Heat Treatment of Cobalt-Chromium Alloy Wire

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Low temperature heat treatment of orthodontic wire to increase spring performance and force delivery has been repeatedly discussed in the dental literature. It is generally accepted that the process improves the elastic qualities of stainless steel archwires by relieving the stresses retained from archwire formation.[1-3] Certain cobalt-chromium alloys, in addition, can be strengthened by heat treatment. The present study evaluates the effects of heat treatment upon cobalt-chromium alloy orthodontic wire.

A particular cobalt-chromium alloy known as Elgiloy has found wide application in orthodontics. This material was developed by the Elgin watch company for use in watch mainsprings. Cobalt-chromium wire is similar in appearance to stainless steel and is actually a cobalt-base alloy containing chromium, nickel, and iron with smaller amounts of molybdenum, manganese, beryllium and carbon.

The advantages claimed for cobalt-chromium wire over stainless steel are: superior physical properties, greater resistance to fatigue and distortion, and longer function as a resilient spring. Also, it can be electrolytically polished, easily soldered, and easily heat-treated to remove internal stresses and increase spring performance.[4]

Certain problems affecting the orthodontic use of cobalt-chromium wire include the tendency to "harden" at the point where two segments are joined by soldering or spot welding and the greater degree of work hardening for the same amount of wire manipulation compared with other materials. Therefore, cobalt-chromium wire is supplied in four tempers to provide flexibility with the differing tempers reacting differently to heat treatment.[4]

In comparing the physical properties of cobalt-chromium alloy with watch-spring steel, the manufacturer claims that cobalt-chromium alloy is superior by 275 percent in resistance to set, 100 percent in fatigue resistance, and has a higher resistance to corrosion and a slightly higher yield strength, ultimate strength, and hardness.[5]

Denver[6] conducted an investigation of cobalt-chromium wire to determine the effects of heat treatment at 900°F for 3 minutes on wire ductility and the ability of a vertical loop to withstand permanent deformation. He reported a 70 percent reduction in ductility and a 60 percent improvement in the ability of cobalt-chromium wire to resist permanent deformation following heat treatment.

Systematic measurements of the relation of strength to heat-treatment procedures have not been reported previously. The present study quantifies the effects that several heat-treatment temperatures have upon the ability of a particular temper of cobalt-chromium wire to resist permanent deformation. Information from this study will benefit the clinical orthodontist by providing data so that he can select a method and temperature of heat treatment for cobalt-chromium archwires which will yield a desired level of resistance to permanent deformation.

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The increase in resistance to permanent deformation of the wires heat-treated with an electrical resistance unit will be compared with the increases seen in the wires heat-treated in a dental furnace.

Specifically, this study (1) determined the temperature of heat treatment which gave a particular temper of cobalt-chromium wire its maximum resistance to permanent deformation and (2) quantified the increased resistance to permanent deformation due to heat treatment at various temperatures.

Method and Materials

Cobalt-chromium orthodontic wire is supplied in four tempers and is composed of 40 percent cobalt, 20 percent chromium, 15 percent nickel, 7 percent molybdenum, 2 percent manganese, 0.15 percent carbon, 0.04 percent beryllium, and approximately 15 percent iron.[4] The softest wire temper was used in this study because it is the most common temper used clinically. This temper of cobalt-chromium wire can be easily shaped with fingers and pliers and is recommended for use which requires considerable bending, welding, or soldering. For increased resiliency, the wire may be heat-treated after fabrication.

Prior to heat treatment, straight wires of .016″ x .022″ were formed into a pattern of loops (Fig. 1) to introduce a degree of work hardening such as might be encountered in clinical procedures. The resulting geometrical configuration was similar to that used by Funk.[2] Three loops were formed on each side of the wire specimen with Tweed loop forming pliers. All loops were formed by the same operator by the same procedure in an attempt to produce specimens of identical geometry and with an equal amount of work hardening.

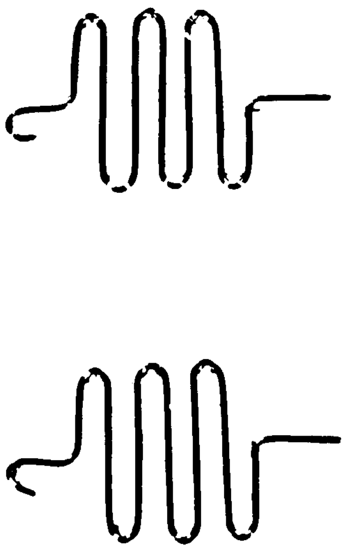

Fig. 1 Two .016″ x .022″ wires prior to heat treatment and deformation.

The wire specimens were divided into twelve treatment groups of six wires each. One of the twelve treatment groups was the nonheat-treated control. One group was heat-treated with an electrical resistance unit using temper-indicating paste designed to flash when the temperature of the wire reached 950°F. The remaining ten groups were heat-treated in an air atmosphere using a conventional electric dental furnace. The furnace was calibrated by use of an electric pyrometer. Each group of wire specimens was heat-treated for 5 minutes at one of ten temperatures from 600°F to 1500°F in 100° increments.

The ability of a wire specimen to withstand permanent deformation was determined by fixing the straight segment of wire extending from one side of the series of loops in a vise (Fig. 2). Weights to deform the wire specimen were added to the hook on the opposite side of the series of loops in 50 g increments until a total load of 650 g was reached. The load was placed on the

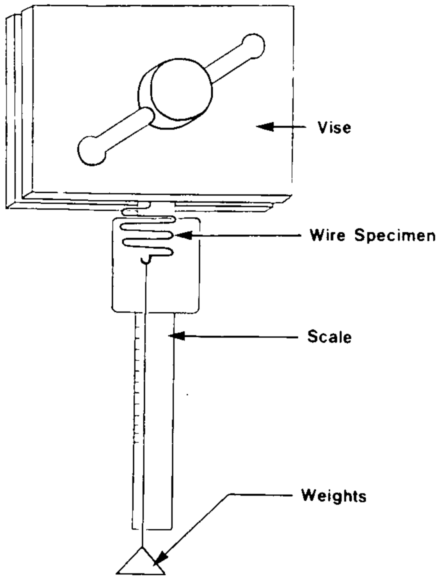

Fig. 2 Sketch of sample configuration during deformation measurement .

wire specimen for 15 seconds and then removed. The change in total length of the unloaded wire specimen was then measured and recorded. This change was measured directly on a millimeter scale with a 0.1 mm vernier. To overcome possible errors from paralax and still avoid contact between the millimeter scale and the wire specimen, the millimeter scale was fixed in the vise directly behind the specimen with a 1 mm metal insert between them.

Results and Discussion

In many alloys increases in strength and hardness are seen following certain heat-treatment procedures. These changes are produced by at least two phenomena. First, some increase in strength following heat treatment is due to a partial relief of the internal stresses retained from cold working. Second, other increases in strength and hardness may be due to precipitation hardening of the alloy system.

In this study, groups of heat-treated and nonheat-treated cobalt-chromium wire specimens were subjected to deforming loads. The mean permanent deformation, in millimeters, for each deforming load is presented with the corresponding standard deviation of the six values recorded for each treatment group. This was chosen as the most convenient way of showing the permanent deformation in a form which could be easily discussed and interpreted.

The observed permanent deformation values for the twelve treatment groups of .016″ x .022″ cobalt-chromium wires are shown in Table I. Figure 3 is a plot of deforming force versus permanent deformation and reveals that heat treatment at temperatures up to 1200°F does increase the resistance to permanent deformation of cobalt-chromium wires. A rapid decline in resistance to permanent deformation is noted in wire heat-treated at temperatures above 1200°F. Wire heat-treated at 1500°F showed a marked increase in permanent deformation when deforming loads greater than 350 g were applied; at loads above 500 g, the wires heat-treated at 1500°F permanently deformed more than wires which were not heat-treated. Wires heat-treated at 1400°F showed a similar, though not as marked, response to loads above 500 g. This marked increase in permanent deformation is due to a partial annealing and overaging of the wires after exposure to 1400°F and 1500°F temperatures. Heat treatment of wires at even higher temperatures would certainly result in further decreases in resistance to permanent deformation.

An 0.1 mm permanent deformation was chosen as the initial observable indication that permanent deformation had taken place in a cobalt-chromium wire specimen. The force required to cause 0.1 mm permanent deformation represents the strength of a wire of this configuration in clinical terms, as

TABLE I

PERMANENT DEFORMATIONS (MM) OF .016" x .022" CHROME COBALT WIRE HEAT TREATED AT VARIOUS TEMPERATURES
Mean and Standard Deviation of Six-Wire Specimens

Heat Treatment Temp.	Deforming Force in Grams												
	50	100	150	200	250	300	350	400	450	500	550	600	650
No Heat	-	-	.15±.05	.67±.23	1.45±.40	2.65±.61	4.15±.80	6.13±1.03	8.72±1.49	11.67±1.86	15.12±2.17	18.87±2.32	21.67±2.70
600°F	-	-	-	.13±.05	.33±.08	.73±.21	1.45±.23	2.42± .33	3.95± .59	6.38± .79	9.87± .71	13.87± .93	18.09±1.09
700°F	-	-	-	-	.17±.05	.50±.17	1.08±.23	1.85± .48	3.00± .67	4.88±1.05	7.50±1.56	11.23±1.90	14.93±2.56
800°F	-	-	-	-	.12±.06	.35±.05	.72±.15	1.28± .18	2.18± .24	3.50± .35	5.63± .51	8.78± .51	12.88±1.41
900°F	-	-	-	-	-	.23±.05	.48±.08	.93± .25	1.52± .33	2.37± .63	3.80± .93	6.12±1.41	9.45±2.15
1000°F	-	-	-	-	-	.13±.08	.32±.12	.50± .13	.82± .27	1.33± .45	2.00± .64	3.12±1.12	4.95±1.82
1100°F	-	-	-	-	-	-	.10±.00	.20± .00	.35± .05	.57± .10	.90± .13	1.45± .27	2.37± .50
1200°F	-	-	-	-	-	-	.02±.04	.15± .05	.30± .11	.53± .15	.78± .15	1.33± .15	2.25± .39
1300°F	-	-	-	-	-	-	.03±.05	.18± .08	.28± .08	.55± .08	.93± .10	1.70± .13	3.12± .40
1400°F	-	-	-	-	-	-	.03±.05	.17± .05	.27± .05	.65± .10	1.30± .14	3.83±1.06	7.12± .93
1500°F	-	-	-	-	-	.10±.00	.53±.26	2.08±1.04	6.10±2.47	11.53±3.45	17.38±3.36	22.38±3.09	26.98±2.88
950°F Flash Paste	-	-	-	.08±.04	.22±.08	.45±.10	.75±.14	1.32± .26	2.05± .43	3.32± .73	5.22±1.19	7.93±1.76	11.48±2.40

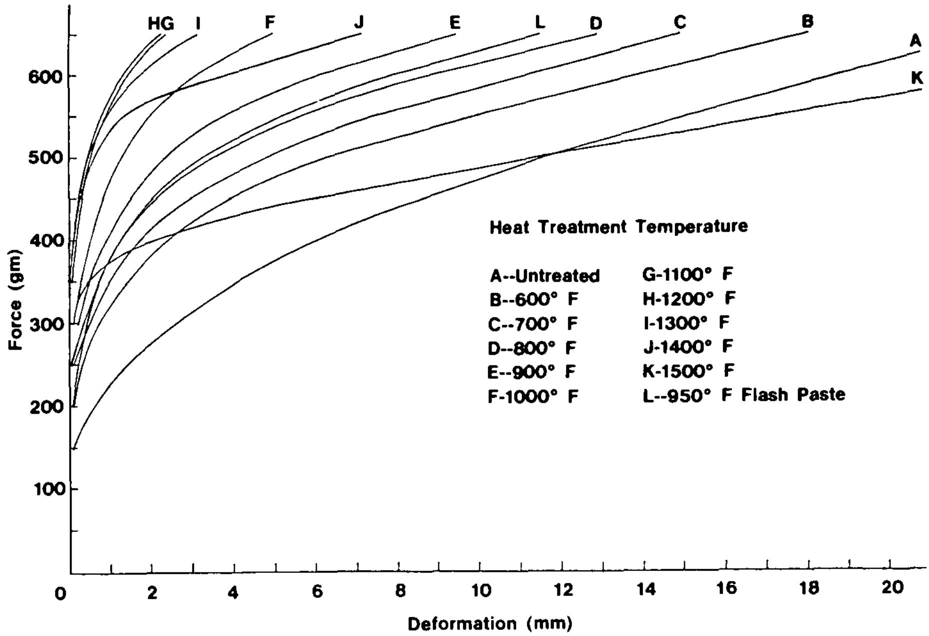

Fig. 3 Permanent deformation versus applied force for wires with various heat-treatment temperatures.

strength is the maximum possible load a wire can withstand without undergoing permanent deformation.[7] The mean force, in grams, required to cause 0.1 mm permanent deformation for each treatment group is presented in Table II. Figure 4 shows the mean force values from Table II in graphical form. From Table II and Figure 4 the increased ability of cobalt-chromium wire to resist permanent deformation may be calculated using the mean force required to cause 0.1 mm permanent deformation. The percent increase is given by the expression

$$\frac{F_2 - F_1}{F_1} \times 100.$$

F_1 is the force required to give non-heat-treated wire 0.1 mm permanent deformation and F_2 is the force required to give heat-treated wire 0.1 mm permanent deformation. Untreated wires and wires heat-treated at 900°F and 1200°F withstood 140 g, 272 g, and 383 g of force, respectively, before 0.1 mm permanent deformation was noted. The increased resistance to permanent deformation due to heat treatment at 900°F and 1200°F when compared with untreated wire is 95 percent and 174 percent, respectively. It also may be noted from Table II that the mean forces required to cause an 0.1 mm permanent deformation in wire heat-treated at 1100°, 1200°, 1300°, and 1400°F were 350 g, 383 g, 375 g, and 375 g, respectively. These values are very similar and indicate that, although the initial resistance to permanent deformation is similar for wires heat-treated at temperatures in the wide range of 1100° to 1400°F, there is little increase in initial resistance to permanent deformation for wires heat-treated at temperatures above 1100°F.

Although wires heat-treated at these temperatures responded in a similar manner initially, the graphical data of Figure 5 depict how these same wires responded to a force of 650 g. Perma-

TABLE II

FORCE REQUIRED TO CAUSE 0.1 MM PERMANENT DEFORMATION IN .016" x .022" COBALT-CHROME ALLOY

Mean and Standard Deviation of Six-Wire Specimens

Temperature	Force (g)	Temperature	Force (g)
No Heat	139.7±12.3	1100°F	350.0±00.0
600°F	191.7±12.9	1200°F	383.3±20.4
700°F	233.3±12.9	1300°F	375.0±22.4
800°F	244.5±16.5	1400°F	375.0±22.4
900°F	272.3± 4.1	1500°F	300.0± 0.0
1000°F	294.5±13.5	950°F Flash Paste	208.3±20.4

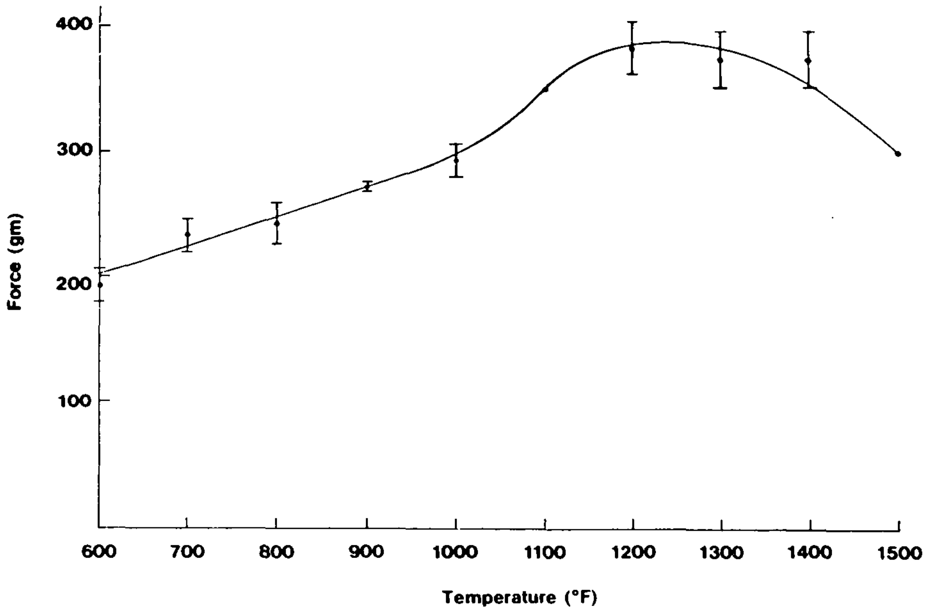

Fig. 4 Force required to obtain 0.1 mm permanent deformation for wires with various heat-treatment temperatures.

nent deformation in the wires heat-treated at 1100°, 1200°, and 1300°F was 2.37 mm, 2.25 mm, and 3.12 mm, respectively, when a 650 g force was applied. The wire heat-treated at 1300°F, therefore, showed somewhat more deformation than the wires heat-treated at 1100° and 1200°F. The wire heat-treated at 1400°F, however, showed a 7.12 mm deformation which is more than twice as much deformation to a load of 650 g as was shown by the wires heat-treated at 1100°, 1200°, and 1300°F. Figure 6 is a photograph of a representative cobalt-chromium wire from each treatment group and shows the permanent deformation caused by 650 g force.

Wire heat-treated with the electrical resistance unit showed values of permanent deformation approximately halfway between the values of permanent deformation for wire heat-treated in the dental furnace at 800° and 900°F. Since the temper-indicating paste used for the resistance heat treatment is designed to flash when the temperature of the wire reaches 950°F, one expects that the resistance to permanent deformation of these wires

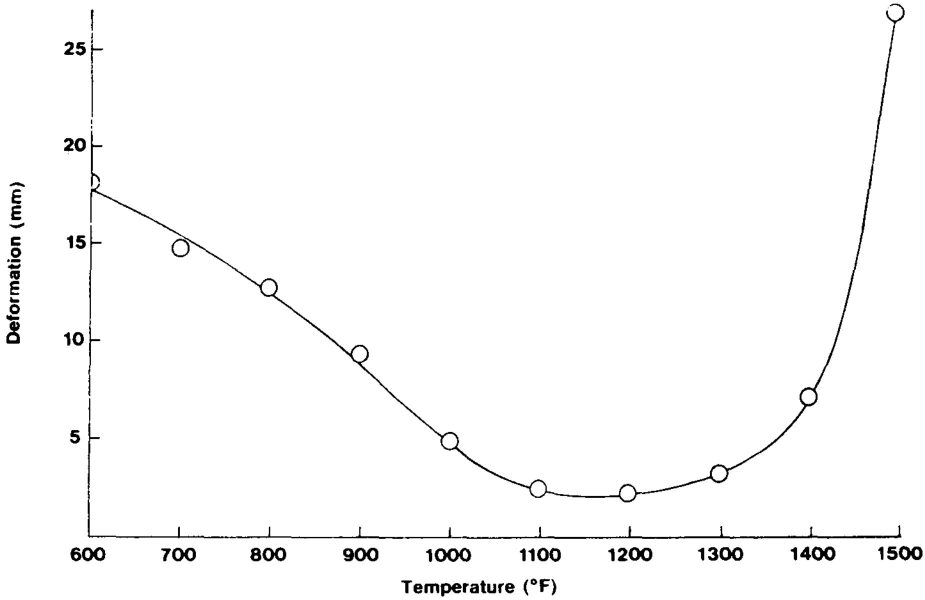

Fig. 5 Permanent deformation obtained from 650 g load for wires with various heat-treatment temperatures.

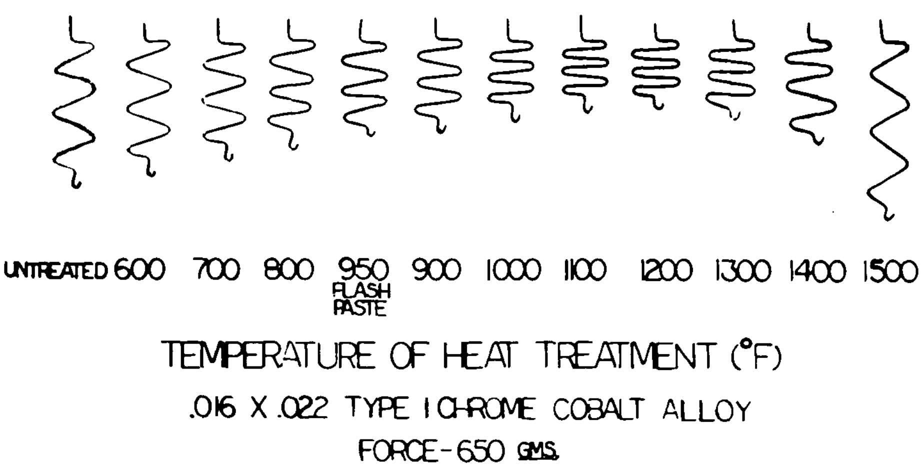

Fig. 6 Photograph of a sample wire from each heat-treatment temperature showing the permanent deformation caused by 650 g load.

should be approximately halfway between the values for wire heat-treated in the dental furnace at 900° and 1000°F. This may not be the case, however, as electric current produces uneven heating of the wire and thus variable results. In addition, the time of heating is less than that used with the furnace. The electrical resistance unit cannot uniformly heat a wire and as arch length, size, and form are changed, the effects of heat treatment vary. In areas where wire segments are in close proximity as in helical loops, heat loss is reduced and the desired temperature of heat treatment is reached while other portions of the wire are below the desired temperature. Sharp bends produce highly work-hardened areas which have increased resistance to the flow of electricity and thus reach the desired temperature of heat treatment before less work-hardened areas. Although this process results in wires that are unevenly heated, its convenience and ease of use make it a popular method of heat treatment.

Conclusions

This study shows that the ability of cobalt-chromium wire to resist permanent deformation is definitely affected by the temperature of heat treatment. For each temperature of heat treatment up to 1200°F there is progressively greater resistance to permanent deformation; at temperatures of heat treatment above 1200°F, however, there is a rapid decline in resistance to permanent deformation due to partial annealing. The maximum resistance to permanent deformation occurs from heat treatment in the temperature range of 1100° to 1200°F.

A clinician desiring maximum resistance to permanent deformation from a .016″ x .022″ cobalt-chromium archwire should heat-treat the wire at 1100° to 1200°F for 5 minutes in a dental furnace. If the wire was in a highly work-hardened condition as were the wire specimens of this study, he could expect an increase in resistance to permanent deformation of approximately 174 percent. Heat treatment at lower temperatures could be used in situations requiring less than maximum resistance to permanent deformation. Heat treatment at 900°F would give approximately a 95 percent increase in resistance to permanent deformation. Of course, heat treatment would not be indicated when the desired level of resistance to permanent deformation was not greater than the amount exhibited in the untreated wires of this study. When an electrical resistance heat-treatment unit and 950°F temper-indicating paste were used, the clinician would expect increased resistance to permanent deformation similar to that seen in the wires heat-treated with a dental furnace at 800° and 900°F, i.e., about half of that obtained by the 1200°F treatment.

This study has determined the effects that various temperatures of heat treatment have on the resistance to permanent deformation of cobalt-chromium wire specimens which were formed into a specific pattern of loops.

The following conclusions can be drawn from the results of this investigation:

1. Heat treatment at 1200°F gives the maximum resistance to permanent deformation to .016″ x .022″ cobalt-chromium wire.

2. Increases in resistance to permanent deformation of approximately 95 percent and 174 percent may be expected from heat treatment of .016″ x .022″ cobalt-chrome wire at 900° and 1200°, respectively.

3. Wires, heat-treated with an electrical resistance unit using 950°F temper-indicating paste, exhibit increases in resistance to permanent deformation

similar to wires heat-treated in a dental furnace at 800° and 900°F.

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