ORIGINAL ARTICLE

A new stainless steel wire for orthodontic purposes

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Abstract

Objective: To develop a method to manufacture austenitic-ferritic stainless steel orthodontic wires (SEW 410 Nr. 14517) using conventional rolling and wiredrawing processes. **Methods:** Austenitic-ferritic steel was produced in an induction furnace. Tensile tests and microhardness measurements were used to evaluate the wires quality. Orthodontic components were fabricated to assess ductility and malleability. **Results and Conclusions:** Austenitic-ferritic stainless steel wires meet the BS 3507:1976 and ISO 5832-1 standards and have excellent ductility for the fabrication of orthodontic parts with complex folds.

Keywords: Duplex stainless steel. Orthodontic wire. Orthodontic wire properties.

INTRODUCTION

The practice of surgical implants was already known in the beginning of the Christian era, although the first documented case in 1565 was the restoration of a patient's palate using a gold plate.[13] Although in use since the 16th century, little is known about the fabrication and quality of the elements used in these procedures. It was only after 1895, when it became possible to visualize metal fixation and bone healing of fractures using X-rays, that the use of metal biomaterials in human implants received greater attention. At first, gold alloys, silver and platinum were used because of their high degree of biocompatibility and malleability.[12,15] Since 1930, metal alloys containing nickel, cobalt, chromium and molybdenum have been used to manufacture partial dentures. The combination of low cost and good mechanical properties made them a good replacement for nobler metals.[10,11] These alloys, called

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basic, require high fusion temperatures and special equipment for surface finishing of the products manufactured. Alloy metallurgy used to be extremely complex, and the chances of success depended on important variables, such as the appropriate chemical composition of the material and the evaluation of its mechanical properties, as well as knowledge about casting techniques.[4,13] In the same technological field, these nonferrous alloys have been gradually replaced with ASTM 300 austenitic stainless steel for orthodontic purposes. This type of steel, in addition to having a lower density than basic alloys, feature appropriate mechanical strength, good resistance to corrosion and sufficient biocompatibility at a lower cost.[1,9,12] In orthodontic treatments, metal wires undergo mechanical strains resulting from mastication, which produces permanent deformation and localized residual stresses. Therefore, the mechanical resistance of wires should be high enough to undergo plastic deformation because they will be exposed to the stresses of joint movements. The ASTM 302 and ASTM 304 types of steel are the most commonly used, whereas the austenitic ASTM 316L stainless steel is more appropriate for surgical implants (Table 1). Currently, knowledge of the mechanical properties of the several alloys may lead to the optimization of orthodontic treatments. In general, wires manufactured using austenitic stainless steel are appropriate for use in the final stages of treatment due to their excellent rigidity and resistance to corrosion in the oral environment.[3,5,8] Other properties, such as toughness, fatigue resistance and ductility contribute to their choice as the most adequate material for these uses. The ideal alloy should be sufficiently resistant to withstand the strains of joint movements, capable of absorbing mechanical impact without plastic deformation, inert to organic fluids and not release toxic products.[2]

Because of its mechanical and corrosion resistance, austenitic stainless steel has been replaced with austenitic-ferritic stainless steel in several industrial applications that require better resistance to stress-corrosion cracking.[6,14] Results in the literature also show that the biocompatibility of austenitic and austenitic-ferritic steel is similar.[1] In the case of orthodontic treatments, the replacement of austenitic stainless steel with austenitic-ferritic steel reduces costs and nickel hypersensitivity to patients.

OBJECTIVE

In this study, austenitic ferritic stainless steel (SEW 410 Nr. 14517) wires were fabricated using

TABLE 1 - Chemical composition (% of weight) of the following stainless steel, mentioned in the text: standard SEW 410 Nr. 14517, austenic-ferritic and austenitic.

	Cr	Ni	Mo	Cu	Man	Si	C	N	P	S
SEW 410 study	25.0	5.6	2.5	3.0	0.6	0.6	0.02	0.14	0.03	0.01
SEW 410 standard	24.5 26.5	5.5 7.5	2.5 3.5	3.0 3.5	1.0 max	1.0 max	0.03 max	0.12 0.25	0.04 max	0.03 max
ASTM 316L commercial	18.0 20.0	8.0 10.0	2.0 3.0	-	2.0 max	1.0 max	0.03 max	-	0.04 max	0.03 max
ASTM 304 commercial	18.0 20.0	8.0 10.0	-	-	2.0 max	1.0 max	0.08 max	-	0.04 max	0.03 max
ASTM 302 commercial	17.0 19.0	8.0 10.0	-	-	2.0 max	1.0 max	0.15 max	-	0.04 max	0.03 max

rolling and wiredrawing, processes that are similar to those used to manufacture commercial stainless steel austenitic wires used in orthodontic treatments. This duplex steel was chosen because it is very used in several industrial applications. To check whether the fabricated wires met the standards, tensile tests and microhardness measurements were used. Material ductility was evaluated using fractographic analyses and by means of fabricating orthodontic components.

EXPERIMENTAL PROCEDURES

Austenitic-ferritic steel was prepared in a 500-kg induction furnace in Grupo Metal (Tietê, São Paulo, Brazil). Liquid metal was poured into an agglomerate sand mold with phenolic urethane resin binder in the form of a keel block (ASTM A781-M) adapted to the commercial component. The chemical composition of steel was defined by means of analysis using optical-emission spectrometry. The starting bar measured about ø11x180 mm in length. It was milled using a mechanical lathe to a diameter of 10 mm and later reduced to a diameter of 2.5 mm by rolling process. The rolled wires were about 1 meter long and were soldered to the ASTM 304 stainless steel wire and reduced to a diameter of 0.4 mm according to conventional cold drawing performed in Superfine Steel (Santa Bárbara D'Oeste, Brazil). To evaluate the tensile strength, wire samples cut during wiredrawing underwent tensile tests in a universal testing machine (EMIC DL 10000) at 1 mm/min strain rate according to the ASTM E 8-00 and NBR 6152/92 standards. These samples were also used for microhardness measurements according to the criteria established in the ASTM E384-89 standard. Orthodontic components were fabricated to evaluate wire malleability in comparison with commercial stainless steel wires. To check the morphological fracture characteristics after the tensile test, a sample of the wire with 0.9 mm in diameter was analyzed under scanning eletron microscope.

RESULTS

Values shown as weight percentages in Table 1 revealed that the element contents met the chemical composition specifications for austenitic-ferritic stainless steel (SEW 410 Nr. 14517).

Table 2 shows mean values of ultimate tensile strength and standard deviations after trials with five specimens. These values meet the requirements of the BS 3507:1976 and ISO 5832-1 standards. The same table shows the microhardness values of the samples used in the tensile tests.

Figure 1 shows a Bionator manufactured using austenitic-ferritic stainless steel wires. Figures 2A, 2B and 2C show representative fractographic features of a sample that underwent tensile testing.

DISCUSSION

The greatest difficulty in this study was to develop a wire manufacturing process in conventional equipment used for large amounts of material, differently from our initial austenitic-ferritic steel sample, which weighed about 500 g. In general, furnace fusions are run for at least 500 kg of steel, which makes it very expensive to obtain material for research purposes. Therefore, to obtain an initial austenitic-ferritic stainless steel sample it was

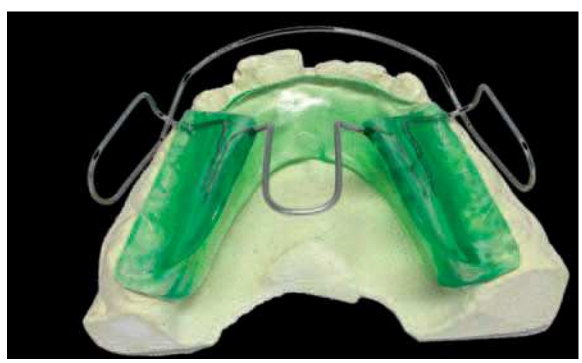

FIGURE 1 - Bionator manufactured using SEW 410 Nr. 14517 steel wire.

TABLE 2 - Ultimate tensile strength and Vickers microhardness of wires manufactured using SEW 410 Nr. 14517 steel.

	ø 2.5 mm	ø 1.1 mm	ø 0.9 mm	ø 0.4 mm
σ_t (MPa)	1,423±16	1,596±26	1,726±41	2,030±25
Vickers (HV)	341±13	427±6	430±5	509±13

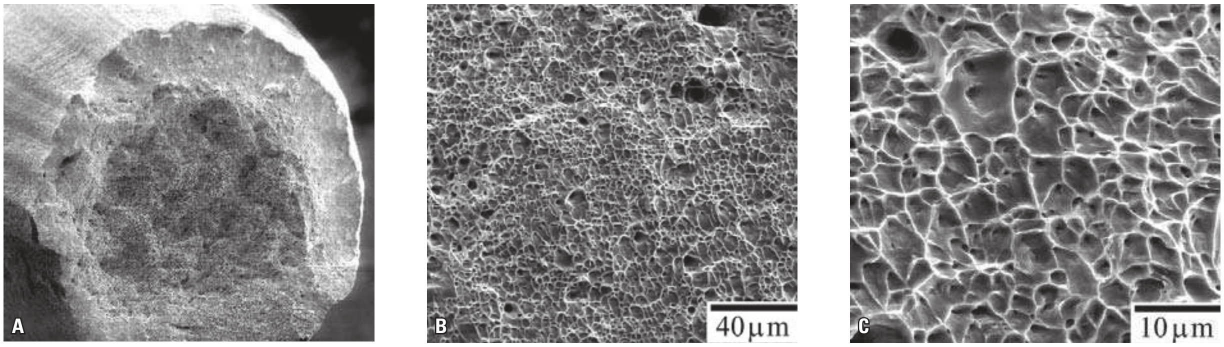

FIGURE 2 - Fractograph of Ø 0.9 mm wire that underwent tensile testing in different magnifications: **A**) surface of wire fracture; **B**, **C**) enlargement of region shown in (**A**).

necessary to adapt a keel block mold to the commercial specimen. The reduction down to a diameter of 2.5 mm was made in a laboratory, and wires of about 1 m in length were obtained. Industrial wiredrawing uses longer lengths to start the process. Therefore, ø 2.5 mm wires had to be soldered to ASTM 304 stainless steel wires, whose composition is compatible with that of austenitic-ferritic steel. The effect of the high degree of cold deformation during the shaping stages is described in Table 2, which shows a reduction of 80.2% in the last wiredrawing pass (ø 0.9 mm → ø 0.4 mm). Despite the significant increase of hardness in the final diameter after wiredrawing, there was no loss of ductility or malleability, which was confirmed by the fact that several parts with different folds were manufactured without any wire break. High mechanical resistance and hardness, a characteristic of stainless steel, are important parameters to ensure that the wire will keep teeth in the correct position after the conclusion of orthodontic treatments. Moreover, the shaping process to achieve the desired diameter was similar to that used in the fabrication of commercial stainless steel wires, which favors large-scale production without changes in steel manufacturing processes. The values of hardness and tensile strength, similar to those of commercial stainless steel orthodontic wires (ASTM 302 and ASTM 304), are an indication that steel can resist to the wear of wire movements between brackets, and that its properties are adequate for use in orthodontics according to the BS 3507/1976 and ISO 5832-1 standards. Steel ductility was confirmed in Figure 2, which shows the classic cone-cup pattern, in which the crack starts in the center of the wire, it propagates along the edge and fractures by shearing.[7] The evaluation of wire malleability revealed that the austenitic-ferritic stainless steel has adequate ductility for intense folding, as required in the fabrication of bionators, and it is appropriate for the fabrication of other orthodontic components as well. The comparison with commercial austenitic stainless steel wires used in routine procedures did not reveal any differences in the handling of the two types of wire.

CONCLUSION

The results of this study showed that austenitic-ferritic stainless steel may have a great area reduction during wire fabrication. Therefore, the value of tensile strenght greater than 2000 MPa, associated with ductility, biocompatibility and processing characteristics, showed that austenitic-ferritic stainless steel may potentially replace austenitic wires in orthodontic uses.

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