Biocompatibility and Mechanical Performance of Ni-Ti

J. H. Kim[1], Y.C. Choi[1], H.S. Kim[1] and S. I. Hong[1,a]

[1] Department of Metallurgical Engineering, Chungnam National University
Taedok Science Town, Taejon, 705-364, Korea
[a]sihong@cnu.ac.kr

Abstract

Biomimetic apatite deposition behaviors and mechanical performance for as-rolled and annealed Ni-Ti plates were investigated . A good biomimetic apatite formation and excellent mechanical performance of Ni-Ti suggests that Ni-Ti can be an excellent candidate material as orthopedic implants.

Keywords : Ni-Ti, Apatite, Simulated body fluid (SBF), Pseudoelasticity

1. Introduction

A biomimetic approach in simulated body fluid (SBF) has demonstrated that the bone like apatite particles can be deposited on metals, ceramics, glasses and polymers [1-4]. Currently this method is used to coat implants [1] with the aim of improving the biological compatibility and osteoconductivity and the generation for biomimetic scaffolds that could support skeletal tissue repair and replacement [5, 6]. The biomimetic apatite deposition is known to be accelerated by raising the solution supersaturation above its critical value and/or inducing heterogeneous nucleation through biochemistry or surface modification [2]. Heterogeneous nucleators have both a strong affinity for the ions which form the nucleus and a suitable structural and electrical topography that will readily allow the absorbed ions to arrange themselves into a stable cluster [2]. NaOH treatment of the surface of metals is known to induce the heterogeneous nucleation of apatite [3].

2. Experimental and Results

Rectangular as-rolled and heat treated (973 K for 1 hr and water quenched) Ni-44.3 % Ti plates with the size of 10 mm x 10mm were used as a substrate for apatite deposition. The surface of metal plates were polished with abrasive papers (#600) and some of them were chemically treated with 5mol NaOH for 1 hr. [3]. The SBF was prepared by dissolving chemicals into deionized water in the sequence of 141 mM NaCl, 4.0 mM KCl, 0.5 mM $MgSO_4$, 1.0 mM $MgCl_2$, 4.2 mM $NaHCO_3$, 5.0 mM $CaCl_2 \cdot 2H_2O$, 2.0 mM KH_2PO_4 and titrated to pH 6.8 at 25°C. The SBF used in this study was 1X modified solution with the concentration of Ca^{2+} and HPO_4^{2-} ions twice as much as those of human blood plasma [6]. Metal plates were immersed in the SBF and kept in an incubator at 37°C. The SBF was refreshed every other day for 10 days in order to replenish the ion concentration to supersaturated levels. XRD was performed for the structural analyses of the deposited layer. The calcium phosphate deposited specimen was coated with a thin layer of gold and observed with a SEM (Topcon SM-500) for the observation of surface morphology. The deposition rate was examined by measuring the wight gain after the formation of apatite film..

Fig. 1 shows the stress-strain responses of as-rolled and heat-treated Ni-44.3 % Ti alloy at room temperature (a) and at 400°C. At room temperature, the heat-treated Ni-Ti exhibits the typical extended superelastic behavior (up to 10 % strain) whereas the as-rolled Ni-Ti exhibits the limited superelasticity as evidenced by a concave (at 10 % strain) on the stress-strain curves. The presence of a concave suggests that the absence of superelasticity is associated

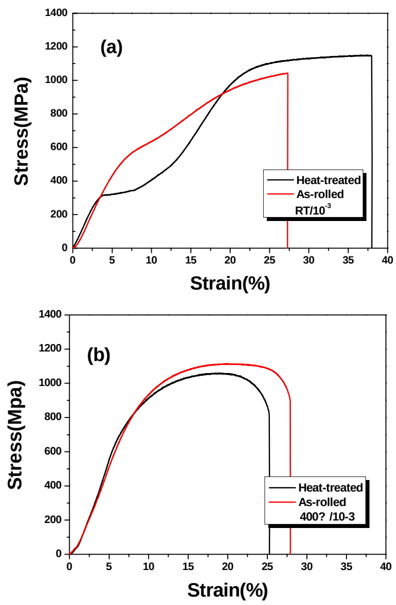

Fig. 1. Strss-strain responses of as-rolled and heat- treated Ni-44.3 Ti. (a) room temperature, (b) 400 °C

with the initial high dislocation density in cold rolled Ni-Ti. The ultimate tensile strength for annealed Ni-Ti, however, increased rapidly after stress-induced matensite formation and reached up to 1200 MPa. At 400 ^{o}C, no superelastic behavior was observed and Ni-Ti alloys with different heat treatments behaved similarly as shown in Fig. 1(b). The superelasticity was attributed to the stress-induced martensite formation [7].

Fig. 2 displays the nodular apatite particles deposited on the surface of as-rolled (c, d)and heat-treated (a, b) Ni-44.3 % alloy with (a, c) and without (b, d) NaOH treatment after 10 days deposition in SBF. The whole surface was covered with nodular crystals and metal substrates are visible. The nodular particles were observed to be larger in the layer formed on the NaOH treated

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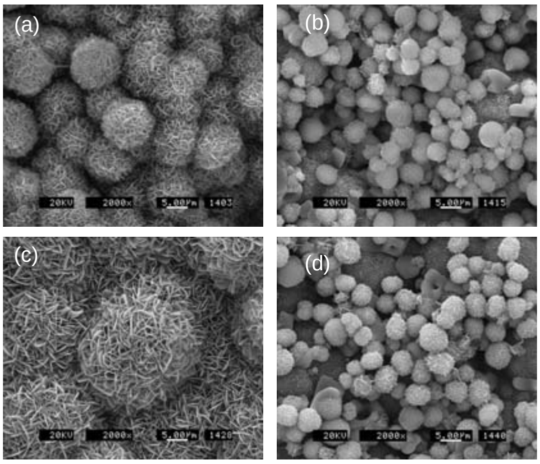

Fig. 2. Surface morphologies of as-rolled and heat-treated Ni-44.3 % Ti alloy after biomimetic deposition of apatite in SBF.

Ni-Ti (a, c) than non-NaOH treated (b, d) Ni-Ti alloy, suggesting that the deposition of apatite is dependent on the surface condition of Ni-Ti substrate. The needle shaped particle on the surface of apatite nodules were suggested to be single crystalline apatite by Hong et al. [8]. The plate or needle-shaped apatites are favored in single crystalline apatites from both knetics and the energy barrier point of view. The surface energy of the apatite crystals can be reduced by taking the shape of plate or needle with the planes with a low surface energy (planes parallel to the c-axis) parallel to the long axis [8]. On a larger scale, the conglomeration of numerous apatite crystals with different orientations and some amorphous calcium phosphate was found to be nodular grains. The conglomeration of apatites can be considered to be isotropic on a macro-scale and the surface energy, therefore, can be reduced by forming the sphere-type apatite grains [8].

3. Summary

Biomimetic apatite deposition behaviors and mechanical performance for as-rolled and annealed Ni-Ti plates were investigated. Stress-strain responses of annealed Ni-Ti displayed the pseudoelastic behavior associated with stress-induced martensite formation whereas the cold worked Ni-Ti displayed no appreciable pseudoelastic region. Apatite nucleation and growth on Ni-Ti in SBF was not appreciably influenced by heat treatment. The nodular apatite particles on the NaOH-treated as-rolled Ni-Ti was greater than any other conditions, supporing the highest weight gain in the NaOH-treated as-rolled Ni-Ti. The nodular apatite was favored on a macro-scale since the surface energy of polycrystalline apatite particles can be reduced by forming nodules. A good biomimetic apatite formation and excellent mechanical performance of Ni-Ti suggests that Ni-Ti can be an excellent candidate material as orthopedic implants.

4. References

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