Improving the Strength of Hair

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Abstract

Hair is remarkably strong. One strand of healthy Caucasian hair can support between 50g and 100g before breakage; this is equivalent to 12kg/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 stabilised by hydrogen bonding, cystine cross-linkages, coulombic interactions and hydrophobic interactions. The 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.

Introduction

Hair is remarkably strong. One strand of healthy Caucasian hair can support between 50g and 100g before breakage; this is equivalent to 12kg/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 stabilised by hydrogen bonding, cystine cross-linkages, coulombic interactions and hydrophobic interactions[1].

When a load is applied to a human hair it stretches. 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).

Insert Chart 1

The diagram shows extension under load, initially the effect is 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 become proportional to load until breakage occurs.

The initial region is termed the Hookean or Elastic Region. The hair structure consists of chains of α-keratin stabilised by hydrogen bonding and the hair behaves like a crystallised solid.

In the yield or plateau region the helical structure is lost and the polypeptide chains unfold. The hair behaves like a liquid.

In the post-yield region the polypeptide chains have completely unfolded and when they reach the limit of their elasticity they break. The slope in this region depends on the cystine content of the hair fibre. The elastic region depends on the cohesion of the α-keratin and all factors affecting this cohesion will depress this value. 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 CO and NH groups in the polypeptide chain but they are disrupted by water. 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 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.

Investigations into improving hair strength

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-in conditioning aid. The betaine used for the study was a natural one extracted from sugar beet molasses by a chromatographic separation technique, and sold under the trade name Betafin[3]. HPA used a Dia-Stron MTT170[4] 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 processing. 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 1g of SLES 15% active solution for exactly 60 seconds, rinsed for 60 seconds, excess water was removed by mechanical squeezing and the tress treated with 1g 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 standardise temperature and humidity factors the hairs were soaked for15 minutes 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 controlled conditions, at a rate of 20mm/minute 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 analyse recorded data to provide a number of critical points on the stress/strain curve.

Results

For European hair six parameters showed a significant difference at $p>0.05$; the betaine treated tress had a higher elastic extension and higher values for plateau stress, for stress at 15% and 25% extension and for the work required to extend the hair by 15% and 25% of its initial length, when compared to the control of hair treated with water. This shows that the hair is strengthened; it retains its initial resistance to yield for longer and is less prone to fracture.

The oriental hair showed statistically higher values for yield extension and break extension but lower figures for the elastic modulus, elastic gradient, plateau stress and stress at 15% and 25% extension and for the work required to extend the hair by 25% of its initial length. 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 that of Oriental hair.

Discussion

The betaine used for the study is quite different to 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

[Insert Betaine Structure]

balanced by a negative charge on the carboxyl group. Unlike the fatty acid betaines and CAPB, betaine has little effect on surface tension and is not a surfactant. The reason being that it does not have a fatty tail so does not form micelles or adsorb at the interface. Luigi Rigano[5] has described its 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 capabilities of betaine and its great affinity for water and there are several possible mechanisms to consider. It is suggested that betaine restores the hydrogen bonds within the hair shaft that are normally disrupted by water. It is also thought that –COOH groups of the betaine form bridges by electrovalent union with the basic amino groups while it also behaves as a methyl donor to the free dicarboxylic groups in the polypeptide chains that make up the hair structure. In addition, 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 betaine in leave-on hair conditioners to improve the strength of hair, and in particularly of Oriental hair that may be subjected to chemical processing, is a very interesting formulation concept.

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