Corrosion trends of Ti based Shape Memory Alloys having biomedical applications: A perspective study

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Keywords: Titanium, Shape memory alloys, Corrosion, Martensitic transformation, Shape memory effect;

Abstract:

Ti-based shape memory alloys (SMAs) have been investigated as materials for medical devices and as a biomaterial that can be implanted in a living system as an alternative of any part. The behavior of such materials is evaluated by its activity, corrosion resistance, stability and compatibility with the living body. The direction of this paper is to deliver a brief description of the trends of corrosion in these materials. Titanium (Ti) shows satisfactory resistance to corrosion in natural and acidic environment but it has a trend toward corrosion in reducing acids. The shape memory alloys based on Ti are much favorable corrosion resistant materials to use in reducing acids. Normally human body fluid is analogous to a solution of about 0.9% NaCl which has a pH value 7.4. During surgery this value can be changed, with an increase of 7.8 and then dropping it to 5.5. Later some days the standard pH value of 7.4 can be re-gained. To evaluate corrosion rate of Ti based shape memory alloys in human body fluid, 0.9% NaCl solution was used as a medium. The basics of the shape memory material i.e. the mechanisms for shape memory, the shape memory effect and characterization of the evaluation of corrosion in systems based on Ti shape memory alloy is also reviewed in this article.

Introduction:

Shape Memory Alloys:

The shape memory materials are absolutely no longer facilitate as magical aids to make money through investigation of basic research only. But it is considerable to note that such materials with discriminating functional properties like memory effect, high damping capacity, pseudo- or superelasticity, also comprising research region of mechanical engineering and chemical engineering fields. This emerging research work which includes pure physical to mechanical and chemical research regions brought this interest from laboratories to commercial areas. [1]

The shape memory alloys are astonishing material characterized by some of characteristics properties which are not present in common metals and alloys. These properties are shape memory effect and superelasticity. This exclusive behavior was discovered in Au-47.5 at% Cd alloy in 1951 and publicized by the discovery of a Ti-Ni alloy in 1963. Growing research and development field make it possible that now-a-days the shape memory alloys are used as latest functional alloys for pipe couplings, antennas for cellular phones and as different actuators in electrical devices, etc. Moreover, they have attracted intense attention as a promising candidate for smart materials, since they act as sensors as well as actuators.

In last some years (Otsuka and Wayman, 1998) shape memory alloys (SMAs) based on Nickel-Titanium (NiTi) have also utilized in various fields of medicine and engineering, and scientific communities also seem to be devoted for this purpose. In recent decades a number of publications on SMAs have been found which shows a strong attraction of researcher towards this field especially who belongs to engineering and materials science. In these reports aspects related to mechanical and functional behavior of NiTi alloys and thermo-mechanical treatment effect and micro-structure properties (Ōtsuka and Ren, 2005) have been deeply analyzed. Such results are of immense attention as functional behavior of NiTi alloys are affected by their thermomechanical history, to fabricate NiTi components, and to understand appropriate design criteria for excellent efficiency throughout organizational life.

Shape memory effect (SME) is the collective response of the two typical behaviors of thermoelastic martensites: microstructural reversibility and pseudoplasticity. Such behaviors are result of distinctive crystallographic inter-relationships revealed in microscopic study of SMAs. Although there are various alloys which show shape memory effect but NiTi are best in shape memory properties and engineering applications. In present era, a long rang of applications came in to play like medical, engineering, nuclear and space applications that fruitfully approach the marvelous biocompatibility, superelasticity, shape recovery, damping characteristics and the high recovery stress of the Ni-Ti based shape memory alloys. Such alloys are costly and comparatively not easy to manufacture. Also shape memory alloys based on Cu and Fe which are not equivalent to Ni-Ti alloys with respect to above mentioned properties, are economical as they are cheap and easily processable. Therefore such alloys are incrementally employed, when price is a main issue. [2]

Ti and Its Alloys for biomedical applications:

Biomaterials should essentially achieve the following demands:

a) Excellent resistance to corrosion

b) Appropriate host response

c) Ability to stick with host tissues for a protracted period of time

d) Suitable mechanical properties according to intended application

e) Ease in fabrication

f) Economical [3]

Ti-based alloys are mostly used in biomedical application because they have almost all the above mentioned properties to satisfactory extent [4]. Ti-based alloys also contain assorted non-hazardous elements, such as Niobium, Zirconium, Tantalum, Tin, Molybdenum and Platinum are appropriate applicants due to their excellent biocompatibility. [5]

Corrosion Behavior of Ti Alloys:

Titanium alloy has been exercised in numerous designs of modular-body stems because of its relatively low modulus of elasticity, strength, ability to get good coherence, and its resistance to corrosion. Although localized corrosion has been found at the junction among the neck taper of titanium alloy stems and cobalt-chromium alloy modular heads, the body of retrieved titanium alloy stems rarely shows evidence of accelerated corrosion, even under conditions of mechanical fretting against bone or cement. Recently, however, severe corrosion has been seen at the interface between titanium alloy stems and acrylic cement in specific stem designs [6]. In Tab. 1 the values for both repassivation time t_e and oxide growth $t_{0.05}$ are shown. Formation 0f oxide layer i.e. $t_{0.05}$ in cp-Ti and its alloys is faster as compared to other materials [10]. To prevent this oxide layer from mechanical damage, a surface coating is applied with hard layers like TiN which also improve its fretting behavior. As the maximum values of the acceleration tension are obtained via ion implantation, the utmost response and binding (compression residual stresses) likely to be happen by this process. It is investigated that ion implantation of TiN on wrought vitallium shown better corrosion behavior of the material in a 0.17M saline solution, in addition to fretting behavior. The pitting potential for the surface treated material evaluated to 1.16V, while the same material on which no surface treatment was done show a potential of 0.83V [11]. Surface layers must be thick. In case of any crack or fissures in the layer, the material will corrode with a fast rate because pH value in these crevices will be lowered. A main query arises is the requirement for a surface treatment on materials other than Ti, because implants prepared from Ti and its alloys are accessible that are usually treated by nitrogen and that additionally, as shown, offer the most excellent corrosion behavior. Investigations of ion implantation of nitrogen in titanium surfaces yield superior results with respect to the fretting behavior. The fatigue strength recorded for surface treated alloys by nitrogen ion implantation was improved due to the residual compression stresses produced by the high acceleration tension of the nitrogen ions [12]. A second way to harden the surface of Ti and its alloys without losing the corrosion resistance and the fatigue properties is a pickup of oxygen by an anodic or thermal oxidation which enhances the oxygen content on the surface of the material [13].

Metallic Biomaterials	**Breakdown potential [2] (V)**	**Repassivation time [4] (msec)**			
		t_e		**$t_{0.05}$**	
		-0.5 V	**+0.5 V**	**-0.5 V**	**+0.5 V**
FeCrNiMo (316L)	0.2-0.3	>72000	35	>>72000	>6000
CoCr (as cast)	+0.42	44.4	36	>>6000	>6000
CoNiCr (as wrought)	+0.42	35.5	41	>6000	5300
Ti-6Al-4V	+0.42	37	41	43.4	45.8
Cp-Ti	+2.4	43	44.4	47.4	49
Cp-Ta	+2.25	41	40	43	45
Cp-Nb	+2.5	47.6	43.1	47	85

Table 1. Breakdown potential, repassivation time t_e and oxide growth $t_{0.05}$ in 0.9% NaCl (pH=7.4) [14]

Bio medical applications of Ti Based SMAs having good corrosion resistance:

Many clinical applications of Ti-Ni shape memory alloy are also reported in medicine. Among many medical fields, orthopedics is one of the most attractive fields for applications of Ti-Ni shape memory alloy. Damaged bone structures can be fixed with screws. Now-a-days available joint prostheses are consisted of bone cement to be fixed in the bone. Stress on the joint prosthesis is quite intense and severe; 3-6 times the body weight of the patient under nominal action and such stress being cycled up to l06 times. Another application is the spinal bent-calibration bar (so-called Harlington bar). One of the problems with a conventional bar is the loss of elastic force after an operation; hence re-operations are necessary for calibrating the force of the bar. A Ti-Ni bar will not loose the elastic force so easily and the number of re-operations will be decreased.

Summary:

Ti based shape memory alloys (SMAs) have been investigated as materials for medical devices, and as biomaterial which can be implanted in living system as replacement of any part. The performance of such materials is measured by its activity, corrosion resistance, stability and compatibility with living body. In this paper the brief description about corrosion trends in these materials has been given. The basics of the shape memory material i.e. the mechanisms for shape memory, the shape memory effect and characterization of the evaluation of corrosion in systems based on Ti shape memory alloy is also reviewed in this paper.

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