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AN EXPERIMENTAL STUDY OF THE STRESS RELIEF OF ORTHODONTIC WIRES

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》國文抄錄《

矯正用 彈線의 Stress Relief에 關한 實驗的 硏究*

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著者는 現在 Light-Wire Technique에서 많이 使用되는 0.016″ 및 0.018″의 圓形 綠色 "Elgiloy" 矯正用 彈線의 Residual Stress가 熱處理에 依하여 除去되는 量을 Testing Jig를 使用하여 測定하였다.

그 結果는 다음과 같다.

1. 0.016″ 및 0.018″의 圓形 綠色 "Elgiloy" 矯正用 彈線은 熱處理 時 溫度의 增加에 따라 除去되는 Residual stress의 量도 增加한다.
2. 同一 溫度條件에서 時間條件의 變化에 따른 Residual Stress의 除去値는 差異는 있었으나 顯著하다고 認定할 수 없다.
3. 通常的 熱處理 方法에 依하면 除去된 Residual Stress의 量은 0.016″인 경우 26.95%~38.54%, 0.018″인 경우 27.06%~41.05%이다.
4. 950°F에서 熱處理 했을 時 除去된 Residual Stress의 量은 0.016″인 경우 38.54%~43.16%, 0.018″인 경우 41.05%~44.56%이다.

INTRODUCTION

Cobalt-chromium alloy, which was introduced to dental science recently, have desirable physical and mechanical properties for orthodontic purposes. These alloy steels are not only nontoxic and corrosion resistant, but also possess the necessary ductility, strength, hardness and resilience to fulfill the very specialized requirements of orthodontic wire materials.

The nominal composition (U.S. Pat. No. 2524661) of the alloys are as follow; cobalt-40%, chromium-20%, nickel-15%, beryllium-0.04%, iron-balance, molybdenum-7%, manganese-2% and carbon-0.15%[1].

It is clear that a certain increase in the elastic properties of an orthodontic wire can be effected by heating it to comparatively low temperatures after it is fabricated into appliances. The proportional limit, modulus of elasticity and modulus of resilience are increased,[2,3] but the ductility is reduced[4]. For example, when a cobalt-chromium wire was held at 480°C(900°F) for 3 minutes, its resistance to permanent deformation increased by 55 to 66% of the

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original value[4]. The ductility, however, was reduced to 60 to 77% of the original[4].

The increase in elastic properties of the cobalt-chromium wires effected by heat treatment varies with the amount of strain hardening. In other word, the increase appears to be greater with the closed loops than when a circular loop is employed. Such an observation suggests that the phenomenon may be related to a partial stress relief rather than to a precipitation hardening. The partial stress relief by the heat treatment of these alloy wires is not a crystalization but a recovery process. This phenomenon will allow the elimination of some point and line defects in the absence of microstructural changes.

Orthodontic wire is formed by drawing successively with annealing heat treatments used during the intermediate stages of drawing to limit the strain hardening thus permit continued reduction in cross section by further plastic deformation during the succeeding draws. An unfortunate consequence of this drawing operation is that nonuniform plastic strains persist in the wire material after the applied forces on the wire body have been removed. The stress distribution associated with this nonuniform microstrain is called "residual stress". The presence of this residual stress can be quite significant on the nature of the wire appliances during its fabrication and working. For example, when a high tensile residual stress persists in an area, it will allow plastic flow after the application of only a small additional tensile stress. As a result, the wire material may no longer be capable of delivering the desired forces required for the fabricated orthodontic appliance. In addition, the wire material appliance should show maximum dimensional stability and elastic properties. It is with these properties in mind that the heat treatment of fabricated wire appliances must be carried out.

Clinically, it has been advocated that the stress relief anneal at temperatures ranging from 600°F to 1000°F for 3 to 5 minutes and then cool it at room temperature[5]. By the conventional method of heat treatment, recovery processes occur and sufficient relief of residual stress occurs[6] to avoid distortion of the arch during clinical use. The amount of residual stress relieved will depend upon state of stress, time and temperature of the heat treatment, as well as the material. It is reported the residual stress relieved 25 to 40% by the conventional heat treatment on austenitic stainless steel wire[7]. The heat treatment needed for more complete residual stress relief is around 1600°F to 1700°F for austenitic stainless steel wire[8]. But this level of temperature allows the recrystallization of the wire material. Once the recrystallization is effected, it is sometimes difficult to prevent grain growth. To avoid the recrystallization of the wire, the partial relief obtained at 600 to 1000°F is satisfactory[7].

The purpose of this study was to take the amount of the stress relief of the cobalt-chromium alloy wire in per cent value and to consider the results in regard to the behavior of clinical orthodontic wire appliance.

METHODS AND MATERIALS

The testing apparatus used in this work were made of a stainless steel testing jig (Fig. 1), an electric resistance furnace and a micrometer with 1/20mm. scale. Samples of 0.016″and 0.018″ round green "Elgiloy" wires were used. The effective length of the wire specimens was 8.5cm. long.

The testing conditions of this work were as follows; the experimental temperatures chosen were 500°F and 650°F to 1050°F in 100°F increments, the holding times used after attaining temperature were 5 minutes and 15 minutes. Because of the mass of the

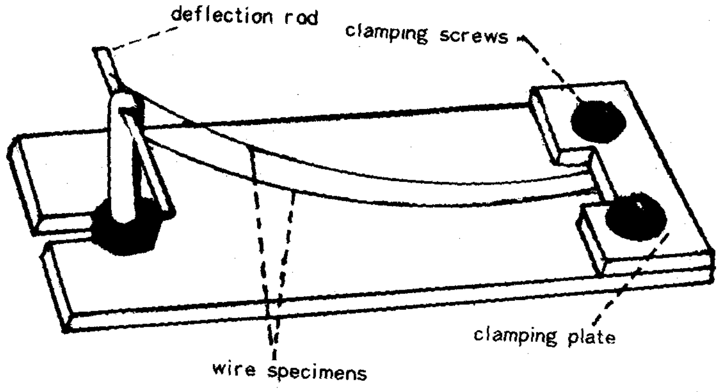
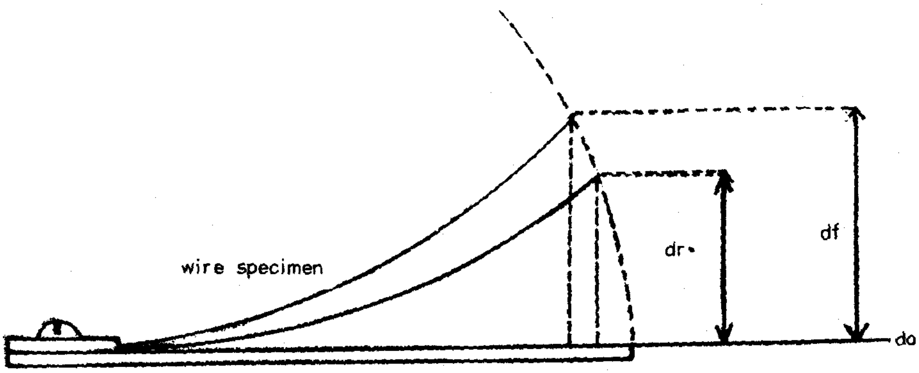


Fig. 1. Stainless Steel Stress Relief Jig



do; Original Horizontal Position
dr; Relaxed Deflection
(The Amount of Stress Relief-mm.)
df; Initial Deflection
(100% Stress Relieved Position)

df-dr; The Amount of Residual Stress Remaining after Heat Treatment

$$\% \text{ Stress Relief} = \frac{dr - do}{df - do} \times 100$$

Fig. 2. The Calculation Expression of % Stress Relief

stainless steel jig, a thermal lag amounting to about 11 to 30 minutes, depending upon the heat treating temperature was encountered. A deflection rod of about 2.9cm on one end and clamping plate with screws on the other end of the jig were used. A constant deflection was carried out on wire specimens in all of the steps (Fig. 1). Following the heat treatment and subsequent cooling of the apparatus in air, the amount of residual stress relief was determined by measuring the return of the wire, if any, to its original horizontal position.

Howe, Greener, Crimmins calculated the per cent stress relief of the stainless steel orthodontic wires by the expression of $\frac{dr-do}{df-do} \times 100$[7] where dr-relaxed deflection; do-original horizontal position; and df-initial deflection (Fig. 3). The amount of wire return was measured by the micrometer from original position. Fig. 3

illustrates the expression of per cent stress relief. If the residual stress of the wire had been eliminated completely, the return of the wire would be zero. In this work, the height of deflection rod was determined by the range of deflection limit of the cantilever beam. It could be calculated from the equation of $\delta = \frac{l^3 F_{max}}{3 EI}$, $M = sI/c = F_{max}$ and $I = \frac{\pi d^4}{64}$ [9,10] where δ-maximum deflection; M-maximum allowable bending moment; I-the inertia of a circular section; Fmax-maximum force loaded on the wire specimen; E-modulus of elasticity; l-length of the wire; and d-diameter of the wire.

RESULTS AND DISCUSSION

The results of the stress relief tests recorded in Table 1 and 2. It is apparant that generally much less than a half of the residual stress is eliminated in the range of conventional heat treatment(650°F to 950°F). In detail, following figures were obtained; the per cent relief of 26.95% at 650°F, 30.75% at 750°F, 32.45% at 850°F and 38.54% at 950°F for 5 minutes and per cent relief 29.35% at 650°F, 34.84% at 750°F, 36.94% at 850°F and 43.16% at 950°F for 15 minutes in 0.016 ″wire. On the other hand, it was shown that 27.06% at 650°F, 31.37% at 750°F, 36.61% at 850°F and 41.05% at 950°F for 5 minutes and 30.79% at 650°F, 35.84% at 750°F, 40.53% at 850°F and 44.56% and 950°F for 15 minutes in 0.018″ wire.

Table 1. Data from the relaxed deflection and the initial deflection

5 minutes				0.016″	15 minutes			
dr mean (mm)	SD	SEM	P-value p<a	TEMP. F	dr mean (mm)	SD	SEM	P-value p<a
6.350	0.247	0.175	0.025	500	7.397	0.345	0.244	0.025
7.650	0.031	0.022	0.005	650	8.650	0.071	0.050	0.005
9.065	0.827	0.585	0.05	750	10.270	0.098	0.605	0.05
9.565	0.067	0.046	0.005	850	10.888	0.795	0.562	0.05
11.360	0.764	0.540	0.05	950	12.720	0.184	0 130	0.01
13.840	0.888	0.628	0.05	1.050	14.825	0.246	0.167	0.01
				0.018″				
7.360	0.509	0.360	0.05	500	8.150	0.707	0.500	0.05
7.975	0.035	0.025	0.005	650	9.075	0.246	0.174	0.025
9.245	0.856	0.605	0.05	750	10.560	0.415	0.293	0.025
10.790	0.904	0.639	0.05	850	11.945	0.134	0.095	0.01
12.100	0.212	0.150	0.01	950	13.135	0.233	0.165	0.01
12.905	1.011	0.715	0.05	1.050	15.260	0.071	0.050	0.005

df; Initial Deflection	df mean (mm)	SD	SEM	P-value p<a
	29.475	0.016	0.011	0.005

Table 2. Per cent relief of the "Elgiloy" wire (%)

DIAM.	TIME \ TEMP. F	500	650	750	850	950	1.050
0.016″	5 min.	21.54	26.95	30.75	32.45	38.54	46.96
	15 min.	25.02	29.35	34.84	36.94	43.16	50.30
0.018″	5 min.	24.97	27.06	31.37	36.61	41.05	43.78
	15 min.	27.62	30.79	35.84	40.53	44.56	51.77

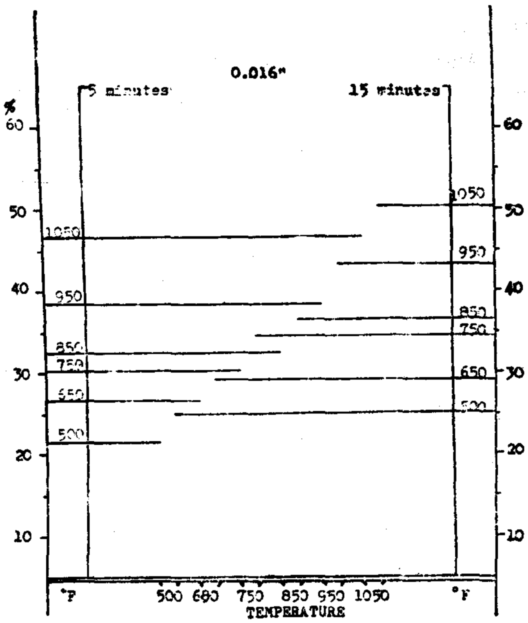


Fig. 3A. Per cent stress relief of 0.016″ round elgiloy wire.

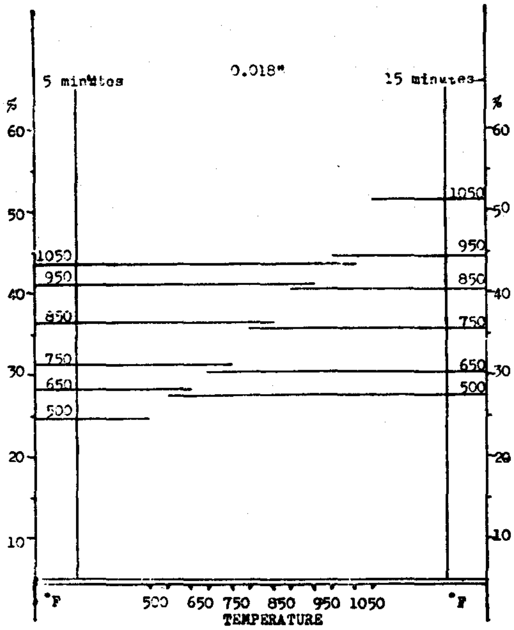


Fig. 3B. Per cent stress relief of 0.018″ round elgiloy wire.

With 0.016″ wire, the difference in per cent relief due to time factor was about 2 to 4%, whereas with 0.018″, the difference was about 1 to 4%. The largest value of this difference was shown at 950°F in 0.016″ wire and at 1050°F in 0.018″wire.

On the one hand, if it were considered on the basis of the heat treating temperature, most increase in the per cent relief value was found at 1050°F for 5 minutes and 950°F for 15 minutes in 0.016″ wire. With 0.018″ wire, it was found at 950°F for 5 minutes and at 1050°F for 15 minutes.

By the treatment of the wire to 950°F, generally advocated as the best method of heat treatmennt, the per cent relief 38.54% to 43.16% for 5 to 15 minutes in 0.016″ wire and 41.05% to 44.56% for 5 to 15 minutes in 0.018″ wire, were shown.

It should be pointed out that the stress relief obtained in this study should be somewhat greater than what could be obtained when the wires alone were heat-treated, since the data shown in this work reflected somewhat longer exposures to heat than would be the case if the wire alone were heat-treated. This was unavoidable due to the thermal inertia of the testing jig.

CONCLUSIONS

Results of the present tests of 0.016″ and 0.018″ round green "Elgiloy" wire permit the following conclusions:

1. The per cent stress relief value could be increased by employment of the heat treatment cycles in both 0.016″ and 0.018″ wires.

2. With both 0.016″ and 0.018″ wises, the difference in the per cent relief value due to holding time employed was about 1 to 4%. Since it was not considered as a significant value, the holding time of the heat treatment was not regarded an essential factor to per cent relief value up to 5 minutes.

3. In the conventional method of the heat treatment (600°F to 1,000°F for 3 to 5 minutes), the per cent relief of 26.95% to 38.54% in 0.016″ wire and the per cent relief of 27.06% to 41.05% in 0.018″ wire were obtained.

4. In the heat treatment to 950°F, the per cent relief of 38.54% to 43.16% in 0.016″ wire and the per cent relief of 41.05% to 44.56% in 0.018″ wire were obtained.

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