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COMPARATIVE STUDY OF THE MECHANICAL BEHAVIOR AND CORROSION OF ALLOYS COMMONLY USED IN ORTHODONTIC APPLICATIONS WITH NEW ALLOY FREE NICKEL

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ABSTRACT

This work is characterized by a comparative study of mechanical properties and corrosion resistance of alloys in common use and under consideration in orthodontics. The study is being conducted in three types of alloys, stainless steel 304V, Ni-Ti alloy which are the most common, and Ni-Free alloy Böhler latest, in order to compare their behavior with mechanical tension stress intraoral and corrosion in environment chloride and artificial salivating of pH 5.99. The corrosion tests were performed prior to ASTM F 2129-08, ASTM B117-07 and beginning all the alloys did not show any sign of general corrosion in chloride solution via Salt Spray, but different strength, especially the alloy Böhler-Free Ni austenite which is presented in value much higher in comparison with the other. However, the electrochemical behavior by test EPR-DL (Electrochemical Potentiodynamic Reactivation - Double Loop) has still been somewhat similar, with the pitting critical potential indefinite absence of hysteresis during the scan potential in descending order, showing an absence of marked growth of density current. Also, the estimate of the forces involved during orthodontic correction, phase alignment and leveling, it was a finite element simulation of the activation of the teeth that showed lower levels of stress for the alloy NiTi than for stainless steel 304 V and Free-Ni alloy.

Keywords: Tension stress intraoral, Salivating artificial solution, Current density, Orthodontic, Pitting potential.

1. INTRODUCTION

In applications orthodontic wires of different profiles characterize the basis of mechanical stress due to movement of the joints and chemical action taking place in oral arches support these devices as studied for (Sarkar *et al.*, 1997) and (Drake, 1998).

These alloys are used in orthodontic correction of intraoral teeth, whichever way their mechanical properties and corrosion as very important and the second (Kim and Johnson, 1999) because it allows the orthodontist notions about the application of forces adjustment for smooth, continuous tooth movement, preparing the set for certain deformations due to its unique behavior combined with their microstructure studied in detail the second specifies for (Segner, 1995).

These wires are commonly used in rectangular or circular sections to fit the exact level of effort due to tooth movement as shown in study of (Mcnaney *et al.*, 2003).

The characterization of these alloys is based on their tensile mechanical properties and corrosion through the saliva of the oral cavity, in addition to having to provide specific biocompatibility of the material with the patient, as presented for (Wever *et al.*, 1998) and (Darabara *et al.*, 2007).

It is that nickel free steel but high levels of manganese are being used in medical applications due to the increased registration of cases in which the nickel appears as an element causing adverse reactions in the human body according to (Fini *et al.*, 2003).

These alloys called body-friendly does not cause allergy for nickel, because its biocompatibility and the combination with good corrosion resistance a condition provides optimal safety for use in contact with the human body.

Recent studies have shown that these steels are suitable for the manufacture of surgical implants, showing a good biocompatibility and excellent mechanical properties (yield strength and elongation) and adequate corrosion studied by (Hanninen *et al.*, 2001).

It is known that according (Darabara *et al.*, 2007)the Ni-Ti arcwires presents corrosion products did form in the oral cavity by the release of organic digestive acids which resulted in the formation of few pits along the arcwires.

However, good corrosion resistance and ability to intoxicate a product are crucial factors for the biocompatibility of the material, and therefore the particular properties of the alloy Böhler Free Ni austenitic, such as the absence of Ni in the release to generate allergic reactions, its low cost in comparison with other NiTi, your best machinability and excellent corrosion resistance, make it well suited for orthodontic and orthopedic reconstructive applications as noted by (Iijima *et al.*, 2002; Fini *et al.*, 2003).

2. MATERIALS AND METHODS

Three types of alloys were analyzed in a spectrophotometer BRUKER-Q4-Tasman with a chemical composition according to (Hanninen *et al.*, 2001)in the Table 1 below, and wired in the form of laminates with dimensions 0.53 x 0.63 mm rectangular sections for stainless steel alloys 304V and NiTi thermoelastic circular and straight sections of 0.60 mm diameter wires of Böhler Free-Ni alloy.

Table-1. Chemical composition of alloys studied

Alloy/Element	%Cr	%Mn	%Mo	%N	%C	%Si	%Ni
Böhler Free Ni	17.3	10.5	3.3	0.5	0.2	0.45	< 0.2
AISI 304 V	18.5	2.0	-	-	0.08	1.1	8.4
NiTi	<0.01	<0.01	<0.01	43.5(Ti)	< 0.05	<0.01	55.79

The characterization of alloys according to (Eliades *et al.*, 2000), are given by metallographic optical microscope micrograph via model LV150 Nikon with increased 500 times. The mechanical tests were performed according to standard traction NBR 6207/82 in WDW machine MC 100 E of 10 tons and adjusted for speed test load equal to 10mm/min for Free Böhler-Ni alloy and NiTi alloys for 1mm/min and stainless steel 304V, with claw-type spiral just for fixing the wires.

However tests general corrosion in salt spray were performed in 5 pieces of wire about 16 mm long, the temperature: +/-35°C for 96 hours in a solution of NaCl 5% in distilled water according to ASTM B-117:2007 and NBR 8094:1983.

However, tests of electrochemical AUTOLAB - PGSTAT302N, which was coupled to a computer with one interface for data acquisition in order to facilitate and enable the analysis of these data through the software NOVA.

The electrochemical measurements of cyclic potentiodynamic polarization tests EPR-DL (Double Loop) according to was carried out a scan rate of $10 mV.s^{-1}$ in pH 5.99 solutions salivary composition artificial as table 2 below, starting from a potential of -1V to a potential of $3V_{SCE}$

(passive region), after which the polarization is reversed to the potential for corrosion in cell contains a reference electrode - Ag/AgCl, a working electrode alloy wire and a counter electrode of platinum, as this is described in ASTM G5-94 standard.

Table-2. Chemical composition of artificial saliva at pH 5.99

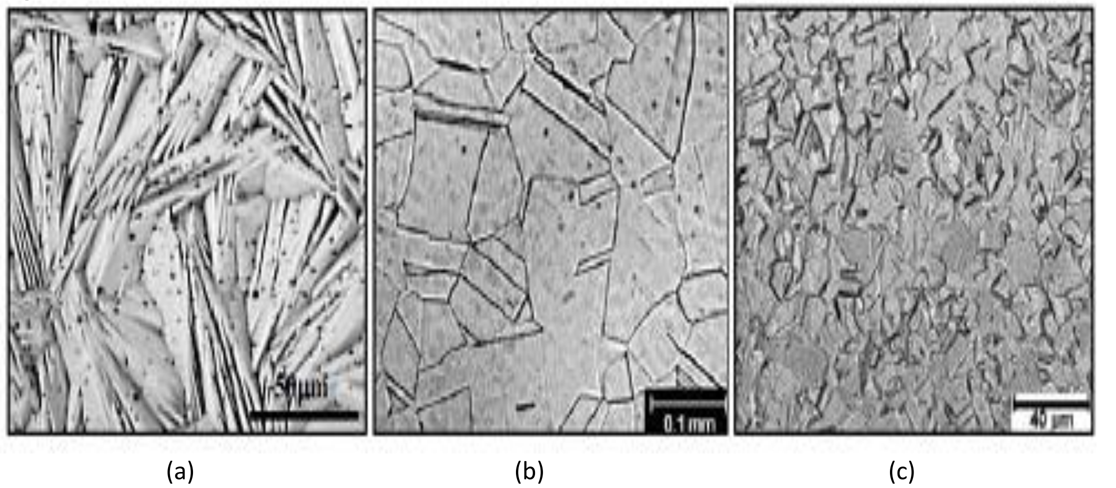
Artificial Saliva		
KCl - 26 mg	$CaCl_2$ - 6 mg	NaF - 200 mcg
NaCl - 38 mg	K_3PO_4 - 35 mg	glycerine -29 ml
$MgCl_2$ - 2.5 mg	Nipagin -124 mg	Distilled water-32 ml

Since the simulation test of tensions through the intraoral $ANSYS_R$ software as (MSC Visual NASTRAN, 2013) succeeding to estimate the forces involved during orthodontic treatment using a finite element simulation of the activation of teeth considering only the forces involved in moving in an XY plane horizontal to the dental arch.

3. RESULTS AND DISCUSSION

The micrographs of the respective alloys studied were revealed as shown in figure 1 below, to check the basic structural differences of these alloys, defined by (Darabara *et al.*, 2007) as a microstructure of the matrix phase.

Figure-1. Photomicrographs of the alloys: (a) NiTi (b) Free Böhler-Ni and (c) Stainless steel 304 V.

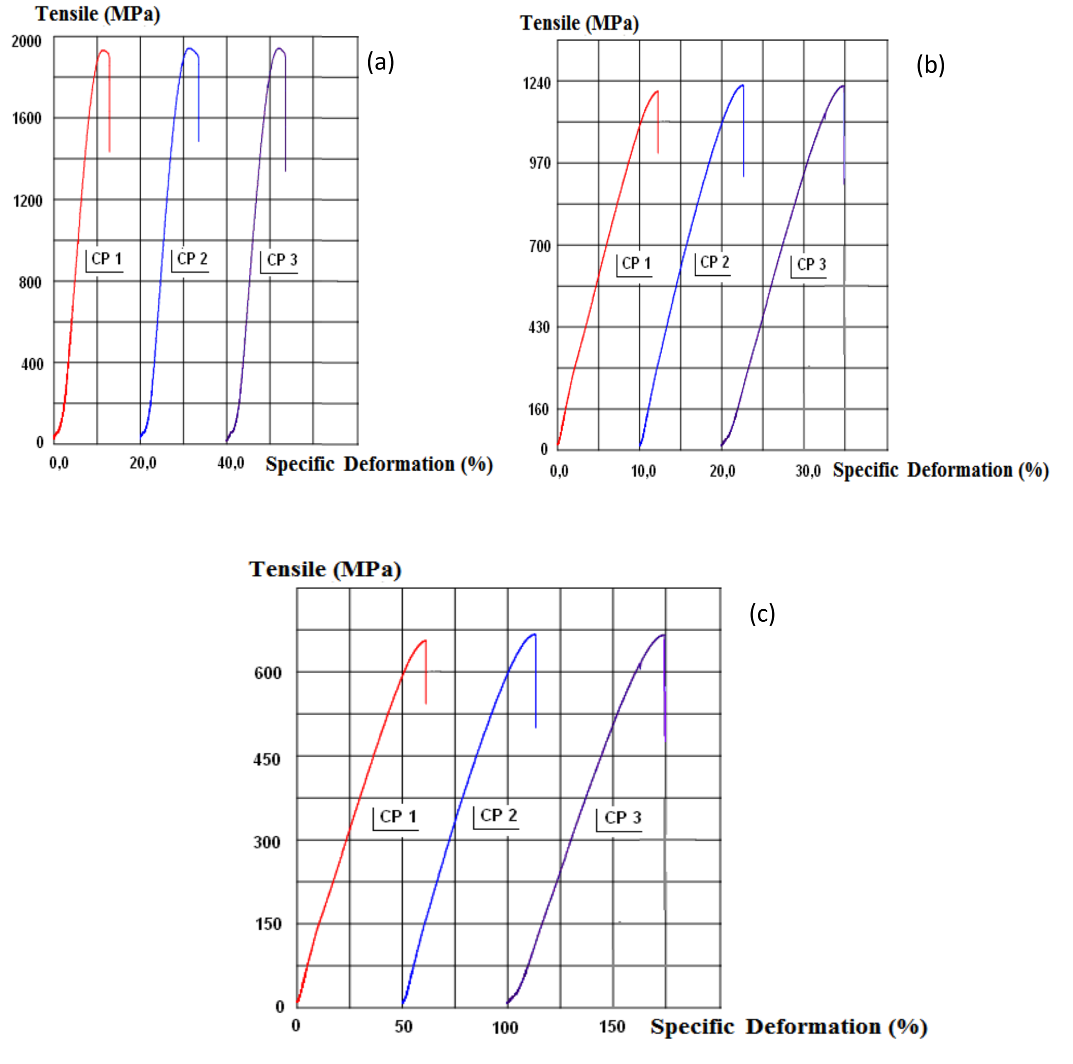


(a) (b) (c)

The microstructures are very different, because the NiTi alloy has been completely martensitic, while the stainless steel alloy 304V (vacuum) have microstructure autenitic-ferritic and the Ni-Free alloy presents completely austenitic microstructure without ferrite and grain boundary precipitates. Figure 2 shown in 2 (a), 2 (b) and 2 (c) the conventional stress-strain curves resulting from three tensile tests of wires of the three alloys performed at room temperature.

The tensile tests of the alloys according to fig. 2, shows that the alloy Ni-Free Böhler presented limit tensile strength of 1900 MPa, 40% higher than the NiTi alloy and 65% higher than the stainless 304V. This material is fully austenitic and without nickel as related (Ren *et al.*, 2004) in its composition, prevents the formation of martensite induced by deformation according to (Milititsky *et al.*, 2008), defining it with paramagnetic character, unlike the strands of stainless Cr-Ni, which are slightly ferromagnetic.

Figure 2: Curves stress/strain for the alloys (a) Free Böhler-Ni, (b)NiTi and (c)304V Stainless Steel.



We can consider that the mechanical properties of superelastic Ni-Ti wires were substantially affected by temperatures changes perhaps because the austenite becomes martensite according (Darabara *et al.*, 2007) and (Iijima *et al.*, 2002).

Figure 3 illustrates below the cyclic potentiodynamic polarization (EPR - Double Loop) curves second (Park and Kwon, 2010) in solution to salivary pH 5.99 that shows the relationship between potential applied as a function of current density of the three alloys, Böhler-Free Ni, NiTi and Steel 304V.

In 3(a), 3(b) e 3(c), illustrates the cyclic potentiodynamic polarization (EPR-Double Loop) curves in solution salivary, showing the relationship between potential of polarization as a function of current density of the three alloys, Böhler Free Ni, NiTi and Steel 304V respectively.

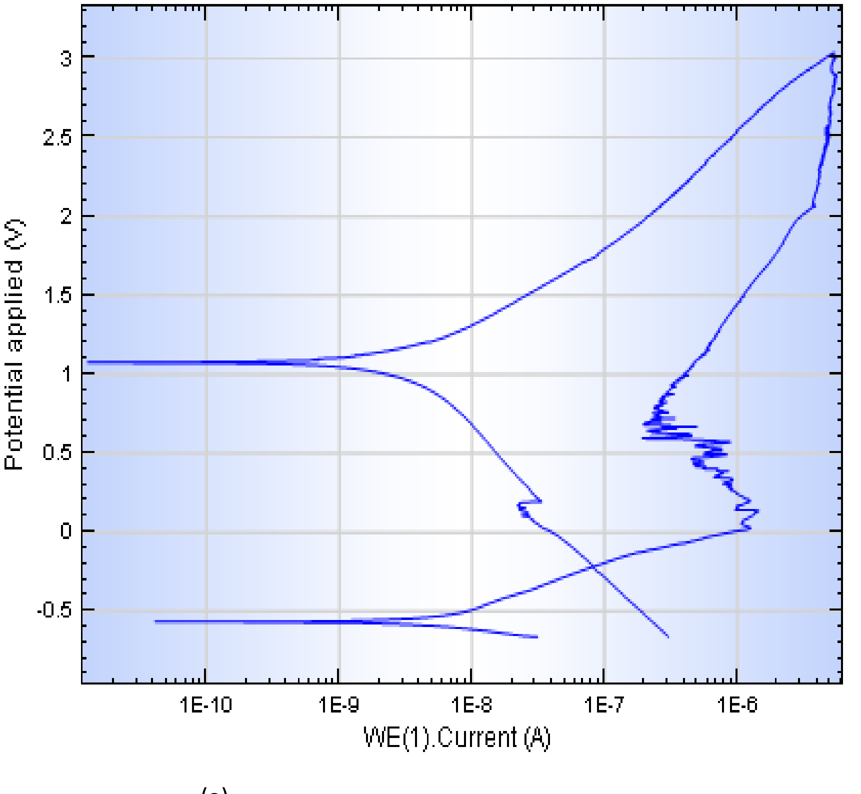
But, we can observe that the polarization occurs to the passive region ($3V_{ECS}$), and that the alloys show a similar active to passive transition behavior, with a same transpassive breakdown potential;

however, critical anodic current density required for passivation (I_{crit}) were different between the alloy Böhler Free-Ni and the others two alloys.

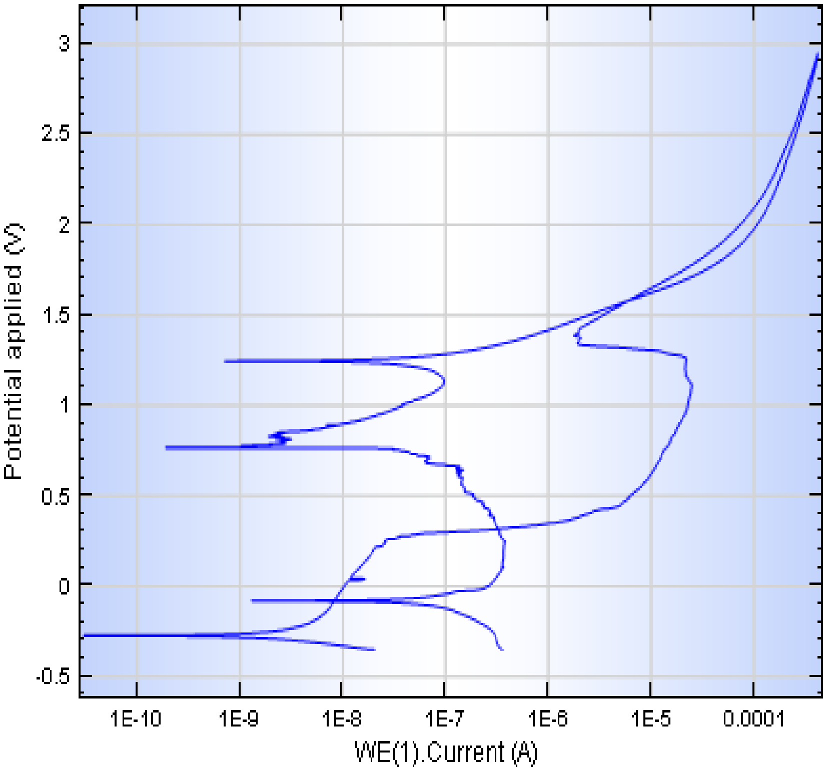
It is possible to observe that the alloys have a maximum active current, with values of current density (I_a) of 3.5.10^{-6} A/cm^2 for the alloys Böhler Free-Ni, 4.2.10^{-4} A/cm^2 for NiTi and 1.10^{-3} A/cm^2 for steel 304V, without reactivation and are not susceptible to intergranular corrosion, with zero degree of sensitization.

However, general corrosion tests showed that the alloys suffer almost no significant change in this way, but in the electrochemical behavior observed critical pitting potential is not defined and no hysteresis while sweeping the potential in descending order, which shows an absence of widening of the current density, as shown in fig.3.
The corrosion potential of 1.1V for the alloy Böhler Free-Ni, showing a much higher value than the alloys presented NiTi (700mV) and Stainless 304V(-300mV).

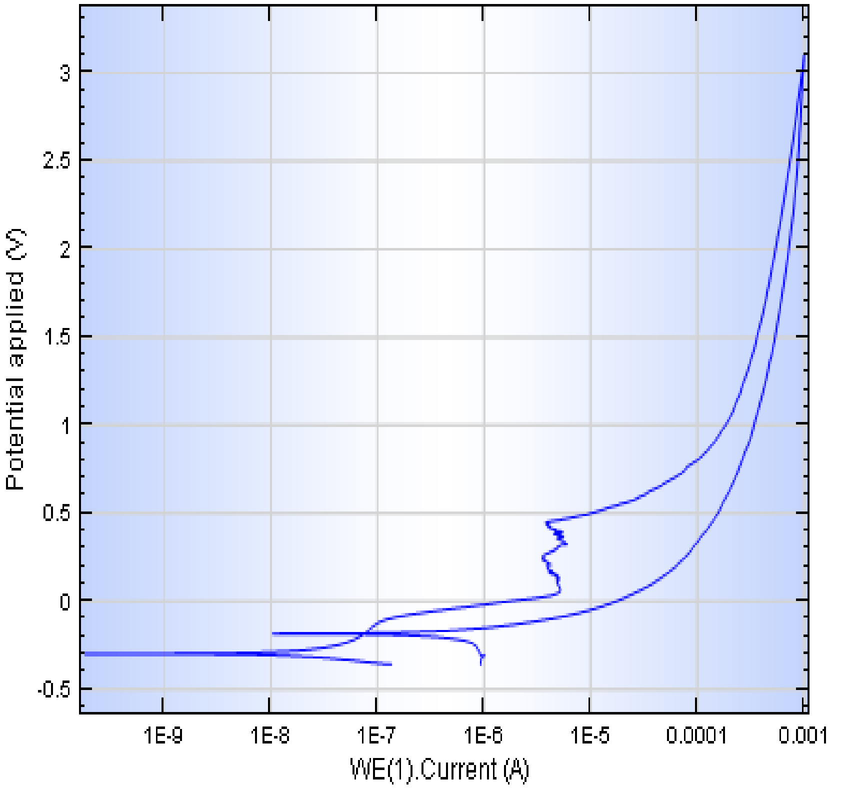
Figure 3: Representative curves obtained from cyclic potentiodynamic polarization tests saliva solution at pH 5.99 for the alloys: (a) Böhler Free -Ni, (b) NiTi and (c) 304V stainless steel.



(a)


Potential applied (V)
3
2.5
2
1.5
1
0.5
0
-0.5
1E-10
1E-9
1E-8
1E-7
1E-6
1E-5
0.0001
WE(1).Current (A)

(b)


Potential applied (V)
3
2.5
2
1.5
1
0.5
0
-0.5
1E-9
1E-8
1E-7
1E-6
1E-5
0.0001
0.001
WE(1).Current (A)

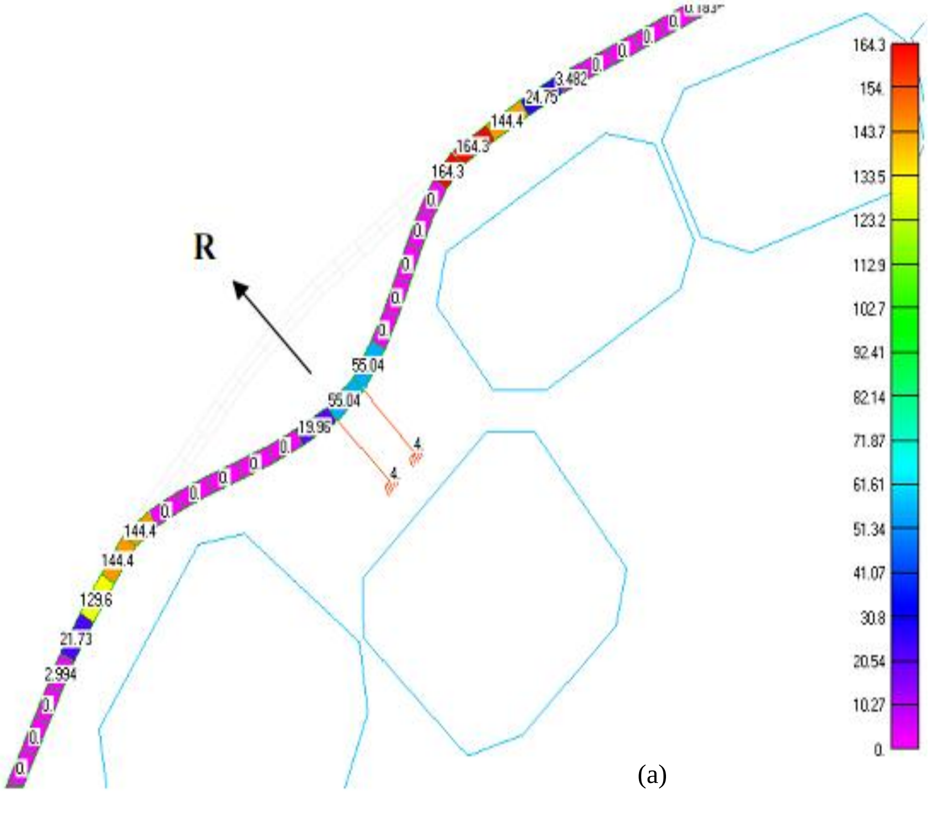
(c)

To estimate the forces involved during orthodontic correction, phase alignment and leveling, using wires of rectangular and circular, and there was a finite element simulation of the activation of teeth considering only the forces involved in movement in an XY plane horizontal to the dental arch.

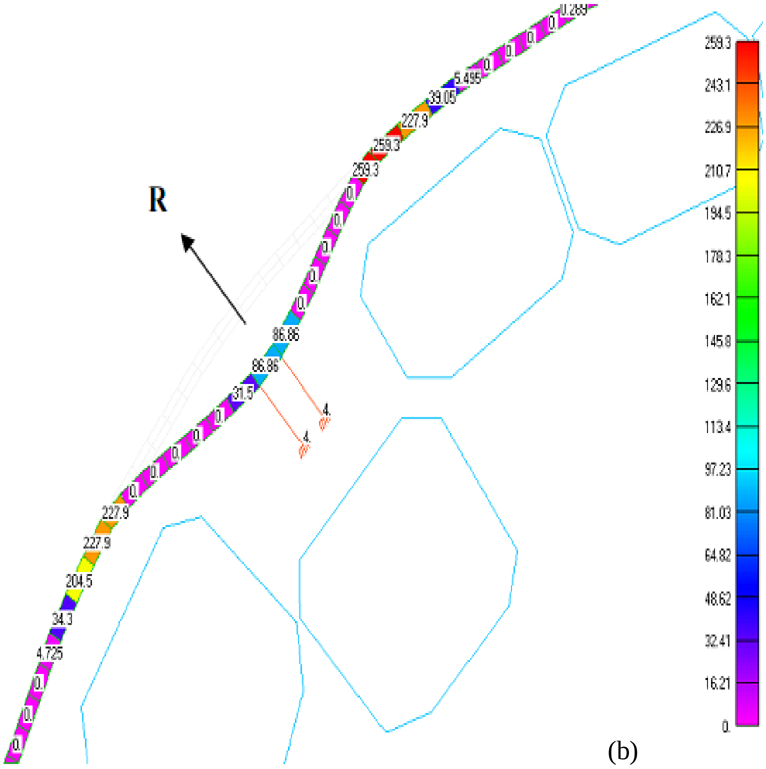
However the simulation efforts as (Karadinović and Mileusnić, 1987), even overestimated done showed that under these conditions, there is no occurrence of the phenomenon of superelasticity during stress for orthodontic NiTi alloys, which diminishes his role in the displacement of the tooth, thereby recording levels lower stress than those presented for the stainless steel 304V and higher stress for the alloy Ni-free austenitic Böhler, as can be seen in fig. 4.

Figures 4(a), 4(b) e 4(c) is shown the forces resulting from radial and tangential perpendicular to the length of the wire as noted by (Warita *et al.*, 1996) and (Hamanaka *et al.*, 1989) and a misalignment of only 1.6 mm.

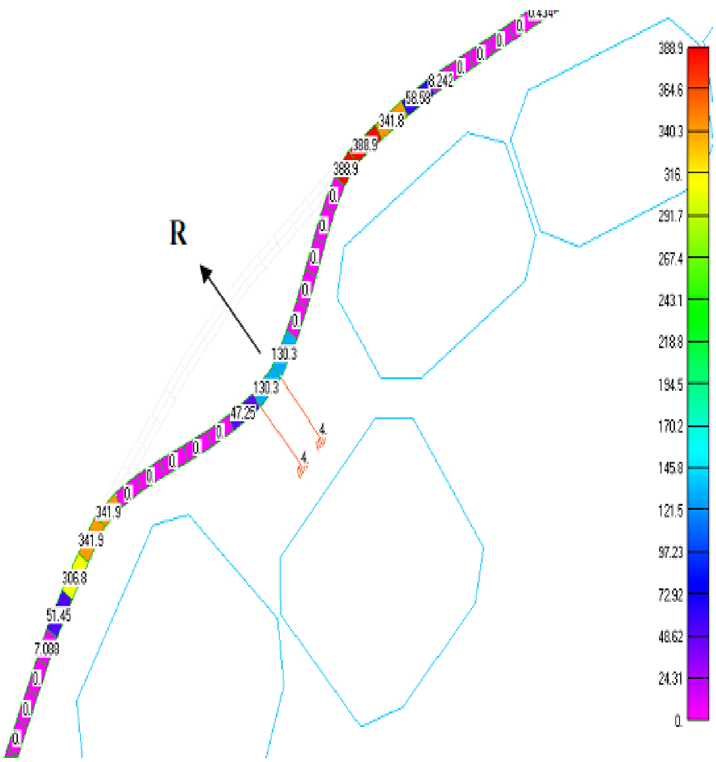
Figure 4: Radial and tangential in the simulation of orthodontic arch only a) NiTi alloys, (b) Stainless Steel 304V and (c)Free Böhler-Ni, using the software Visual NASTRAN 2013 in oral teeth and deflection of 1.6 mm orthodontic arch.



(a)


R
259.3
243.1
226.9
210.7
194.5
178.3
162.1
145.8
129.6
113.4
97.23
81.03
64.82
48.62
32.41
16.21
0.

(b)


R
388.9
364.6
340.3
316.
291.7
267.4
243.1
218.8
194.5
170.2
145.8
121.5
97.23
72.92
48.62
24.31
0.

(c)

4. CONCLUSIONS

The tensile test performed on the wires of orthodontic applications, showed that the alloy Böhler Ni-Free among them was the best performance presented, with a limit value of tensile strength well above that of other alloy orthodontic applications.

However, the corrosion tests in specific cyclic potentiodynamic polarization in solution salivary pH 5.99, showed a much higher corrosion potential for the alloy Ni-Free Böhler(1.1V), and a current density to transition active-passive ($3.5.10^{-6}$ A/cm^2) much less than the other two alloys.

Thus, as the simulation effort on their part also showed a superiority of Böhler Free-Ni alloy with approximate values of tension 1.5 times higher than those of alloy steel 304V and 2.4 higher than that of NiTi, indicating that the alloy Böhler Free-Ni can become an important alternative for their use in patients allergic to Ni.

Therefore, we can define the alloy Böhler Free-Ni in comparison with the other usual two alloys studied, may have important application in orthodontics elements, especially in patients with rejection or allergic to Ni.

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