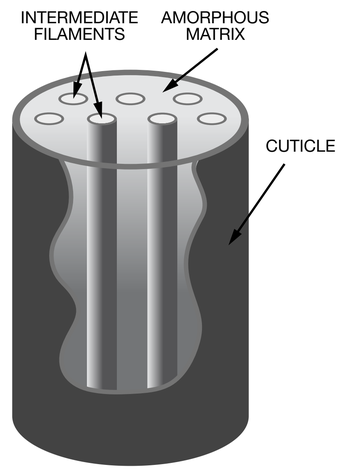
APPLICATION OF A NEW "CURL REVERSION" IMAGE ANALYSIS METHODOLOGY TO QUANTIFY HEAT DAMAGE TO THE INTERMEDIATE FILAMENT STRUCTURE OF HAIR

INTERMEDIATE FILAMENTS (IFs)

IFs are central to the mechanical strength and shape memory of human hair fibres. Composed primarily of keratin proteins, intermediate filaments are densely packed within the cortex of the hair to form a robust, fibrous network that resists deformation and provides the main contribution to the overall fibre tensile strength.

The integrity of IFs plays a crucial role in determining the shape of the hair fibre depending on the distribution of IFs within the cortex along with overall asymmetry of the cortical cells.

SIMPLIFIED HAIR SHAFT



THE IMPACT OF HEAT ON HAIR SHAPE

- When hair is styled or exposed to heat, the amorphous matrix protein becomes plasticised allowing temporary reshaping of the fibre. Upon cooling and drying, the matrix re-solidifies, locking the fibre into its new shape configuration.
- Styling at temperatures below 200°C, enables plasticisation of the hair fibres without compromising the IF protein integrity, retaining a "memory" of the original fibre shape. Upon exposure to moisture, the temporary hydrogen bonds within the matrix protein break allowing the IFs to revert to their original, energetically favourable configuration, causing the hair to return to its natural shape where the hydrogen bonds reform as the hair cools.
- Above 200°C, the IFs undergo irreversible denaturation. Consequently, when the hair is later exposed to moisture, and the hydrogen bonds in the amorphous matrix protein break, there is no residual structural force from the IFs to drive the fibre back to its original shape. In curly or wavy hair this is most noticeable as the transformation becomes permanent, (meaning the natural curl is lost) as the internal architecture responsible for curl formation has been fundamentally altered.

QUANTICATION OF IF PROTEIN INTEGRITY

Curl reversion, defined as 'the ability of a fibre to return to its original curvature upon exposure to moisture', offers a functional proxy for assessing the integrity of IFs.

This approach enables targeted evaluation of substructural damage, advancing beyond bulk mechanical testing to provide molecular-level insight into heat-induced degradation.

By quantitatively assessing the fibres' ability to revert to its natural curl following heat styling, we aim to isolate and measure the extent of IF structural integrity and offer a new consumer relevant avenue for evaluating the performance and damage of heat styling technologies.

METHOD DEVELOPMENT

HAIR TRESSES: Curl Type 3-4 (International Hair importers and products inc., Glendale, NY, USA, 0.15g/cm, 280mm (l))

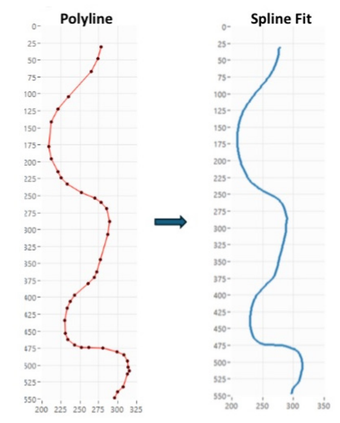
STYLER SELECTION: Seven commercial stylers operating across a range of plate temps (185–235 °C) and widths (26-45 mm).

HAIR TREATMENT: up to 300 passes with a styler at 44mm/s (reflective of the average speed of untrained consumers). At least 40 single fibre samples were taken at minimum 3 equal treatment intervals. To mimic consumer behaviour, the samples were scrunched (by hand) upwards for 3-4s twice and left to dry overnight (23°C, 50%RH).

MEASUREMENT: Once dry, the quantitative curvature analysis of the hair fibres was measured using Bossa Nova Vision's Shuffle System with Single Fibre attachment; designed for automated single-fibre aeometric characterization. The system calculates the local curvature (κ_i) for each point along the spline-fit path using the standard planar curve formula.

The **MEAN CURVATURE** $(\bar{\kappa})$ for each fibre was defined as the arithmetic mean of the absolute curvature values.

$$\bar{\kappa} = \frac{1}{N}\sum_{i=1}^{N} | \kappa_i |$$

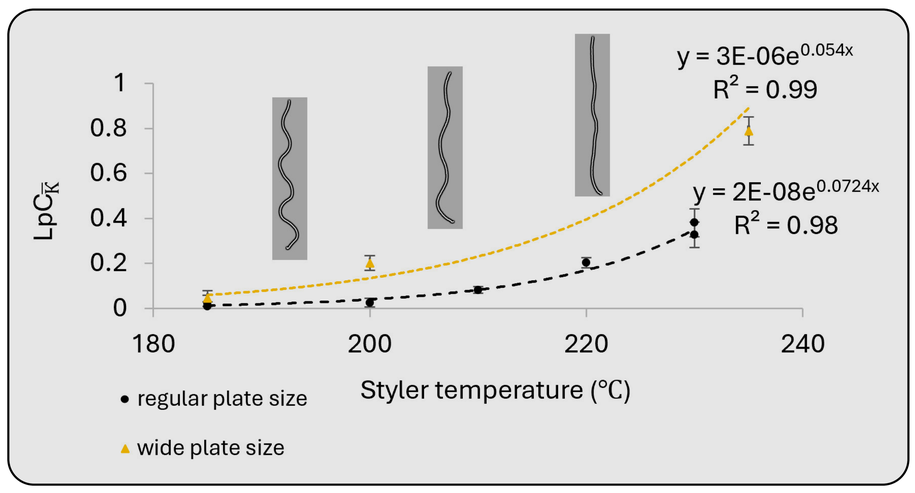


DATA ANALYSIS: To determine if the treatment has affected the hair shape memory, a linear regression was conducted, and the p-value monitored. The results were first normalised by dividing the averaged values of parameter measured after 0, 100, 200 and 300 treatment intervals by the value for the control sample (virgin, untreated). If $p < 0.05$, the samples are considered significantly different at 95% confidence level, and a negative gradient is indicative of a change in fibre shape from curly to straight. The change in curl shape is then quantified by expressing the gradient as a fractional loss per cycle of the mean curvature $(LpC\bar{\kappa})$.

COMPARISON OF DIFFERENT HEATED APPLIANCES

The new methodology allowed for a comparative study of impact of the characteristics of the hair styling tool (plate temperature) and contact area (plate size) on the IF integrity of the hair fibres.

- For regular size stylers set to up to 200°C, fibres reverted to their original shape and thus no stat. sign. differences were found ($p > 0.05$) between the mean curvature of fibres measured before and after heat treatment.
- For a wide plate styler operating at 200°C, measurable changes were detected ($p < 0.05$), demonstrating that the contact area plays a significant role in the extent of IF damage.
- Beyond 200°C, the mean curvature was shown to decrease linearly upon increased number of treatment cycles. The rate of fibre damage increased exponentially with rising styler plate temperature.



CONCLUSIONS

- Curl reversion behaviour can be used as a quantitative and functionally relevant indicator of IF integrity in human hair fibres following heat styling.
- By measuring changes in mean curvature after controlled moisture exposure, it is possible to isolate heat-induced damage to the IF network that cannot be resolved by bulk mechanical testing alone.
- Hair fibres exposed to repeated straightening treatments with ghd stylers retained their ability to revert to their original curl shape, indicating preservation of IF structure even after extensive treatment cycles, unlike commercially available competitor products.
- Overall, curl reversion analysis offers a robust and accessible method for evaluating heat-induced IF damage, enabling more discriminating assessment of heat-styling devices and supporting the development of styling technologies that minimise irreversible structural degradation of the hair fibre.
- The ghd styled tress looks less frizzy than the control due to improved cuticle and hair fibre alignment

GHD SCULPT

When tested using the methodology outlined above ghd Sculpt can be shown to be not significantly different statistically from virgin hair at the 95% confidence level, after 300 passes. ghd sculpt is designed such that the combination of technologies, sensors and software algorithms ensure that there are minimal plate hotspots and that the plate temperatures do not spike above the damaging level.

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