Materials Science and Engineering C 33 (2013) 2084–2093

Contents lists available at SciVerse ScienceDirect

Materials Science and Engineering C

journal homepage: www.elsevier.com/locate/msec

Comparative study on corrosion behaviour of Nitinol and stainless steel orthodontic wires in simulated saliva solution in presence of fluoride ions

M. Mirjalili, M. Momeni *, N. Ebrahimi, M.H. Moayed

Metallurgical and Materials Engineering Department, Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad 91775-1111, Iran

ARTICLE INFO

Article history:
Received 17 June 2012
Received in revised form 10 December 2012
Accepted 14 January 2013
Available online 20 January 2013

Keywords:
Stainless steel
Nitinol
Pitting corrosion
Crevice corrosion
Passivity

ABSTRACT

Localized corrosion and effects of pre-passivation treatment of Nitinol and SS304 orthodontic wires in simulated saliva solution in the presence and absence of fluoride ions were investigated by means of potentiodynamic and potentiostatic polarisations. Results revealed that Nitinol does not show pitting corrosion in saliva solution however, SS304 shows pitting corrosion. Meanwhile fluoride ion has deteriorative effect on pitting corrosion of Nitinol, while its effect on SS304 was marginally constructive. Additionally, the presence of artificial crevice has no effect on corrosion behaviour in the presence of fluoride. Pre-passivation treatment has positive influence on pitting corrosion of both alloys in the presence of F^- ions.

1. Introduction

The orthodontic metal wire has been progressed from cobalt–chromium–nickel (Co–Cr–Ni) and stainless steel (SS) alloys to nickel–titanium (NiTi) alloy. In clinical orthodontic treatment, different alloys have a wide range of applications. These applications relate to NiTi alloy properties including superelasticity, thermal shape memory, good corrosion resistance and good biocompatibility [1]. The characteristics of NiTi wire alloy can reduce chair time and shorten treatment times. The biocompatibility of NiTi relies on the tendency of its surface to be covered by TiO_2 based oxides in natural conditions [2,3]. Oxide films present on the surface of alloys such as stainless steel and titanium based alloys are responsible for their corrosion resistance.

To achieve good oral hygiene care during orthodontic treatment, practitioners recommend that their patients use fluoride mouthwashes. In particular, most patients are adolescents who do not always follow a satisfactory oral hygiene regime and are subjected to high risk of dental decay. Fluoride mouthwashes which are typically available in 0.05% and 0.2% concentrations of fluoride ions are frequently prescribed by orthodontists daily or weekly to reduce prevalence of cavities [4]. Because of ionic, thermal, microbiological and enzymatic properties of oral environment, it is favourable for the biodegradation of metal. Therefore, it can be presumed that patients are exposed to a certain extent of corrosion processes [2,5,6]. Fluoride promotes the formation of calcium fluoride globules that adhere to the teeth and stimulate remineralisation while protecting against acid attack. Thus, fluoride mouthwashes help prevent the development of caries and protect dental enamel.

Much research have been conducted on the effect of chloride containing fluoride ions on localized corrosion of NiTi orthodontic arch wires and indicate the destructive influence of fluoride on corrosion behaviour of NiTi orthodontic wire. Research by Schill et al. [2,6] on NiTi alloy in artificial saliva with different pH and fluoride content showed a remarkable localized corrosion phenomenon of this alloys in fluoride and acid–fluoride saliva solutions. Li et al. [7] proposed a conversion of corrosion on NiTi orthodontic wire from localized to general corrosion when they were exposed to the chloride solution and solution containing chloride and fluoride. Examining various Ti containing dental orthodontic wire in solution containing chloride and fluoride ions, Lee et al. [8] found that the corrosion rate of all alloys in the presence of fluoride ions increases up to 1000 times and a remarkable decrease in passive film breakdown potential was also recorded.

Stainless steels as well as NiTi alloy are applied for the dental applications especially as the brackets and screws. Kocijan et al. [9] have studied the evolution of the passive films on 2205 duplex stainless steel (2205 DSS) and AISI 316L stainless steel in artificial saliva in the presence and absence of fluoride ions. According to their findings, the extent of the passive range increased for the 2205 DSS compared to the AISI 316L in both solutions and the passive films on both materials predominantly contained Cr-oxides. Wiegman-Ho and Ketelaar [10] have studied the corrosion of stainless steels in saliva solution quantitatively. Nie et al. [11] have investigated the effect of crystalline size on the corrosion behaviour of SS304 in an artificial saliva solution. They found that nanocrystalline structure is more resistant to corrosion than microcrystalline one. Mahato et al. [12] have illustrated that pitting

* Corresponding author. Tel.: +98 5118763305; fax: +98 5118763301.
E-mail address: mojtaba.momeni@stu.um.ac.ir (M. Momeni).

0928-4931/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.msec.2013.01.026

corrosion of SS304 in saliva solution can happen in the absence of chloride ions by some commonly used dietary spices such as red chilli. There are also some other works that deal with the corrosion of stainless steels in human body [13–17].

Exposing stainless steel alloys in nitric acid solution for improving their corrosion resistance has been already investigated in detail. Hong et al. [18] examined the effect of nitric acid passivation on type 430 ferritic stainless steel using potentiodynamic polarisation, EIS, and Auger electron spectroscopy (AES). Pitting potential and total impedance magnitude were positively correlated to surface Cr concentration. In response to this study, Crolet [19] remarked that causality does not always follow from correlation of results from electrochemical tests and results from surface analysis. Strictly speaking, the effect of inclusion removal on pitting potential cannot be distinguished from the effects of Cr surface enrichment.

Noh et al. [20] characterized pitting potentials and metastable pitting transients of pre-passivated SS316 in HNO_3 solutions ranging in concentration up to 50 wt.% immersed in deaerated 1 M NaCl solution at 70 °C. MnS inclusions were removed to certain extents at all concentrations. Furthermore, an optimum concentration for HNO_3 based on Cr/Fe ratio of passive layer was introduced in which maximum E_{pit} was achieved. Additionally, correlation between E_{pit} and Cr/Fe ratio was not a linear one, suggesting the influence of other factors, such as inclusions, in determining E_{pit}.

The effect of pre-passivation in HNO_3 on improving corrosion behaviour of heat treated NiTi wire at 500 °C was also reported by O'Brien et al. [21]. Improvements of corrosion behaviour after passivation are primarily attributed to a reduction of Ni or NiO content in surface and an increase of TiO_2 content in surface, rather than being related to oxide thickness.

Present study intends to investigate pitting and crevice corrosion behaviour of NiTi orthodontic arch wire in artificial saliva solution containing fluoride ions. Further investigation was conducted on the effect of pre-passivation of wires in HNO_3 on pitting and crevice corrosion in the same solution.

2. Materials and methods

2.1. Materials

In this study two types of orthodontic wires are used; Nitinol (purchased from Dentaurum, Germany) and SS304 (purchased from Tiger Ortho, USA). The wire diameters are 0.4 mm. First, to characterize the chemical composition of the wires, energy dispersive X-ray (EDX) was used and the type of elements which form the wire was identified. Then, quantitative chemical compositions of major elements were measured by atomic adsorption spectroscopy (AAS). Fig. 1 shows the results of EDX analysis of Nitinol and SS304 surfaces. As it can be seen, Nitinol wire contains only nickel (Ni) and titanium (Ti) peaks in its EDX result and the oxygen (O) appears due to surface oxide layer. SS304 results show iron (Fe), chromium (Cr), nickel (Ni) and molybdenum (Mo) peaks in addition to silicon (Si), sulphur (S), phosphorus (P) and manganese (Mn) which exist in all types of steels. The AAS results of these two wires are presented in Table 1 showing that the chemical composition of these materials is in agreement with the Nitinol and SS304.

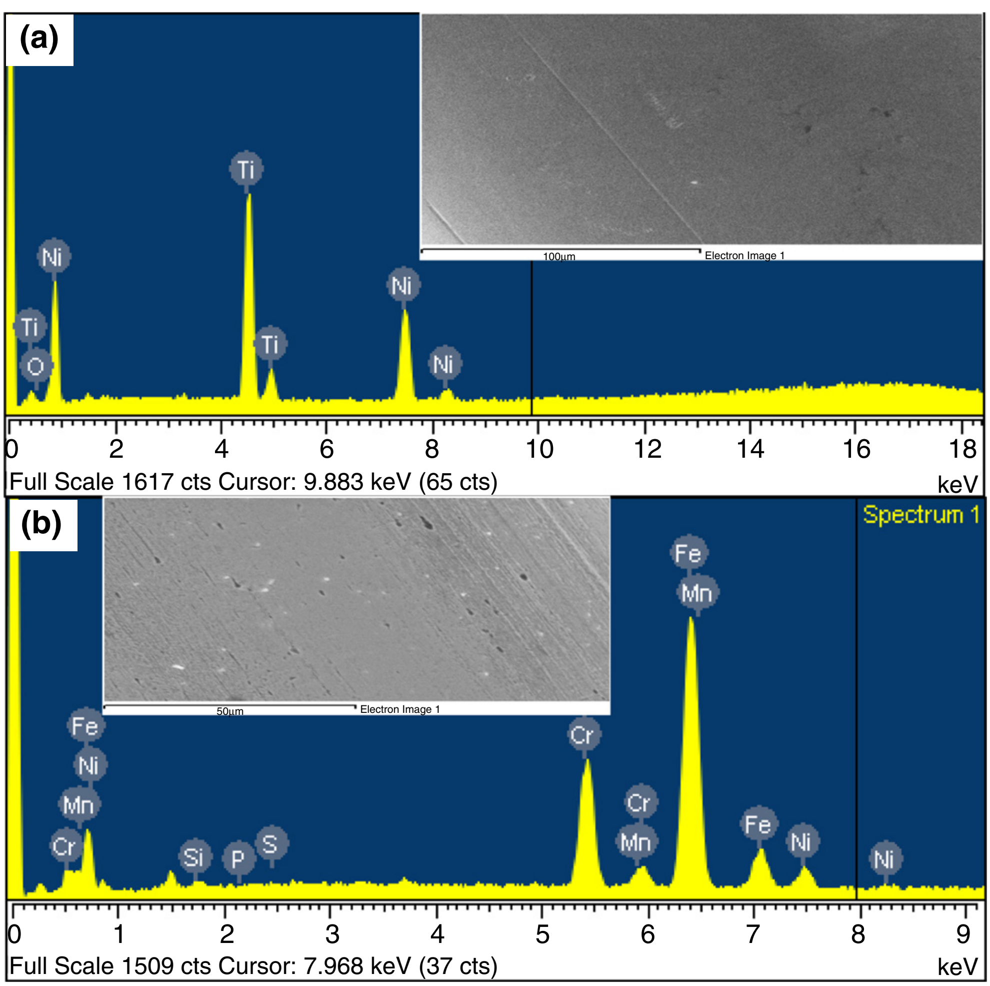

Fig. 1. Results of EDX analysis for (a) Nitinol and (b) SS304 orthodontic wires.