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THERMAL HAIR STRAIGHTENING:

Supporting Claims About the Benefits of Silicones

REV 1015

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Abstract

With the help of functionalized silicones, hair care products can promote (1) better flat-iron straightening with less frizz and greater hair fiber alignment; (2) satisfactory permanent straightening at moderate flat iron temperatures; and therefore, (3) thermal hair straightening that is easier and safer for the consumer. Momentive scientists have devised measurement techniques that substantiate these outcomes. Learn here about the corroborated role of Silsoft AX-E, an alkyl-modified amino fluid, in improving thermal hair straightening.

Body

Steering clear of harsher chemical straightening, many stylists and consumers are now straightening hair thermally with flat irons, often in combination with milder chemical treatments. To keep pace with this trend, hair product formulations must include agents that are protective of hair, thermally stable at flat iron temperatures, and able to minimize frizz.

Silicones provide these benefits. Moreover, when performed with products that include newer "functionalized" silicones, progressive thermal straightening has shown promise in achieving high-quality, permanent straightening with no chemical treatment. One such functionalized silicone product is Momentive's Silsoft AX-E alkyl-modified amino fluid.

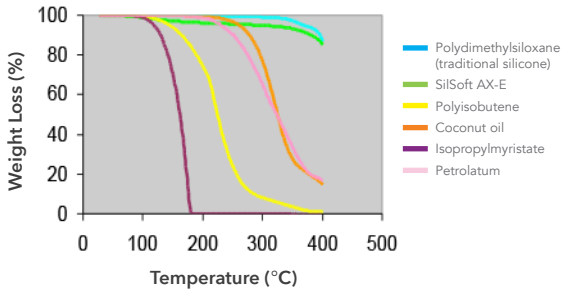
Having engineered products like Silsoft AX-E, scientists at Momentive have also now created methods to measure and back up claims about these products' effectiveness in thermal hair straightening. Comparing thermal straightening with and without silicones, these measurement methods have shown that Silsoft AX-E promotes better alignment of hair fibers at lower flat-iron temperatures. The implication is that hair products containing Silsoft AX-E enable consumers to straighten their hair more easily at lower, less damaging iron temperatures.

Silicone Thermal Properties

Several characteristics of silicones bear out their applicability to high-temperature environments, like those encountered in thermal hair straightening. Their good thermal stability is illustrated in thermal gravimetric analysis (Figure 1). While various organic oils—esters, petrolatum, triglycerides—decompose at lower temperatures, both traditional polydimethylsiloxane and Silsoft AX-E remain relatively stable at temperatures exceeding 400°C.

Silicone's ability to transfer heat is seen in two characteristics (Table 1): its specific heat, which indicates the energy required per unit mass to raise the temperature by 1 degree; and its thermal conductivity, which indicates the quantity of heat that passes through a fluid in a unit of time.

Table 01:



Note: Test data. Actual results may vary.

	Specific heat (J/kg/C)	Thermal conductivity J/(s.m.K)
Silicone	1500	0.1
Air	1000	0.024
Water	4180	0.58

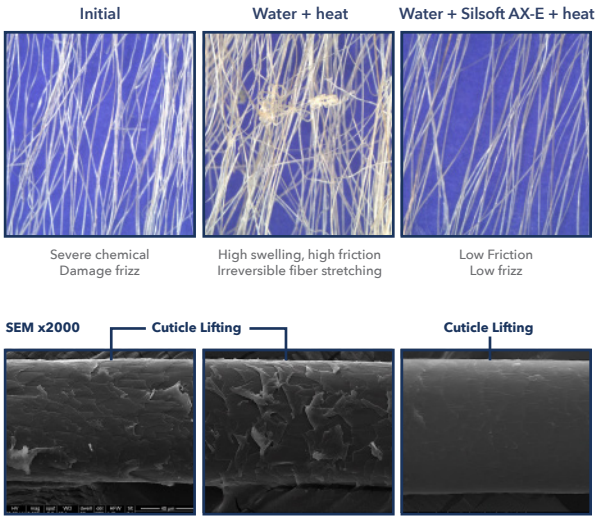
- Very good thermal stability vs. organic oils
- High thermal conductivity, low specific heat: good thermal medium

Qualitative Evidence

Knowing that Momentive's customers face demands for evidence to support any claims they make about their hair products, Momentive scientists have devised methods that produce such evidence. An initial qualitative study (Figure 2) has demonstrated the visible effectiveness of Silsoft AX-E on damaged hair.

Figure 2

The hair in this study was platinum bleached and then further damaged by dipping for one minute in a caustic bath of 0.5 percent sodium hydroxide (NaOH), rinsed and blown dry. The hair was then dipped for one minute in various baths, excess liquid squeezed out, and the hair ironed until dry at a flat-iron temperature of 130°C. The control bath was water only, while the silicone baths included an aqueous dispersion of one percent active silicone emulsion. The improved hair alignment and decreased frizz of the tress treated with Silsoft AX-E is easily perceived.



Note: Test data. Actual results may vary.

Closer examination of the tresses was performed with a stereomicroscope, and closer still with a scanning electron microscope. The original damaged hair contains kinks and the presence of cuticle lift. Hair that was iron-treated after a water-only bath includes collapsed fibers which, under the high swelling and high strain produced by ironing, contracted irreversibly. This tress shows even more cuticle lifting than the original tress.

On the other hand, the tress treated with Silsoft AX-E and ironed did not undergo irreversible stretching. Instead, decreased friction due to the silicone film allowed the fibers to align and straighten. The film also reduced cuticle lifting.

Quantifiable Evidence

In order to produce quantitative results, Momentive scientists needed a means to control and/or measure the various factors that affect thermal hair straightening (Figure 3). Thermal hair straightening is brought about primarily by stretching, heating and cooling. Stretching depends on factors including the contact force of the iron, the initial curliness of the hair, the amount of hair in the iron at one time, and of course, the treatment that the hair has undergone.

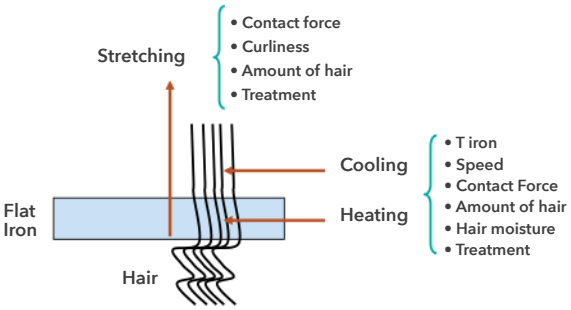
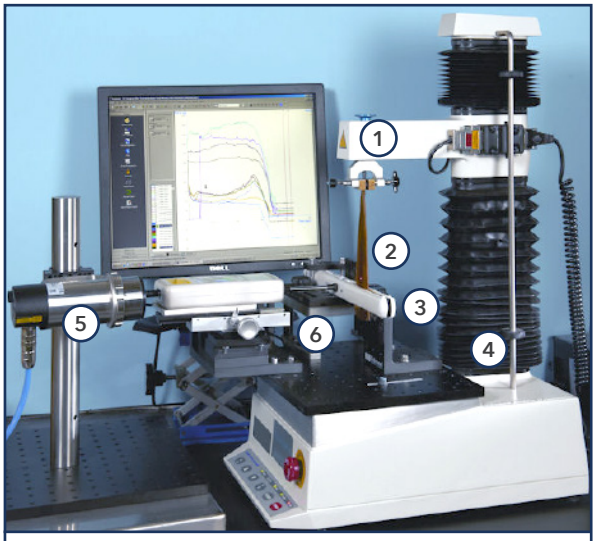


Figure 3

Effectiveness of the heating and cooling cycle depends on the temperature of the flat iron, the contact force and speed with which the hair moves through the iron, the amount of hair in the iron at one time, hair moisture at the time of ironing, and hair treatment.



1. Tangential force sensor
2. Hair tress
3. 1" Flat iron
4. Motorized vertical translation speed control
5. IR thermometer
6. Control force control

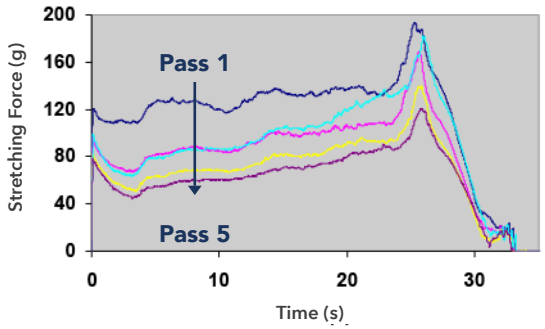
Figure 4

The scientists devised an automated iron to control these variables. In this apparatus (Figure 4), the flat iron is held in a fixed position. A rigid holder connected to a force sensor closes the iron's two plates. A vertical motorized stage pulls the hair tress at a constant speed through the iron while a load cell measures stretching force. An infrared thermometer, which can be moved into different positions, measures hair temperature. Thus, contact force, speed and hair temperature can be controlled.

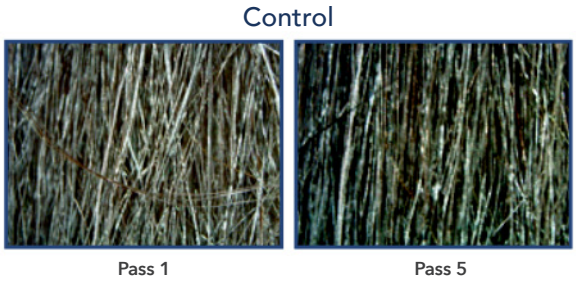
For consistency in hair treatment, each tress of undamaged naturally curly hair was dipped in the appropriate bath and excess water squeezed out. Each was then dried and placed in a chamber with forced-flow 90 percent relative humidity (RH). Then each underwent five ironing passes in the automated apparatus, with stretching force measured as a function of time.

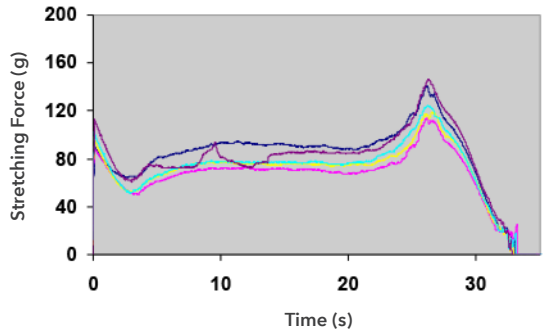
Claim Support from the Experiments

As a result of experiments conducted with the automated iron, Momentive scientists now have documented evidence of Silsoft AX-E's benefits in thermal hair straightening:



Note: Test data. Actual results may vary.





Note: Test data. Actual results may vary.

Aqueous treatment, dried, 30 min 90% RH chamber, Iron @ T=175°C

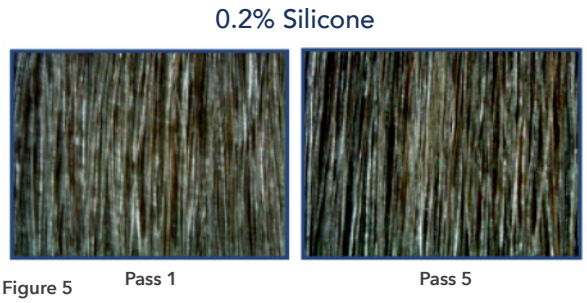
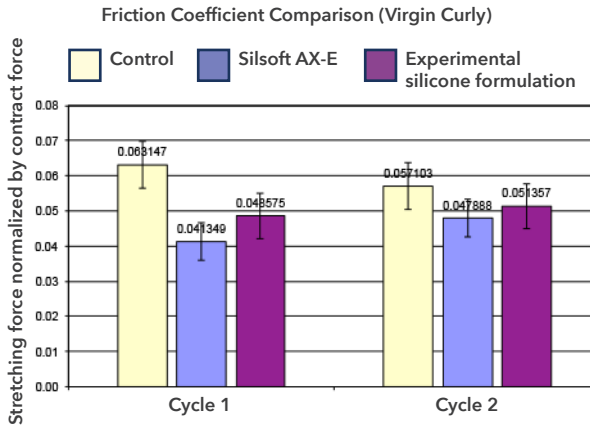


Figure 5

Silsoft AX-E enhances hair fiber alignment while lowering stretching force (Figure 5). With contact force, speed and iron temperature constant (175°C), tresses treated with a silicone bath experienced lower stretching force (especially in the first pass) and more regular fiber alignment than tresses treated with water alone (i.e. the control tresses).



- Stretching force results form both friction and fiber alignment
- Stretching force data can help discriminate treatments
- Stretching force decreases as hair straightens

Note: Test data. Actual results may vary.

Figure 6

Silsoft AX-E lowers the coefficient of friction, which also helps to lower stretching force. Focusing on the plateau region of the plot of stretching force versus time, the graph in Figure 6 shows that silicones significantly lower the hair's coefficient of friction. Friction and fiber alignment both contribute to stretching force.

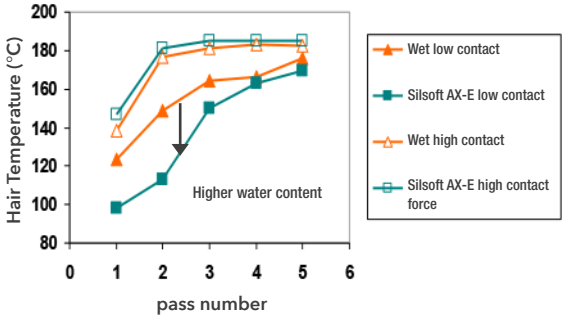
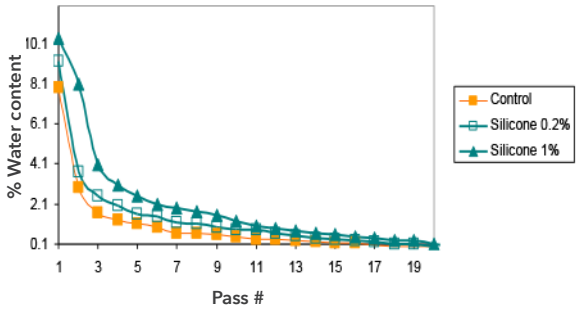


Figure 7

- Cooling with silicone film, seen at low contact force, due to water retention

Note: Test data. Actual results may vary.

Silsoft AX-E increases moisture retention and lowers hair temperature when ironing with low contact force. Hair temperature (as measured at the middle of the tress) of tresses ironed with low contact force starts and stays lower for tresses treated with Silsoft AX-E (Figure 7). This effect may be attributed to slower water evaporation due to the silicone film that forms on the hair fibers.



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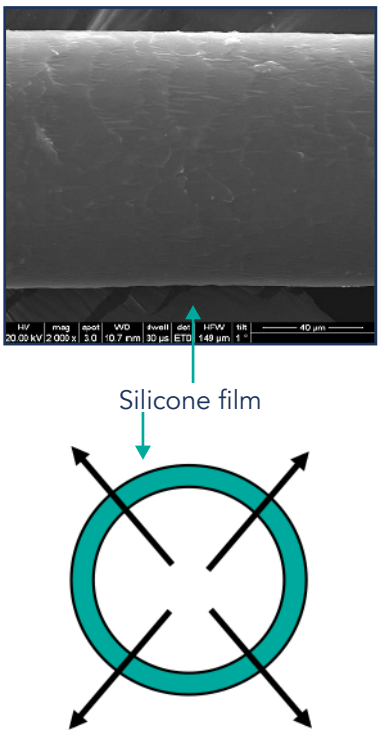


Figure 8

- After few passes, hair has more moisture with silicone than without

The Promise of Permanent Thermal Straightening

The evidence discussed so far reinforces two key claims for hair products utilizing Silsoft AX-E: first, they may reduce the stress on hair fibers produced by flat irons; and second, they may create better hair alignment in thermally straightened hair.

Another key question to answer for stylists and consumers regards the permanency of hair straightening through thermal treatment alone. That is, can progressive thermal treatment

produce permanently straightened hair without chemical treatment–and without such high iron temperature or contact force that significant hair damage occurs?

Experiments conducted at Momentive indicate that the answer may be yes–and Silsoft AX-E may help to produce greater hair alignment at moderate flat iron temperatures than thermal treatment without a functionalized silicone. In the experiments, hair tresses of undamaged naturally curly hair underwent cycles in which they were treated and conditioned at 90 percent RH, ironed with the automated apparatus for five passes, stored overnight, washed and conditioned at 90 percent RH, ironed again, and so forth.

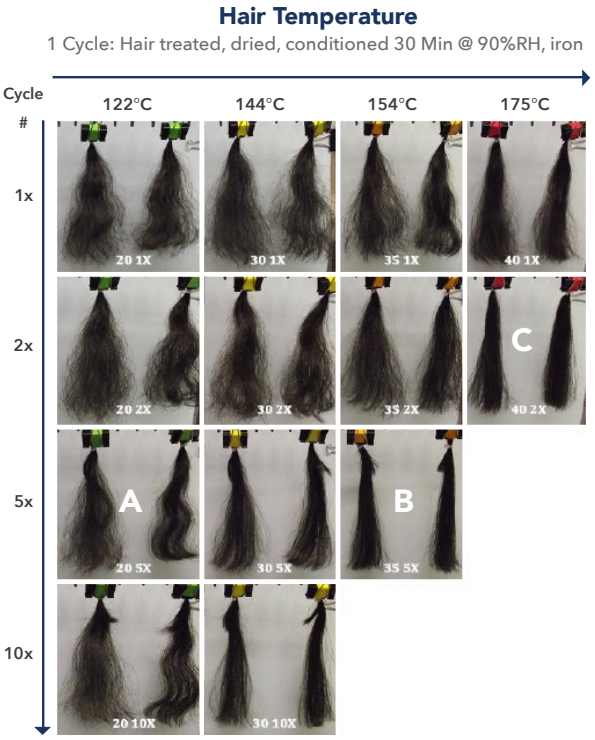
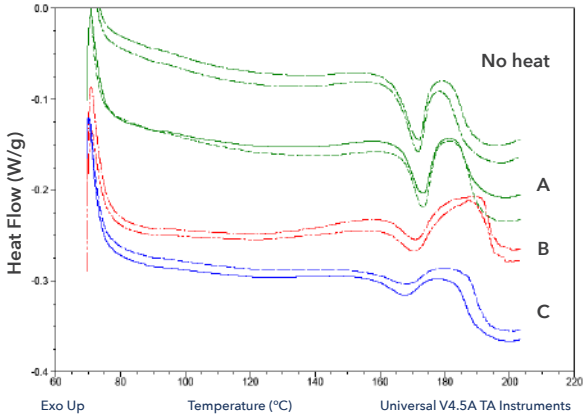


Figure 8

Results (Figure 8) indicate that permanent straightening may be achieved at the high iron temperature of 223°C after two cycles; and at the lower iron temperatures of 204°C after five cycles and 190°C after 10 cycles.



- Permanent straightening observed at high temperature and after multiple cycles
- DSC: low change in a-keratin with curly hair (A), significant change with straight hair (B, C)
- With silicone: better fiber alignment

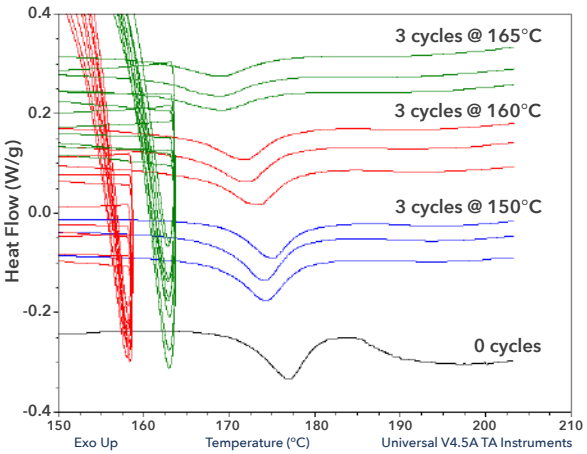
More significantly, these experiments indicate the following benefits of including Silsoft AX-E in hair treatment products for permanent thermal straightening:

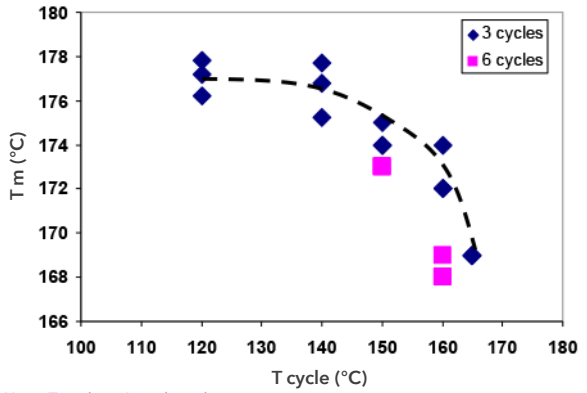
<u>In every case, greater straightening and less volume are observed in the hair treated with Silsoft AX-E.</u> The tresses on the left in each photo of Figure 8 are tresses treated with water alone, while the tresses on the right were treated with Silsoft AX-E. At all temperature settings and numbers of cycles, the Silsoft AX-E tresses have greater fiber alignment, and a correspondingly smaller volume.

<u>Lower flat iron temperatures may decrease keratin crystallinity with less loss in crosslinking.</u> To study the mechanisms behind thermal straightening, Momentive scientists performed differential scanning calorimetry (DSC) on strands from the tresses in this study. A graph (Figure 9) of straightened tresses labeled A, B and C in Figure 8, along with a control tress, shows a relatively sharp peak in DSC for the tress treated to five cycles with an iron temperature of 160°C, while straightened samples (five cycles at 204°C and two cycles at 223°C) show a shallow endotherm and therefore a decreased enthalpy. This result corresponds to decreased keratin crystallinity in the straightened hair.

Yet birefringence studies indicate that loss of crosslinking (i.e. rate of disulfide bond scission) significantly increases at flat iron temperatures

above 150°C. So the decrease in keratin crystallinity of the straightened hair treated at 204°C was accompanied by much less loss of crosslinking than the straightened hair treated at 223°C.



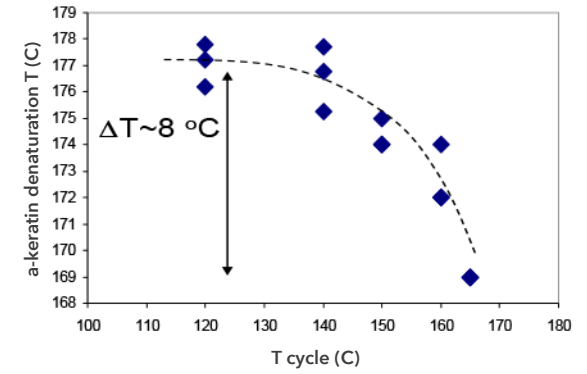


Note: Test data. Actual results may vary.

Figure 10

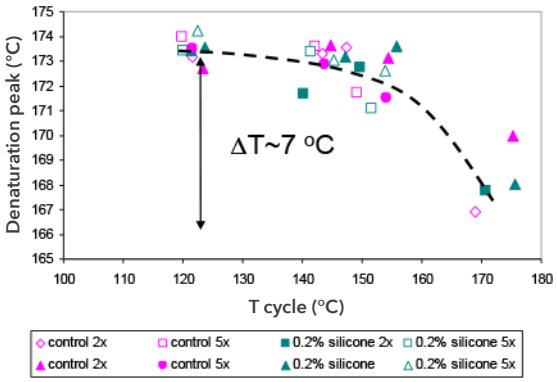
- Multiple heat/cool cycles at temperature much lower than melting peak temperature causes significant denaturation of a-keratin.
- Non-linear dependence of cycle temperature on T_m

Multiple heat/cool cycles in DSC pan



Note: Test data. Actual results may vary.

Multiple heat/cool cycles in hair iron



Note: Test data. Actual results may vary.

- Although heating/cooling rate and moisture conditions in the hair iron are quite different than the ones in DSC pan, the a-keratin denaturation upon multiple heat/cool cycles showed very similar trend

<u>Keratin denaturation can be effected with flat-iron temperatures well below melting peak temperature,</u> Performing multiple heat-cool cycles in a DSC pan, Momentive scientists found that keratin denaturation (indicated in Figure 10 by the shift in melt temperature) was achieved at these lower heating temperatures. They found that the shift in melting peak temperature exhibited nonlinear behavior with a transition around a heating temperature of 140°C and a significant drop around 150°C. A larger shift in melting peak temperature is associated with greater disulfide bond scission (i.e. loss of crosslinking)

A graph with data plotted from the flat-iron experiments shows a similar curve, despite the significant difference in heating and cooling rate (approximately 10°C/min in DSC pan versus 10°C/sec with flat iron) and in moisture content.

Major Claims and Support

Putting all of this evidence together, Momentive scientists have produced support for the following claims:

Hair treated with aqueous dispersion, dried, equilibrated @ 90% RH, 3 iron cycles @ 154°C

Initial

	T_m (°C)	ΔH (J/g)
Initial	172 ±1	5.7 ±0.6
No Silicone	171.7 ±0.2	3.3 ±0.2
Silicone	172.2 ±0.5	3.7 ±0.4

Note: Test data. Actual results may vary.

Figure 11

- Both samples have 40% change in a-keratin crystallinity and no change in T_m
- Silicone treatment enhanced straightening at low concentration due to fiber alignment

Silsoft AX-E changes the quality but not the mechanisms of thermal hair straightening. A final experiment compared tresses subjected to three iron cycles at the 204°C iron temperature. Both tresses (Figure 11) exhibited a similarly small shift in melting peak temperature (suggesting low loss of crosslinking) and similar changes in enthalpy (suggesting similar decrease of keratin crystallinity). Yet the silicone-treated hair exhibited enhanced straightening due to better fiber alignment.

The higher quality straightening of hair treated with Silsoft AX-E enables permanent hair straightening with flat iron temperatures that are better for hair integrity. Permanent thermal straightening with no chemical treatment and with good hair integrity (due to lower loss of crosslinking compared to high-temperature ironing) seems a probable outcome of moderating flat iron temperature to 204°C and performing multiple straightening cycles.

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