Bond multipliers relying on cross-linking are able to restore strength to damaged fibers, but this increased strength is associated with increased brittleness.

management of the dermatological disorder *Epidermolysis bullosa*.[6] This oxidized form of keratin exploits the established biological function of keratin in cell growth, development and healing.[7] Extending the application of oxidized keratins to hair care, however, is a new approach.

The interaction of oxidized keratin with the skin and its potential to positively affect biological functions is due to the keratin's ability to interact with cells in a manner similar to the body's own keratin. This is dependent on the high degree of homology between the oxidized keratin and human keratin, which is ensured by similarities in the amino acid sequences of the two proteins.

Sheep wool intermediate filament keratin protein has a 91% homology to human intermediate filament keratin protein, based on a side-by-side comparison of the amino acid sequences. As such, experiments were undertaken, as described here, to investigate the effect of oxidized sheep wool keratin on human hair when used in bleach and as a post-bleach recovery treatment.

The results were compared with that of a leading industry synthetic bond multiplier (BM) based on bis-aminopropyl diglycol dimaleate. Effects were quantified using single fiber tensile testing, combing breakage and sensorial tests.

The global hair care market was valued at US $81.3 billion in 2015 and is expected to reach US $105.3 billion by 2024, registering a steady CAGR of 3.0%.

Source: Transparency Market Research

Oxidized keratin also was applied to severely damaged hair in order to investigate its repair capabilities. This was followed by multiple washing cycles to examine the longevity of effects.

Materials and Methods

Materials: Oxidized keratin (OK) was used as supplied[a], as were the bond multiplier in-process treatment[b] and bond protector post-treatment[c].

Hair tresses: Dark brown (grade 2) hair tresses (~2 g, 20 cm) were pre-bleached without oxidized keratin or with the synthetic BM. Bleaching paste (1 part bleach powder: 1.5 parts of 20 volume (6%) peroxide solution) was applied evenly to the hair tresses with a brush. Tresses were left in ambient conditions for 1 hr, rinsed under warm water for 1 min and gently toweled dry. Tresses were hung to air dry and a comb was passed through them whilst still damp.

Bleached control: Control bleached tresses were prepared by application of the bleaching paste described previously.

Bleach with oxidized keratin: An OK bleach paste was prepared by adding one part oxidized keratin (as supplied) to four parts bleach paste.

[a] *INCI: Water* (aqua) *(and) Oxidized Keratin (and) Sodium Lactate (and) Hydroxyethyl Cellulose (and) Phenoxyethanol (and) Fragrance* (parfum)*, Keraplast Manufacturing Ltd.*

[b] *INCI: Water* (aqua) *(and) Bis-Aminopropyl Diglycol Dimaleate (and) Sodium Benzoate (and) Phenoxyethanol*

[c] *INCI: Water* (aqua) *(and) Bis-Aminopropyl Diglycol Dimaleate (and) Propylene Glycol (and) Cetearyl Alcohol (and) Behentrimonium Methosulfate (and) Cetyl Alcohol (and) Phenoxyethanol (and) Glycerin (and) Hydroxyethyl Ethylcellulose (and) Stearamidopropyl Dimethylamine (and) Quaternium-91 (and) Sodium Benzoate (and) Cetrimonium Methosulfate (and) Cetrimonium Chloride (and) Fragrance* (parfum) *(and) Polyquaterium-37 (and) Tetrasodium EDTA (and) Sweet Almond Oil (and) Tocopheryl Acetate (and)* Aloe Barbadensis *Leaf Juice (and) Panthenol (and)* Simmmondsia Chinesis *(Jojoba) Seed Oil (and) Citric Acid (and) Potassium Sorbate*

Bleach with BM: The BM bleach paste was prepared by addition of 1.0 mL of BM to 10 g of bleach paste (per manufacturer specification).

Hair treatment protocol: All tresses were wrapped in plastic film and placed in an oven at 43 ± 3°C. After 20 min, tresses treated with bleach only were removed from the oven and rinsed under warm water for 1 min. They were then gently toweled dry and partially dried off under a stream of hot air whilst combing for 10 strokes. The OK and BM bleached tresses were left under heat until they achieved the same lightness as the bleached control tresses. After approximately 40 min, all tresses were removed, rinsed and dried as previously described.

Post treatment with oxidized keratin: OK was rubbed into the tresses and they were heated at 43 ± 3°C for 20 min, rinsed under warm water, conditioned with Paul Mitchell Original Conditioner, and rinsed and dried as previously described.

Post treatment with BM: Some tresses bleached with BM were further treated with bond protector cream following the manufacturer's guidelines. The cream was applied and combed through. This was left for 20 min, rinsed off and the tresses were shampooed using Herbal Essences Naked Shampoo, rinsed, and conditioned with Paul Mitchell Original Conditioner. Following a final rinse, the tresses were dried as previously described.

Tensile testing: Hair tresses were supplied for single fiber tensile testing using a standard method based on ISO 5079:1995(E), Textile Fibers—Determination of Breaking Force and Elongation at Break of Individual Fibers. All strands were conditioned for 24 hr at 50% RH and 20°C prior to testing using a tensile tester[d]. The student's *t*-test was used to determine the statistical significance of the data sets.

Combing breakage: Each hair tress tested was first secured onto a clamp stand. A plastic comb was run through from root to tip taking approximately 2 sec to achieve a combing

[d] *Diastron LEX820 tensile tester and ASL1500 automatic sample loading module*

stroke. Each tress was combed 1,600 times and the broken fibers were collected and counted.

Sensorial assessment: A blind, paired comparison test was conducted on hair tresses. Non-expert volunteers were provided with sets of paired tresses and asked to assess each pair based on several parameters related to appearance and feel.

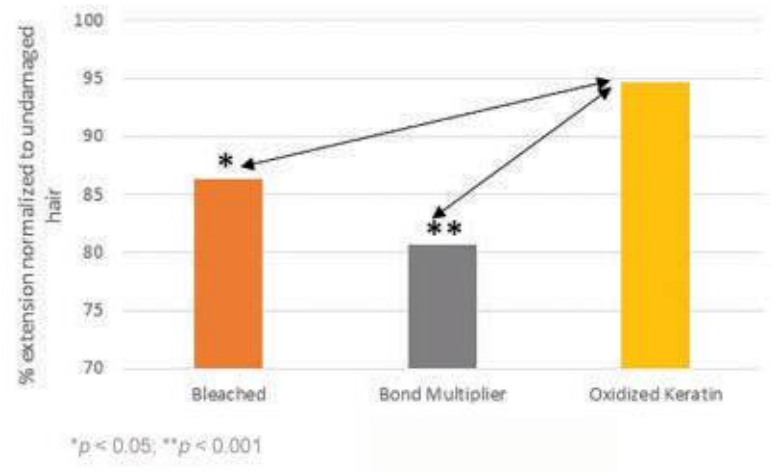
Durability of OK treatment: Hair tresses were bleached twice using 6% peroxide solution and permed three times using the Perfect Touch Perm by Fancy-full brand following the manufacturer's guidelines before being subjected to a series of washes. Each hair wash cycle included hand washing with Paul Mitchell's Baby Don't Cry Shampoo followed by Paul Mitchell Conditioner and rinsing. Hair was blown dry between washes. Hair tresses were submitted for single fiber tensile testing using a method based on ISO 5079:1995(E) and tensile tester[e] apparatus. Hair was soaked in distilled water for 30 min prior to testing.

Further bleaching: Bleached tresses were subjected to a further bleaching process either in the presence or absence of OK and synthetic BM. Some of the tresses were exposed to a second treatment with OK or bond protector cream, according to the manufacturer's instructions.

[e] *Instron 4204*

● Table 1. Single Fiber Tensile Results

Treatment	Highest Force (SD) in gF	Energy at 25% extension (SD) in mJ	Extension at peak (SD) in %	Total Energy at peak (SD) in mJ
Undamaged	95.68 (22.40)	0.47 (0.11)	89.23 (16.23)	2.58 (0.94)
Pre-bleached	93.18 (18.29)	0.41 (0.09)	78.92 (15.47)	2.02 (0.74)
Bleached control	85.69 (17.82)	0.42 (0.11)	77.05 (15.08)	1.91 (0.66)
Bleached/oxidized keratin (OK)	85.81 (21.84)	0.44 (0.11)	84.41 (17.12)	2.18 (0.82)
Bleached with BM	87.49 (17.27)	0.41 (0.09)	71.98 (12.67)	1.74 (0.57)
Bleached/OK and post treated OK	92.41 (22.27)	0.46 (0.11)	78.49 (16.40)	2.15 (0.83)
Bleached/BM and post treated BM	98.47 (25.26)	0.46 (0.14)	80.08 (17.55)	2.26 (0.92)



● Figure 1. Percentage of extension in bleached/OK- and bleached/BM-treated hair fibers

Results: Hair Strength

Tensile analysis was then performed on the samples; results are summarized in **Table 1** and **Figures 1** and **2**. The first bleaching process (pre-bleached) appeared to adversely affect tensile properties and this effect was significant ($p < 0.05$) for all parameters except highest force. A second bleaching (bleached control) resulted in all tensile parameters significantly decreasing compared with undamaged hair.