Improving Hair Strength

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Hair strength can be improved. One way to do this is to treat it with betaine. This article describes hair structure and the results of tensile testing experiments on hair that has been treated with betaine. It postulates a possible theory for the improvement in hair strength.

Hair Structure and Strength

Hair is remarkably strong. One strand of healthy Caucasian hair can support between 50 g and 100 g before breakage; this is equivalent to 12 kg/mm^2. Healthy Oriental hair is even stronger but all hair is weakened by chemical processing and physical abrasion.

The strength of hair is due to its structure of helical chains of keratin polypeptides orientated in parallel to the longitudinal axis of the hair shaft. The helical structure is stabilized by hydrogen bonding, cystine cross-linkages, coulombic interactions and hydrophobic interactions.[1]

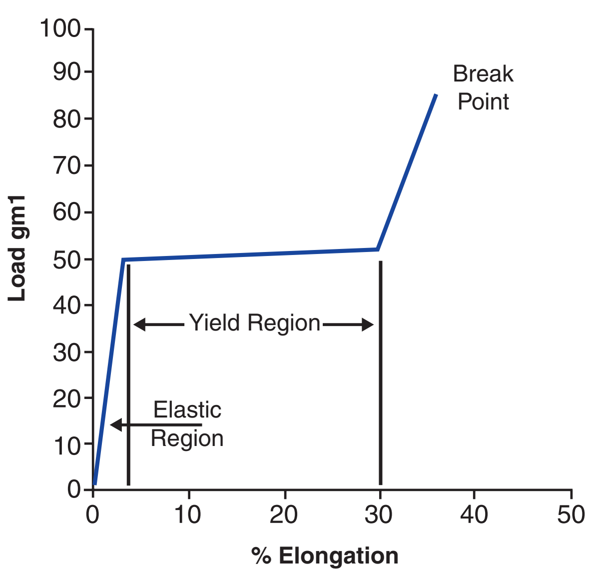

Figure 1. Load-Extension curve for human hair

When a load is applied to a human hair, it stretches (Figure 1). Initially the elongation is proportional to the load applied. After it has stretched by approximately 2% of its initial length it stretches very rapidly to 25-30% of its initial length with little increase in load; this is called the yield region. Load and elongation then become proportional in the post-yield region until breakage occurs.

The strength of hair can be measured using a suitable tensile testing instrument. Individual hairs are mounted in a jig and pulled at a fixed rate until breakage occurs. The load is applied under computer control and, for each hair, the load against extension is recorded. Using measured hair diameters and a fixed gauge length, this data may be converted to stress (load/unit area) against strain (% extension).

As Figure 1 shows, when the load is applied the effect is initially linear, but at the yield point further elongation requires little load to continue and a plateau is seen. At about 30% extension, further load is required and extension again becomes proportional to load until breakage occurs.

The Elastic region: The initial region is termed the Hookean or Elastic region. The hair structure consists of chains of α-keratin stabilized by hydrogen bonding, and the hair behaves like a crystallized solid.

The slope in the Elastic region depends on the cohesion of the α-keratin, and all factors affecting this cohesion will depress this value. Polypeptide chains

Key words

hair strength, hair structure, Oriental hair, tensile testing, betaine

Abstract

This article describes hair structure and the results of tensile testing experiments on hair that had been treated with betaine. It postulates a possible theory for the improvement in hair strength.

are the condensation products of amino acids; 18 different ones occur in human hair. In the unstretched state the polypepetide chains are helical in struc–ture and this brings the various linkages into close proximity. The cystine –S-S-bond is the strongest and occurs every fourth turn of the coil. Salt links are weaker but occur every two turns. Hy–drogen bonds between C=O and H-N groups occur at nearly every turn.

The Yield region: In the Yield or Plateau region the helical structure is lost and the polypeptide chains unfold. The hair behaves like a liquid. These changes result from the loss of stabilizing forces in the Yield region as coulombic forces and hydrogen bonds are disrupted.

Coulombic interactions form through the electrovalent union of dicarboxylic acid groups and basic amino groups in side-chains, but their strength is greatly reduced in water and more so in acidic or alkaline media.

Hydrogen bonding occurs between the C=O and H-N groups in the polypep–tide chain but the bonds are readily dis-rupted by water, which can insert itself between the O…H link. When hair is wet the yield value may be half that of dry hair.

Hydrophobic bonding occurs between non-polar hydrocarbon groups in the presence of water. Although the bonds are weak they occur in large numbers and impart significant strength to the hair structure; they are considerably reduced in the presence of wetting aids.

The Post-Yield region: In the Post-Yield region the polypeptide chains have completely unfolded and when they reach the limit of their elasticity they break. The cystine cross-linkages are the strongest bonds and are mainly responsible for hair strength in the Post-Yield region, however they are susceptible to attack by reducing agents.

Improving Hair Strength: The HPA Study

Recent work[2] undertaken by Hazel Pool Associates (HPA) shows that the strength of human hair, and particularly that of Oriental hair, may be increased by the use of trimethylglycine (betaine) as a leave-on conditioning aid. HPA used a commercial, natural betaine[a] extracted from sugar beet molas–ses by a chromatographic separation technique. A suitable instrument[b] was used to measure the tensile properties of hair.

Tresses of single-bleached European hair and of double-bleached Oriental hair were used to provide damaged samples for study. Bleaching was carried out with tresses of each type as a group, such that each received exactly the same extent of process-ing. All tresses were washed in a 15% active solution of sodium laureth sulfate (SLES) and left to dry naturally. In order to provide a baseline for the study, a number of hairs were taken from one tress in each group and were measured without further treatment.

The test tresses were treated with 1 g of SLES 15% active solution for exactly 60 sec, rinsed for 60 sec, excess water was removed by mechanical squeezing and the tress was treated with 1 g of 5% aqueous betaine solution. The tress was then combed and allowed to dry naturally. To provide a control, further tresses were subjected to the same washing procedure but water was used in place of the betaine solution.

For each measurement 50 hairs were taken at random from each tress and their diameter was measured to a resolution of 1 micron. In order to standardize temperature and humidity factors, the hairs were soaked for 15 min in water to ensure that they were fully wetted. Each hair was individually mounted in the tensile jig, and pulled in the same direction under con–trolled conditions, at a rate of 20 mm/min until breakage occurred. Load and extension were continuously recorded and converted to stress and strain to provide stress/strain figures. Computer software was used to analyze recorded data to provide a number of critical points on the stress/strain curve.

Results of the HPA Study

Selected results from the HPA study are shown in Table 1.

European hair: For European hair, six parameters showed a significant difference at $p>0.05$. They show that the hair is strengthened; it retains its initial resistance to yield for longer and is less prone to fracture.

[a] *Betafin, Finnfeeds Finland Ltd, Espoo, Finland*
[b] *Dia-Stron MTT170, Dia-Stron Ltd., Andover, England*

Table 1. Relationship of measured values of selected hair strength parameters in betaine-treated European and Oriental hair, compared to measured values in untreated European and Oriental hair (HTC = higher than control; LTC = lower than control)

Hair strength parameter	European	Oriental
Elastic extension	HTC	-
Yield extension	-	HTC
Break extension	-	HTC
Elastic modulus	-	LTC
Elastic gradient	-	LTC
Plateau stress	HTC	LTC
Stress at 15% extension	HTC	LTC
Stress at 25% extension	HTC	LTC
Work required to extend the hair by 15% of its initial length	HTC	-
Work required to extend the hair by 25% of its initial length	HTC	LTC

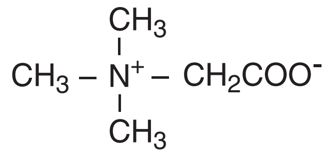

Figure 2. The trimethylglycine form of betaine

Oriental hair: For Oriental hair, eight parameters showed a significant difference at $p>0.05$. Higher yield extension and break extension figures show that hair has extended further before breaking and therefore the hair is less brittle. This improved elasticity imparts improved strength to Oriental hair.

Discussion

The trimethylglycine form of betaine used for the study is quite different from fatty acid betaines or cocamidopropyl betaine (CAPB). Like them it is a zwitterion; that is, the nitrogen atom carries a positive charge regardless of pH and this is balanced by a negative charge on the carboxyl group (Figure 2). Unlike the fatty acid betaines and CAPB, this betaine has little effect on surface tension and is not a surfactant, owing to the fact that it does not have a fatty tail and therefore does not form micelles or adsorb at the interface.

Luigi Rigano[3] has described trimethylglycine's chemical, physical and physiological properties and given many interesting ideas for its use in personal care products. Rigano made special mention of its buffering capacity, its biocompatibility, its ability to reduce the irritation effects of surfactants and its special skin feel.

Of particular interest in the context of hair strengthening is the strong hydrogen bonding capability of betaine and its great affinity for water. There are several possible mechanisms to consider.

It has been suggested that betaine restores the hydrogen bonds within the hair shaft that are normally disrupted by water. It is also thought that carboxyl groups of the betaine form bridges by electrovalent union with the basic amino groups while betaine also behaves as a methyl donor to the free dicarboxylic groups in the polypeptide chains that make up the hair structure.

To those ideas, I add my own, that although most of the bonds present in dry hair are lessened in the presence of water, the water-affinity shown by betaine reduces water availability and lessens its disruptive effects.

Whatever the mechanism, the use of the trimethylglycine form of betaine in leave-on hair conditioners will improve the strength of hair – including chemically processed hair, and especially Oriental hair that has been chemically processed. This is a very interesting formulation concept.

References

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