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Changes Observed in Human Head Hairs Exposed to Heat

ABSTRACT

Evidence from an arson case was submitted for forensic analysis. It required the examination of the microscopic characteristics in burnt human hair. Burnt hairs are expected to exhibit a color change, expansion, and a 'bubbled' appearance [1, 2] of rounded vacuoles in the cortex. However, a literature search failed to yield definite statements regarding at what temperatures these changes occur with respect to human hair encountered in forensic casework and whether these temperatures are within the range of heated hairstyling tools.

This study was done to determine the temperature at which human hairs start exhibiting burnt characteristics. Human head hairs were placed within a furnace heated to 100-400 °C. Hairs were examined before and after heat exposure to determine at what temperatures color changes, expansion, and bubbling occur without a flame. Changes to the hairs were documented using photomicrography. Discoloration and bubbling were observed in specific circumstances at temperatures as low as 190 °C, which is within the operating range of some heat styling tools.

Keywords: Hair, burnt hair, heat exposure, hair exposed to heat, forensic hair examinations, microscopic, hair characteristics, arson

INTRODUCTION

A fire investigation case required the microscopic examination of hair to determine if it was burnt. The suspect's hair was submitted for microscopic examination after it had already been put through a passive headspace procedure for the separation of ignitable liquid residues. The passive headspace procedure called for the hair to be incubated at 65 °C for 16 hours. To demonstrate that the damage observed in the hair was not caused by the laboratory incubation procedure, a control test was performed in which several hairs were examined and photographed before and after exposure to the

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incubation conditions. The incubation conditions were found to be insufficient to impart burnt hair characteristics. The next step would be to determine what conditions would impart the color change, swelling, and bubbled appearance of burnt hair. The conditions under which these changes take place have not been published in the available forensic literature. Several variables required consideration, such as the temperatures to which hair is exposed, the heating rate, the total time the hair is exposed to the temperatures, and how the heat is applied to the hair. Previous studies have simulated the burning of hair through direct contact with a hot plate or an open flame. A 1985 abstract from Ayres [3] reported that a color change could be observed in Caucasian head hair after four minutes of heating on a hot plate. Hairs exposed directly to flame exhibited charring and bubbling without a color change. In 1997, Wąs [4] reported research on thermal changes to synthetic fibers, sheep wool, cotton, jute, and flax. Additional studies by Wąs-Gubała and Krauß [5] were published in 2006 regarding the characterization of thermal changes in synthetic fibers, wool, and cotton.

The method by which the heat is imparted to the hair is especially significant with respect to human head hair. Many people intentionally alter the shape and appearance of their hair through heat styling tools such as blowdryers, hot rollers, curling irons, straightening irons, and hot pressing combs. If burnt hair characteristics could reasonably be attributed to hairstyling effects, the significance of burnt hair characteristics observed in any individual allegedly associated with a fire investigation may diminish.

Two local cosmetology schools were surveyed regarding which professional techniques and tools they use to apply the highest temperature to hair. Both referred to curling and straightening procedures achieved with Belson irons. Belson Products manufactures and markets professional curling irons generally capable of heat settings from 100-220 °C [6]. These irons are capable of exceeding temperatures known to cause serious damage to human skin. For instance, a hot liquid at 140 °C can cause severe burns by scalding within five seconds [7]. However, the highest temperature a Belson curling iron [8] was found to be advertised to reach was 440 °F (226.7 °C). Belson also manufactures thermal irons and hot pressing combs for specialized heat styling techniques in which tools heated to higher temperatures are moved quickly through hair. Thermal irons are heated inside ceramic stoves [9] advertised to reach 460 °C. Hot pressing combs are either heated on stoves or are electric self-heating [10] to 500 °F (260 °C). Cosmetology practical exams [11] state that heated tools should be tested against paper for excessive heat prior to use on hair. The tool is too hot to use if it scorches the paper [12]. The commonly accepted auto-ignition point of paper is 451 °F (233 °C). Therefore, during the course of professional heat styling, it would be expected that human head hair could be subjected to brief direct contact with tools heated to no more than 233 °C.

MATERIALS AND METHODS

Study 1

The first study simulated the effect of hairs pressed within an iron. A laboratory scientist donated untreated Caucasian origin head hairs (27 cm long and less) for this project. These hairs were mounted in Permount, examined for signs of heat damage prior to being exposed to heat for the purposes of the study, and photographed. There was no evidence of coloring or bubbling consistent with heat damage. The hairs were removed from their mounts with xylenes.

Temperatures investigated in this first study were 100, 200, 225, 250, 275, 300, 325, 350, 375, and 400 °C. For each of these temperatures, three hairs were placed on the surface of a metal block inside a Barnstead Thermoline 1400 Furnace. A second block was placed on top of the hairs to simulate pressing as well as to prevent loss of the test items. Figure 1 contains a diagram of this apparatus. The furnace door was closed and the furnace was set to heat to the desired temperature. Upon reaching temperature, the furnace was powered off and the door of the furnace was opened. The hairs were removed from the metal blocks and examined once the temperature cooled enough for the items to be handled. The hairs were again mounted in Permount, examined, and photographed.

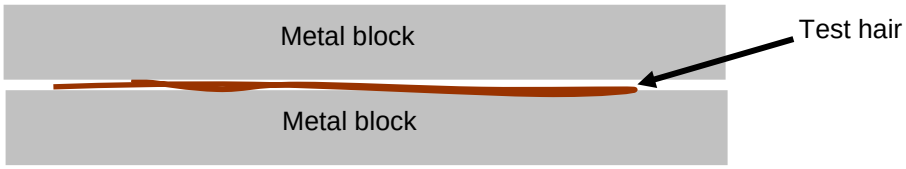

Figure 1: A diagram of the test apparatus inserted into the furnace in Study 1. The hairs were pressed between the metal blocks that are shown partially inserted into the open furnace.

Study 2

The second study simulated the effect of hairs exposed to a heated environment. The hairs were obtained and documented as in the first study described above. Temperatures investigated in this second study were lowered to account for the insulation provided by the metal block in the first study. This time, the test hairs were suspended in the furnace area with a clip apparatus. The temperatures observed were 100, 150, 175, 185, 200, and 300 °C. Three hairs were tested at each temperature. After heat exposure, the hairs were examined for any changes attributable to heat. A diagram of the clip apparatus used to suspend the test hairs is shown in Figure 2.

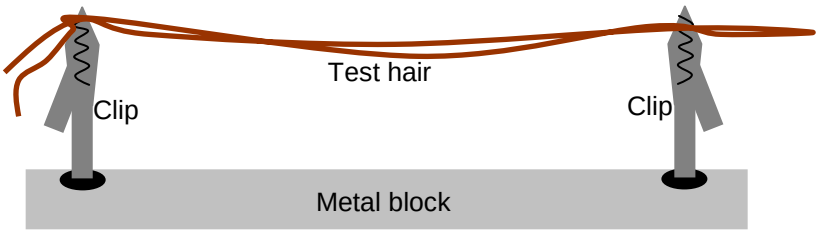

Figure 2: A diagram of the test apparatus inserted into the furnace in Study 2 and Study 3. The hair was clipped between two alligator clips and suspended in the air within the furnace.

Study 3

The procedure of Study 2 was repeated with a minor alteration. The test hairs were suspended with the same clip apparatus as in Study 2 but with the support oriented diagonally inside the furnace so that the ends of the hair were farther away from the furnace wall. The orientation of the block inside of the furnace was altered in order to place the hairs more centrally in the oven. This was done because Study 2 indicated that the portions of the hair closest to the edges of the furnace walls were preferentially showing heat exposure characteristics. A photograph of the apparatus is shown in Figure 3. The furnace was set to 180, 185, 190, 195, and 200 °C. Three hairs were tested at each temperature. After heat exposure, the hairs were examined as above for any changes attributable to heat.

Figure 3: A photograph of the apparatus inside the oven for Study 3. The diagonal orientation of the metal block and the test hair with respect to the oven walls and thermocouple is shown. Study 2 was set up similarly, except for the orientation of the metal block.

Study 4

The proximal 1 cm was cut from 21 test hairs. Each proximal hair fragment was mounted onto a glass microscope slide with Permount and a cover slip. The fragments were examined microscopically to confirm no pre-existing heat damage was evident prior to testing. Photomicrographs were taken to document the observations. Each

hair fragment was removed from its mount, rinsed in xylenes and dry-mounted onto a glass slide with a cover slip. The samples were exposed to a set temperature between 100 and 250 °C within a Mettler FP82HT Hot Stage mounted onto an Olympus BX40 microscope and controlled by a Mettler Toledo FP90 Central Processor. Figure 4 depicts the instruments used. The hot stage was programmed to the set temperature prior to the insertion of the slide. The slide was inserted and time was allowed for the hot stage to restore itself to the programmed temperature. Once the programmed temperature was restored within ±1 °C, exposure was timed for approximately five seconds and then the slide was removed. Three fragments were tested at each temperature. After heat exposure, the samples were immediately mounted with Permount and cover slip for microscopic examination and photographic documentation.

Figure 4: A photograph of the Mettler Hot Stage equipment and microscope used in Study 4.

RESULTS

Study 1 was originally intended to simulate hairs pressed within an iron. However, the furnace thermocouple measured the chamber temperature rather than the temperature between the metal blocks where the hairs were placed. Therefore, this study was more of a simulation of hairs separated from a heated environment by an insulating object. Distal darkening and central bubbling was observed in two of three hairs at 325 °C and bubbling and brittle texture for all three hairs at 400°C. The range of observed changes, as outlined in Table 1, ranged from an ashy and bubbled appearance throughout the shaft, as observed in Figure 5, to minimal bubbling and color change in some areas, as observed in Figure 6. The heat treatment may have been uneven between hairs tested at the same temperature due to the slight variance in their location between the metal blocks and proximity to furnace walls.

Figure 5: Two photomicrographs of a hair from Study 1. This hair was exposed to a temperature of 400 °C. Color change, expansion, and bubbling are evident. Both photos were originally taken at 400x magnification.

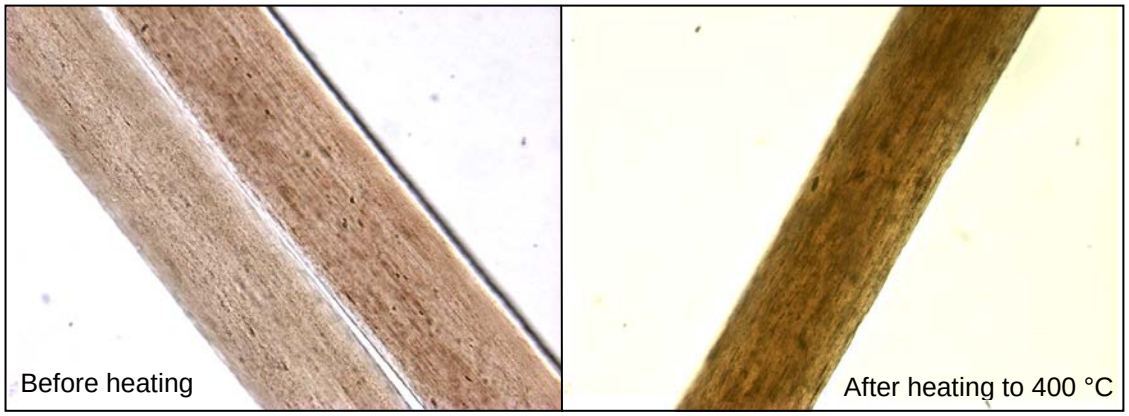

Figure 6: Two photomicrographs of a hair from Study 1. The image on the left depicts two hairs (side by side) prior to heat exposure. The image on the left depicts a hair that was exposed to a temperature of 400 °C. It shows a slight color change but bubbling and expansion are not observed. Both photos were originally taken at 400x magnification.

Table 1: Results of Study 1 – Test hairs sandwiched between metal blocks and heated in furnace

Goal Temperature	Changes in appearance after heating to goal temperature		
	Hair 1	Hair 2	Hair 3
100 °C	None observed	None observed	None observed
200 °C	None observed	None observed	None observed
225 °C	None observed	None observed	None observed
250 °C	None observed	None observed	None observed
275 °C	None observed	None observed	None observed
300 °C	None observed	None observed	None observed
325 °C	None observed	Distal area darkened in color and bubbles were observed in the medulla	Distal area darkened in color and bubbles were observed in the medulla
350 °C	None observed	None observed	None observed
375 °C	None observed	None observed	None observed
400 °C	Hair became brittle and darker in color and bubbles were observed in the medulla toward the distal end of the shaft	Hair became brittle and darker in color and bubbles were observed in the medulla toward the distal end of the shaft	Hair became brittle and darker in color and bubbles were observed in the medulla toward the distal end of the shaft; one portion of the hair showed no sign of heat treatment

Since the first study indicated that the metal blocks surrounding the hairs could have resulted in uneven heating across the shaft, the hairs were suspended inside the oven for Study 2. This would simulate hairs that have been blow dried or exposed to a heated environment without contact with a specific heated object. A subtle darkening in color of the hairs was observed at heat exposure as low as 175 °C with bubbling at 200 °C. Changes along the entire length of the hair occurred at 300 °C, see Table 2.

Table 2: Results of Study 2 – Hairs mounted on clips and heated in furnace (linear placement)

Goal Temperature	Changes in appearance after heating to goal temperature		
	Hair 1	Hair 2	Hair 3
100 °C	None observed	None observed	None observed
150 °C	None observed	None observed	None observed
175 °C	Some areas exhibited a slight darkening in color. The change may not have been recognized without comparison to the untreated sample.	Some areas exhibited a slight darkening in color. The change may not have been recognized without comparison to the untreated sample.	Some areas exhibited a slight darkening in color. The change may not have been recognized without comparison to the untreated sample.
185 °C	One area became brittle, darker in color, and exhibited bubbling. No changes observed in the remainder of the shaft.	Some areas exhibited a slight darkening in color. The change may not have been recognized without comparison to the untreated sample.	Some areas exhibited a slight darkening in color. The change may not have been recognized without comparison to the untreated sample.
200 °C	Some areas became brittle, darker in color, and exhibited bubbling while no changes were observed in other areas	Some areas became brittle, darker in color, and exhibited bubbling while no changes were observed in other areas	Some areas became brittle, darker in color, and exhibited bubbling while no changes were observed in other areas
300 °C	The entire length of the hair became brittle, darker in color, and exhibited bubbling	The entire length of the hair became brittle, darker in color, and exhibited bubbling	The entire length of the hair became brittle, darker in color, and exhibited bubbling

The third study suspended the hair diagonally across the center of the oven to improve the simulated exposure to a heated environment. The clips holding the ends of the hair were oriented toward the corners of the oven rather than close to a wall. Areas of bubbling and discoloration were observed at temperatures of 190 °C. However, these changes were not uniform throughout the length of the hair at either 195 or 200 °C. It is not known if these inconsistencies are a reflection of variation within the hair itself. See Table 3.

For the fourth and final study, the hairs were dry-mounted onto microscope slides and inserted into a Mettler Toledo hot stage system pre-set to the test temperature. The smaller system was meant to simulate direct contact with a styling tool or other hot object within a heated environment. One hair exhibited distal discoloration, expansion, and bubbling at 180 °C. However, only hairs exposed to the 235 and 250 °C test temperatures showed color changes and bubbling in all three hairs, see Table 4. Figures 7 and 8 show two hairs, from this study, before and after heating. This variation may be related to a slight variation in exposure time due to the difficulty of introducing and removing the slide from the hot stage.

Table 3: Results of Study 3 – Hairs mounted on clips and heated in furnace (diagonal placement)

Goal Temperature	Changes in appearance after heating to goal temperature		
	Hair 1	Hair 2	Hair 3
180 °C	None observed	None observed	None observed
185 °C	None observed	None observed	None observed
190 °C	Some areas exhibited a reddening and yellowing of color as well as bubbling while no changes were observed in other areas	Some areas exhibited a reddening and yellowing of color as well as bubbling while no changes were observed in other areas	Some areas exhibited a reddening and yellowing of color as well as bubbling while no changes were observed in other areas
195 °C	Some areas exhibited a reddening and yellowing of color as well as bubbling while no changes were observed in other areas	Some areas exhibited a reddening and yellowing of color as well as bubbling while no changes were observed in other areas	Some areas exhibited a reddening and yellowing of color as well as bubbling while no changes were observed in other areas
200 °C	Some areas exhibited a slight color change while no changes were observed in other areas	Some areas exhibited a reddening and yellowing of color as well as bubbling while no changes were observed in other areas	Some areas exhibited a reddening and yellowing of color as well as bubbling while no changes were observed in other areas

Table 4: Results of Study 4 – Hairs dry-mounted onto slides and heated in hot stage apparatus

Goal Temperature	Changes in appearance after heating to goal temperature		
	Hair 1	Hair 2	Hair 3
150 °C	None observed	None observed	None observed
165 °C	None observed	None observed	None observed
180 °C	None observed	None observed	None observed
195 °C	None observed	None observed	Distal discoloration and bubbling
210 °C	None observed	None observed	None observed
235 °C	Discoloration observed	Discoloration observed	Discoloration observed
250 °C	Discoloration was observed and bubbling was observed within the root and radiating from the center of the shaft	Discoloration was observed and bubbling was observed within the root and radiating from the center of the shaft	Discoloration was observed and bubbling was observed within the root and radiating from the center of the shaft

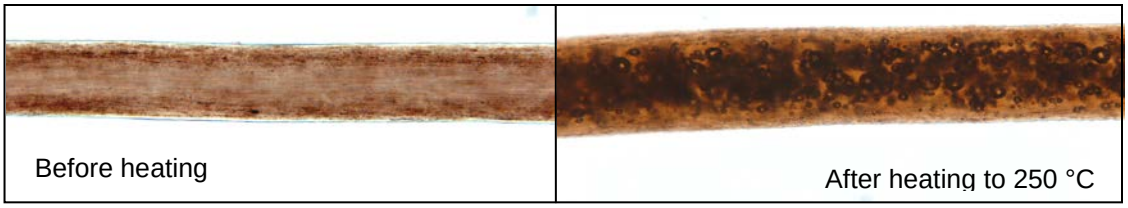

Figure 7: Two photomicrographs of a hair from Study 4. This hair was exposed to a temperature of 250 °C. Color change, expansion, and bubbling are evident. Both photos were originally taken at 200x magnification.

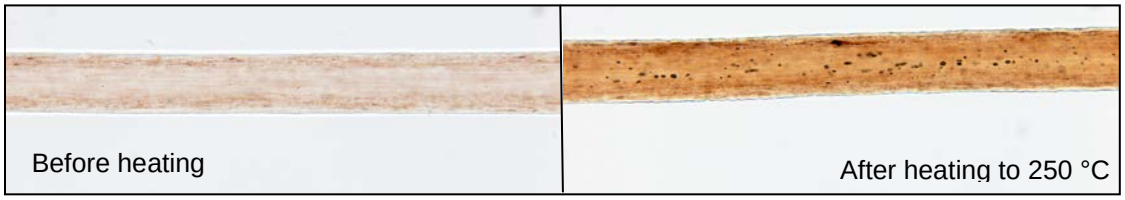

Figure 8: Two photomicrographs of a hair from Study 4. This hair was exposed to a temperature of 250 °C. Color change and some slight bubbling are evident. Both photos were originally taken at 200x magnification.

DISCUSSION

The results of this study show that hair can exhibit microscopic characteristics consistent with heat treated hair at temperatures within the range of heat styling tools. Discoloration and bubbling were observed, in some circumstances, at temperatures as low as 190 °C.

This study is merely an introduction of how variables such as heating rate, total time the hair is exposed to elevated temperatures, and the method of imparting heat to hairs can produce the color changes, expansion, and bubbling characteristic of hair that has been exposed to heat and/or flame. Additional studies could further examine the temperature effects over smaller temperature increments. Effects on wet hair, hair of somatic origins other than the head, hair of other biogeographical ancestry (ethnic origin), chemically treated, or diseased hair have yet to be investigated. Further study is encouraged in these areas, perhaps utilizing actual heat styling tools marketed for salon or personal use. Additionally, to aid in prosecuting arson cases, further investigation is needed in areas such as: damage to hair observed in a quick "flash" of fire, damage to hair caused by brief exposures to intense heat, and damage to hair caused by common non-arson events such as sparks in bonfires and welding.

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