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Development of rolling mill for rectangular orthodontic wires production

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Manufacturing and processing

ABSTRACT

Purpose: In orthodontic treatments, wires of different metallic alloys are used for alignment, leveling, correction of the molar position, space closing, finish and retention. The purpose of the paper is the characteristics of austenitic stainless steel wires, with a square traverse section, which were produced using a rolling mill built for this purpose, are presented here

Design/methodology/approach: With respect to finish and retention, these wires are responsible for adequate positioning of the upper teeth on the lower teeth. Wires that are subjected to incisor torque require high resistance and stiffness. For this, wires of rectangular austenitic stainless steel are used due to high modulus of elasticity and good corrosion resistance in the oral environment. Because of the rectangular geometry, wire production requires process development suitable for industrial scale manufacture with geometric characteristics and mechanical properties better adapted to the use conditions.

Findings: To obtain wires with such characteristics, a rolling mill was developed for the production of rectangular wires by a rolling process with the objective of reducing cost of the cold drawing process that is currently used which utilize complex and expensive wire-drawing dies. In addition to the rolling process itself, wire deformation, microhardness, tension and bend tests were also performed.

Research limitations/implications: A rolling-mill was built that successfully produced dental wires within acceptable tolerances and physical/mechanical properties.These wires exhibited excellent hardness and tensile strength, although slightly less than analogous commercial wires. It is expected that this problem are corrected by using initial wires with a higher hardness, since this property is directly related with the tensile strength.

Originality/value: In these tests, wire geometry, surface finish and mechanical properties were successfully adapted for use in orthodontic treatments.

Keywords: Manufacturing and processing; Rectangular wires; Orthodontic; Rolling mill

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1. Introduction

Wires of AISI 304 stainless steel are used in biomaterial applications where high mechanical resistance, durability and corrosion resistance in aggressive environments is demanded. Steel wires, suitable for uses for oral correctional, posses sections with round and rectangular sections, are used for orthodontic correction .For these applications, it is necessary to produce a torque which is required for positioning of the tooth, promotion of a good occlusion and the improvement of the facial aesthetics [1-3]. In Figure 1(a) the wire mounted in the brackets and which is glued to the teeth is shown. Figure 1(b) is a schematic ilustrating details of the torque applied by the wire to the brackets and thus to the teeth.

Most wires (98%) for this application are austenitic stainless steel, because of its relatively low cost and favorable properties such as high yield strength to avoid plastic deformation. Biocompability and corrosion resistance are also required for use in an oral environment. Excellent surface finish is important to maintain a high degree of cleanness of the braces in the mouth since surfaces irregularities can trap food and lead to surface corrosion and mouth diseases [1-3]. AISI 304 stainless steel is adequate for this use.

Production of the wires with rectangular sections, with respect to their dimension and parallelism among the faces, is a technical challenge. Worldwide, relatively few companies produce them. The traditional production processes, utilize high- cost wire-drawing dies, that are manufactured from sintered diamond. In Brazil, only one company commercialy imports orthodontic wires. This problem was the motivation for the current research to develop a wire forming process with an appropriate combination of mechanical resistance and surface finishing of the final product.

Among the various metals forming processes, rolling, a process consisting of passing a metallic part between two or more rolls, leading to a variation in the traverse section, due the tensions imposed by the rolls is used more often. Cold rolling can be used in the production of high quality foil or wire [4-8]

To develop an improved process for lower cost production of orthodontic wires that meet the requirements of BS 3507:1976 [9] Standard, a rolling mill was developed and built. Rectangular wires were produced using a cold- rolling process instead of the traditional drawing process. Because of the small section size of the wire, superior control of the movement of rolling mill shafts was necessary. The system, in addition to being low cost, allows for adjustments and a limitless variety of wire cross section sizes (by appropriate rolling mill adjustments). This should be contrasted to the current wire drawing process which demands specific and expensive dies for each wire cross section size.

The characteristics of austenitic stainless steel wires, with a square traverse section, which were produced using a rolling mill built for this purpose, are presented here. Analyses of the sectioned wires, microhardness and tension tests were conducted to evaluate the quality of the wires. Characteristics of commercial wires for comparison purposes are also discussed.

2. Materials and methods

The rolling mill was built with four cylinders which were attached to a shaft and coupled with roller bearings and fastened to a plate. The assembly scheme is shown in Figure 2. The positioning of the modules in a crossed form allows the movement of the groups in the horizontal and vertical directions. With this configuration ,it is possible to adjust the disks depending on the dimensions of the opening required for drawing of the wire to the desired gage. This process is less expensible than a traditional drawing process which requires expensible dies and which are specific for each gage of wire to be produced.

a)

b)

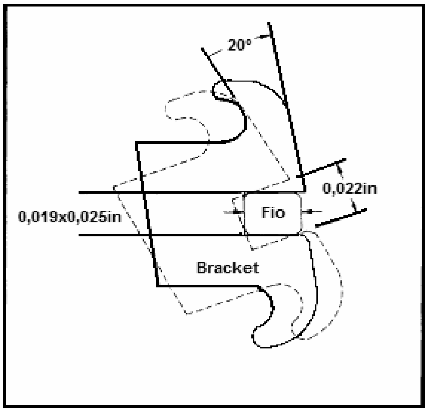


Fig. 1. Picture showing the set-up of the wire in the bracket (a) and schematic showing the torque applied by the rectangular wire to the bracket (b)

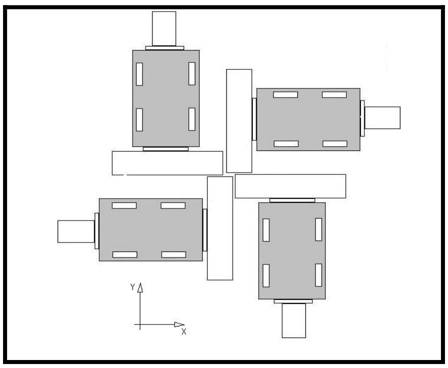


Fig. 2. Schematic diagram of the four groups roller-bearing/shaft/cylinder used for cold-drawing of square wire

The rolling mill shown in Figure 3 was constructed from carbon steel. The mill was anchored using carbon steel angle bars. The cylinder movement is performed using pulleys adapted to motors with constant rotations.

The material used in the rolling tests was AISI 304 stainless steel round wire. For the observation of the aspects and dimensions the wire was sectioned in the perpendicular to the rolling direction, and sanded sequencially with sandpaper from 320 to 2000 mesh and then polished with diamond 1µm. photographs of the surface finish of the wires was performed using an optical microscope equipped with a CCD camera, linked a microcomputer that coordinates the system. To analyze wire deformation, hardness and tensile strength was measured before and after rolling. Microhardness measures were obtained according ASTM E384-97 Standard [10]. The load used in the test was 200gf. Hardness was performed before and after rolling. Tensile tests were performed according to ASTM E8-00 and NBR 6152/92 Standards [11-12]. The tests were conducted directly with steel wire in the machine using special claws adapted for test.

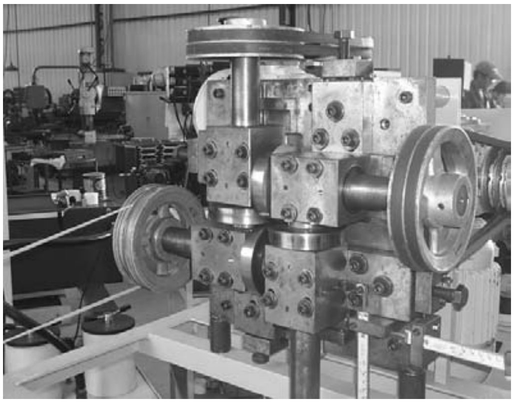
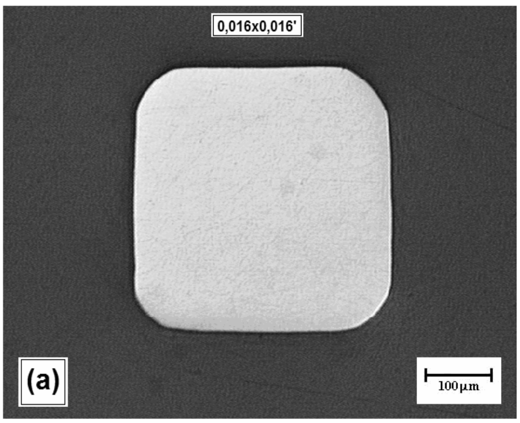


Fig. 3. Aspect of the rolling mill

3. Results and discussion

Figures 4 to 8, illustrate traverse sections of varied gage wires and compared corresponding commercial.



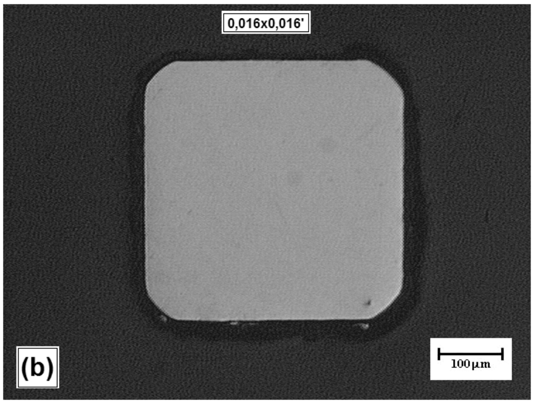


Fig. 4. (a) Traverse section of the rolled wire 16x16. (b) Traverse section of the commercial wire 16x16

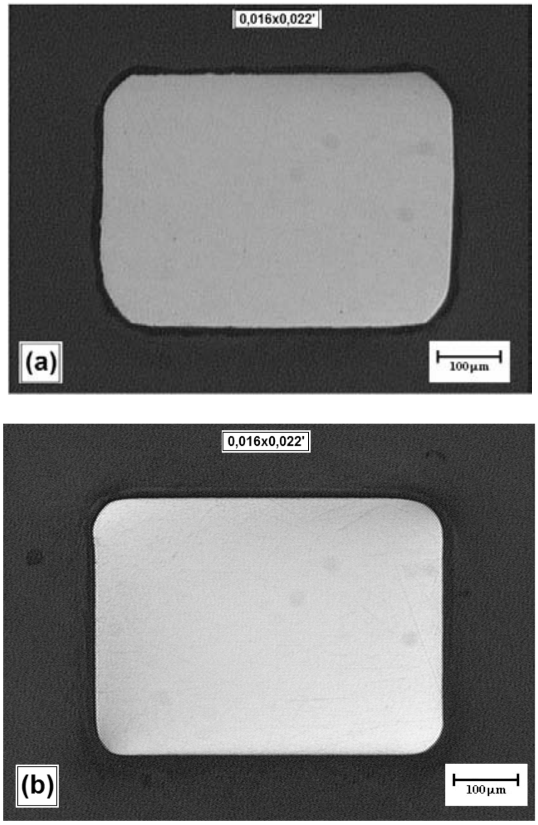


Fig. 5. (a) Traverse section of the rolled wire 16x22. (b) Traverse section of the commercial wire 16x22

These figures show that the appearance of the wires produced in the experimental rolling mill are comparable to commercial wires. The comparative data in Tables 1 and 2 show that the edges, bend radius and traverse section area of the laminate are also comparable to the commercial wire. Dimensional variation of the edges are within the specification BS 3507:1976[9] which allows a variation of ±0,01mm.For example, a rectangular wire with a cross-section of

0,016x 0,016 (Figure 4) can vary between 0,395x0,395 mm and 0,415x0,415 mm. With respect to the bend radius, Yoshida et. al. [13] showed that, rectangular wires must be smaller 1,0mm to be acceptable. Table 1 shows that all the wires yielded curvature less than 0,8mm, and meet the necessary requirements.

Tables 1 and 2 also show the results of the dimensional measurements of the hardness and tension tests obtained for the wires produced by rolling and for commercial wires. The results of hardness and tensile strength were obtained from an average of 50 and 15 measurements, respectively.

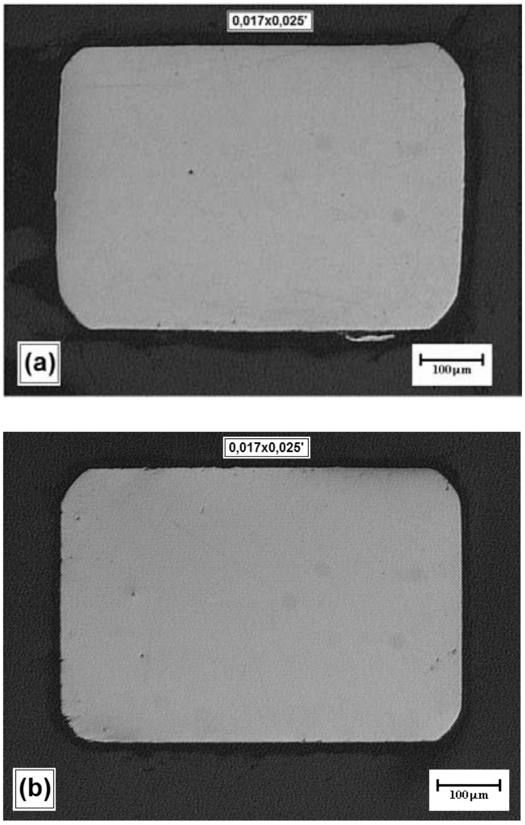
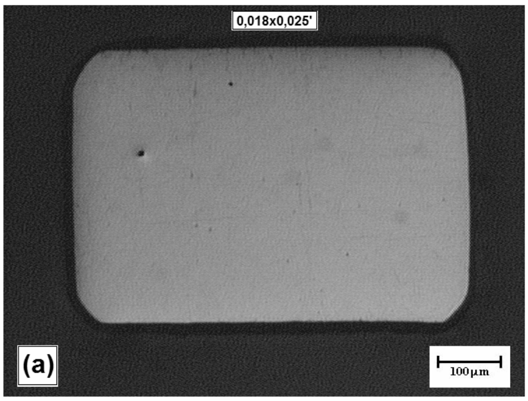


Fig. 6. (a) Traverse section of the rolled wire 17x25. (b) Traverse section of the commercial wire 17x25



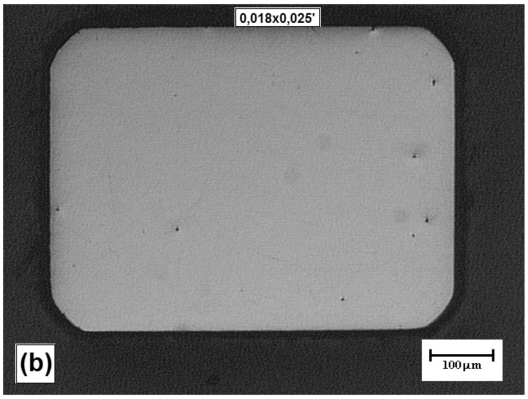


Fig. 7. (a) Traverse section of the rolled wire 18x25. (b) Traverse section of the commercial wire 18x25

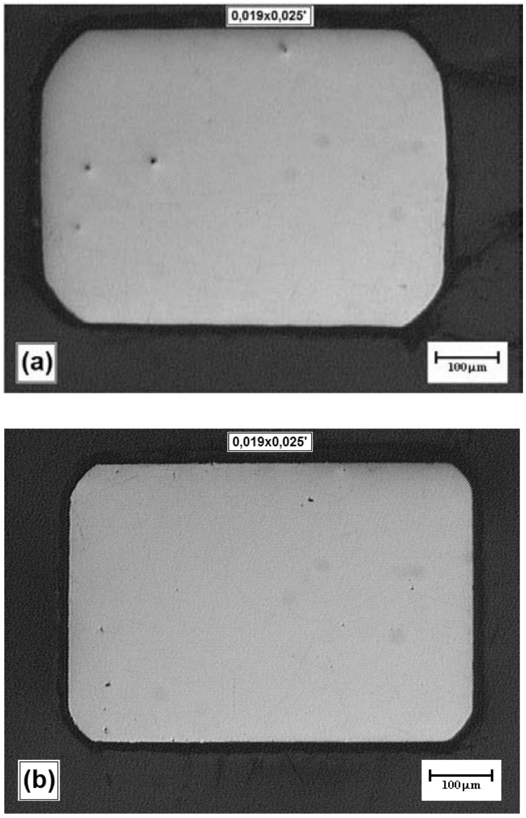


Fig. 8. (a) Traverse section of the rolled wire 19x25. (b) Traverse section of the commercial wire 19x25

For the analysis of the quality wire, the critical dimensions shown schematically in Figure 8 are considered.

These figures show that the appearance of the wires produced in the experimental rolling mill are comparable to commercial wires. The comparative data in Tables 1 and 2 show that the edges, bend radius and traverse section area of the

Table 1.
Dimensions and properties of rectangular wires obtained by rolling

Rolled wire	Arestas (mm)	R (mm)	A (mm^2)	HV_i	HV_f	σ_i (MPa)	σ_f (MPa)
16x16	0,409x0,395	0,732	0,154	436±21	485 ±15	1653 ± 14	1780 ± 7
16x22	0,551x0,399	0,610	0,214	425±4	444 ± 5	1624 ± 1	1781 ± 5
17x25	0,629x0,436	0,602	0,269	414±7	444±5	1597±1	1787±2
18x25	0,651x0,454	0,584	0,286	413±3	468±8	1600±6	1768±6
19x25	0,646x0,471	0,78	0,292	418±3	446±6	1550±4	1678±3

Table 2.
Dimensions and properties of the commercial wires

Commercial wire	Edges (mm)	R (mm)	A (mm^2)	HV_f	σ_f (MPa)
16x16	0,426x0,428	0,692	0,158	498±22	2020±17
16x22	0,556x0,404	0,621	0,224	548±6	2041±34
17x25	0,634x0,434	0,513	0,271	546±7	2058±9
18x25	0,627x0,472	0,503	0,289	547±5	1876±16
19x25	0,659x0,457	0,495	0,296	526±4	1923±4

laminate are also comparable to the commercial wire. Dimensional variation of the edges are within the specification BS 3507:1976[9] which allows a variation of ±0,01mm.For example, a rectangular wire with a cross-section of 0,016x 0,016 (Figure 4) can vary between 0,395x0,395 mm and 0,415x0,415 mm. With respect to the bend radius, Yoshida et. al. [13] showed that, rectangular wires must be smaller 1,0mm to be acceptable. Table 1 shows that all the wires yielded curvature less than 0,8mm, and meet the necessary requirements.

Tables 1 and 2 also show the results of the dimensional measurements of the hardness and tension tests obtained for the wires produced by rolling and for commercial wires. The results of hardness and tensile strength were obtained from an average of 50 and 15 measurements, respectively.

For the rolled square wires, the process produced an increase in hardness of 8,6%, and an increase of tensile strength of 9,6% due to hardening resulting from the rolling process when compared to the original round wire.

This difference can be eliminated easily using round wires initially with greater hardness, which will result in increased tensile strength after the rolling to rectangular sections.

Initial test results show that the wires produced by the new method are actually being tested in actual orthodontic applications. Although testing is not completed, excellent results have been reported by dentists and patients.

The rolling mill developed for the orthodontic wire production, can be used too for the production of other wire type, with different materials, increasing its application potential.

4. Conclusions

A rolling-mill was built that successfully produced dental wires within acceptable tolerances and physical/mechanical properties.

These wires exhibited excellent hardness and tensile strength, although slightly less than analogous commercial wires. It is expected that this problem are corrected by using initial wires with a higher hardness, since this property is directly related with the tensile strength.

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