IN-VITRO CORROSION MEASUREMENTS OF NI-TI WROUGHT ALLOYS

Salwa E. Khier, BDS, MSD, MSc, PhD*; William A. Brantley, PhD**

دراسة الإستقطاب الديناميكي لخلاط أسلاك النيكل تيتنايم المستعملة في تقويم الأسنان

تعتبر سبائك أسلاك النيكل – تيتنايم المستخدمة في تقويم الأسنان من السبائك المهمة والتي يجرى عليها كثيراً من الأبحاث العلمية. وقد تم تسويق عدة أنواع من هذه الأسلاك خلال فترة الأعوام القليلة السابقة. وتتميز تلك الأسلاك بقدرتها على التنشيط وعكسه بمستوى قوة ثابت تقريباً.

كان الغرض من هذه الدراسة هو تحديد وتمييز خاصية قوة التحريك لعدة أسلاك من سبائك النيكل – تيتنايم المستخدمة في تقويم الأسنان ومقارنتها ببعضها البعض ودراسة خاصية التآكل وقد استخدمت ستة أنواع من هذه الإسلاك ثلاثة منها عادية المرونة وثلاثة أخرى ذات مرونة عالية وتراوحت أقطار الأسلاك بين ٠,٠١٦ و ٠,٠١٨ وكذلك ٠,٠٢٥ × ٠,٠٢١ إنس. وقد تم وضع عينات من هذه الأسلاك في اللعاب الصناعي باستخدام جهاز خلية التآكل «البرنستون» وقد أجريت تجارب الإستقطاب السالب والموجب باستعمال جهاز «الأردفارك». وقد أظهرت نتائج هذا البحث أن القوة المحركة لكل الأسلاك المستعملة ظلت متشابهة تقريباً وقد ظهر تلف في الطبقة الرقيقة السطحية للأسلاك عادية المرونة بينما لم يحدث أي تلف لهذه الطبقة الرقيقة السطحية للأسلاك عادية المرونة بينما لم يحدث أي تلف لهذه الطبقة السطحية للأسلاك ذات المرونة العالية.

Abstract

Nickel-titanium (Ni-Ti) orthodontic wire alloys are the current focus of intensive research activity. Several new brands have been introduced. These wires are capable of being activated or deactivated at a nearly constant force level. The purpose of this investigation was to characterize the potentiodynamic polarization behavior for various Ni-Ti wire alloys and to compare their in-vitro corrosion. Six different types of Ni-Ti wires were selected, Nitinol SE, Sentinol, NiTi, Titanal, Orthonol and Nitinol alloys, with cross-section dimensions of: 0.016 and 0.018 inch for round specimens or 0.018x0.025 and 0.021x0.025 inch for rectangular specimens. Specimens were maintained in an artificial saliva which was adjusted to a pH = 6. A 500 ml air-exposed saliva solution was used in a Princeton corrosion cell. The anodic and cathodic polarization experiments were conducted using an Aardvark potentiostat. The potentiodynamic behavior of all six Ni-Ti wires was generally similar. Sentinol, Titanal and Orthonol wires showed breakdown of passive film during testing and the other three wires remained passive over the entire range of the cyclic voltage used.

Introduction

In principle, it would be difficult to predict the corrosion behavior of nitinol alloys, because nickel is not corrosion resistant in saline solutions such as sea water while titanium has excellent corrosion resistance under the same conditions.[13] The resistance of some nitinol alloys to corrosion in sea water has been evaluated by conducting high velocity impingement, cavitation erosion, stress corrosion and crevice corrosion measurements.[4,5] The results of these tests have shown these alloys to be quite resistant to marine corrosion.

Received 07/04/96; revised **11/09/96,** accepted **20/10/96**

* Associate Professor, Department of Removable Prosthetic Dental Sciences, college of Dentistry, King saud University. P.O.Box 60169, Riyadh 11545, Saudi Arabia

** Professor, Department of Restorative & Prosthetic Dentistry, College of Dentistry, The Ohio State University, Ohio, U.S.A.

Address reprint requests to : Dr. S. Khier.

Resistance to corrosion in the oral environment is an important consideration in the selection of a metallic orthodontic appliance, although most of these appliances are temporary.[6] The corrosion behavior of nitinol orthodontic wire alloys in a 1% NaCl solution has been evaluated by cyclic polarization, with stepwise increases (forward direction) in the potential differences from 500 mV SCE (Saturated Calomel Electrode) to +300 mV SCE followed by a stepwise decrease (reverse polarization) back to -500 mV.[7]

It is common to explain the potentiodynamic polarization curves as follows: the higher the current density at a given potential, the more corrosion prone is the material at that potential. It is also believed that the more negative the corrosion potential, the more electrochemically active is the alloy.[8-10] In another study,[11] it was reported that the breakdown potential of Nitinol orthodontic wire in a saliva-type solution is relatively higher than for other types of orthodontic wire alloys. In contrast, some investigators have suggested that the apparent pitting of Nitinol wires during potentiodynamic polarization is due to the presence of surface defects generated during manufacturing and not to the effects of corrosion. The flexural properties were evaluated for both control and corroded Nitinol samples and were found not to be statistically different. There have been no published studies on the laboratory behavior of the lately introduced super elastic nickel-titanium wire alloys. It was the purpose of this investigation to measure and compare the potentiodynamic corrosion behavior of some Ni-Ti wire alloys.

Materials and Methods

The six orthodontic wire alloys used in this investigation are listed in Table 1. These wire types were selected to provide three brands with known superelastic behavior and three brands which do not show superelastic behavior. For the potentiodynamic polarization experiments, the anodic and the cathodic polarizations were obtained by an Aardvark potentiostat.*

Table 1. Nickel-Titanium orthodontic wires used in the present investigation.

Wire Type	Cross-section (inch)	Manufacturer
	0.016,0.018	Unitek Corporation
Nitinol Se	0.018x0.025	2724 South Peck Road
	0.021 x 0.025	Monrovia, CA 91016, U.S.A.
	0.016,0.018	International
Sentinol	0.018x0.025	185 Oval Drive
	0.021 x 0.025	Central Islip, NY 11722, U.S.A.
		SeOrmco Div, Sybron Corp.
Ni-Ti	0.016,0.018*	1332 S Lone Hill Ave.
		Glendora,CA 91740 U.S.A.
	0.016,0.018	Lancer Orthodontics
Titanal	0.018x0.025	6050 Avenida Encinas
	0.021 x 0.025	Carlsbad, CA 92008 U.S.A.
	0.016,0.018	Rocky Mountain Orthodontics
Orthonol	0.018x0.025	P.O. Box 17085
	0.021 x 0.025	Denver, CO 80217 U.S.A
	0.016,0.018	Unitek Corporation
Nitinol	0.018x0.025	2724 South Peck Road
	0.021 x 0.025	Monrovia, CA 91016, U.S.A.

Only these two round wire cross-sections were available at the time of this investigation.

The 0.016 inch diameter wires in a length of 1.5 inches were used in all cases with exposed area of 0.075 in^2. For each orthodontic alloy, wire electrode segment was prepared by mounting about a 0.5 inch of the cut off wire sample into Epo-Kwick resin. A stainless steel electrode rod was mounted from the back of the resin holder to achieve an electrical contact with the embedded wire. The exposed length of wire sample was abraded with a 600 grit paper and rinsed with acetone immediately before insertion into the saliva solution. The test segment of investigated wires were subjected in a stepwise manner to potential differences ranging (a) from -0.6 V SCE (Saturated Calomel Electrode) to +0.8 V in the forward direction followed by (b) reverse polarization back to -0.06. The purpose of this cyclic polarization treatment was to grow then break down films of corrosion products on the surfaces of the wire samples under highly accelerated conditions. For each wire, the log of current output (A) was plotted versus the applied potential (V vs. SCE).

Results

The potential-current profiles of nickel-titanium orthodontic wire alloys obtained by cyclic polarization are presented in Figures 1 and 2. The recorded traces for the superelastic wires are shown in Figure 1. During the forward scan, both Ni-Ti and Nitinol SE remained passive while Sentinol exhibited breakdown in passitivity at about +0.25 V. In the case of the non-superelastic wires, Titanal and Orthonol broke down their passitivities around +0.18 V, whereas Nitinol maintained its passitivity for the entire forward scan up to +0.8 V. [Fig.2].

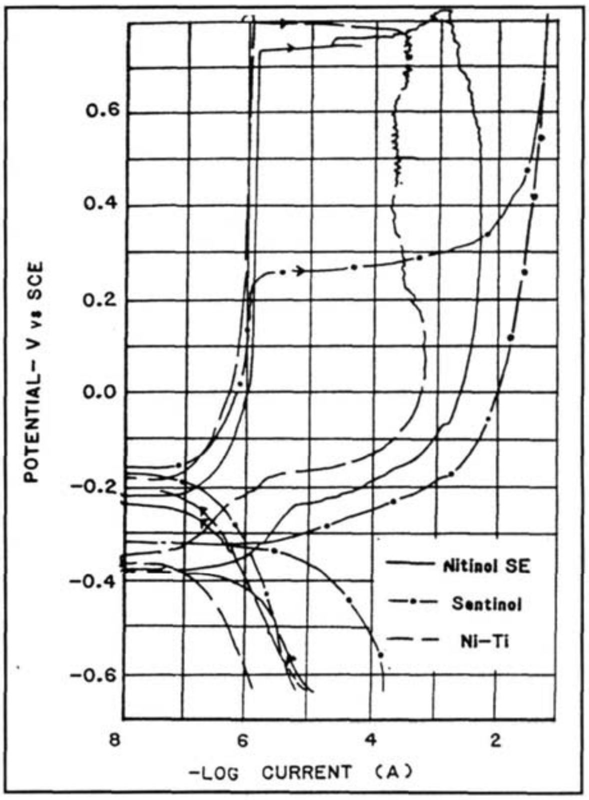

Fig. 1. Potentiodynamic polarization curve for superelastic orthodontic wires obtained by the cyclic polarization technique.

* E7G, EGN-G Model 1362, Princeton, NJ, USA.

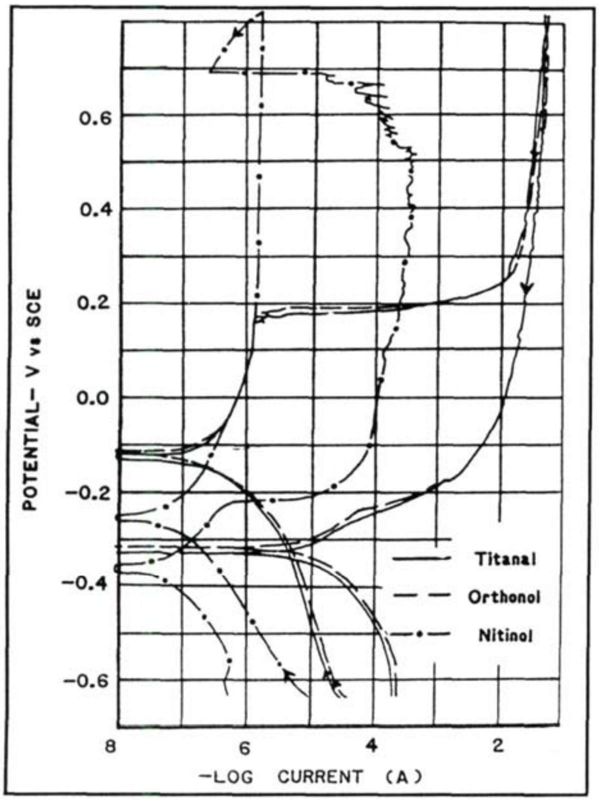

Fig. 2. Potentiodynamic polarization curve for non-superelastic orthodontic wires obtained by the cyclic polarization technique.

Discussion

Prolonged and effective corrosion resistance is a prime consideration in materials to be used in the oral cavity. It is well known that corrosion is the result of a variety of interaction between the material and the environment. The metallurgical nature of these materials, such as composition, structure, surface finish and thermal history, controls their corrosion behavior. The resistance of the original Nitinol nickel-titanium orthodontic wire alloy to corrosion in artificial saliva and saline solutions has been evaluated by conducting the potentiodynamic polarization technique.[8,11]

In general, during the reverse scan for the potentiodynamic polarization curves, the zero-current potential for all the nickel-titanium orthodontic wire alloys occurred at a more negative value (-0.1 to -0.25 V) than the corrosion potential (change from cathodic to anodic sense of the current) for the forward scan. The initial anodic portions of the forward scan curves are considered to be associated with the growth of a passive film of mixed nickel-titanium oxides on the exposed surface. The horizontal portion of the anodic forward scan is attributed to breakdown of this film with formation of localized pitting when the potential difference reaches some critical value. The breakdown of passivity results approximately in three orders of magnitude increase in current density during the forward scan, and a corresponding plateau in the plot is observed during the reversed scan at a lower value of voltage. This increase in current density can be attributed to the change in the geometric surface area of the alloy resulting from the formation of pits. The change in the zero-current potential for the reverse scan can be explained by the exposure of the pit-free alloy surface to the NaCl solution at localized areas associated with the breakdown of the passive film. These results generally agree with the past observations from similar electrochemical studies,[7,8,11] and are consistent with long-term laboratory and clinical studies.[12-13] In the present investigation, it was assumed that the breakdown of the passive film on the nickel-titanium orthodontic wire surfaces may also arise from surface defects generated during the manufacturing processes, along with general effects of accelerated corrosion.

Conclusion

The potentiodynamic behavior of all investigated Ni-Ti wrought wire alloys was generally similar. Sentinol, Titanal and Orthonal wires showed breakdown of passive film during testing. The other three wires remained passive over the entire range of cyclic voltage used.

Acknowledgement

The author gratefully acknowledge the valuable assistance and comments offered by Dr. H.J. Muller, Research Associate, American Dental Association, Chicago, U.S.A. Miss Thelma Tirad is kindly acknowledged for typing the manuscript.

References

1. Tomashov ND, Chernova RE. Passivity and protection of metals against corrosion. New York:Plenum Press, 1967:67.
2. Scully JC. The fundamentals of corrosion. 2nd ed. New York:Pergamon Press, 1975, Chap 2.
3. Ida K, Togaya T, Tsutsumi S, Takeuchi M. Effect of magnesia investments in the dental casting of pure titanium or titanium alloys. Dent Mat J 1982;1:8-16.
4. Buehler WJ, Wang FE. A summary of recent research on the nitinol alloys and their potential application in ocean engineering. Ocean Engr 1968;1:105-20.
5. Chern Lin JH, Moser JB, Taira M, Greener EH. Cu-Ti, Co-Ti and Ni-Ti systems: corrosion and microhardness. J Oral Rehabil 1990;17:383-91.
6. Greener EH, Harcourt JK, Lautenschlager EP. Materials science in dentistry. Baltimore:Williams & Wilkins Co, 1972:352.
7. Sarkar NK, Redmond W, Schwaninger BM, Goldberg AJ. The chloride corrosion behavior of four orthodontic wires. J Oral Rehabil 1983;10:121-28.
8. Sarkar NK, Fuys RA, Stanford JW. The chloride corrosion of low-gold casting alloys. J Dent Res 1979;58:568-75.
9. Chern Lin JH, Lo SJ, Ju CP. Bio-corrosion study of titanium-cobalt alloys. J Oral Rehabil 1995;22:331-35.
10. Holland RI. Corrosion testing by potentiodynamic polarization in various electrolytes. Dent Mater 1992;8:241-45.
11. Mueller HJ, Chen CP. Properties of Fe-Cr-Mo wire. J Dent 1983;11:71-79.
12. Scwaniger BM, Sarkar NK, Foster BE. Effect of long-term immersion on the flexural properties of nitinol. Am J Orthod 1982;92:45-9.
13. Edie JW, Andreasen GF, Zaytoun MP. Surface corrosion of nitinol and stainless steel under clinical conditions. Angle Orthod 1981;51:181-92.
14. Machiarelli R. Pre-historic ifish eatersi along the eastern Arabian coast: Dental variation, morphology and oral health in the Rafs Al-Hamra community (Qurum, Sultanate of Oman, 5th - 4th millenia BC). Am J Phys Anthropol 1989;78:575-94.