
	Before	After	
Tress 1	6.18	6.76	9.39
Tress 2	6.06	6.43	6.10
Tress 3	6.21	6.60	6.28
Average			7.26 ± 1.85

Table II
Shine Values and Changes of Dark Brown Hair after Commercial Shine Shampoo Treatment

Hair sample	Shine value		Change (%)
	Before	After	
Tress 1	48.2	53.3	10.6
Tress 2	46.9	52.2	11.3
Tress 3	50.3	54.8	8.85
Average			10.25 ± 1.16

Table III
Shine Values and Changes of Asian Black Hair after Commercial Shine Shampoo Treatment

Hair sample	Shine value		Change (%)
	Before	After	
Tress 1	42.1	47.0	11.5
Tress 2	44.6	47.8	7.06
Tress 3	42.3	46.7	10.3
Average			9.62 ± 2.30

hair tresses. The average changes in shine values of hair samples after the shine shampoo treatments are shown in Figure 6. It can be seen that this shine shampoo improved hair shine for all tested hair. Average hair shine indexes of treated hair tresses increased 9.4%, 9.8%, 12.4%, and 8.25%, respectively, for bleached, medium brown, dark brown, and Asian black hairs. The percent reductions in average cuticle angles of hair samples after treatment with this shine shampoo are presented in Figure 7. It is observed that the average apparent cuticle angles of treated hair decreased 17.5%, 12%, 7.5%, and 10.9%, respectively, for bleached, medium brown, dark brown, and Asian black hair. All these changes were statistically significant. The average changes in shine values of hair samples after the shine conditioner treatments are presented in Figure 8. Statistical analysis showed that there was no significant improvement in hair shine after the conditioner treatment for both bleached and Asian black hair samples.

ENHANCEMENT IN HAIR SHINE AND SURFACE SMOOTHNESS BY PBEM CONDITIONER

Quaternium-91 (Q-91) conditioners with and W/O additional 2% PBEM were used to study its effects on hair shine and smoothness for bleached, blond, medium brown and Asian black hair samples. The compositions of these two conditioners are listed in Table IV.

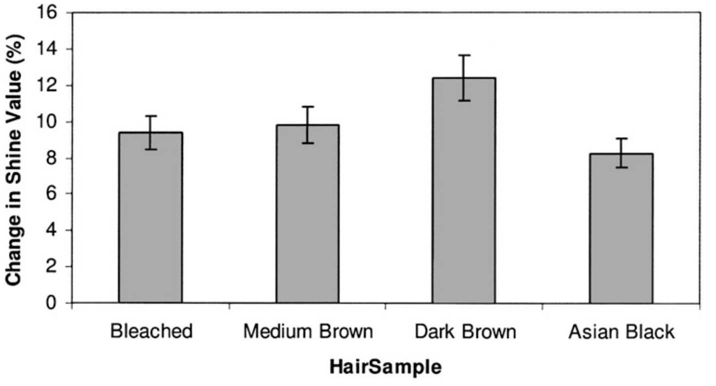

Figure 6. Changes in average hair shine values after shine shampoo treatment.

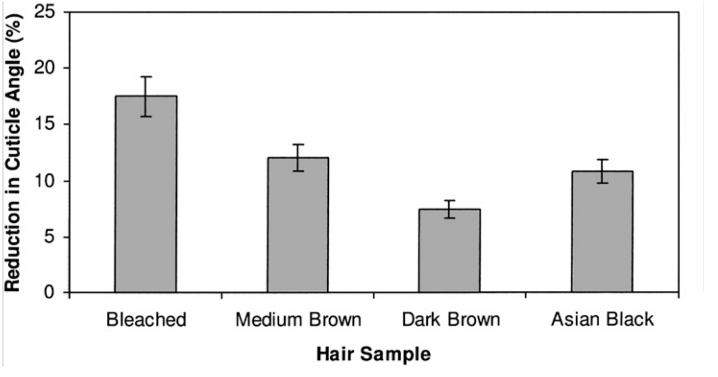

Figure 7. Change in apparent cuticle angle after shine shampoo treatment.

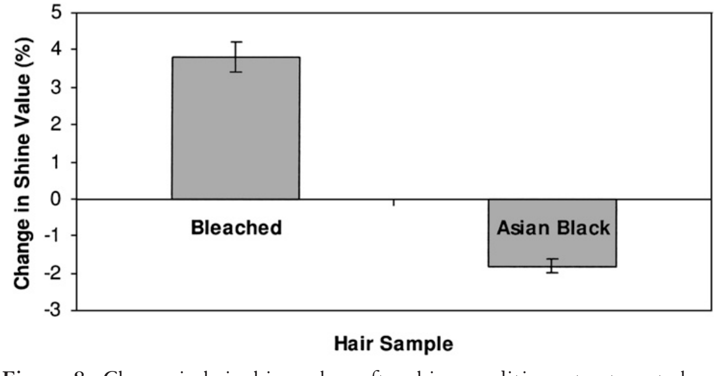

Figure 8. Change in hair shine values after shine conditioner treatment alone.

The average changes in shine values of hair samples treated with these two conditioners are shown in Figure 9. It is interesting to note that the Q-91 conditioner W/O PBEM only improved the hair shine for bleached hair but reduced hair for other type of hair samples. The shine improvement for bleached hair may be attributed to the deposited

Table IV
Tested Conditioner Compositions

Composition	Q-91 Conditioner	Q-91 Conditioner with PBEM
Quaternium-91 (and) cetrimonium methosulfate (and) cetearyl alcohol	2.14%	2.14%
Cetearyl alcohol	3.86%	3.86%
PPG-3 benzyl ether myristate (PBEM)	0	2.0%
Phenoxyethanol and propyl paraben and butyl paraben and methyl paraben and ethyl paraben	1.00	1.00
DI water	93.0%	91.0%

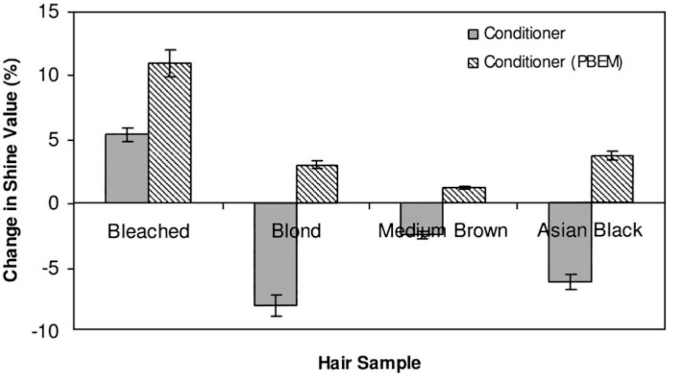

Figure 9. Change in hair shine values after conditioner treatment

conditioning agent on the damaged hair surface. It is clear that addition of PBEM to the Q-91 conditioner gave improved hair shine performance to all tested hair samples; the average shine index values increased about 5% for bleached, blond, and Asian black hair. Statistical analysis showed that these changes were significant. We also examined changes in average apparent cuticle angle of hair samples after different treatments (Figure 10). It is clear that addition of PBEM to the conditioner formula not only improved hair shine but also increased surface smoothness of treated hair.

ENHANCEMENT IN HAIR SHINE AND SMOOTHNESS BY PBEM HAIR SPRAY

Previously, using shine box experiments, we examined hair tresses treated with a commercial hair spray with and without additional 2% of PBEM, and found that the formula containing additional PBEM outperformed the original formula (7). By using the SAMBA system, we further confirmed the shine enhancement effect of PBEM. PBEM hair spray formula consisted of a mixture of 45% PBEM and 55% Cyclomethicone (DC345 Fluid from Dow Corning, USA). Each hair tress was treated with 50 µl of product per gram of hair, and we examined the shine enhancement of the hair spray on light bleached and medium brown hair. The results are presented in Figures 11 and 12. It is apparent that the hair spray formula with PBEM enhanced the hair shine (higher shine value) and improved the surface smoothness (lower apparent cuticle angle value).

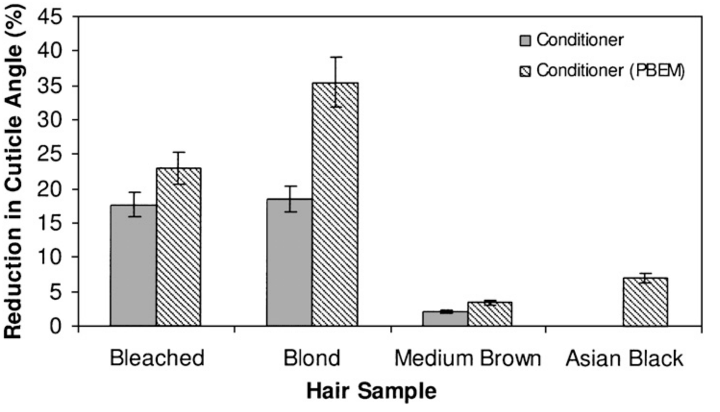

Figure 10. Change in apparent cuticle angle after conditioner treatment.

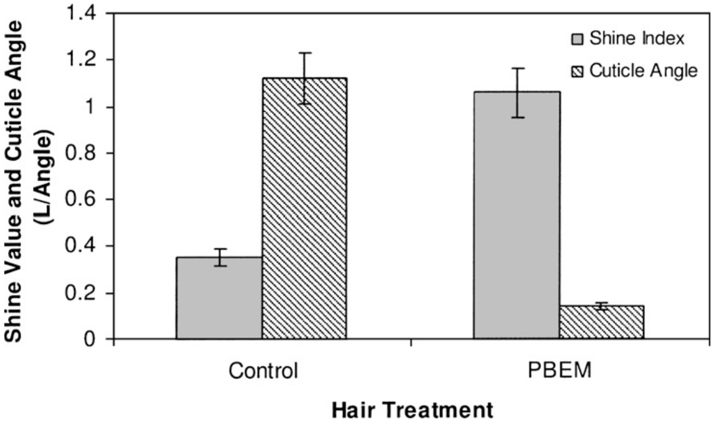

Figure 11. Changes in shine values and apparent cuticle angles after PBEM spray treatment (light bleached hair).

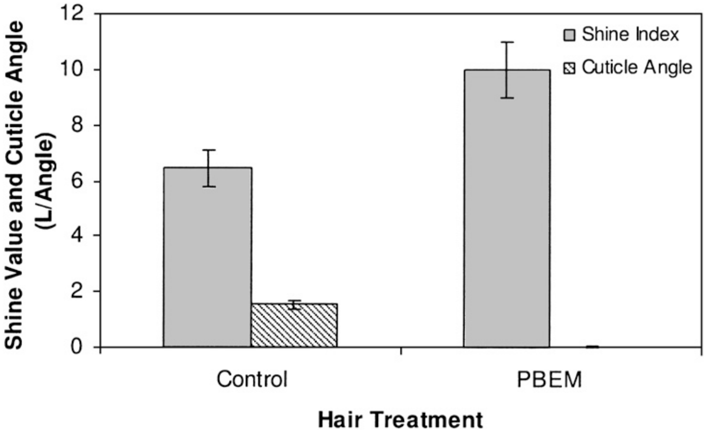

Figure 12. Changes in shine values and apparent cuticle angles after PBEM spray treatment (medium brown hair).

SHINE PERFORMANCE OF THREE COMMERCIAL SHAMPOO PRODUCTS

Three commercial shampoos were evaluated to determine whether the SAMBA system can detect changes in shine after different shampoo treatments, Experiments were conducted on virgin blond hair. Average change in hair shine index for each of the shampoos was 9.73%, 7.9% and 2.04%, respectively (Figure 13). It can be seen that only shampoos 1 and 2 improved hair shine on blond hair significantly.

SHINE PERFORMANCE OF SHAMPOO AND CONDITIONER

It is interesting to note that SAMBA measurements demonstrated that shampoo samples provided better shine enhancement than the corresponding shine conditioner. Since a shampoo frees the hair surface from foreign residue, the cleaned surface will generate stronger specular light intensity, therefore, enhancing shine. If the shampoo formula not only cleans the hair surface, but also deposits some thin smooth film such silicone oil or PBEM on hair surface, it will result in more surface shine. In contrast, the main purpose of hair conditioner is to deposit conditioning agents onto the hair surface such as cationic surfactants (polymers), silicone oil, fatty alcohol, etc. There always is a competitive deposition between conditioning agent and shine-enhancing agent, which will reduce the amount of shine-enhancing agent on hair surface and may also generate an uneven-distributed film. If the deposited substance does not form a thin and uniform (evenly distributed) film on hair surface, it will not improve the surface specular light intensity. In fact, in many cases, the depositions reduce hair shine because of the increased light scattering by the non-smooth surface and discontinuous spots of substance depositions. This may explain why a conditioner is less effective in hair shine enhancement than a shampoo.

CONCLUSIONS

We have established an experimental protocol for the evaluation of hair shine index (luster) and surface apparent cuticle angle of hair samples treated with rinse-off products (shampoo and conditioner), and successfully applied the protocol to study the effects of shampoos, conditioners and hair spray products. We demonstrated that addition of 2%

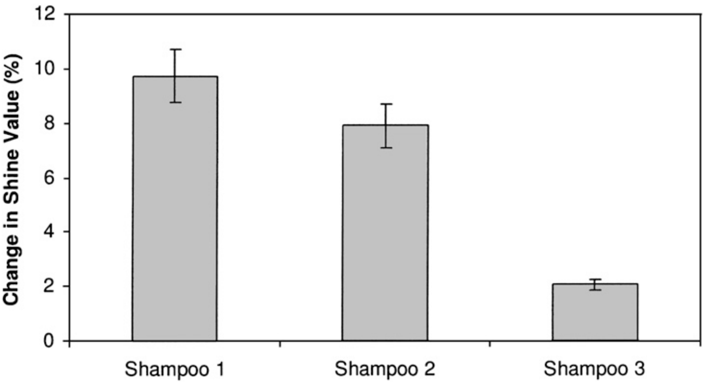

Figure 13. Change in blond hair shine values from three commercial shampoo products.

PBEM to a Quaternium-91 conditioner formula provided improved hair shine and smoothness. We also saw shine improvements on bleached, Asian black, medium brown, and dark brown hairs by a commercial shine shampoo. The results also showed that shampoos are more effective in hair shine enhancement than the corresponding conditioners.

ACKNOWLEDGMENT

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REFERENCES

(1) Crodamol STS (INCI name: PPG-3 Benzyl Ether Myristate) is covered by U.S. Patents No. 7,217,424 and 6,987,195 assigned to Croda Inc..
(2) P. Clemenceau, S. Breugnot, and B. Pouet, In vivo quantitative evaluation of gloss, *Cosmet. Toiletr.,* **119**(10), 71–78 (2004).
(3) J. M. Lim, M. Y. Chang, M. E. Park, T. J. Kwak, J. J. Kim, and C. K. Lee, A study correlating between instrumental and consumers' subjective luster values in oriental hair tresses, *J. Cosmet. Sci.,* **57**, 475–485 (2006).
(4) R. F. Stamm, M. L. Garcia, and J. J. Fuchs, The optical properties of human hair. II. The luster of hair fiber, *J. Soc. Cosmet. Chem.,* **28**, 601–609 (1977).
(5) C. Reich and C. R. Robbins, Light scattering and luster measurements of human hair: A sensitive probe of the hair surface, *J. Soc. Cosmet. Chem.,* **44**, 221–234 (1993).
(6) F. J. Wortmann, E. Schulze zur Wiesche, and B. Bourceau, Analyzing the laser-light reflection from human hair fibers. II. Deriving a measure of hair luster, *J. Cosmet. Sci.,* **55**, 81–93 (2004).
(7) T. Gao, A. Pereira, and P. Obukowho, A new multifunctional, shine-enhancing emollient: PPG-3 benzyl ether myristate, *J. Cosmet. Sci.,* **55**(Suppl.), S143–S150 (2004).