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The Influence of Surface Nanocrystallization Induced by Shot Peening on Corrosion Behavior of NiTi Alloy

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Nickel-titanium (NiTi) shape memory alloys have been widely used as implant materials, due to their superior shape memory properties and similar mechanical behavior to bone tissue. The presence of nickel on the surface of nickel-titanium alloy and release of this ion in the body environment will result in some allergic reactions. In current study, we used shot pinning process to produce nanocrystalline nickel-titanium alloy with increased corrosion resistance. Field emission scanning electron microscopy (FE-SEM), x-ray diffraction (XRD) analysis, and atomic force microscopy were employed to investigate the surface features of samples. The quantitative chemical analysis of NiTi and modified NiTi samples was conducted by energy dispersive x-ray method. The electrochemical behavior of NiTi alloy was evaluated using the potentiodynamic polarization scan and electrochemical impedance spectroscopy tests in Ringer solution after and prior to the shot pining process. The result of XRD analysis of modified samples showed an average crystalline size of 23 nm. Moreover, FE-SEM confirmed the development of a nanostructured alloy induced by shot pinning process. Modification of NiTi alloy by shot-peening process resulted in corrosion resistance improvement and decrease in the corrosion rate, which consequently led to less release rate of the toxic nickel ions in the corrosive environment, compared to the non-modified samples.

Keywords corrosion, nanocrystaline, NiTi alloys, shot peening

1. Introduction

The shape memory properties, high elasticity, high fatigue resistance, and mechanical properties similar to natural bone, made NiTi alloys a promising alternative over stainless steel, magnesium, and titanium alloys in biomedical applications (Ref 1, 2). NiTi alloys are taken into consideration for some medical applications such as artificial joints, dental implants, stents, and metallic implants in orthopedic devices (Ref 3, 4). Despite the previously mentioned characteristics of NiTi alloys which are suitable to be used in biomedical applications, the high concentration of nickel at the alloy-tissue interface (alloy's surface) has limited their medical application. Release of ions most likely will result in some allergic reactions such as inflation and blister and will also cause necrosis in tissues around the permanent implant (Ref 4, 5). Controlling nickel ion release from NiTi alloys exposed to human body environment is the most challenging and also the most important factor to be considered (Ref 6). Surface modification is one of the most widely used methods to control the ion release behavior of NiTi alloys (Ref 7). The surface modification often leads to improvement in corrosion resistance of NiTi alloys (Ref 6). Increase in corrosion resistance of NiTi will suppress the release of nickel ions in body environment (Ref 6). Natural oxide layer on the metal surface provides protection against the corrosive environment, but this layer does not have a high-corrosion resistance in long term (Ref 7, 8). Vast number of researches reported the surface modification of metal as a proper way to enhance the corrosion resistance (Ref 8-10). Moreover, microstructural modification of metal surface can also be performed at nanoscale, which will lead to further improvement in physical, chemical, and mechanical properties (Ref 11-13). Improvement of corrosion properties of nanostructured metal is mostly due to increasing the amount of grain boundaries (Ref 13, 14). Many researchers claim that improvement of the corrosion behavior characteristics of nanostructured metals, in comparison with the micro-scale modified ones, is due to formation of the more resistant passive layer and increased atomic activity (Ref 15). Shot-peening method is a cold-working process used to produce a layer containing huge compressive residual stresses, modifying the metal surface structure, and creating the ultrafine grain and nano structure (Ref 16, 17). It entails bombardment of the surface with shots (round metallic, glass, or ceramic particles) inducing the sufficient force to create plastic deformation resulting in increased compressive residual stress on the metal surface (Ref 16, 17). Wang et al. (Ref 18) applied the shot-peening process on 304 stainless steel, which resulted in a nanostructured surface. They evaluated the corrosion behavior of micro and nanostructured samples in NaOH (3.5%) solution, reported the better corrosion resistance of the nanostructured one (Ref 18). Authors studied the surface hardness (in the range of 3 nm) of samples, reported larger hardness values of the passive film in nanostructured samples (Ref 18). The corrosion resistance of nanostructured stainless steel in sodium chloride solution is higher than that of the non-modified one. This is mostly due to the fact that, the nanostructured stainless steel has significantly more nucleation sites which led to formation of more uniform passive film (Ref 13, 15). Mhaede et al. (Ref 19) reported a considerable improvement in corrosion resistance of shot-peened magnesium alloy AZ31 in NaOH (0.9%) solution.

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