EFFECT OF HEAT TREATMENT ON STAINLESS STEEL ORTHODONTIC WIRE

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ABSTRACT

The purpose of this in vitro experimental study was to study the effects of heat treatment on the direct tensile strength and maximum strain (at breakage point) of stainless steel orthodontic wires.

The prepared specimens were 180 mm long chunks of 1.13 mm diameter stainless steel wire were heat treated in a furnace at three temperature variables of 500, 600 and 700C and four time variables of 30, 60, 90, and 120 s. Heat treated specimens as well as a control group with no treatment were tested on a tensometer for direct tensile strength following which the broken pieces were assembled to measure the maximum strain at the breaking point.

The results showed that maximum strain at the point of breakage increased when time and / or temperature of annealing were increased while the direct tensile strength decreased when the same variables of time and temperature are increased.

It was concluded from the present study that heat treatment of stainless steel orthodontic wires does affect their mechanical properties as their direct tensile strength decreases and the maximum strain (at the breaking point) increases.

Key words: *Heat treatment, stainless steel orthodontic wires*

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INTRODUCTION

The austenitic stainless steel (SS) wires are commonly used in orthodontics. SS orthodontic wires are usually taken as the reference material when characteristics of other materials wires are considered for orthodontics[1].

Their importance in orthodontics is due to their biocompatible, low cost, easy manufacturing process, attainment of desired strength through cold work and heat treatment during manufacturing, easy to manipulate in practice as further cold work possible without fracturing, ease of welding and soldering and corrosion resistance making them suitable for the warm and wet oral environment. [2-4]

These are ferrous alloys and the usual composition includes: 17-20 % chromium to impart passivation properties. 8-12 % nickel to stabilize the fcc crystal structure and 0.08-0.15 % carbon to increase the hardness. Some manufacturers may include additional elements like molybdenum.[2] Their crystal structure depends upon the carbon content and the sequence of heat treatment and cold working .[2-4] The austenitic SS wires (designated as the γ-phase with an fcc crystal structure) also develop a new phase-the martensite (designated as the $\alpha`$ phase with a bcc crystal structure).[2-4] The SS wires can be fully annealed with recrystallization in a few seconds at temperatures of 700-800°C.[2] The manufacturers optimize the mechanical properties by controlling the annealing time and temperature as well as cold working. [2, 4] It has been reported that heat treatment can improve the elastic properties of SS wires as the stresses introduced during the drawing process are relived between 400-500°C. [2-5] Adverse effects have also been reported in the regions of SS wire that are exposed to heat during soldering or welding processes. Adverse changes in mechanical properties include, a decrease in hardness as well as yield strength [2-4,6,7] affecting the working range of the orthodontic appliances,[2] loss of re-

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sistance to corrosion due to formation of chromium-iron carbides at the grain boundaries,[2-4] and effects of weld decay resulting in poor fatigue resistance and early failure at weld edges has also been reported.[3,8] These reported effects are more pronounced with the increase of temperature and/or duration of heat treatment.[2,3,7,9] Due to these possible adverse heat treatment changes during the welding and soldering processes it has been recommended that while designing and planning the orthodontic appliances these possible effects must be borne in mind.[6,10]

Some publications reviewing the latest developments in orthodontic materials therefore predict that use of solders will be decreased substantially while laser welding will be more widely used as the heat affected zone of the metals being welded is considerably decreased.[11] Small changes in the welding parameters can significantly affect the mechanical properties of orthodontic wires.[6,12] It is therefore the purpose of this study is to investigate the effects of increasing temperature as well as increasing duration of heat treatment on the direct tensile strength and maximum strain of SS orthodontic wires.

MATERIALS AND METHODS

An original lab experimental study was conducted. Specimens were made by cutting straight chunks of 180 mm from a 1.13 mm SS orthodontic wire (KC Smith Hadley works, Hertz, United Kingdom). Length and the diameter of the specimens were verified using a vernier caliper (Moore and Wright, Sheffield England). The specimens which were to be heat treated were heated for the required time duration in a digitally controlled furnace (Vulcan 3-550, Dentsply Ceramo, PA, USA). After the heat treatment the specimens were allowed to cool down to room temperature before being tested. Now two marks exactly 50 mm from each end of the specimen were made on the wire using a permanent marker, the distance between the two marks on the wire was 80 mm. To test the direct tensile strength wire specimens were held in wire holding clamps of a tensometer (Type-W, Monsato limited instruments group, Wiltshire, England). It was made sure that as the clamps held the wire there was exactly 80 mm of wire between the clamps, this was made sure by locking the clamps at the permanent marks made earlier on the wire. A maximum load of 5 KN was applied and the wire was extended by slowly turning the handle of tensometer by hand till failure. The load at failure was recorded on a chart recorder (Curken chart recorder model 125-1 A, Curken scientific Inc, CT, USA) which was connected to the tensometer through a pulse generator, the chart paper was set to turn at 10 cm/min. The broken pieces of the wire were collected and the distance between the two marks measured to record ant change in length.

The tensile strength was measured by using the formula:

$\sigma = F/A$ where F is force and A is area.

The strain at compression was measured using the formula:

$\varepsilon = \Delta L/Lo$ where ΔL is the change in length and Lo the original length.

Specimens were randomly placed in 13 groups, each having 5 specimens (This sample size was selected after a pilot study confirmed minimum scatter of values in results).

First group was the control group which under went no treatment. The remaining groups were tested after annealing at 500, 600 and 700° C for 30, 60, 90 and 120 s for each of the three temperature variables.

Once the results were obtained ANOVA statistical analysis was done using Microsoft Excel 2010. Two graphs were also generated in Microsoft Excel 2010 software, first one for the Maximum Strain at the Breaking Point and the second one for the Ultimate Tensile Strength

RESULTS

The results have shown that the strain at the breaking point increases both with increasing the temperature for heat treatment as well as the time duration for heat treatment. The results also showed a decrease in direct tensile strength with increasing temperature and time duration of heat treatment.

The results for the direct tensile strength showed that significant difference is observed at higher temperatures and longer time durations of heat treatment.

The results are presented in the following figures.

DISCUSION

Although the readings recorded for different specimens in the same group were similar but while measurements were done before testing it was found that the diameter varied between 1.13 and 1.21 mm. With a help of a vernier caliper (Moore and Wright, Sheffield England) it was assured that all the specimens for this study had similar diameters. This along with other inconsistencies in the finishing process has been previously reported[13] as well recommendations for good finishing stages (proper annealing and polishing) during the manufacturing process are proposed to obtain the desired mechanical properties for orthodontics.[13] The results have shown that increasing both the time and temperature variables during the heat treatment results in an increase in ductility where as the values for the ultimate tensile strength decreases. The results

TABLE 1: MAXIMUM STRAIN VALUES AT THE BREAKING POINT

	30s	60s	90s	120s
500°C	0.01250	0.01250	0.01250	0.01875
600°C	0.01250	0.01250	0.01250	0.01875
700°C	0.01250	0.01875	0.02500	0.02500

Control Value: 0.00625

TABLE 2: ULTIMATE TENSILE STRENGTH VALUES IN RELATION TO TEMPRATURE AND TIME

	30s	60s	90s	120s
500°C	456.25	450.00	431.25	425.00
	450.00	450.00	425.00	425.00
	456.25	418.75	437.50	425.00
	443.75	450.00	425.00	422.50
	465.50	400.00	387.50	425.00
600°C	425.00	431.25	450.00	443.75
	443.75	468.75	450.00	437.50
	437.50	437.50	456.25	447.50
	431.25	450.00	431.25	440.00
	456.25	431.25	431.25	437.50
700°C	456.25	460.00	425.00	375.00
	462.50	437.50	425.00	356.25
	468.75	462.50	425.00	350.00
	462.50	468.75	400.00	350.00
	465.00	456.25	400.00	343.75

Control	4625.50
	450.00
	462.50
	481.25
	475.00

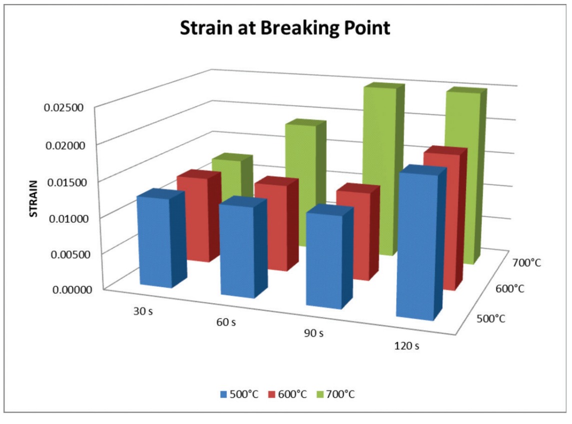

Fig. 1: Maximum strain at breaking point in relation to increasing Temperature (in degree centigrates) and Time (in seconds)

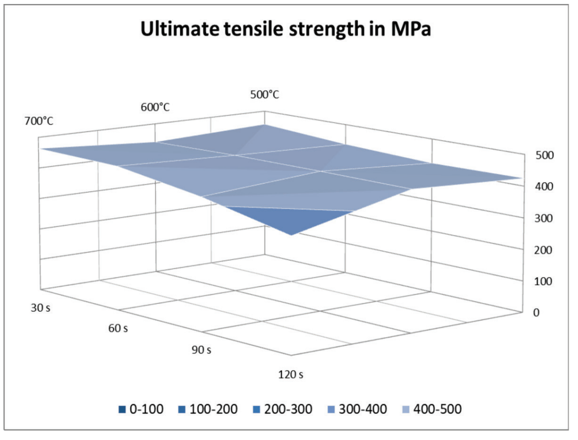

Fig.2: Ultimate Tensile Strength in MPa in relation to increasing Temperature (in degree centigrates) and Time (in seconds).

were consistant with similar studies published.[2-4,7,9] The changes were more prounonced at the higher temperature and time variables. After the heat treatment at 700° C noticeable increase (but not statistically significant P-value: 0.077478) in strain was recorded at 30, 60, and 90 s where as the strain recorded at 120 s was similar to the 90 s value. The tesile strength decreased slightly with the increase in time duration reaching a minimum value after the 120 s of heat treatment . After the heat treatmet at both 500 and 600° C the values of maximum strain at 30, 60 and 90 s were similar and slightly higher than the control group where as the values at 120 s were noticebly higher making the change statistically significant (P-value:0.000792) . The values tensile strength were not much affected altough slightly lower at 120 s. These changes observed are due to stress relaxation and growth and refinement in the grain size.[2-4] In stainless steel heat treatments at temperatures between 650 and 716°C can result in formation of a new phase-the sigma phase. Due to this phase reduction in both ductility and toughness of the austenitic SS has been reported therefore decrease in tensile strength observed in this study may be because of this sigma phase formation.[3] To avoid the adverse effects of heat treatment low fusing solders are recommended as well as the duration of welding and soldering processes should be kept as short as possible (although the temperature changes are not very high but still adverse effects have been reported).[2,3] Loss of corrosion resistance due to the formation of carbides is another adverse effect of heat treatment, although not investigated in this study causes considerable weakening of the soldered and welded joints.[2,3,6] It must be mentioned here that despite the adverse changes due to heat treatment orthodontic appliances having soldered and welded components continue to be used widely and successfully perhaps because the service duration of these appliances is not very long and also they are routinely inspected by the dentist.[2] Another reason for their popularity is the ease of repair at the dentist's office in case of failure which sometimes do happen. Similar to another articles [14] and all text books this study showed that all dental practitioners must have thorough knowledge of the physical and mechanical properties of all the dental materials used in clinics.

CONCLUSION

Within the limitations of this study it was concluded that heat treatment of stainless steel orthodontic wires does affect their mechanical properties as it causes a decrease in their direct tensile strength and an increase their maximum strain (at the breaking point).

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3	**Sadia Rashid:**	Discussion and Proof Reading.