Orthodontic Effects of Loop Design and Heat Treatment

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Light wire orthodontic techniques utilize wires of small cross section to produce low-level forces over long distances. An additional advantage of the small wire size is that it can be easily shaped. Some wires, such as Blue Elgiloy, are manufactured in a soft form to further facilitate shaping. The manufacturer recommends that this wire be heat treated after bending to improve spring characteristics and to remove internal stresses. The extent of these changes is of paramount clinical interest.

Previous studies have dealt with the modification of properties of various types of wires. Although several investigations have dealt with the effect of heat treatment on stainless steel wires,[1-5] little attention has been placed on the chrome-cobalt-nickel alloys. Mahler and Goodwin[6] provided such information for several wire types including Red, Green and Yellow Elgiloy. Comparable data for Blue Elgiloy, the newest and softest Elgiloy, have not been reported in the literature. Since this wire is used extensively in clinical orthodontic practice, it was the objective of this investigation to provide clinically applicable data on the effects of loop configurations and heat treatment regimens on Blue Elgiloy wire.

Materials and Methods

This study was conducted in two phases. First, the effects of various heat treatment regimens on the mechanical properties of straight Blue Elgiloy wire were investigated. Then, the effect of heat treatment on the force delivery characteristics of various loops made from the wire were determined.

Square (0.016 " x 0.016") Blue Elgiloy wire was utilized for all tests. Seven-inch lengths of wire were cut from the as-received material. Five lengths of wire were randomly assigned to each of six groups for various heat treatments. One group was heat treated for 10 minutes at each of the following Fahrenheit temperatures: 700, 800, 900, 950, 1000 and 1050. These temperatures were chosen to bracket the 900°F suggested by the manufacturer. The length of time for heat treatment (10 minutes) was selected since it is practical clinically, and because previous studies have indicated that greater improvements are not obtained with longer times.[1,2,5] The heat treatment was performed in a Jelrus dental oven calibrated with a thermocouple and potentiometer.

After completion of heat treatment, all the straight wires were tested in tension to failure on an Instron test machine (Fig. 1). Rubber grips were used to distribute the load and minimize grip-related failures. The tensile strain was measured using an Instron extensometer (Model G51-11) with a 1 inch gauge length. A counterweight support was fabricated to minimize the effects of the extensometer weight (Fig. 1). The tests were conducted at a crosshead rate of 0.1 in/min. Any samples that failed outside the gauge length were discarded.

To assess the effects of heat treatment on bent wires, twenty wires were formed in each of the following loop

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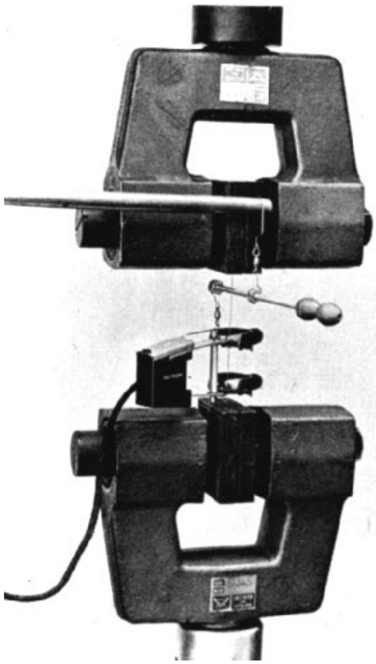

Fig. 1 Setup for tensile testing of straight wires.

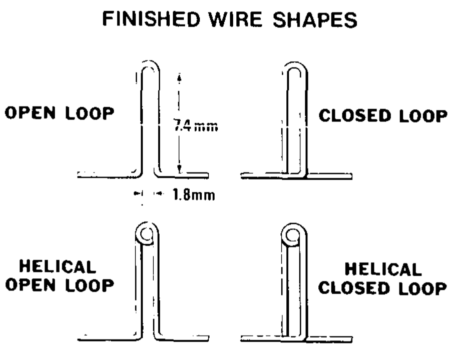

Fig. 2 Loop configurations tested.

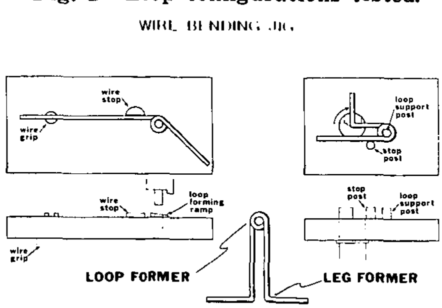

Fig. 3 Schematic of wire bending jig.

configurations: open loop, helical open loop, closed loop, and helical closed loop. These configurations are illustrated in Figure 2. Special forming jigs were designed and fabricated to bend the wires consistently with minimum work hardening. The wire bending jig consists of two parts, as shown in Figure 3. The upper member of the loop former fits in the hole in the center of the wire loop and winds the wire into the shape of a simple or helical loop depending upon the number of times it is rotated. The leg former bends each leg of the loop to a sharp, reproducible right angle. After completion of all wire bending operations, half of the loops were heat treated at the optimum temperature determined from the straight wire tests. The remaining loops were not heat treated.

The force-activation characteristics of all the loops were determined in the Instron utilizing special custom grips (Fig. 4). The grips were designed so that rigid support was provided for the wire and exact alignment was accomplished. Friction between the legs of the closed loops was eliminated by adjusting the grips laterally to provide a slight space between the legs. The loops were loaded at a rate of 0.1 in/min, the open loops in compression and the closed loops in tension.

The data were statistically evaluated using a Student t analysis at the UCLA Health Sciences Computing Facility.

Results

The straight wire tensile tests disclosed that heat treatment does have a pronounced effect on the mechanical properties of Blue Elgiloy. Figure 5 shows the variation of yield strength (0.2% offset) and ultimate strength with heat-treatment temperature. The maximum values are obtained at approximately 950°F. It can be seen that both these properites are improved with

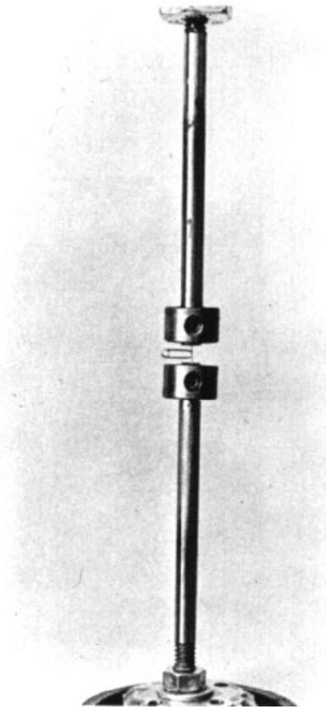

Fig. 4 Test setup for loops.

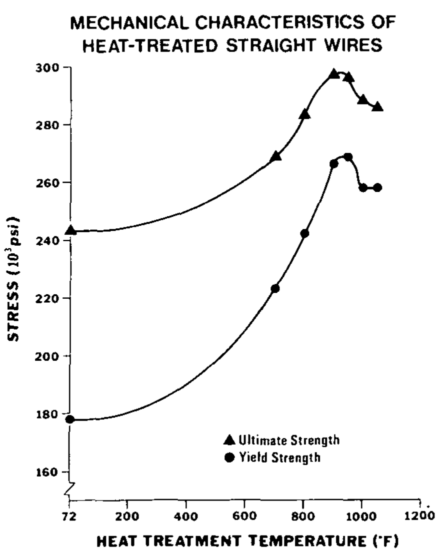

Fig. 5 Variation of yield and ultimate strengths with heat-treatment temperature.

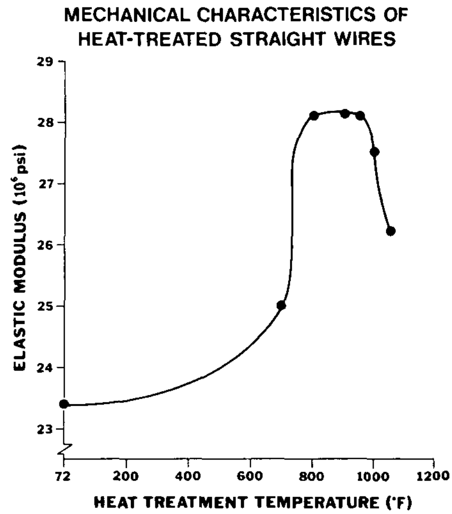

Fig. 6 Variation of modulus with heat-treatment temperature.

heat treatment, the most dramatic effect being an increase in yield strength of nearly 50%. Figure 6 illustrates the variation of elastic modulus with heat treatment temperature. An increase in modulus of approximately 20% accompanies an increase in heat treatment temperature. Again, a maximum is reached at about 950°F.

Figure 7 presents the force-activation data for open-loop designs in the heat treated and nonheat-treated condition. The graph shows the force required to deflect the wires over a range of 1.5 mm. The force-activation curves are exceptionally straight over the range shown. The heat-treated samples re-

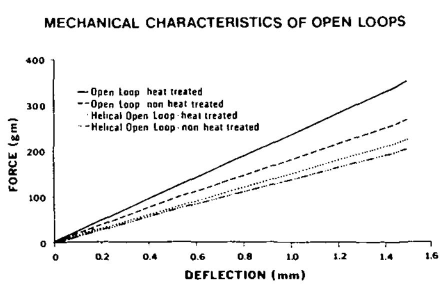

Fig. 7 Force-activation characteristics of open loops.

quired a consistently higher force than the nonheat-treated wire to produce the same deflection. The helical open loops generate lower forces than do the open-loop configurations. At the maximum deflection the effect of heat treatment is greater for the open-loop configurations. At the maximum deflection the effect of heat treatment is greater for the open loops (about 30%) as compared with 11% for the helical open loops. The heat-treatment effects were statistically significant at the 1% level for the open loop and the 5% level for helical open loop.

Figure 8 presents the data for the heat-treated and nonheat-treated closed loop designs. These values are lower than the open-loop values. Again, a greater percentage increase was noted for the closed loops than for the helical closed loops. These heat-treatment effects were statistically significant at the 1% level.

The data for all the loops are summarized in Figure 8 in a different form. The initial slopes of force-deflection curves were calculated and the inverse (deflection/force or Δ/F) is plotted in Figure 9. In all cases the heat-treated loops show a lower value than the nonheat-treated loops reflecting less deflection for equal forces.

Discussion

There is by no means a consensus among orthodontists as to the necessity of heat-treating appliances fabricated from Blue Elgiloy wire. However, the results of the straight wire tests revealed that heat treatment of this wire produced significant increases in the ultimate and yield strengths and modulus of elasticity. Improvement of these properties, especially the yield strength, means that the wire will be more resistant to masticatory forces not directly related to the intended use of the appliance.

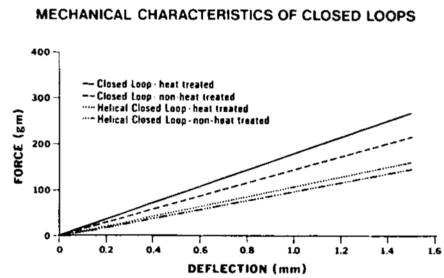

Fig. 8 Force-activation characteristics of closed loops.

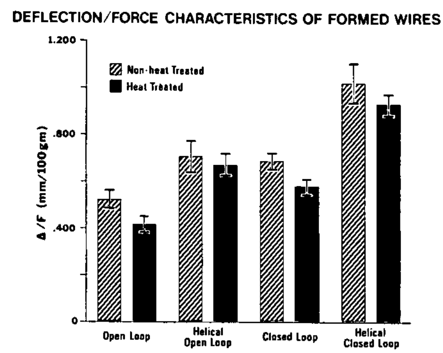

Fig. 9 Deflection/Force characteristics of formed wires.

Additionally, the heat treatment relieves residual stresses which lead to an improvement in fatigue characteristics.

The alterations in the deflection force characteristics for open and closed loops resulting from heat treatment were not identical and did not exactly correspond to the percentage change in modulus. Although similar observations were previously made by Mahler and Goodwin,[6] the reasons are not clear at this time.

The narrow range of heat-treatment temperatures that produces these increases in ultimate and yield strengths warns of the importance of employing accurate methods of heat treatment. For example, an incompletely preheated oven or an inaccurately set oven can produce less than optimal results. Control of other modes of heat treatment are obviously of equal importance. While clinically acceptable results have been reported with this wire that was not subjected to heat treatment, the experimental evidence suggests that, for a greater long-term effect, the best results with the best force control can be obtained after heat treatment.

Conclusions

The effects of heat treatment on Blue Elgiloy wire and loops formed from this wire were determined. The optimum heat treatment temperature was established to be in a narrow range in the vicinity of 950°F. This regimen increases the yield and ultimate strengths of this wire. Heat treatment also produced a modification of the load-deflection characteristics of the loop configuration tested. Overall, heat treatment of the wire is indicated by this study.

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