Heat Treatment of Cobalt-Chromium Alloys of Various Tempers

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Recently the authors[1] reported the effects of various temperatures of heat treatment on a cobalt-chromium alloy. The alloy, known commercially as Elgiloy, is available in four tempers (conditions of prior strain hardening and heat treatment). The earlier article described experiments on wire of the softest temper, hereafter referred to as type 1. There it was found that maximum strength for the wire could be obtained by a five minute heat treatment at 1200° F. In this paper, heat-treated wires of stainless steel and the four tempers of cobalt-chromium alloy are compared to determine the amount of increased resistance to permanent deformation resulting from heat treatment.

Methods 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.[2]

The type 1 (blue) wire can be shaped easily with fingers and pliers and is recommended by the supplier when considerable bending, welding, or soldering is required. For increased resiliency the wire may be heat-treated after fabrication. Type 2 (yellow) cobalt-chromium wire is more resilient than type 1 wire. It is relatively ductile and can be bent with fingers or pliers. For maximum resiliency and spring performance it should be heat-treated. Type 3 (green) cobalt-chromium wire is more resilient than type 2 wire and is of spring temper. It allows some plier manipulation before heat treatment. Type 4 (red) cobalt-chromium wire is of the most resilient temper and has exceptionally high spring qualities. It should not be used for techniques requiring sharp plier manipulation since it will withstand only a minimum of working.[3]

Prior to heat treatment, straight .018″ round wires were formed into a definite pattern of loops in an attempt to introduce a degree of work hardening such as might be encountered in clinical procedures. The resulting geometrical configuration was the same as reported by the authors in the article on type 1 wire[1] and similar to that used by Funk.[4] Three loops were formed on each side of the wire specimen with a Tweed loop forming plier. All loops were formed by the same operator by the same procedure in an attempt to produce specimens of identical geometry with equal amounts of work hardening.

For each type of .018″ round wire specimen (stainless steel and the four tempers of cobalt-chromium alloy) there were two treatment groups of six wires each. One of the two treatment groups was the nonheat-treated control and the other group was heat-treated for 5 minutes at 900° F in an air atmosphere using a conventional electric dental furnace. The furnace was calibrated with an electrical pyrometer.

The ability of a wire specimen to withstand permanent deformation was determined by measuring the increased length of the loops due to loading. The straight segment of wire extending from one side of the series of loops was fixed

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in a vise (Fig. 2 in Ref. 1). Weights to deform the wire specimen were added to the hook on the opposite side of the series of loops in 25 gram increments until a total load of 350 grams was reached. The load was placed on the 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 directly measured from 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

This cobalt-chromium alloy is similar in composition to other cobalt alloys which harden during aging by precipitation of complex chromium carbides. In some cases the hardening is facilitated by cold working in the solution treated condition.[5,6] Here, it is assumed that the difference among the various tempers is the degree of prior strain hardening and heat treatment.

In this study, groups of heat-treated and nonheat-treated wire specimens were subjected to deforming loads as previously described. The total permanent deformation, in millimeters, for each deforming load is presented as the mean with the corresponding standard deviation of the six values recorded for each treatment group.

The observed permanent deformation values for the ten treatment groups of .018″ stainless steel and cobalt-chromium (all four tempers) wires were recorded and means and standard deviations were calculated. Each type of wire had two treatment groups containing six wires each. Figures 1 and 2 show the deforming force versus permanent deformation for the untreated and

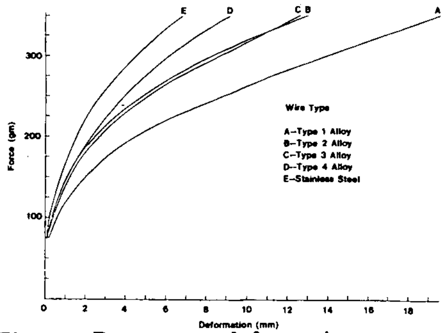

Fig. 1 Permanent deformation versus applied force for nonheat-treated .018″ wires.

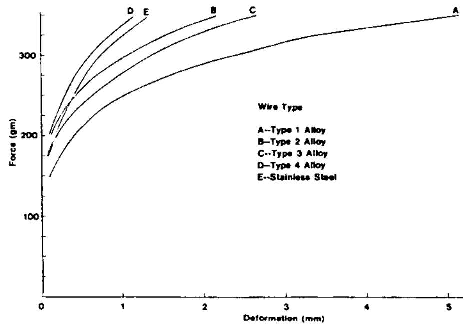

Fig. 2 Permanent deformation versus applied force for 900°F heat-treated .018″ wires.

heat-treated wires, respectively. Examination of the mean permanent deformation of the nonheat-treated wires from Figure 1 indicates that type 1 cobalt-chromium wire had the least resistance to permanent deformation while stainless steel wire showed the most resistance to permanent deformation, and type 2, type 3, and type 4 cobalt-chromium wires showed intermediate amounts of resistance to permanent deformation.

Examination of the mean permanent deformation of the 900° F heat-treated wires from Figure 2 revealed that, for any given deforming force, type 1 cobalt-chromium wire showed the least resistance to permanent deformation; type 4 cobalt-chromium wire showed the most resistance to permanent deformation; and stainless steel wire, type 2, and type 3 cobalt-chromium wires showed intermediate amounts of resistance to permanent deformation.

In this study nonheat-treated stainless steel wire was somewhat more resistant to permanent deformation than type 4 cobalt-chromium wire, although the supplier claims that untreated type 4 wire is superior to stainless steel wire in resiliency. Interestingly, type 2 and type 3 wires showed almost identical resistance to permanent deformation when untreated, although the supplier believes type 3 wire is more resilient than type 2. The reasons why types 2 and 3 wires showed similar strength, and why stainless steel showed greater strength in comparison with type 4 wire, are uncertain without detailed knowledge of the manufacturing procedure. Perhaps type 2 wire, when compared with type 3 wire, experienced a greater degree of work hardening for the same amount of wire manipulation. That is, it had a greater work-hardening rate. If this hypothesis is true, the greater response to work-hardening would give type 2 wire a greater resistance to permanent deformation than type 3 wire after heat treatment as the amount of work hardening increases the nucleation of the subsequent precipitation hardening. This hypothesis would also be supported by the resulting mean permanent deformation of the heat-treated .018" round wires presented in Figure 2. Heat-treated type 2 wires showed less permanent deformation than type 3 wires for any given deforming force.

The increased ability of .018" round wires to resist permanent deformation after heat treatment was described in the earlier article[1] with the rectangular type 1 cobalt-chromium wires. Again, 0.1 mm permanent deformation was used as the initial observable indication that permanent deformation had occurred. The mean force in grams, required to cause 0.1 mm permanent deformation, is presented in Table I for each treatment group. The stainless steel wire showed 139 percent increased resistance to permanent deformation after heat treatment at 900° F, while types 1, 2, 3, and 4 cobalt-chromium wires showed respective increases of 138 percent, 164 percent, 133 percent, and 167 percent in resistance to permanent deformation. All .018" round wires used in this study showed increases of similar magnitude in resistance to permanent deformation after heat treatment at 900° F. Figure 3 is a photograph of a representative round wire from each treatment group and shows the increased resistance to permanent deformation due to heat treatment at 900° F. The permanent deformation shown was due to 350 gms force.

TABLE I

Force required to cause 0.1 mm permanent deformation in 0.018" stainless steel and cobalt-chromium wire. Each value is the mean of six wire specimens.

Wire Type	Untreated Wire Force (gm)	900° F Treated Wire Force (gm)
Stainless Steel	75.0	179.2
Type 1 Alloy	63.0	150.0
Type 2 Alloy	75.0	198.0
Type 3 Alloy	75.0	175.0
Type 4 Alloy	75.0	200.0

Comparison of the rectangular type 1 cobalt-chromium wire from the earlier article[1] and round type 1 cobalt-chromium wires heat-treated at 900° F revealed that the .016" x .022" wires had increased in resistance to permanent deformation by 95 percent while the .018" wires showed a 138 percent increase. The effect of heat treatment on the resistance to permanent deformation was, therefore, greater in the smaller dimension wire. This may indicate that there is increased work hardening required to manufacture the smaller dimension wire, since the response of cobalt-chromium wire to heat treatment is a function of the amount of cold work.

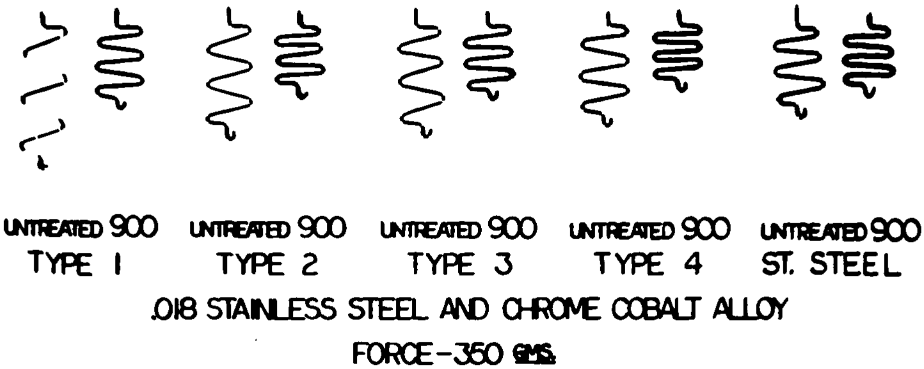

Fig. 3 Photograph of a representative wire from each treatment group showing the permanent deformation caused by 350 g. load.

Conclusions

General observations applicable to clinical situations may be inferred from the deformation of the .018" round wires. The clinician may expect increases of similar magnitude in resistance to permanent deformation of highly work-hardened stainless steel and cobalt-chromium wire after heat treatment. Also, greater increases in resistance to permanent deformation may be expected in small dimension wires in comparison with larger dimension wires when heat-treated at the same temperature. A clinician may expect untreated type 2 and type 3 cobalt-chromium wires to exhibit almost identical resistance to permanent deformation and, after heat treatment, type 2 wire would show greater resistance to permanent deformation than type 3 wire.

This study has determined the effects of heat treatment at 900° F on the resistance to permanent deformation of stainless steel and the four tempers of cobalt-chromium wire specimens which were formed into a specific pattern of loops. Similar information about wire formed into other geometrical patterns would be valuable for comparison. In addition, investigation of the effects of heat treatment on other properties of cobalt-chromium wire such as ductility and hardness would help clarify the over-all effect of heat treatment on this material. To further widen our knowledge about the effects of heat treatment on the mechanical properties of type 2, type 3, and type 4 cobalt-chromium wire, similar investigations using several temperatures of heat treatment would be indicated.

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

1. The type 1 cobalt-chromium round wires showed greater increases in resistance to permanent deformation than did the rectangular type 1 cobalt-chromium wires when heat-treated at 900° F.

2. When compared with untreated wires of the same type, .018" round wires heat-treated at 900° F may be expected to show increases in resistance to permanent deformation as follows: stainless steel, 139 percent; type 1 cobalt-chromium, 138 percent; type 2 cobalt-chromium, 164 percent; type 3 cobalt-chromium, 133 percent; and type 4 cobalt-chromium, 167 percent.

3. Untreated .018" type 2 and type 3 cobalt-chromium wire exhibited almost identical resistance to permanent deformation; however, after heat treatment at 900° F, type 2 wire showed

greater resistance to permanent deformation than type 3 wire.

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