# MECHANICAL RESISTANCE OF HAIR: A NEW APPROACH TO EVALUATE THE EFFECT OF CHEMICAL TREATMENTS IN THE MECHANICAL BEHAVIOR OF THE FIBER.

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## 1 INTRODUCTION

Chemical treatments are widely used to modify the hair's physical appearance, by altering the hair fiber structure and, as a result, its mechanical behavior. Thereby, characterizing the mechanical properties is an interesting methodology to measure the structural changes occurring within the hair fiber. However, although the mechanical behavior of the natural hair fiber is well known and abundantly reported, the data on the hair properties after chemical treatments are usually restricted to the evaluation of some tensile strength parameters without further interpretations of the whole stress-strain curves. Consequently, it is challenging to compare the effect of chemical treatments that affect the stress-strain curve in different ways.

This work aims to investigate the stress-strain curves of human hair fibers submitted to different chemical treatments, with the objective of highlighting each technology's signature and to propose a multivariate way to compare the effect of these treatments in terms of the impact upon hair integrity.

## 2 MATERIALS AND METHODS

### HAIR FIBERS AND CHEMICAL PROCEDURES

The hair tresses were prepared from randomized and standardized fibers of natural human hair in 2.7 g swatches, with curliness degree type 3, according to De la Mettrie's scale [1], and original from people with Brazilian nationality. The assemble of hair swatches was divided into the groups described in Table 1, each of them submitted to different chemical transformation procedures to achieve different levels of sensitization.

*Table 1. Application protocol for the chemical procedures used in each treatment.*

| GROUP | PROTOCOL APPLICATION |
|---|---|
| Natural hair | These groups were washed with shampoo with low treatment properties. |
| 2 x Bleaching | The hair fibers were submitted to 1 bleach application using a bleach mixture containing 12% hydrogen peroxide for 45 minutes in a 27 °C heat plate. |
| 2 x Bleaching (more aggressive) | The hair fibers were submitted to 2 bleach applications using a mixture containing 12% hydrogen peroxide for 45 minutes on a stove at 37°C, wrapped in aluminum paper. |
| 1x Ammonium Thioglycolate | The hair fibers were submitted to 1 thioglycolate application in a 27°C heat plate for 30 minutes pause time, then brushed, in sequence flat ironed, then the neutralizer was applied with 10 minutes pause time. |
| 1x Formaldehyde and 3x Formaldehyde | The hair fibers were submitted to 1 and 3 application of formaldehyde with 19% of the active compound for 30 minutes, then brushed and in sequence flat ironed |
| 1x Glyoxylic acid | The hair fibers were submitted to 1 application of glyoxylic acid in a 27°C heat plate for 40 minutes pause time, then brushed, in sequence flat ironed, then the neutralizer was applied with 10 minutes pause time. |

### TENSILE ASSAY

Tensile assays were performed under wet conditions and using 50 individual hair fibers, measuring 3 cm long, per group (Table 1) to ensure statistical rigor. The wet tensile assays were performed using MTT 670 - Automated Tensile Tester from Dia-Stron at 80% relative humidity using a 10 mm/min extension rate and a pre-strength of 20 mN.

## 3 RESULTS & DISCUSSION

Chemical treatments cause structural modifications in the hair fiber and correspondent changes in the stress-strain response. In general, while the oxidative bleaching and ammonium thioglycolate promote stress reduction along the entire tensile curve without a significant effect in the strain at break, the acid straighteners (formaldehyde and glyoxylic acid) application promotes the opposite effect, reducing the strain at break significantly. In addition, a marked increase in the slope of the curve after formaldehyde and glyoxylic acid can be observed.

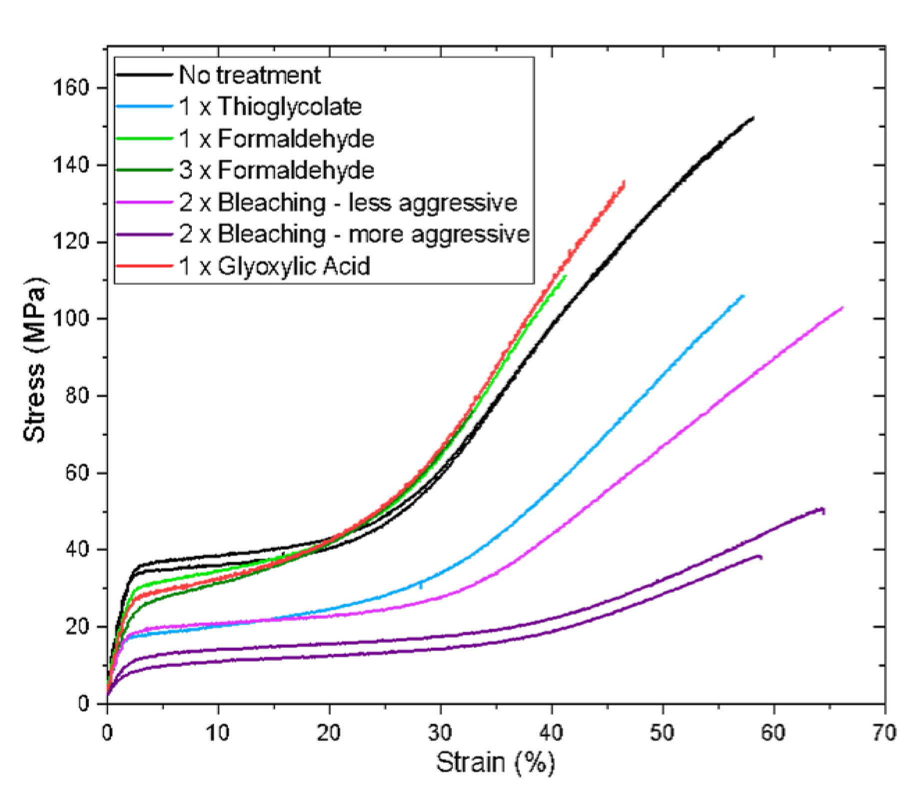


Figure 1. Average stress – strains curves overview

Both bleaching and ammonium thioglycolate reduce the disulfide bond content and promote the supercontraction of the a-helix structure, leading to a similar effect on the hair fiber's stress-strain response. A possible explanation is that as the disulfide bond content decreases with the treatment, the sliding of the IFs and protein is facilitated.

Despite the differences in the curve shape and the different effects each treatment causes in the hair fiber's tensile response, the wet stress at break seems to indicate hair damage for all cases. Attention must be paid to the fact that different types of damage can cause a similar decrease in stress. The stress at break (Figure 2.A) of the hair treated with 1-time thioglycolate, 1-time formaldehyde, and 2-times bleaching less aggressive are nearly the same. However, looking at the extension at break (Figure 2.B) and the shape of the tensile curve (Figure 3) of the hair fibers submitted to these three treatments, one can note that each breaking stress was reached in a different extension of the hair fiber. While the extension after thioglycolate treatment has no significant change, the 2-times bleached hair fiber can extend a little more, and the formaldehyde hair can extend much less compared to the non-treated hair. An alternative is to analyze the properties simultaneously, as in Figure 2.C. The difference in the break behavior before and after the treatments is more evident and better to distinguish than when changes are not significant.

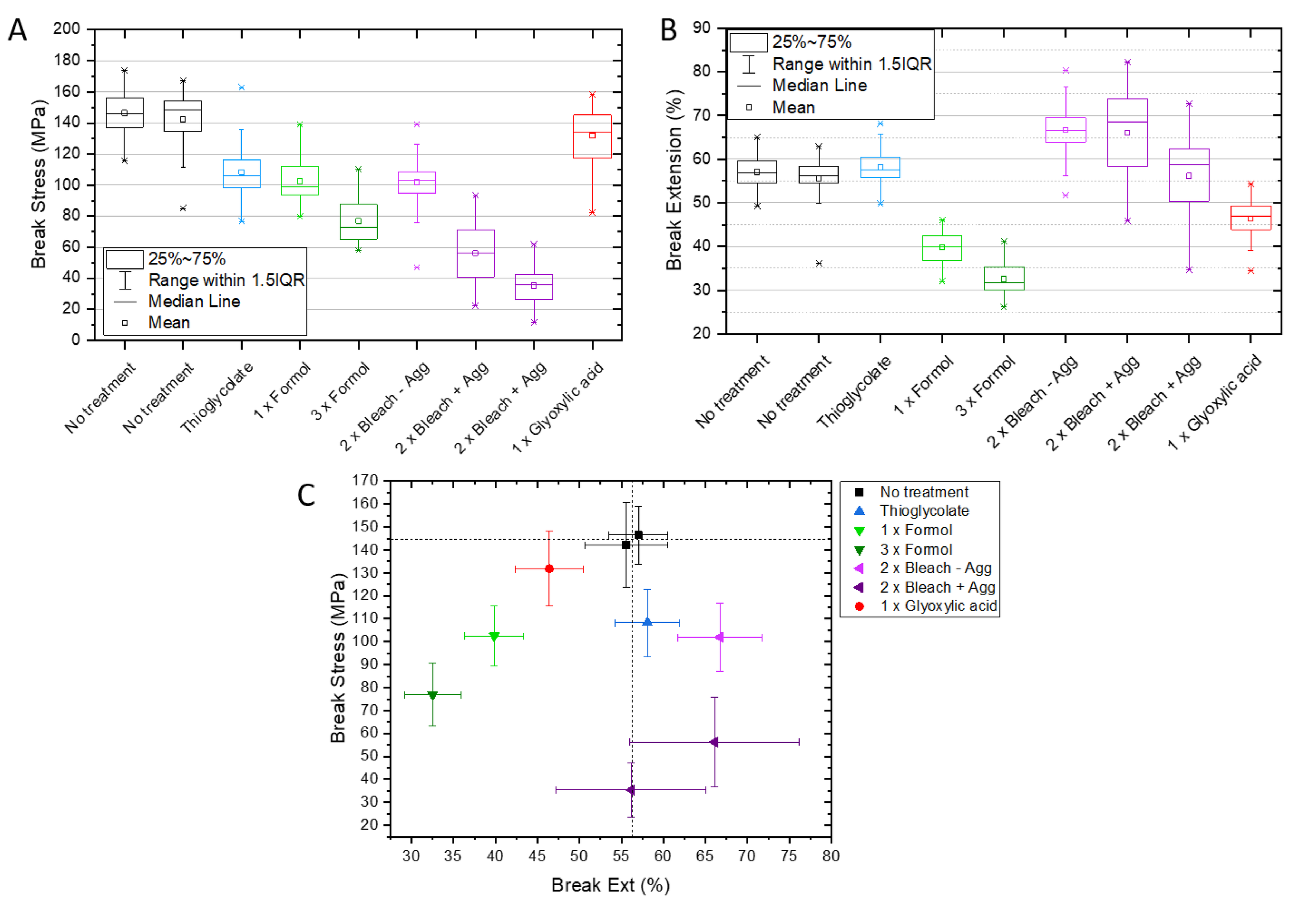


*Figure 2. Mean break strain for each group (A) Break extension for each group (B) Break stress and extension for the treatments and references (C).*

All treatments led to a decrease in the toughness, also a parameter indicating hair damage. Meanwhile, different treatments that cause different types of damage to the hair fiber and generate tensile curves with significantly different shapes can still result in similar toughness. For example, the hair fiber after 3-times formaldehyde application and the hair fiber after more aggressive bleaching presented statistically the same mean value of toughness despite the entirely different stress-strain response.

The measurement of a single tensile parameter can indicate damage, but further comprehension of the degree of damage in order to compare fibers submitted to different mechanisms of sensitization needs a multivariate analysis of the stress-strain curves' parameters. The most suitable properties for comparing treatment effects are the elastic modulus, plateau stress, yield extension, yield slope, postyield gradient, break extension, break stress, and toughness.

Figure 3 shows a proposed holistic visualization of the hair damage based on the absolute relative differences between the treated and non-treated hair fiber in a linear combination of the selected parameters. It is important to remark that some parameters can have a greater weight than others in the damage perception, and adjustments may be necessary to a final equation.

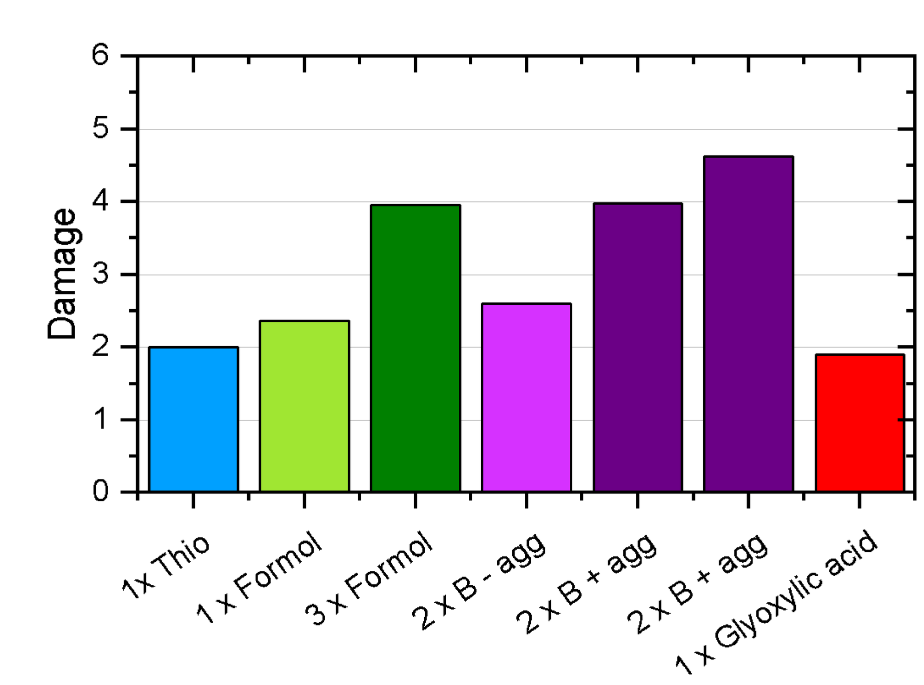


*Figure 3. Quantification of the damage degree in the hair fiber of different groups.*

## 4 CONCLUSIONS

Some alternative ways to evaluate the fiber damage are proposed and discussed in this work. The evaluation of break stress and break strain in a Cartesian coordinate system allows a better distinction of the differences in the breakage behavior after the structural changes caused by chemical treatments. Finally, a reasonable quantification of the hair fiber integrity is obtained by calculating a damage factor that considers the variation of the eight properties highlighted compared with the reference values.

References:

De La Mettrie, R., Saint-Léger, D., Loussouarn, G., Garcel, A., Porter, C., & Langaney, A. (2007). Shape variability and classification of human hair: a worldwide approach. *Human biology*, 79(3), 265-281.

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