Influence Of Heat Treatment On The Physical Properties Of Bent Orthodontic Wire

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INTRODUCTION

It is generally accepted that the elastic properties of formed orthodontic archwires of 18/8 stainless steel are improved by low-temperature heat treatment at 300-500°C for a short period. This procedure is often referred to as hardening, stress relieving or, simply, heat treatment. Its effect has been the subject of investigation at frequent intervals throughout the last few years.

In experiments in which wires bent into a series of V-shaped loops were heat treated and subjected to tension, Funk[5] found a marked improvement in the elastic properties; no such improvement was observed for treated straight wires subjected to deflection. Backofen and Gales,[2] who studied the expansion of U-shaped loops under tension, found a marked increase in the elastic strength after heat treatment. Wittmer[12] determined the elastic limit expanding annular specimens; some were prepared by forming to a definite shape and others by overbending and bending back to the same shape; the latter group proved to have the higher elastic limit. Annealing reduced the elastic limit of the specimens of both groups to a small but consistent extent. Kemler[6] concluded from an experiment on the expansion of uniform round loops of stainless steel that a low temperature heat treatment resulted in an increase in the elastic limit and elastic modulus. In experiments on the proportional limit, tensile strength and hardness of austenitic stainless steel, Wilkinson[11] found that the properties depended on the period of heat treatment and the temperature. Using 18/8 stainless steel coiled around a cylinder to obtain spirals Mutchler[7] showed that heat treatment resulted in changes in elastic limit and moduli of elasticity and resilience. In resilience experiments with straight and bent wires Callender[4] found an increase in the modulus of resilience after heating.

It is evident from the above that while there is convincing evidence that, so far as the expansion of formed archwires is concerned, suitable heat treatment of orthodontic wires increases the elastic limit, and in some cases also the elastic modulus, the effects on these properties in the case of further bending of the archwires and the forming of straight wires have been largely if not completely neglected.

It is clear that a thorough knowledge of all aspects of the effect of heat treatment on the mechanical properties of formed archwires is necessary if these appliances are to be put to the best clinical use. The object of the present study was to examine the behaviour of these properties more closely, with heat treatment at different temperatures and for different periods.

MATERIAL AND METHODS

The experiments were performed on one make of stainless steel wire of the austenitic group, with a composition of 18 per cent chromium and 8 per cent nickel. The wire, which was 0.45 mm in diameter, was obtained from the factory in straight lengths of 300 mm. These were cut into 122 mm pieces, and at

From the Royal Dental College.
This study was supported in part by a grant from the Danish Dental Association (F.U.T.).

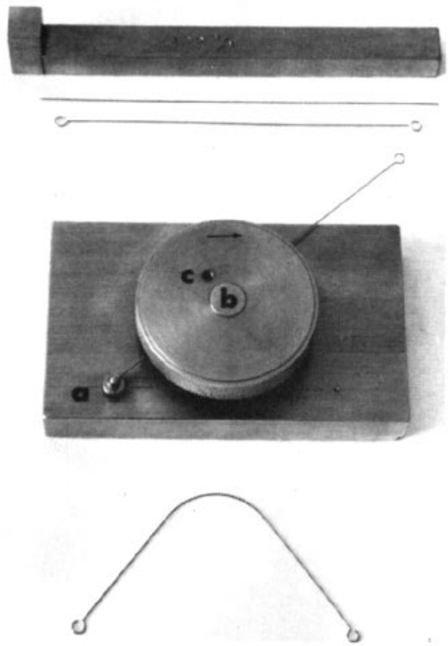

Fig. 1 *Top.* — Standard 122 mm measuring rod for the wire specimens, and wire with one loop at each end. *Middle.* The arch former with a wire in place; one loop is placed on the pin *a*, and the pin *c* keeps the wire in a horizontal groove in the cylinder *b*. By turning the knurled disc clockwise through a predetermined angle the standard arch is produced (bottom).

each end a round loop 3-3.5 mm in diameter was bent with loop forming pliers. To obtain a shape comparable with a finished orthodontic archwire, a standard arch former was used (Fig. 1).

One end of the wire was fixed so that the wire rested in a horizontal groove in a stationary cylinder. On top of this was then placed a rotating part with a vertical pin to keep the wire in the groove; when rotating this top part of the arch former the wire was carried round the centre. The rotation was identical for each piece of wire, thus ensuring a very small variation in the shape of the arches.

The standard archwires were subjected to loads in specially designed apparatuses (Figs. 2, 3, 4) after they had been exposed to a definite temperature for a definite time. The load was

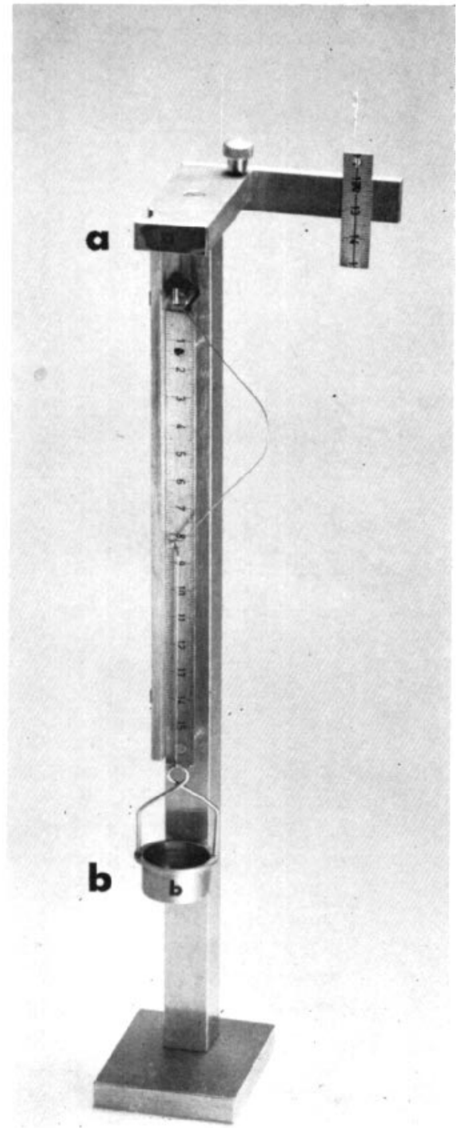

Fig. 2 Apparatus for determining the elastic and plastic deformation of a standard archwire on expansion. One end of the wire is fixed by placing the loop over the pin just below platform *a*. The expansion of the arch under the load *b*, which is suspended from the free loop, is represented by the distance the lower loop travels; it is read off directly on the scale.

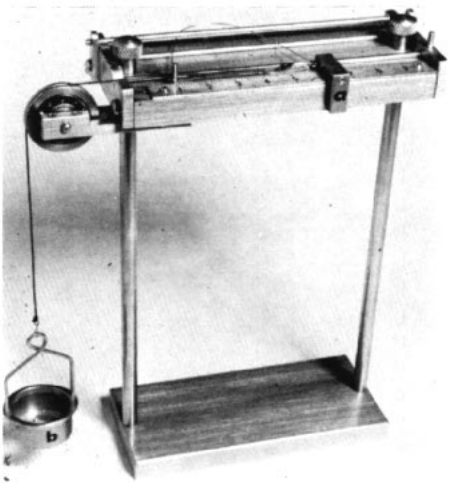

Fig. 3 Apparatus for determining the elastic and plastic deformation of the standard archwire on compression. One loop of the wire is fixed at the one cm mark; the load is attached to the free loop, whose displacement is read off directly on the scale with the aid of the slide *a*.

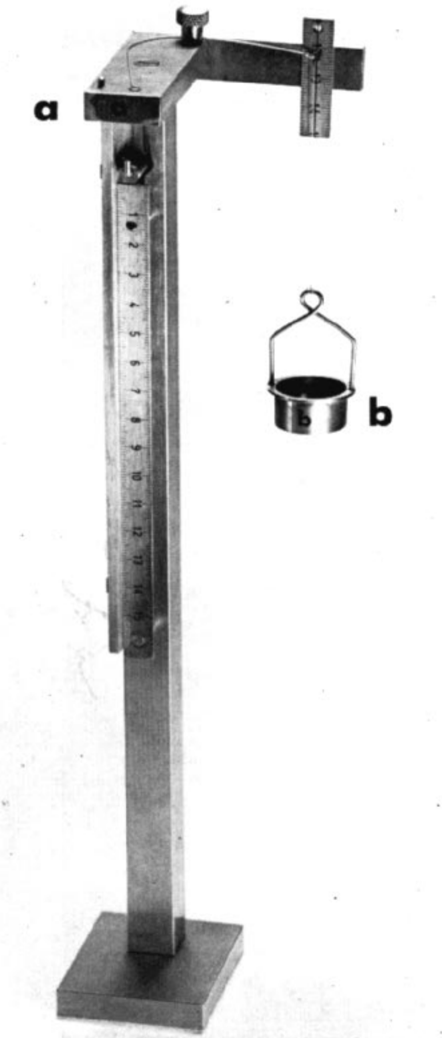

Fig. 4 Apparatus for determining the elastic and plastic deformation of a straight segment of a standard archwire. The wire is placed on the platform *a* so that the free loop lies on the perpendicular line on the smaller scale. The load *b* displaces this loop along the scale, the magnitude of the deformation being read off directly.

applied in three directions; the first tended to straighten out the arch, the second increased the curvature, and the third bent one of the straight limbs of the standard arch. For expansion or compression of an archwire, it was applied with one loop fixed and the other free for application of the load (Figs. 2 and 3). The bending of a straight piece of wire was performed by loading an arch limb (Fig. 4) which at no time during the preparation of the arch had been deformed plastically. The free loop of the archwire in all three apparatuses moved along a scale so that both elastic and plastic deformations could be read off directly.

Each wire was subjected to four different loads, all within the elastic limit, and the elastic deformation was read off. The modulus of elasticity was hereby defined as the relation between the load and the elastic deformation. The load was then increased gradually in steps until the wire no longer recovered its shape completely and there was a permanent deformation of 0.5 mm. The load required to produce this plastic deformation was taken as the elastic limit for the standard wire with the apparatus and the method used. Since plastic deformation of a wire, for instance, in determining the elastic limit for expansion, might influence the subsequent determinations of the elastic limit for further bending, these measurements were not performed on the same specimens. The first set of observations was made with no previous heating of the archwires and the subsequent ones with heat treatment at nine temperatures for a constant period of seven minutes.

The heating was performed in a Pontica dental furnace and the temperature at the point in the furnace where the wires were placed was controlled with an iron-constantan thermocouple.

Twenty standard archwires were treated at each temperature, the elastic and plastic deformations being determined on ten specimens for expansion and ten others for compression. The measurements on the straight parts of the specimens were performed by placing ten of the twenty treated wires in a horizontal plane so that only a straight segment of each was free. The load was applied at right angles to the plane of the archwire.

The second part of the study consisted of an examination of the influence of the duration of heat treatment. This was performed only for expansion of the wires and only the elastic limit was determined. The times used were: 2, 4, 7, 15, 30 and 60 minutes, for each of which ten determinations of the elastic limit were carried out at the temperatures 100, 200 and 300°C, and so on, until the elastic limit remained constant, that is to say, had reached its maximum. To determine more accurately the temperature at which this maximum was reached, measurements were made at 50° lower and 50° higher than that at which the observed maximum had been recorded.

To find whether the elastic limit is likely to change at 37°C maintained for a long period, forty-five specimens were placed in a thermostatically controlled chamber at this temperature; fifteen were removed after fifteen days and the elastic limit was measured during expansion. Fifteen more wires were taken out and tested in the same way after one month, and the last batch after six weeks. Batches of fifteen specimens instead of ten were used because the changes in elastic limit were expected to be extremely small.

Corrosion resistance

It is obvious that in a study of heat treatment of stainless steel wire account must be taken of the resistance of the material to corrosion. Although this normally is extremely high for 18/8 stainless steel, certain changes in the handling of the material or in the environment can reduce the resistance of the metal to attack, and corrosion ensues; that is to say, the metal is attacked directly by a substance with which it is in contact. The chromium in stainless steel is important for creating and maintaining a chemically passive surface so that further corrosion of the material is prevented. If, however, the steel is raised to a temperature of between 400 and 900°C, the chromium combines with the carbon of the stainless steel forming chromium carbide (CCr_4); this precipitation takes place mainly at the grain boundaries where both chromium and carbon atoms are moving at high speeds. Since chromium carbide consists of about one part of carbon to nine of chromium, the formation of chromium carbide will remove a large proportion of the chromium present in the grain boundaries with the result that the level falls below the twelve per cent passivity limit, and intergranular corrosion becomes possible. Not only does corrosion render the appliance unaesthetic, it can also impair the mechanical properties. It is therefore important to be able to determine when corrosion may occur.

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TABLE I

ELASTIC LIMIT (GRAMS) OF STANDARD ARCHWIRE AFTER HEATING FOR SEVEN MINUTES AT VARIOUS TEMPERATURES. MEANS OF TEN OBSERVATIONS.

Temperature	Expansion		Compression		Bending	
C°	Mean	S.D.	Mean	S.D.	Mean	S.D.
20	5.4	0.4	45.8	2.5	69.6	1.7
37	5.7	0.5	44.9	2.7	70.3	2.3
100	7.8	0.9	38.5	2.6	72.9	2.7
200	12.8	1.7	35.7	2.7	75.3	3.3
250	17.9	2.4	34.2	1.9	77.9	3.4
300	23.0	2.5	33.4	1.2	82.0	3.2
350	31.0	2.2	32.6	1.4	83.7	3.3
400	33.3	2.6	32.8	1.2	83.9	3.0
450	35.2	2.6	33.0	1.3	83.6	3.2
500	35.3	2.9	32.6	1.7	83.7	3.2

ferricyanide was used as an indicator for ferrous ions, in the presence of which Prussian blue is precipitated (Stegemann[9]). If the solution contains small amounts of potassium ferri- and ferrocyanide it will serve as an indicator for both ferrous and ferric ions, by precipitation as Prussian blue. Sodium chloride was chosen as the electrolyte, and gelatine was added to give a sharper borderline of the blue regions and to maintain the correct relationship to the specimen by eliminating flow. The final indicator solution had the following composition: gelatine 3-4 per cent; sodium chloride 1 per cent; potassium ferro- and ferricyanide, equal parts, 0.05 per cent; acetic acid 0.5 per cent. The acetic acid renders the indicator more sensitive.

To obtain a general impression of corrosion, short straight wire specimens were treated with the time-temperature combinations that had given the maximum elastic limit. These pieces were placed in the corrosion indicator; the appearance of a blue colour showed the presence of corrosion. To ensure that any corrosion detected was not due solely to a thin layer on the surface of the wire, the specimens were placed first in the indicator without gelatine, observed for any corrosion after twenty-four hours, then removed, rinsed in alcohol and replaced in the indicator with gelatine. The wires were placed on a glass plate left to right beginning with the lowest temperature at which they had been treated.

Results

The results of the investigation are shown in Tables I-V and Figures 5-9.

Elastic limit

The means and standard deviations of the elastic limits are given (Table I) for expansion and compression, respectively, of the standard archwires, and for bending of straight specimens of these after heat treatment at different temperatures. For the expansion of the wires and the bending of the straight segments there was a clear increase in the elastic limit with temperature, expressed as the mean of ten experiments; on the other hand, for compression of the wires there was a fall in the elastic limit with temperature. The results in Table I are presented graphically, the dispersion is given as $\pm 2\sigma$ (Fig. 5). The dispersion is about the same for all temperatures in the bending experiment while it diminishes for compression and increases for expansion. It is further noticed that the steepness of the three curves differs. This point is examined in Figure 6 in which the change in elastic limit per 50°C, at constant time of

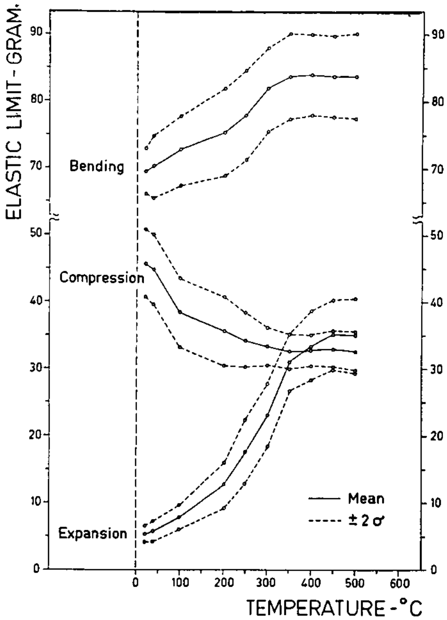

Fig. 5 Elastic limit as a function of temperature at constant time of heat treatment, seven minutes. The elastic limit is given for bending straight wire and for compression and for expansion of standard archwires.

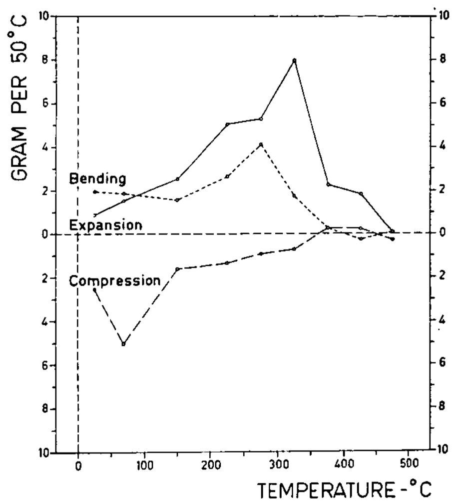

Fig. 6 Change in the elastic limit (g per 50°C) at constant time of heat treatment, seven minutes.

heat treatment of seven minutes, is shown for each of the three curves. It is evident from this graph that the greatest rate of change of elastic limit did not occur at the same temperature for all three experiments, the peak for the compression curve lying between 50° and 100° whereas the maximum changes for deflection of straight pieces and for the expansion are located a little below and a little above 300°, respectively. Not only do the peaks of the three curves not coincide, they are not of the same magnitude, the greatest

TABLE II

ELASTIC LIMIT (GRAMS) FOR EXPANSION OF STANDARD ARCHES AFTER HEATING AT VARIOUS TEMPERATURES FOR VARIOUS TIMES. MEANS OF TEN OBSERVATIONS.

Temperature C°	2 Min. Mean	2 Min. S.D.	4 Min. Mean	4 Min. S.D.	7 Min. Mean	7 Min. S.D.	15 Min. Mean	15 Min. S.D.	30 Min. Mean	30 Min. S.D.	60 Min.* Mean	60 Min.* S.D.
20					5.4	0.4						
100	8.4	0.9	7.6	0.9	7.8	0.9	9.0	1.1	9.0	1.3	11.0	1.0
200	12.0	1.9	12.6	1.5	12.8	1.7	15.6	1.9	19.5	1.9	20.9	2.0
300	19.1	2.0	21.1	2.5	23.0	2.5	28.3	2.2	32.4	2.5	34.2	3.0
350							33.3	3.3	34.4	3.0	34.8	3.1
400	26.6	3.4	29.7	2.8	33.3	2.6	35.2	2.4	34.0	3.4		
450			33.2	2.5	35.2	2.6	35.0	2.7				
500	33.7	2.8	34.9	2.8	35.3	2.9						
550	35.0	2.5	34.9	2.4								
600	35.9	2.2										

* As the mean elastic limit at 300°C was very close to the maximum, a determination was made at 325°: Mean 34.8; S.D. 3.0.

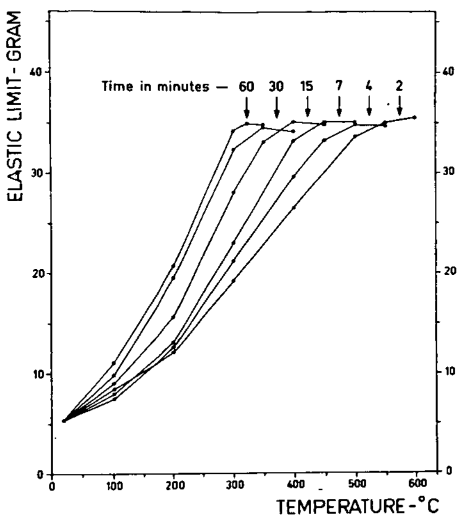

Fig. 7 Elastic limit as a function of temperature for expansion of standard wires. Means of ten observations for each of the specified periods of heat treatment.

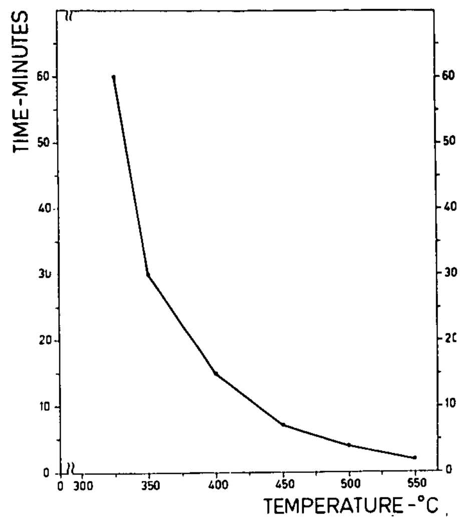

Fig. 8 Period of heat treatment required at various temperatures to attain the maximum elastic limit of 34.8 g ± 0.5 for expansion of standard wires. The elastic limits are means of ten observations.

change in elastic limit per 50° lying at four grams for the bending of straight segments, at five for compression of standard archwires and at eight for expansion.

The means and standard deviations for the elastic limits are given for expansion of the standard archwires after heat treatment for different times and temperatures (Table II). The elastic limit is expressed as a function of time and temperature for expansion of the wires (Fig. 7). It is shown that the maximum elastic limit was the same for the different times of heat treatment; the dispersion, however, increased with time. Likewise, the longer the treatment, the lower the temperature required to attain the maximum elastic limit. On the basis of these results the relationship between time and temperature was derived for the maximum elastic limit (Fig. 8).

In the next experiment in which the specimens were maintained at 37°C for .5, 1 and 1.5 months there was a significant improvement in the elastic limit for expansion of the archwires corresponding to 45, 52 and 62 per cent of the value at 20°C.

Elastic modulus

The mean elastic deformation of ten standard archwires is given for each load and temperature for the three directions of load (Table III). All the elastic deformations were measured in millimetres with four loads for each temperature, and on this material a two-tailed variance analysis was performed for each load distinguishing between the three methods, to examine the possible influence of temperature on the magnitude of the elastic deformation and hence on the modulus of elasticity. The results of these analyses are given in Table IV. It is clearly seen that a variation of the temperature produces a significant change in the magnitude of the elastic deformation for the same load. This applied, however, only for experiments with expansion and compression of standard archwires. During the heat treatment of the wires a perma-

TABLE III

ELASTIC DEFORMATION (MM) OF STANDARD-ARCHWIRE ON APPLYING VARIOUS LOADS AFTER HEATING TO VARIOUS TEMPERATURES FOR SEVEN MINUTES. MEANS OF TEN OBSERVATIONS.

	Expansion (G)				Compression (G)				Bending (G)			
C°	0.5	1	2	3	10	11	12	13	5	10	20	30
20	0.94	1.90	3.33	4.53	17.98	20.89	22.39	24.14	1.79	3.37	6.51	9.48
37	1.02	1.93	3.31	4.46	17.59	19.86	22.44	24.18	1.72	3.41	6.53	9.50
100	0.92	1.82	3.14	4.36	17.17	19.28	21.43	23.43	1.75	3.44	6.68	9.61
200	0.96	1.87	3.22	4.30	15.80	17.85	20.00	21.95	1.77	3.47	6.63	9.56
250	0.85	1.77	2.93	3.98	16.34	18.14	20.54	22.42	1.78	3.49	6.65	9.57
300	0.94	1.80	2.88	4.08	16.42	18.38	21.57	22.52	1.83	3.58	6.73	9.78
350	0.93	1.84	3.01	4.12	16.37	18.38	20.74	22.60	1.81	3.50	6.70	9.78
400	0.91	1.80	2.96	4.02	16.06	17.83	19.80	22.03	1.80	3.39	6.59	9.76
450	0.88	1.77	2.89	3.95	15.97	17.76	19.94	21.72	1.78	3.39	6.48	9.70
500	0.90	1.18	2.85	3.87	15.85	17.69	19.49	21.46	1.82	3.47	6.57	9.62

TABLE IV

SURVEY OF TWELVE TWO-TAILED ANALYSES OF VARIANCE OF ELASTIC DEFORMATION. VARIANCE RATIOS FOR THE INFLUENCE OF VARIATION IN WIRE AND TEMPERATURE ON THE MAGNITUDE OF THE ELASTIC DEFORMATION.

	Expansion		Compression		Bending	
Load**	Wire	Temp.	Wire	Temp.	Wire	Temp.
1	0.76	1.52	1.34	13.99×	1.25	1.91
2	1.60	1.82	0.90	15.83×	1.03	1.18
3	1.34	7.96×	1.27	16.66×	0.66	0.92
4	0.33	11.58×	1.20	19.20×	0.75	0.95

×Indicates a highly significant variance ratio.
**Loads 1-4: Expansion .5, 1, 2, 3 g
Compression 10, 11, 12, 13 g
Bending 5, 10, 20, 30 g.

TABLE V

MEANS AND STANDARD ERROR OF THE MEANS FOR DETERMINING THE INFLUENCE OF PERMANENT CHANGES IN THE STANDARD ARCHES DURING HEAT TREATMENT ON THE ELASTIC DEFORMATION, MEASURED FOR THE LARGEST OF FOUR LOADS BY TWO METHODS, EXPANSION AND COMPRESSION. MEANS OF TEN OBSERVATIONS.

	Expansion		Compression	
	$\bar{X}$	$\sigma_{\bar{x}}$	$\bar{X}$	$\sigma_{\bar{x}}$
After heating to 400°C	4.02	0.060	22.03	0.246
No heat treatment	4.06	0.066	21.91	0.222
After heating to 500°C	3.87	0.047	21.46	0.151
No heat treatment	3.98	0.052	21.64	0.159

nent opening was observed which was directly proportional to the temperature. To examine the extent to which this change in shape could give rise to changes in the magnitude of the elastic deflection, archwires were made with the same shape as the standard wires which were heat treated at, respectively, 400° and 500°C. The elastic deflection was measured, in addition to the previous temperature effect, for the largest of the four loads used for both expansion and compression and the results are seen in Table V. It is seen from the table that there is no significant difference between the variances and between the means for the heat treated standard archwires and the wires of the same form but without temperature effect. This means that heat treatment of the standard wires has not resulted in any change in the modulus of elasticity.

Corrosion resistance

The corrosion experiment shows a very marked blue colouration of the last four wire specimens of each series. It is clear that the combinations of time and temperature above 400°C caused general corrosion of the specimens.

Discussion

It is well known that cold working of stainless steel produces internal stresses as a consequence of which the material tends to recover its original shape; thus, archwire specimens formed for the present study tended to expand. Further analysis showed that the force applied to expand such wires permanently is assisted by the stresses already present, and consequently the force necessary to expand them permanently is smaller than for wires without internal stresses. Similarly, it would seem that the force required to effect further permanent deflection will be greater for wires with stresses introduced in forming than for the same wires free from such stresses. In other words, complete or partial removal of these stresses will increase the force necessary to obtain permanent expansion of the archwire and decrease that necessary for permanent deflection (Fig. 5). The stresses set up in the material by cold working arise from irregularities in the atom lattice, there being slipping along the principal planes. This can occur in all three dimensions and give rise to irregular grain boundaries through interaction. Such a condition is known as slip interference and, as a result, there is an increase in the surface hardness, the strength and proportional limit. In common with other metals, stainless steel exhibits the property of atomic diffusion. At room temperature this migration is negligible, but on raising the temperature the rate of diffusion increases because of the higher internal energy. A stainless steel wire that has been cold worked is not in a state of equilibrium; the tendency is for the atoms to reform into a regular space lattice without internal stresses. This does not mean that the plastically deformed steel recovers its original form but it is of interest that the archwires expand slightly during the heat treatment. This constitutes proof that bending introduces latent stresses which can be relieved by heating. The shape of the curve for the bending of straight wire segments can be explained in a similar way: during the manufacture of stainless steel wire stresses are introduced, the final gauge of the wire being attained by drawing it through dies with the appropriate lumina. The grains become elongated as a result of the distortion in the space lattice, the individual atoms tend to assume unstable positions, and internal stresses are thus produced. The material will therefore present an increasing resistance to an imposed permanent expansion, while the resistance to compression in the longitudinal direction, if such could be conceived, will gradually decrease.

These changes take place mainly near the surface of the wire. If an attempt is made to bend a straight wire containing no stresses, compression will occur on one side and tension on the other, and these two forces will be equal in magnitude. When a wire is bent that contains stresses set up when it was drawn during manufacture, the resistance on the outside of the bend will be greater, and that on the inside smaller, than in the case of a stress-free wire, since there are already stresses present that tend to act in the direction of the compression of the wire. It is reasonable to suppose that the wire will bend when the smallest force is overcome; the resistance to extension on the outside of the bend is of secondary importance in this connection. If the stresses produced by drawing are removed, they will not assist compression on the inside, and a greater force will therefore be required to produce permanent curvature. It follows that the elastic limit will increase with temperature.

It is evident from the above that we are concerned with the Bauschinger effect, whereby the load that can be resisted by a plastically deformed metal object without undergoing further permanent deformation is greater if applied in the same direction as the force responsible for the original plastic deformation than if applied in the opposite direction.

The fact that the three curves in Figure 6 for the change in the elastic limit with temperature at constant time have their maxima at different temperatures might appear surprising, since it would be thought that the stresses that resist further bending and those that assist straightening would decrease at the same rate. The explanation is to be sought in the method and particularly the shape of the specimen and the angle between the direction of loading and the wire. As the load acts perpendicularly to the wire, the force will be expended entirely in bending it; otherwise, departure from the perpendicular line of action will introduce a component of the force acting along the wire and this will not tend to bend it. An increasingly large part of the force expended will be lost in the longitudinal direction of the wire. In the case of expansion of the wire and deflection of a straight segment this component will increase in magnitude, while in the case of further bending it will diminish and the bending component will increase. This means that the peak of the two positive curves will be displaced slightly to the left, most for the solid, and for the negative curve slightly to the right. The peaks might thus coincide, i.e., the stresses will diminish with temperature at the same rate. This mechanism accounts only for part of the difference in temperature at which the curves level out; the rest is due to inertia of the apparatus regarding the compression study, and the use of a different length of wire for the experiment on deflection of straight segments.

As mentioned above, the rate of diffusion of the atoms, and hence the temperature, are crucial factors for the time elapsing until the maximum stress relief. This is evident from Figure 7. It will be noted that the change in the elastic limit takes place mostly in the first minutes of the experiment; thus, at 300°C over one half of the changes occurred in the first four minutes, the remainder requiring about fifty to sixty minutes. A short period of heat treatment can therefore be fairly effective at certain temperatures. A small rise in temperature does not produce any appreciable stress relief even over a long period. At 37°C the change in elastic limit after six weeks was not quite one tenth of the maximum relaxation. Even though there is a significant change in elastic limit, such a change will hardly be of clinical interest because of the low rate of atomic diffusion at 37°, except in respect of archwires present in the mouth for a year or more without being activated.

Elastic modulus

The stiffness of a wire is dependent on the modulus of elasticity which in these experiments was shown to be unaffected by the heat treatment. All wires of the same gauge and the same alloy must therefore be of the same stiffness, irrespective of the cold working, and they will all behave identically below the elastic limit for the softest wire. The stiffness of wire is of major clinical importance, for it indicates what force will be produced by a particular elastic deformation, and hence what force will be applied to the teeth. To change the thickness of the wire is the most convenient way of varying the stiffness of an orthodontic appliance; the choice of material is of much less importance.

Corrosion

Apart from the above mentioned blue colouration of the specimens treated at the highest temperatures, corrosion was evident at practically all the wire ends. These attacks are, however, of minor importance in this experiment because they do not represent the effect of the heat treatment on the resistance to corrosion but the effect of a number of factors associated with the cutting of the wire.

Conclusions

It has been shown in a series of experiments that heat treatment of formed archwires made of 18/8 stainless steel at a temperature chosen with regard to, for instance, resistance to corrosion, can produce changes in the elastic limit for expansion and compression of the wire and for deflection of straight segments of the same wire. It is evident that the changes in the elastic limit are due to resolution of the internal stresses introduced during the cold working of the wire. Because heat treatment in the formed 18/8 archwires resulted in an increase in the elastic limit for testing in one direction and a reduction for testing in the opposite direction, it is necessary to state the direction when reporting hardening of the wire. The "heat treatment" that takes place at mouth temperature over a period of six weeks did not alter the physical properties of the wire to a degree of any clinical importance.

The modulus of elasticity was not affected by heating with the temperature-time combinations used. An archwire of 18/8 stainless steel used should not be heated at 400°C or more for this will considerably reduce the resistance to corrosion.

The study shows the principles of changes in the most important physical properties produced by heating for times and at temperatures that will not impair resistance to corrosion. On the basis of these results it is possible to decide in the individual case whether such changes are desirable, with due regard to the shape and function of the archwire. For maximum effect heat treatment of 18/8 stainless steel should be performed at 350-375°C for 20-25 minutes. This period, however, can be considerably reduced, since about 70 per cent of the total effect is attained after only four minutes.

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Acknowledgments

The author is indebted to Dr. Odont. K. D. Jorgensen, Professor of Technology, the Royal Dental College, for his great help and interest in this study. Grateful acknowledgment is also made for valuable advice to Dr. Odont. A. Björk, Professor of Orthodontics, the Royal Dental College.

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