The Heat-Treatment of Stainless Steel[1]

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Since the advent of scientific tooth movement, man has been searching for a more efficient mechanism. The earlier appliances were mainly palatal plates with attachments emanating therefrom. Another variation entailed using a jack-screw principle. These methods were crude and cumbersome. They acted singularly on the teeth and relied entirely on direct pressure as the motivating force; thus tooth movements were limited.

After a period of years an orthodontic appliance consisted of bands on the teeth and the use of a wire or wires extending around the arch to produce the necessary forces of tooth movement. This brought forth a myriad of ideas: for example, the size and thickness of the bands and the number necessary for adequate treatment; a difference in design of the attachments, and principles involved during treatment; the various sizes of wires for these attachments; and the several types of metals from which they could be constructed.

Generally speaking, the orthodontic archwires available today are constructed either from alloys of gold or from stainless steel. Thus with this choice of materials we assume a vast difference in the properties of each, and we must accept the differences in technique involved with their usage.

Gold arches are the ideal choice for rectangular archwires. Gold is truer in dimension and quality. The dies used for the manufacture of gold wire remain more accurate, and gold is incorporated with base metals as a true alloy; therefore, its composition can be more constant. This metal can be more accurately conformed to archwires because it can tolerate more cold working before rupturing. The biggest advantage of the use of gold over steel is the ease of soldering the necessary attachments to the archwire.

If a reliable tempering and annealing device practical for office use were designed, a substantial majority of orthodontists would use gold almost entirely when a rectangular arch is desired. But at the present the advantages of gold over steel can be definitely outweighed by the lack of a suitable tempering-annealing device.

The latest heat-treating pots are an improvement over the original models, but there is still much to be desired. To have a heat-treating pot available, one must maintain a battery of them, and they always have the faculty of burning out when most needed. To temper gold, there is a small margin of error between wire too soft and too brittle; so a device with an accurate oven and pyrometer is necessary. Can an instrument be devised and constructed at a price practical for installation in an orthodontist's office? If such a unit can be devised, then experimentation must be conducted to establish that critical temperature ideal for gold tempering and the amount of latitude available.

Many orthodontists have spent a long period of time producing a gold archwire with the necessary bends, and have placed it in the brackets, only to see the archwire distort or rupture because of improper tempering. A Strang

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loop, if it were incorporated, also has a tendency to break upon reactivation. These tribulations are very disheartening, discouraging — and unnecessary.

The trials encountered because of the lack of a suitable gold tempering-annealing device has diverted attention to the use of steel.

My introduction to steel heat treatment was the demonstration presented by Dr. Mathew Lasher. The treatment seemed to improve the properties of the archwires; immediately a Huppert's Mighty Midget Oven was obtained for the office, and all steel archwires were heat-treated. The lack of imformation about heat-treatment of steel warranted investigation. Could stainless steel performance be improved by heat-treatment? What is the best temperature-time ratio for heat-treatment of steel arches? Would the best temperature-time ratio be suitable for office use? Would different manufacturers' products act similarly after being heat-treated? For example, would a soft, more pliable wire be more resilient than a harder, stiffer wire after both were heat-treated? Would the stainless property of steel be lost during processing? Would the latitude of degrees of temperature at which a wire was heat-treated be such that inexpensive equipment could be utilized? How much would the temperature-time ratio vary in treating archwires of different diameters? Could the wires be tempered before bending the archwire?

This paper is not designed to help settle the gold-steel controversy, but is merely a report on the effect of heat-treatment of steel for those who desire to use stainless steel archwires.

Note the term "heat-treatment" is used rather than "tempering." Not being a physicist or chemist, I do not know what the internal arrangement of atoms and molecules is during these tests. I can only report the observations of simple manual tests.

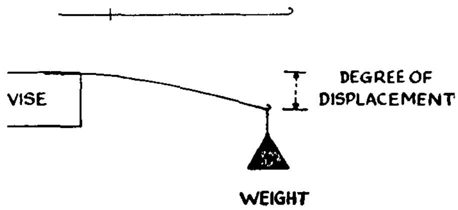


Fig. 1—Illustrating the device first used to measure the displacement induced in different wire specimens by the same weight. All forces were within the elastic limit of the wire.

My first idea was to procure a number of different manufacturers' wires—all of like size, .021 x .025, and routinely examine these after heat-treatment; then I would arrive at a temperature-time ratio which would give the best qualities for stainless steel. It was later found that this first idea was wrong.

The method of testing was as follows: the oven for heat-treatment was a Huppert Mighty Midget burn-out oven. This oven is very practical for an orthodontist's office. Temperatures used were from room temperature to 1400 degrees Fahrenheit. A General Electric Timer was used and time intervals varied from half a minute to seventy-five minutes. It is not practical to attempt to use the Mighty Midget for any work closer than fifty degrees variation, because it is difficult to maintain a constant temperature for a long period of time. During testing, opening and closing the over door caused variation of the heat to the extent of fifty degrees — especially at the higher ranges.

The wire that was to be heat-treated and tested was carefully selected. Wire of the same manufacturer, type size and batch was chosen. Each section of .021 x .025 archwire was cut into pieces of about three and one-fourth inches long. A rounded hook was placed on one end. Then a scratch mark was carefully placed two and three quarter inches from the curve of the hook. This was the length of the lever to be tested. The

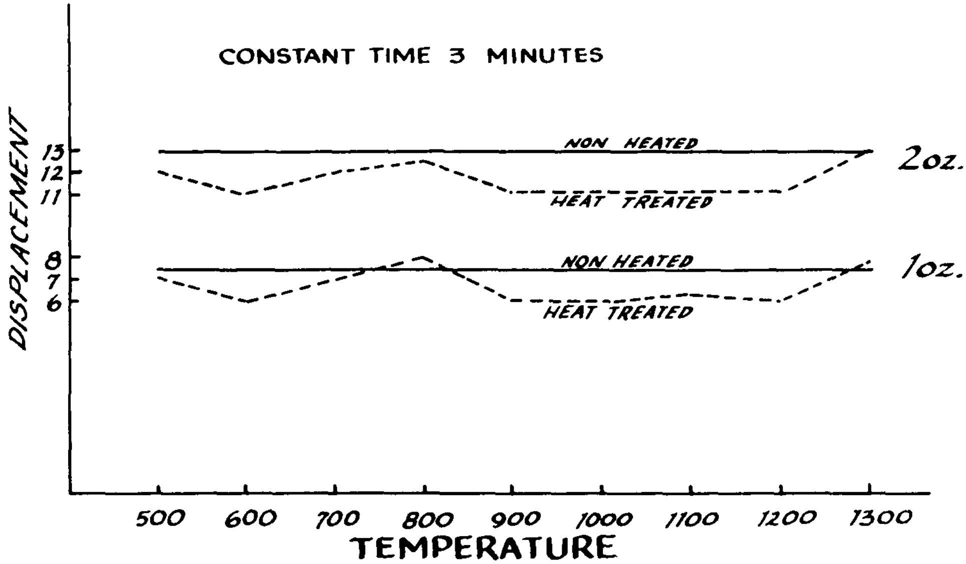


Fig. 2—A comparison of heat-treated and non-heat-treated wires, showing that at certain temperatures increased stiffness is produced, as indicated by a lesser degree of displacement by the same force.

additional half inch was the portion placed in the vise during the testing operation, and was sufficient to give a secure attachment to prevent an error in displacement from slippage.

The wires were selected and heat-treated at various times and temperatures. Figure 1 illustrates the method followed in testing. One end of the wire was placed in the vise, a like weight was suspended from the other end of the wire, and the vertical displacement was measured. Weights were used which would not carry the wire beyond its elastic limit. After the degree of vertical displacement was recorded, the wires were compared with one another and with the non heat-treated "normals".

The first experiment was one to test the properties produced by a constant time but a variable temperature. The time constant was three minutes. The temperature varied from 500 degrees, progressing at 100-degree intervals, to 1300 degrees.

In figure 2 the upper line, or solid line, is the non-heated normal. The lower broken line shows the results of heat-treatment. The smaller the degree of vertical displacement, the stiffer are the wires.

To test the results of heat-treatment, a two-ounce weight was suspended from the end of the lever, and the vertical displacement was compared with that of a non heat-treated normal. The normal which was not placed in the heat-treating unit was displaced 1.3 inch. The wire treated at 500 degrees was displaced 1.2 inch. The wire at 600 degrees was displaced 1.1 inch. At the 800-900 degree range displacement was about 1.2 and 1.1 iniches. This is the range where the wires should show less displacement according to the previous instructions; that is, the ideal temperature-time ratio was 850 degrees for three minutes. At the higher temperatures they stayed at 1.1 inch displacement.

At first observation, this would lead one to think that heat-treatment is not improving the properties of the wire, as there is only .1 inch improvement in

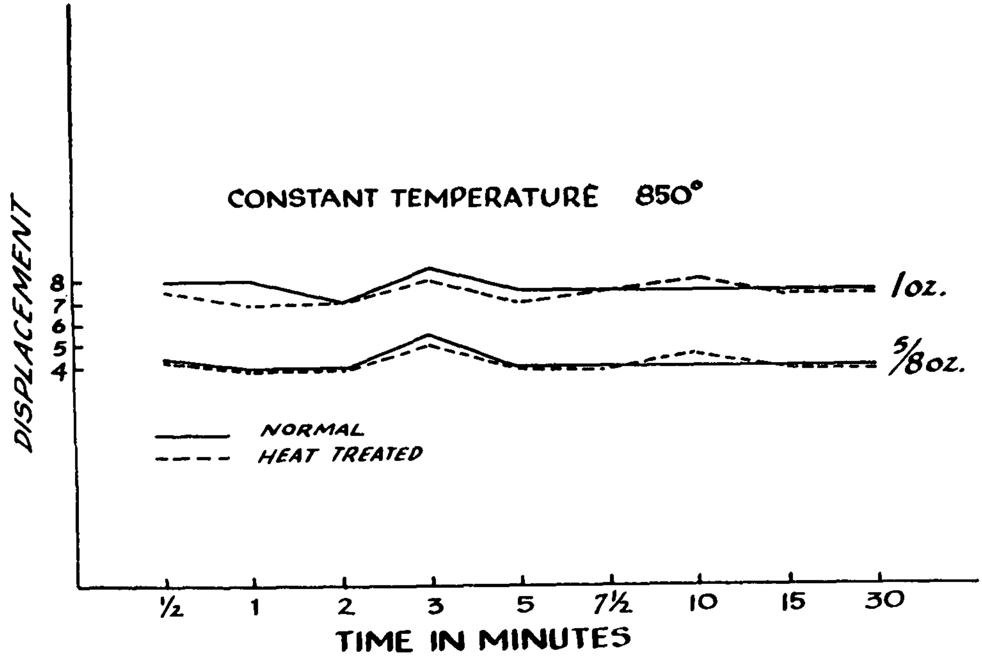
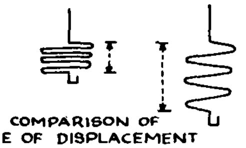


Fig. 3—Showing the effects of variations in duration of heat-treatment at a constant temperature. No important difference in the behavior of heat-treated wire as compared with non-heat-treated can be demonstrated *with this test.*

vertical displacement. It was thought that perhaps a lesser weight would allow the elasticity to better manifest itself, thereby bringing about a more definite result. The lower graph shows the results after using one-ounce weight suspended from the lever. The nonheated wire showed displacement of .75 inch, and the 500 degree showed .7 inch displacement. Along the line .7, .6, .7, .7, .6, .6 inch displacement shows there is not much change. However, there was a slight improvement in all cases of heat-treatment (broken line) over the normal or non-heated wire (solid line), but there was not enough improvement from this test to justify heat-treatment or to claim its beneficial results. All steel archwires which were placed in the mouth seemed to exhibit much better properties in performance than those which were unheated. The next thought was that the length of the lever of the wire tested was not long enough for the action in the wire to express itself. Two lengths of wire as long as the heat-treating oven could accommodate were heated to 850 degrees for three minutes and compared with similar lengths of unheated wires. There was a proportional improvement but still not enough to make any definite claims for heat-treatment.

Figure 3 illustrates the results from the testing of these variables: maintaining a constant temperature and varying the time interval. Since there was no apparent best temperature during the previous tests, a constant temperature of 850 degrees was selected, and the time chosen was from thirty seconds to seventy-five minutes. A time period over fifteen minutes is impractical for office usage, but longer periods were observed for informational purposes. Every precaution was taken to have identical wire samples. Hooks were bent



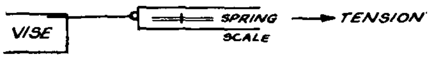


Fig. 4—Experimental apparatus designed to imitate conditions found in an archwire, in a reproducible fashion. Each specimen was bent exactly like the others, and all were stressed in the same amount by spring tension.

on one end of the wire samples, and then a known length was measured and scratched on the wire.

The vertical displacement of the non-heated wires was compared with the heat-treated wire lengths. The non heat-treated wires tested with a five-eighths ounce weight varied somewhat from .4 inch to .55 inch. This discrepancy is negligible and can be attributed to slight differences in the properties of the wires and also to error in measurement. These wires were then placed in the oven and heat-treated. The heat-treated wires showed no significant difference, as noted by the broken line on the bottom graph.

These same wires were again tested by using a heavier weight, a one-ounce weight. The vertical displacement produced by the heavier weight was similar in proportion to the lighter weight, as noted by comparing the two graphs.

It was dissappointing indeed to evaluate the tests and come to the conclusion that heat-treatment was not producing a spectacular change in the wire as was anticipated. All the archwires placed in the mouth during normal office procedure were heat-treated and seemed to show definite properties not exhibited in the archwires used which were not heat-treated.

Why should the archwires used in the mouth show superior quality, while those tested in an experiment showed apparently no change? Was the "heat-treating" psychological? The archwires placed in the mouth during treatment had numerous bends; the wires tested were straight. Why not test a wire which was more like an archwire, that is, one with numerous bends? This procedure brought about remarkable improvement.

To investigate further, a definite pattern of bends was selected, a pattern that would have enough bends to simulate the stress and strain of an archwire during treatment. Also it would have to be one that could be reproduced easily and accurately. The wire samples were bent into a design with three V's on each side of the wire and a hook on one end.

The method of testing was as follows. The length of the tight V loop was measured. The free end of wire was fixed in a vise (Figure 4). Then an accurate spring scale was attached to the opposite end on the hook, and an arbitrary tension was selected to exert tension to the spring. Care was taken to select a tension below the limit of elasticity. After the wire samples were stretched from the tension, they were removed from the vise and the length of the V loops was again measured. The amount of distortion was compared with the normal and with the other heat-treated wire samples.

In Figure 5 is shown the wire before heat-treatment or before any tension has been applied. Actual specimens are shown, stitched to the card so that the first bend (near the vise) lines up with the same point on the other specimens. Reference is made to different manufacturers' wires, so that the reader may see the reaction of the type of wire he might use in the office. These wires are .022 x .028 stainless steel procured from Tri-State Dental Supplies in Arizona. In the figure, the second wire from the left with a zero beneath was

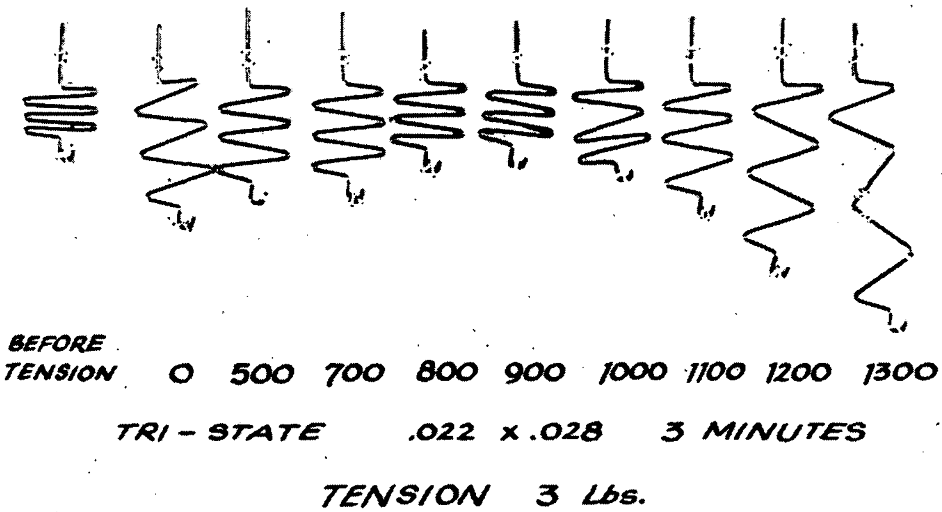


Fig. 5—The actual specimens from one source of supply, after having been similarly stressed as in Fig. 4, following heat-treatment for 3 minutes at the indicated temperatures. A specimen for 600° was tested, and was identical in form to that for 500°, although it was omitted from this Figure.

not heat-treated. A tension of three pounds caused a distortion of approximately two and one-half times its original length. The rest of the wires have all been heat-treated from 500 degrees to 1300 degrees, for three minutes, then tested by the three-pound test. There is a progressive improvement or less distortion up to the 900 degree wire, then a rapid decline down to the 1300 degree wire. The 1300 degree wire broke during testing. For the stainless steel heat-treatment, there is a wide temperature latitude for steel improvement, that is, from about 700 degrees to 1000 degrees. The optimum temperature seems to be about 850 degrees. Keeping the wire at the lower temperatures will also better maintain the stainless qualities of the steel.

Figure 6 shows Unitek .021 x .025 wire. The wire in Figure 5 was .022 x .028; naturally it resisted displacement better. The first on the left is the normal, or non heat-treated wire. The 900 degree wire has the least displacement, and again a decline at the higher temperatures.

The results of heat-treating Tru-Chrome .018 x .021 stainless are illustrated in Figure 7. The tension used for testing was two pounds. The previous wires were tested with three-pound tension. Again about the same results were achieved, the 800 to 900 degree being the least distorted.

Figure 8 shows the improvement of Tru-Chrome soft and hard wires from heat-treating. The heat-treated soft and hard wires are not to be compared. The tension used was not sufficient to show the differences between the heat-treated wires.

On the left, the heat-treated hard variety showed a very great improvement. As for stiffness, the hard type is superior to the soft type regardless of heat-treatment.

One fact that should be stressed is that heat-treatment does not put a new magic quality in a wire. Figure 9 shows Hard Tru-Chrome .021 x .025. First, on the left, the non heat-treated, then progressive improvement, then a gradual decline. The testing tension, three pounds.

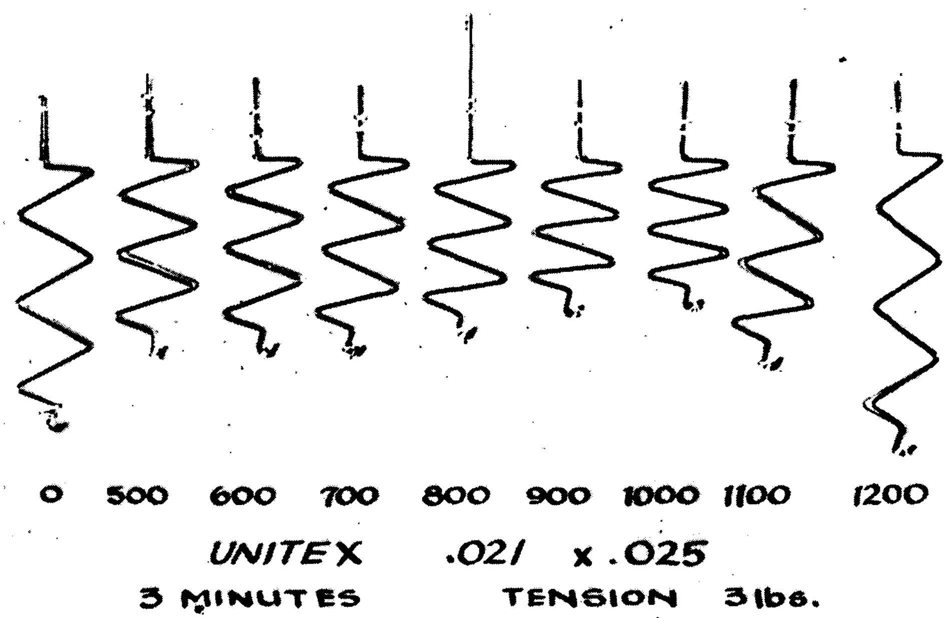


Fig. 6—A similar test, using .021 x .025 wire instead of .022 x .028. For "Unitex" read Unitek. The same tension produces more displacement here since the wire is smaller.

Figure 10 pictures the soft variety of Tru-Chrome, but the testing tension was only two pounds. The response to the different temperatures was the same as that of the previous illustrations. However, if a three-pound tension had been used on the soft type, the distortion would be so severe that a comparison of the results from different temperatures of heat-treating could not be measured.

An exceptionally soft wire will be slightly more improved than a hard one, but generally speaking, the improvement will be directly proportional to the original state.

Figure 11 poses the question: Can the archwire be improved by heat-treatment prior to the placement of bends in the archwire? The one on the left is the result of a straight wire which was heat-treated; the bends were placed later and tested. At the right, a wire of the same material was bent and heat-treated. The wire heat-treated after bending exhibits the least displacement. Heat-treating before placement of bends is not beneficial.

Does heat-treatment destroy the stainless properties of the steel? After heat-treatment at 850 degrees, the wires turned slightly straw-colored. It is quite possible to polish them with gold rouge on a three-inch rag wheel, powered by a lathe motor, a process which takes only a few seconds. An anodic polisher is unnecessary unless one has other uses for it to warrant its purchase.

A straight steel wire showed little variation because heat-treatment did not change its internal structure. This fact may be further substantiated by taking a straight wire and drawing it carefully between one's finger and thumb nail until an arc is formed. This curved wire will tend to return to its original shape because its internal arrangement was not sufficiently altered to prevent its return. The improvement of heat-treated wires with the V-bends

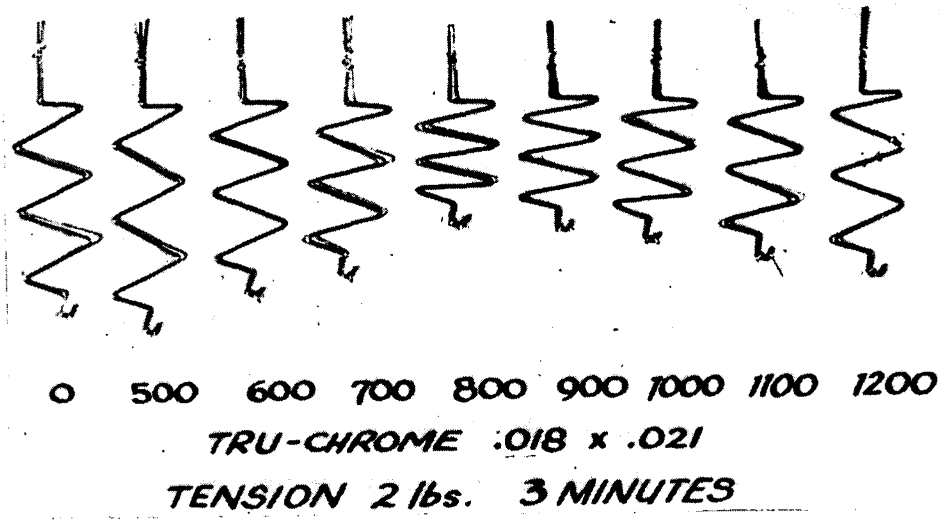


Fig. 7—Similar results with wire of still smaller dimensions. Cross-sectional area of the specimens was small enough that a 2-lb. tension had to be used.

was due to the fact that manipulation of the pliers was sufficient to alter down the internal structure. Heat-treatment at the optimum temperature resulted in a beneficial rearrangement, which restored the resiliency of the steel.

Experimenting with the wires with eight V-bends, one accepts the disarrangement; because the property of steel to return to a straight line is lost, the wires become pliable and powerless. After heat-treatment the internal structure rearranges itself to a new mechanical advantage. The power is restored.

Steel heat-treatment seems to be a quantitative factor. That is, heat-treatment is the resultant of temperature multiplied by time. Temperature from 700 to 950 degrees can be utilized for time intervals from three to fifteen minutes. The apparent requisite seems to be enough heat absorbed to change the internal structure of the wire. Temperatures below 700 degrees do not have much effect, and those above 1000 degrees are too hot. Time intervals over fifteen minutes are impractical for daily office procedure.

Heat-treatment can be compared with a steel soldering operation. If too much heat is applied the wire becomes dead, and if not enough heat is applied, nothing happens.

The most practical index of heat-treatment for everyday purposes is a color index. As in soldering, a straw color is obtained when the wire has received the optimum amount of heat. When too much heat is applied, the wire becomes dark chocolate in color, as it does when too much heat is applied during soldering.

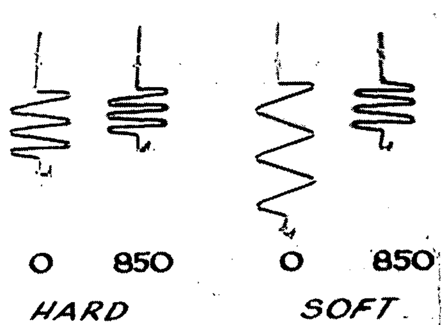


Fig. 8—Comparison between "Tru-Chrome" Hard and Soft. Results of heat-treatment, starting with "hard" and "soft" wires.

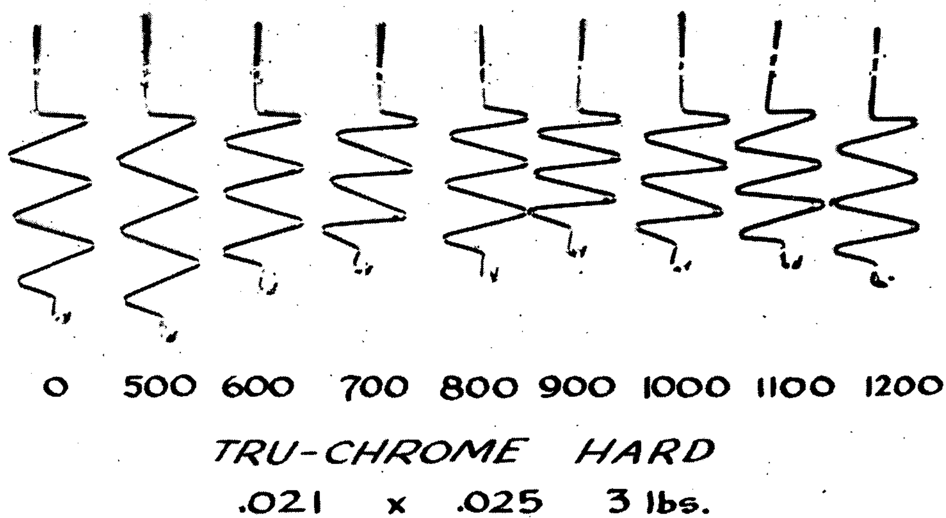


Fig. 9—To be compared with results shown in Fig. 10.

Conclusions

Heat-treatment is very beneficial for stainless steel archwires. The beginning round wires, if heat-treated, will maintain their form for a longer period and positive tooth movement will occur. The archwires which have loops for opening or closing spaces will have a stronger action, if this is desired. Arches used for stabilization will maintain themselves better and longer; anchorage will be enhanced.

Heat-treatment is best at 850 degrees Fahrenheit for a period of three minutes.

The Mighty Midget is a practical oven for use in an orthodontist's office. A temperature of 850 degrees Fahrenheit can be readily maintained.

The temperature latitude, where good results can be obtained, is approximately 200 degrees.

The stainless properties are not lost during heat-treatment, and polishing can restore the original color.

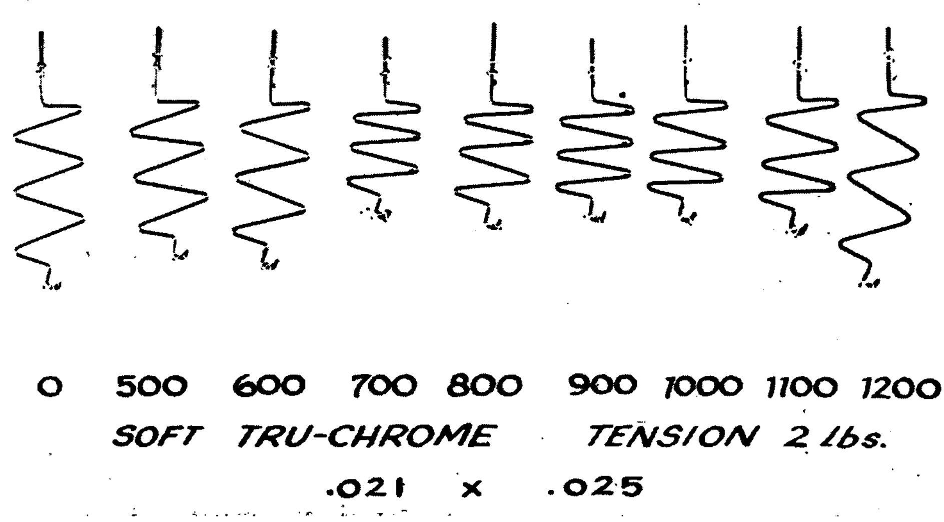


Fig. 10—To be compared with results shown in Fig. 9.

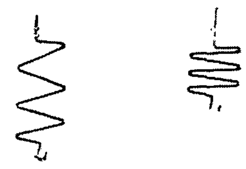


Fig. 11—Demonstrating that heat-treatment of this kind is beneficial only after bends have been placed.

Heat-treatment is a quantitative factor. Wires of smaller diameter will absorb heat more quickly than will a larger wire, but the discrepancy is not sufficient to have a temperature time ratio for various sizes of wires.

The archwire should be heat-treated only after completion of all necessary bends, not before.

A steel archwire which has lost its temper from a soldering operation cannot be restored by heat-treatment.

Archwires of either gold or steel can be used successfully in daily practice. One must be ready to accept the peculiarities of either material in the plan of treatment. The ultimate choice will be one to suit the personality of the operator.

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