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ORIGINAL ARTICLE

Fretting-corrosion of Orthodontic Arch-wire/bracket Contacts in Saliva Environment

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ABSTRACT

Aim: The study aims is to investigate the combined effect of the corrosion and the fretting induced by small deflections imposed on the orthodontic stainless steel and nickel-titanium arch-wire in contact with stainless steel bracket in neutral artificial and acidified saliva which simulate the aggressive conditions.

Materials and methods: Electrochemical analysis of orthodontic materials has been firstly conducted in the oral environment and under the combined effect of fretting and corrosion using an experimental test bench designed for this effect. Analysis of contact area between elements has also been conducted using scanning electron microscope (SEM) and energy dispensing spectroscopy (EDS).

Results: The results indicate that the pH of an oral environment has an important influence on the corrosion resistance and the effect of fretting-corrosion process affects significantly the corrosion behavior of materials tested in the oral environment.

Conclusion: The combined effect of fretting and corrosion tests conducted in artificial saliva show that nickel titanium wire is more resistant than stainless steel wire in contact with stainless steel brackets after 100000 cycles. Also, the corrosion resistance in acidified saliva is very pronounced for stainless steel wire and bracket as it reported by many authors.

Clinical significance: The degradation of the orthodontics materials in the oral environment can cause major problems for the patient's health.

Keywords: Corrosion, Fretting, Orthodontic, pH acid, Stainless steel, Ni-Ti alloy

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INTRODUCTION

Orthodontic wires are one of the most important components of fixed orthodontic elements. They are attached to orthodontic brackets and join the teeth together. During orthodontic treatment, arch-wires play an important role because they provide the force systems necessary for tooth movement. Once a wire is engaged into the bracket, exerts forces on the tooth.

The orthodontic elements remain in the oral cavity of patients between 6 months,[1] for very small displacements, and 3 to 4 years for very complex cases.[2] The localized corrosion and microbial sites that occur between wires and bracket are mainly caused by fretting-corrosion,[3] which is induced by micro-slip displacement generated between the two contacting surfaces in the corrosive environment. The science that associates friction and corrosion in a biological environment is defined as bio tribocorrosion. This type of science has recently been explored by research.[4]

The corrosion resistance of nickel-titanium (Ni-Ti) and stainless steel orthodontic elements is generally attributed to a passive film of chromium oxide and titanium dioxide (TiO_2).[5] These oxides are compact, adherent and protective passive, and the action of fretting greatly reduced corrosion resistance of the elements in saliva environment. Understanding the mechanism of the degradation process by fretting corrosion is an important field of interest. According to the recent investigations of orthodontic elements in the oral environment, the results reported by Jean Geringer,[6] show that the degradation is significantly important and very pronounced when the fretting and corrosion are combined.

The study aims is to investigate the combined effect of corrosion (electrochemical behavior) and fretting induced by small displacement (fretting-corrosion) of orthodontic stainless steel and Ni-Ti wires in contact with stainless steel bracket in neutral and acidified artificial saliva.[7,8]

MATERIALS AND METHODS

To carry out the fretting-corrosion tests between orthodontic wires (stainless steel and Ni-Ti wires) and a stainless steel bracket in the oral environment, the present study is conducted in two steps:

- Fretting-fatigue tests of materials in contact.
- Fretting-corrosion tests of materials in artificial saliva.

Materials

The arch-wire chosen for this study concerns the stainless steel and Ni-Ti wires and stainless steel bracket as its currently used as orthodontics elements.[9,10] The stainless steel arch-wire is 0.018-inch diameter (0.46 mm) and manufactured by Ortho-Mexico Organiser® company. The nickel–titanium wire is also 0.018–inch diameter (0.46 mm) and manufactured in the United States by the company of G and H® arch. The chemical composition of each orthodontic element is given in Table 1. The composition of the Ringer artificial saliva used is also given in the Table 2.[11,12]

Fretting Corrosion Tests

Using an experimental fretting-fatigue test bench (Fig. 1),[13-15] tests on orthodontic elements was conducted to examine firstly the fretting contact aspect between arch-wire and bracket. With a frequency of 2 Hz and an applied normal and tangential force of 5 N and 3 N respectively which generate a displacement of 100 m, tests were conducted in artificial saliva during 100000 cycles. The imposed load generates deflection between wires and brackets surface of 10 mm. After 100000 cycles–contact surfaces between elements were examined for each test, using the same test bench with the same operating conditions, fretting-corrosion of orthodontics elements in artificial saliva acidified to pH = 3 was also conducted and electrochemical analyze of samples were achieved after 100000 cycles. After all tests, the contact surface of the samples was analyzed using SEM and EDS.

Table 1: Chemical analysis of materials

Wire	*Composition (in % weight)*
Stainles steel	18% Cr. 10% Ni, balance Fe
Ti-Ni	55% Ni, 45% Ti
Bracket	*Composition (in % weight)*
Stainless steel	18%. 10% Ni, balance Fe

Table 2: Composition of saliva ringer

Composant	*Concentration*
Sodium chloride (NaCl)	9 gL
Potasium chloride (KCl)	0.42 gL
Calcium dihydrate chloride ($CaCl_2$)	0.2 gL
Sodium hydrogencarbonate ($NaHCO_2$)	0.2 gL

Fig. 1: Fretting-corrosion test bench

Electrochemical Analysis

To monitoring the evolution of the corrosion potential of wires after fretting-corrosion tests,[16,17] a potentiostat VoltaLab 301 connected to an electrochemical cell as shown in Figure 2,[18,19] is performed. The working electrode was the tested sample, and the reference electrode was a saturated calomel electrode (SCE).

Inclusion Criteria

- Patients included needed orthodontic treatment
- Examination of the fret-ting corrosion phenomenon in oral environment of orthodontic alloys
- Lab study
- Dental material study, or SEM
- Study on the tightening and loosening of orthodontic wires

Exclusion Criteria

- Patients should not be allergic to Ni-Ti alloys
- Temperature effect is excluded for this study
- Study is valid only when microslip occurs between orthodontic elements

RESULTS

Fretting Fatigue Tests

In this present work, the analysis of the fretting fatigue will be limited only to micro-slip areas both on the wires and on the stainless steel bracket. Fretting contact areas between elements will be therefore firstly examined before corrosion tests without saliva solution after 100000 fretting cycles. The results are summarized.

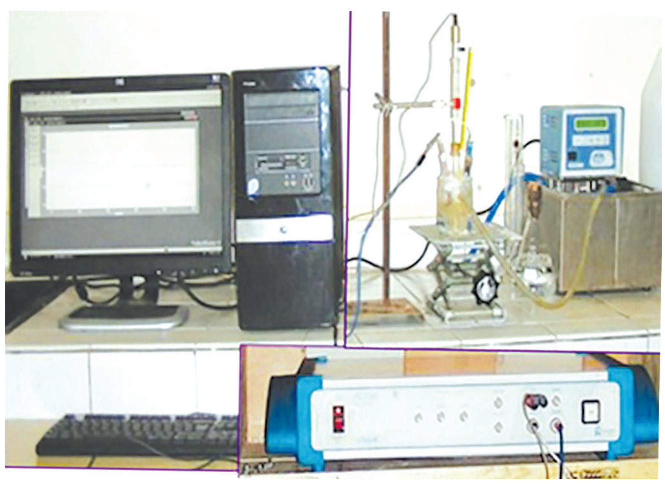


Fig. 2: Potentiostat VoltaLab 301

Ni-Ti Wire and Stainless Steel Bracket Contact

Under the fretting fatigue conditions described previously and according to researchers experimental protocols,[20,21] fretting contact between elements after 100000 cycles were analyzed using SEM and EDS. Examination of the stainless steel bracket has shown two contacts area generated on the two sides of the stainless steel bracket which differs according to the imposed displacement. Examples of the contact areas generated on the Ni-Ti wire and stainless steel bracket toward the eccentric side are shown in Figure 3. The EDS analysis of the contact area and outside the contact on the bracket are shown in Figures 4 and 5 respectively.

Stainless Steel Wire and Stainless Bracket Contact

Comparatively to Ni-Ti wire case, analysis of fretting contact areas between stainless steel wire and stainless steel bracket revealed a pronounced deformation aspect at the edge of the bracket as shown in Figure 6.

Fretting Corrosion and Morphologic Examination of Contact Areas with Simulated Saliva

Using a simulated media acidified saliva of pH = 3,[22-25] fretting-corrosion tests, and contacts areas are examined after 100000 fretting cycles for each contact of Ni-Ti and stainless steel wires with stainless steel bracket.[26-29]

Ni-Ti Wire and Stainless Bracket Contact

In artificial saliva, the fretting contact areas between stainless steel bracket and Ni-Ti wire after 10000 fretting cycles were analyzed using SEM and EDS. Toward the eccentric side, the contact area generated on stainless steel bracket which is about 0.02 mm^2 reveals the simultaneous presence of a stick area and a microsslip area which are characterized by oxides (Fig 7). EDS analysis of each zone on the contact area [stick zone (1), micro-slip zone (2) and outside the contact area (3)] are given in Figures 8 to 10.

Concerning the Ni-Ti wire, SEM analysis of contact area highlights the presence of oxides as shown in Figure 11. The chemical composition of the Ni-Ti wire away from the contact is given as an indication on (Fig. 12).

After 10000 fretting cycles, and using the Potentiostat Volta Lab 301 given in Figure 2, potential corrosion for Ni-Ti wire has been followed immediately in the same artificial media and the result is shown in Figure 13 in which the potential corrosion curve without artificial saliva is reported.[30]

Stainless Steels Wire And Bracket Contact

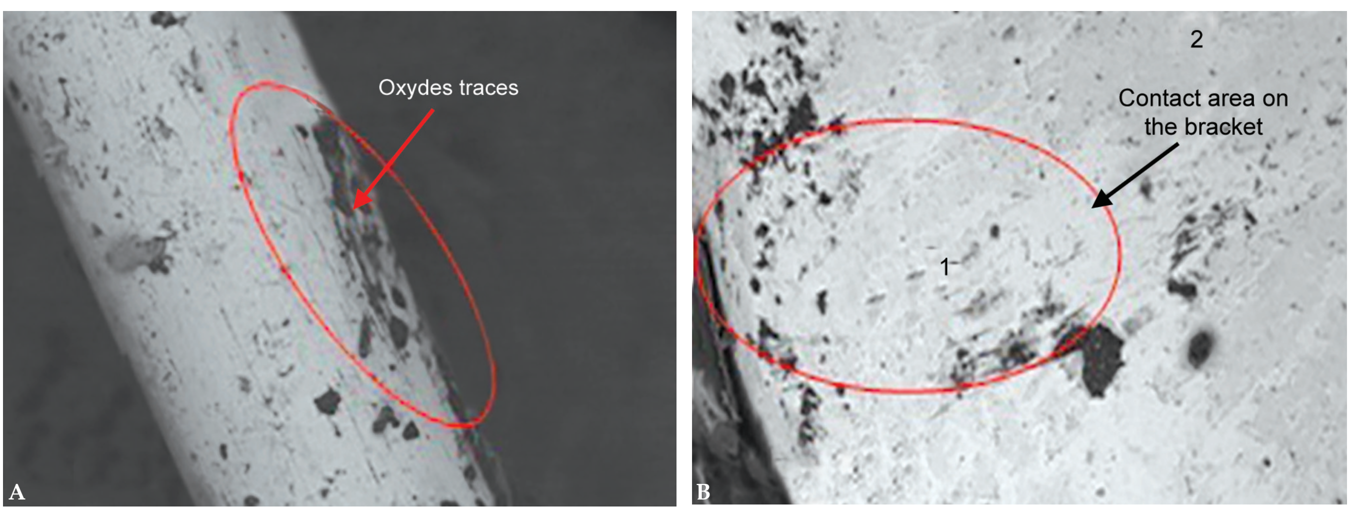
As in the case of the contact area between Ni-Ti wire and stainless steel bracket,[31] morphological aspects of the contact area between stainless steel wire and bracket generated in artificial saliva has been examined. Figures 14 and 15 show the morphological aspects of the contact area on the wire and on the bracket respectively.

The study of the corrosion of the orthodontic elements through the corrosion curves which shows the potential as a function of the current density in both cases, before and after the fretting test are shown in Figure 16.[32]

DISCUSSION

Fretting Fatigue Analysis

Under the operating conditions chosen with the used test bench, we noticed that there will be a micro-slip area toward the eccentric side and a stick area at the opposite side between the wires and the bracket.[33-35] In effect, and as it was observed on the performed tests, the morphological aspects of each contact area differ as a function of the imposed load and displacement. In the case of the contact between Ni-Ti wire and stainless steel



Figs 3A and B: Morphological aspect of the contact zones under a magnification 500X (A) Ti-Ni wire , (B) stainless steel bracket

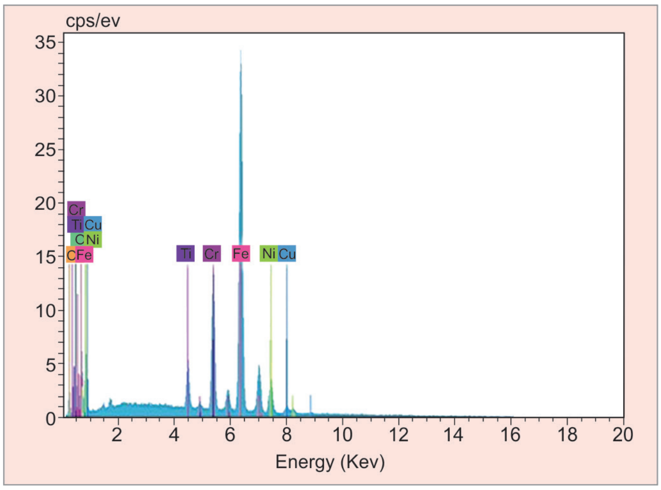


Fig. 4: EDS Analysis inside contact zone on stainless steel bracket

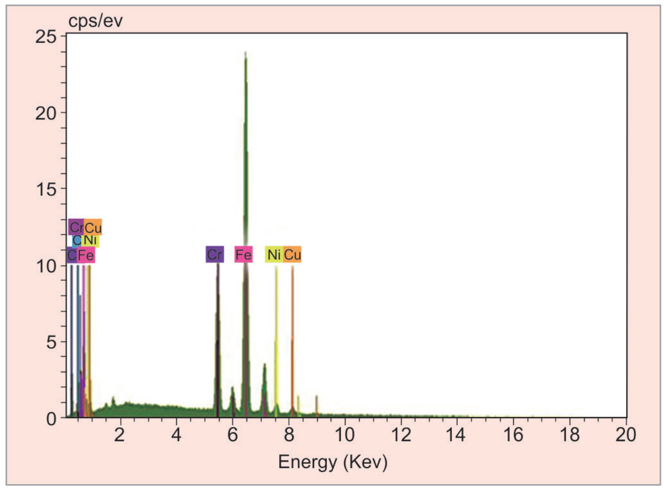


Fig. 5: EDS analysis outside contact zone on stainless steel bracket

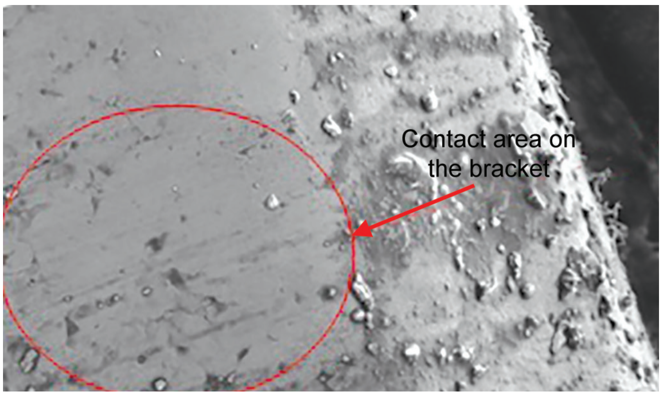


Fig. 6: Contact zone between stainless steels wire and bracket under a magnification of 505X

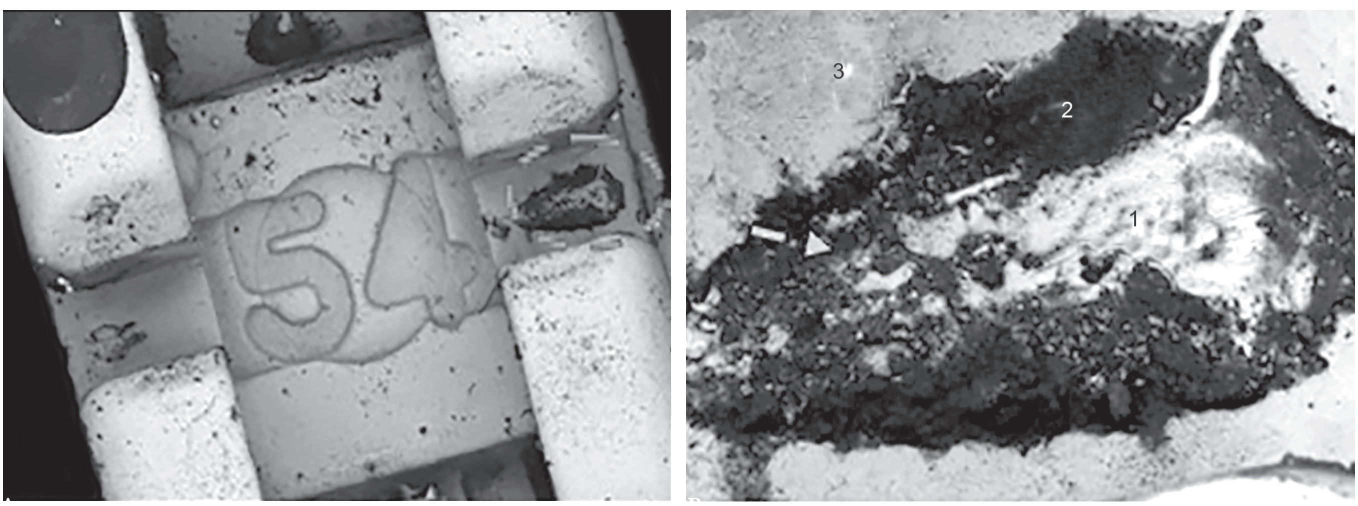
bracket, the analysis of the contact areas reveals some oxides which were mainly attributed to the micro-slip comparatively to the opposite side. On the stainless steel brackets areas, the EDS analysis has revealed some traces of titanium element generated by adhesive wear phenomenon comparatively to the stainless steel brackets outside the contact area. Inside the fretting contact area toward the eccentric side, Titanium element was however found to reach 3.89%. The EDS analysis has also detected some oxides in which the amount of oxygen was increased to 4.86%. The presence of titanium and oxides show a simultaneous existence of adhesive wear and friction between the Ni-Ti wire and stainless steel bracket.[35-36]

Concerning the stainless steel wire and stainless bracket contact, and as the two materials in contact have practically the same ductility, examination of the contact areas reveals deformation aspect at the edge of the bracket which is caused probably by work hardening during fretting between bracket and wire.

Fretting corrosion and morphologic examination of contact areas with simulated saliva

Ni-Ti wire and Stainless Bracket Contact

Based on the EDS analysis in the stick area, in the micro-slip area and outside the contact area, the chemical composition outside the contact area (3) shows a normal composition of stainless steel, and no oxides are detected. Inside the contact area, the titanium element was found to be about 1.87%at which is generated by Ni-Ti wire during micro-sliding mechanism. In the micro-slip area (2), the amount of oxygen was increased to 20.48% at Result of



Figs 7A and B: Fretting contact zone on the stainless steel bracket Ti-Ni wire

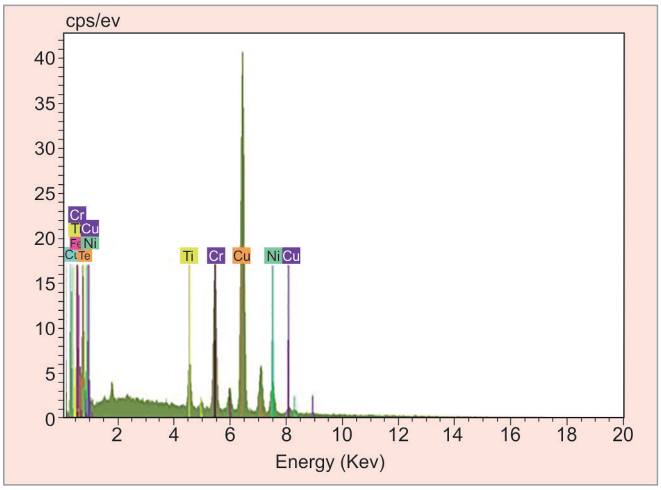


Fig. 8: EDS analysis of stick zone on the stainless steel bracket (zone 1)

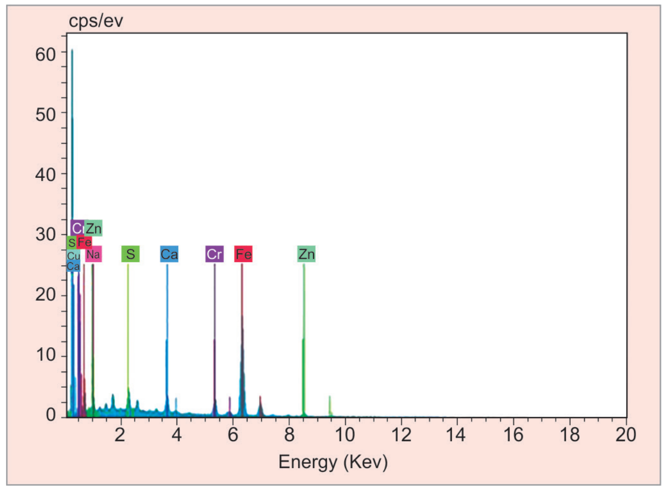


Fig. 9: EDS analysis of micro-slip zone on the stainless steel bracket (zone 2)

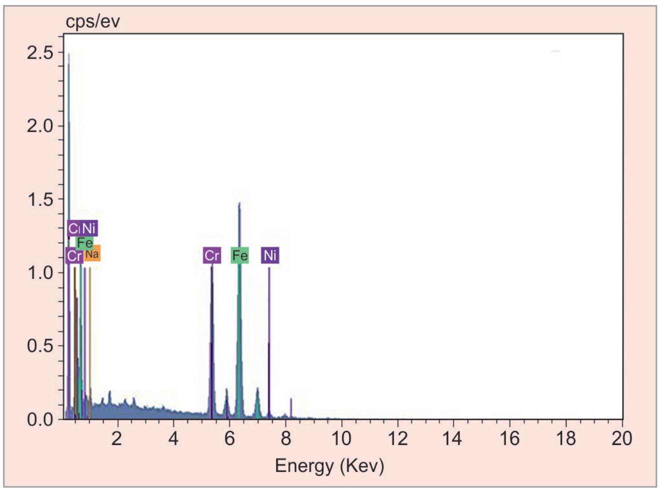


Fig. 10: EDS analysis outside the contact zone on the stainless steel bracket (zone 3)

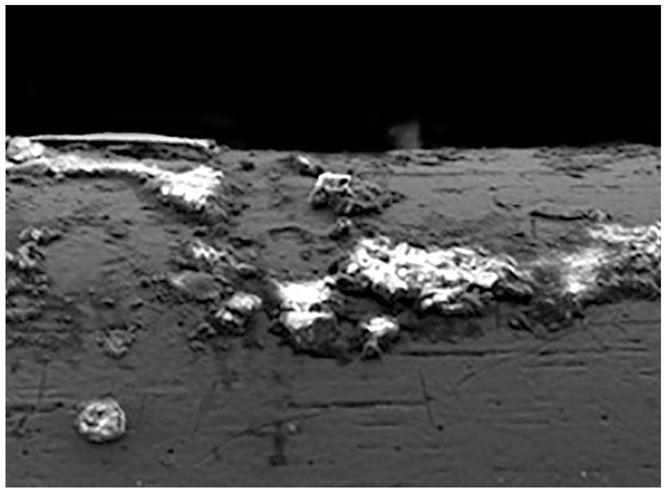


Fig. 11: SEM analysis of Ti-Ni wire contact

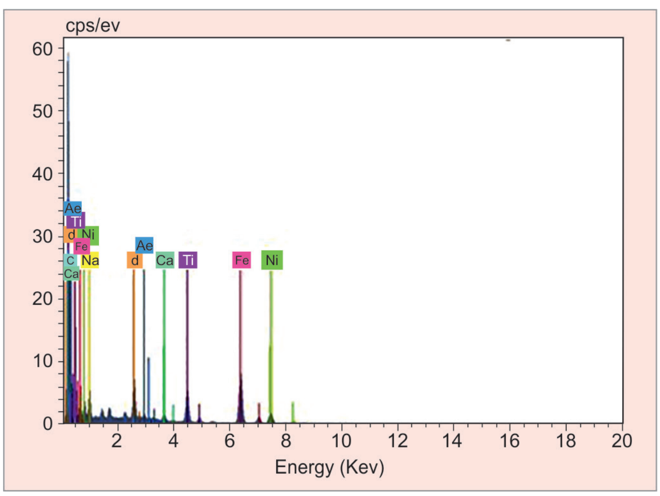


Fig. 12: EDS analysis inside the contact zone on Ti-Ni wire

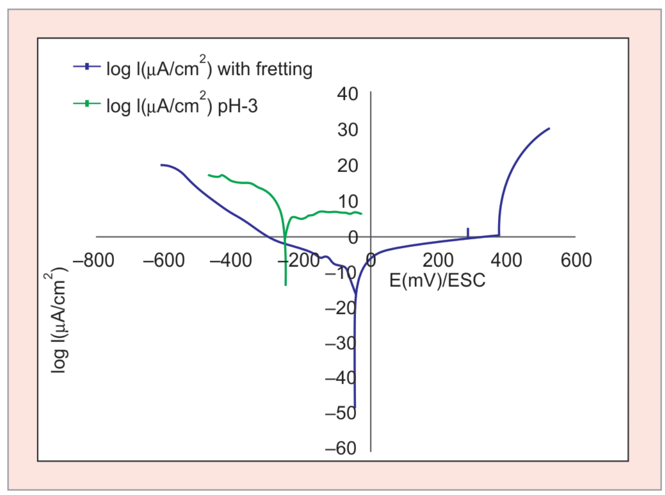


Fig. 13: Evolution of potential corrosion for Ti-Ni wire during fretting

EDS analysis of Ni-Ti wire confirm the high amounts of oxygen (about 28.78% at) in the mico-slip area. The examination of polarization curves for Ni-Ti wire and stainless bracket contact shows clearly the combined effect of fretting and the corrosion where a reduction of the potential corrosion in acidified media is observed.

Stainless Steels Wire and Bracket Contact

The SEM analysis of the contact area on stainless steel wire shows several pitting corrosion which highlights very pronounced attack under the combined effect of the corrosion and the fretting fatigue.

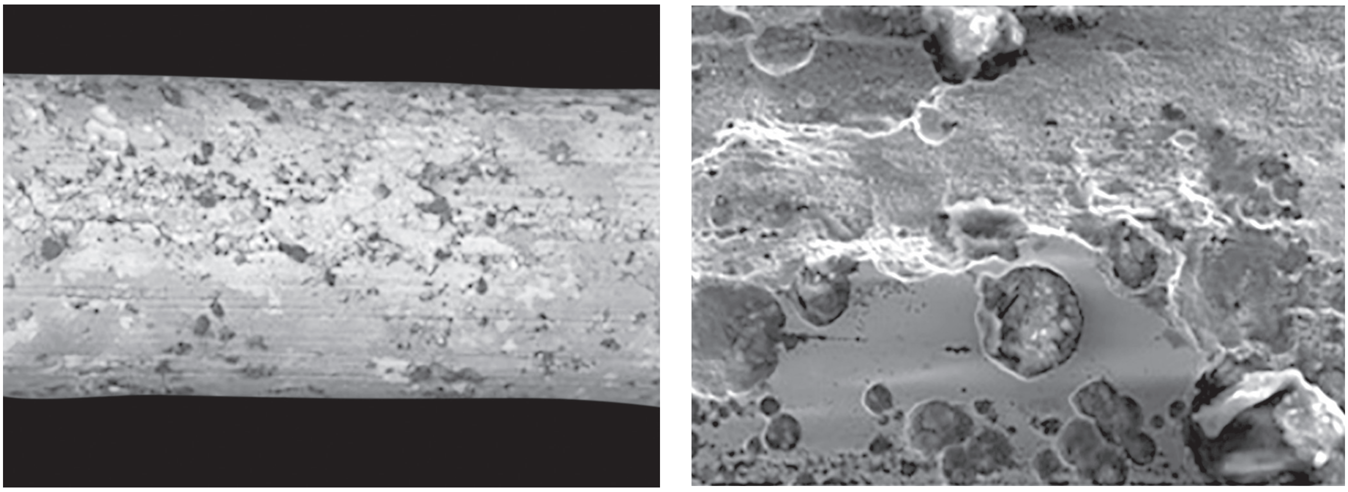
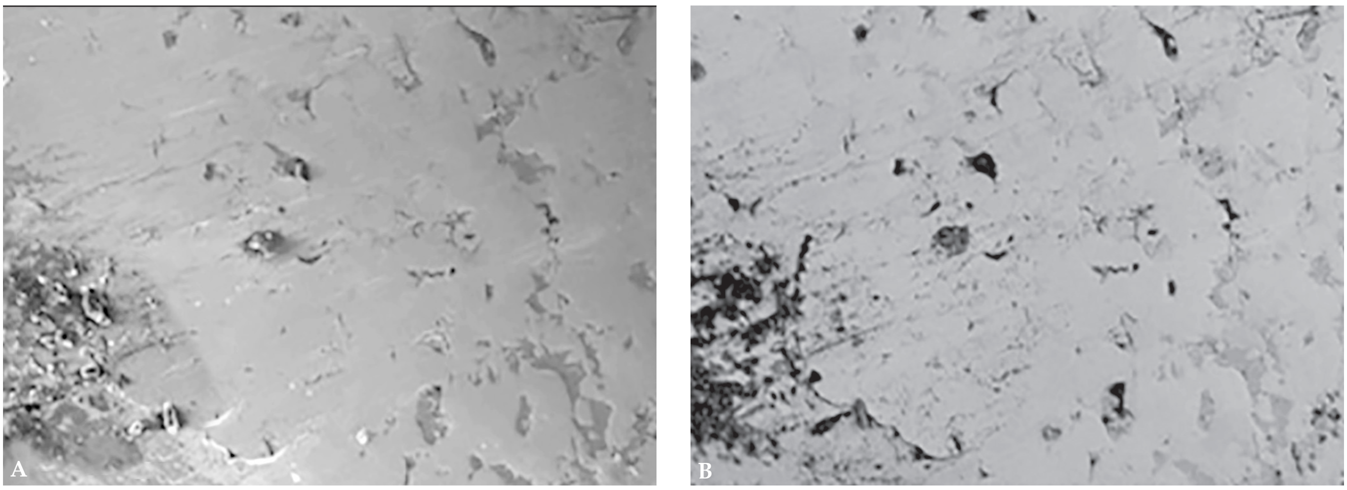


Fig. 14: The SEM investigation of the stainless steel wire with fretting SS/SS



Figs 15A and B: The SEM investigation of the stainless steel bracket during freeting in artificial saliva pH = 3

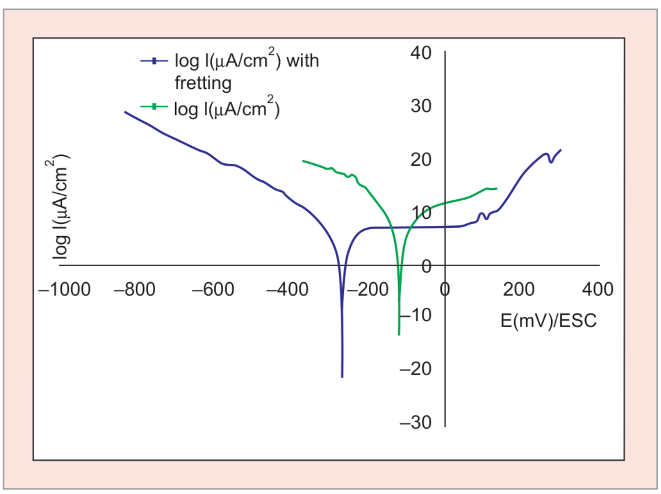


Fig. 16 : Evolution of the corrosion potential for stainless steel wire during fretting

The analysis of the polarization curves for stainless steel wire and bracket under the conditions described previously, confirms that the wire which has undergone the fretting test resist less than the wire which was only emerged in the artificial saliva. In this case, several pitting corrosion were observed which are nevertheless the most common type of corrosion observed in orthodontic wires and brackets. Under the acidified saliva, many pits can be seen. This feature is thought to increase the susceptibility to corrosion because this pitting localized reduction in pH and depletion of oxygen, which in turn affect the passivation process.

CONCLUSION

The present manuscript is a contribution to understanding fretting and fretting-corrosion phenomena of the contact between orthodontic stainless steel and nickel titanium wires with stainless steel bracket in neutral and acidic artificial saliva. Using an experimental test bench, electrochemical analysis of the chosen wires has first been examined and the fretting-corrosion under an imposed cyclic displacement has also been conducted.

Using scanning electron microscopic (SEM) coupled with energy dispersive spectroscopy (EDS), contact surfaces were examined. We observe that the contact between wires and brackets cause stick areas and microslip areas which generated oxides that may affect the health of patients in the orthodontic field.

During the tests, traces of titanium were observed on the contact areas of the stainless steel bracket that highlights an adhesive wear between nickel titanium wire and stainless steel bracket.

With regard to the corrosion test conducted after 100000 cycles, we found that Ni-Ti wire is more resistant than stainless steel wire in artificial saliva. Also, the corrosion resistance in acidified saliva is very pronounced for stainless steel wire and bracket as it reported by many authors.

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