

# Correlating Porosity and Tensile Strength of Chemically Modified Hair

*This study validates the porosity method against the widely accepted method of tensile strength for determining the hair damage imparted to hair due to cosmetic treatments.*

**key words:** hair porosity, hair tensile strength, hair damage, permanent hair colors, avid permanent waves, hair relaxers, hair bleaches

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Over the years, many individual studies have been conducted regarding the extent of damage imparted to hair. These studies deal with the damaging effects of various chemical processes such as permanent waves, permanent colors and hair bleaches.<sup>1–8</sup>

The most commonly employed method to quantify this damage is the measurement of change in tensile properties of the hair. This method takes two to three days in the preparation of samples of hair fibers. It also requires a minimum of 30–40 fibers for statistical analysis. Therefore, there is a need for other simpler methods that are equally valid and less time-consuming.

One such method could be the determination of hair porosity or water uptake of hair fibers as described by Valko et al.<sup>9</sup> and by Menkart et al.<sup>1</sup> However, to the best of our knowledge, no study so far has correlated the tensile strength method with the water uptake (swelling/porosity) method following chemical treatments such as permanent waves, permanent colors, hair bleach, and permanent hair relaxers.

Therefore, we have conducted a study whose purpose was to validate the porosity method against the tensile strength method. Another purpose of this study was to use these two methods to compare the magnitude of hair damage between permanent waving, permanent coloring, hair bleaching, and permanent straightening processes. Finally, this study ranked the various chemical processes in terms of their hair damage potential. We believe this is the first comparative damage ranking for various chemical processes in the hair care field.

## Swelling or Porosity of Hair

Professionals who are involved in the art of styling hair define the porosity of hair as the capacity of hair to absorb liquids. Hair that absorbs a larger quantity

of liquid is said to be more porous than hair that absorbs less liquid. Hair stylists associate higher porosity of hair with higher degree of damage.<sup>10</sup>

Water is able to penetrate into hair after a sufficient contact time. As explained by Feughelman, the absorption of water takes place initially onto the hydrophilic sites of the globular protein matrix and on the surface of the microfibrils. After the initial absorption, more sorption of water builds up on water molecules already attached to the protein structure.<sup>11</sup> According to Chamberlain and Speakman, the total uptake of water is 31.18% at 100% humidity.<sup>12</sup> The uptake of water or swelling of hair can be measured by two methods: the volume method or the weight method.

**Volume method:** Shansky, in 1963, was the first person to measure the change in the diameter of the individual hair fibers using a microscope.<sup>13</sup> In 1990, Nothen et al. devised a more accurate instrument utilizing an optical unit for sensing the diameter of a single fiber, and an online analyzer for displaying the data in real time.<sup>14</sup> In 1998, Syed et al. measured real time swelling of individual fibers using a laser micrometer that measured the major and minor axis of the fiber simultaneously during the immersion of the fiber in an appropriate solution.<sup>15</sup>

In each of these volume methods, the selection of the fibers takes a long time and then swelling of each fiber has to be measured over a 20–30 minute period. Also many individual fibers have to be used in order to get statistically significant results. Additionally, this method may not be appropriate for measuring the change in diameter of African-descent fibers where the inherent variation in diameter is significant within a single fiber along the hair shaft.<sup>16</sup>

**Weight method:** The weight method is much less tedious and has the ability to study the swelling or water uptake of hair fibers using a centrifuge. With this method, a single operator can conduct more than 50 measurements a day.<sup>17</sup> The weight method is also known as the liquid retention or porosity test. Valko and Barnett have defined porosity as the capacity of hair fibers to absorb water.<sup>9</sup> Chemically damaged fibers are considered hydrophilic or porous and therefore would more readily pick up moisture and retain water than the untreated or unmodified hair. Valko and Barnett believed that the greater the porosity of hair, the greater was the damage to the hair fiber. They found the uptake of water for unmodified or normal hair to be 31.10%. Therefore, the porosity technique may become a primary method for determining hair damage due to cosmetic treatments if it correlates with most widely accepted methods for measuring hair damage. One of those methods is the measurement of tensile strength.

### Tensile Strength of Hair

The tensile properties of hair fibers play an important role in determining the efficacy of hair treatments such as permanent waves, permanent hair colors, bleaches and permanent hair straighteners. The influence of various hair treatments on the tensile properties of hair can be measured using tensile meters such as Instron<sup>a</sup> and Dia-Stron<sup>b</sup>.<sup>18</sup>

One commonly used method to determine if hair fibers have been altered by treatment with cosmetic products is to extend the fibers to 20% of their length before and after treatment and determine the so-called F20 Index. A single fiber

is stretched to 20% strain or elongation at a specified constant rate (elongation per minute). The area under the curve (Energy) required to stretch the fiber to 20% strain is used to assess the condition of the fiber. The index values (After/Before Treatment) are calculated and used to assess the extent of hair damage. An Index of less than 1.0 indicates damage to the hair fiber produced by the chemical hair product. This method was first developed by Speakman in 1947 in order to study the effects of physical and chemical processes on keratin properties. Speakman used a percentage to express the changes in the stress for a fixed strain of fibers.<sup>18</sup>

Sookne and Harris coined the term 30% index as the ratio of extension values.<sup>19</sup> This test is similar to the F20 test except that the single fiber is stretched to 30% strain or elongation.

Over the last 50 years, it has become a standard practice to ascertain the F20 Index of the fibers before and after the given treatment in order to determine the positive or negative effect of the treatment on the fibers. In 1966, Menkart et al. compared the F20 Index of hair and wool and found hair to have slightly higher F20 Index than wool.<sup>1</sup>

In addition, many published studies have examined the changes in the tensile strength of cosmetically modified hair in the area of permanent hair colors, permanent hair waves, and hair bleaches.<sup>2-8</sup> The field of permanent hair relaxers is not well researched, although Syed et al. have compared the tensile strength of Caucasian hair against African-American hair using the methods of Speakman<sup>18</sup> and Menkart et al.<sup>1</sup>

Therefore, in order to verify the reliability of the porosity/weight method, we designed a study to correlate the porosity of hair fibers at 100% humidity with the tensile strength of hair fibers at 100% humidity. We hypothesized that a negative correlation would exist between porosity and tensile strength. Additionally, we asserted that if the coefficient of determination ( $r^2$ ) is at 0.95 or higher, then the porosity/weight method would be considered correlated and thereby established as a reliable method for future use in the laboratory.

This method will enable the hair researcher to obtain results that are both faster and reliable. This method will also allow the hair chemist to compare the degree of damage imparted during various cosmetic treatments.

## Experimental

**Treating the hair:** For the porosity testing, all hair used was Caucasian hair 8 inches long, assembled into six tresses of equal weight. The tresses were accurately weighed on an analytical balance at  $4.0\text{ g} \pm 0.1\text{ mg}$ .

For testing the tensile strength of the hair, dark brown European-descent fibers (Level 2) of 80–90 microns were obtained<sup>c</sup> and separated into six different groups.

Of the six weighed tresses, one was left untreated as a control, and each of the other tresses was subjected to one of the following cosmetic treatments: permanent hair color, acid wave, permanent hair relaxer (sodium hydroxide), permanent hair relaxer (guanidine hydroxide) and hair bleach. Details of these treatments are presented in **Table 50.1**. The method of treatment employed in each case was the same as practiced in the market place.