

# Electrochemical corrosion and tribological evaluation of TiAl alloy for marine application



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## ABSTRACT

In order to evaluate the potential of the new light-weight structural TiAl alloy for marine application, the electrochemical corrosion and tribological behavior of TiAl alloy in a sea water environment have been investigated in this paper. A commercial Al 5083 marine product was selected as the control tests. The counterface materials include SiC, GCr15 steel and Hastelloy C276 alloy. TiAl alloy exhibits excellent corrosion resistance over Al 5083 alloy in sea water. The wear behavior of the two materials in sea water is sensitive to counterface materials. With GCr15 steel and C276 alloy as the mating surfaces, the wear resistance of TiAl alloy is significantly superior to that of Al 5083 alloy in sea water.

## 1. Introduction

Today, the demand for energy-efficiency and high performance for offshore structures and marine industry drives the material choice move toward light-weight, high strength and excellent corrosion resistance in sea water [1,2]. Titanium alloys that can meet these requirements are considered to be one of the most promising materials for marine application [3–5]. But in practical application, one problem with the use of conventional titanium alloys like Ti6Al4V is the severe wear in either dry-sliding or lubrication condition [6–8]. When exposed to the sea water environment, they are not immune to combined corrosion and wear attacks. Although protective passive films with a thickness of 3–5 μm readily form on the surface of titanium alloy in sea water, they are too thin to resist the shear stress and removed quickly, accelerating the metal dissolution and wear [9]. Compared to titanium alloys, gamma titanium aluminides known as a new generation of light-weight structural material can offer better creep, superior strength at high temperatures and the increased wear resistance [7,10,11]. The combination of these advantages will push TiAl alloy to be used in automotive, aerospace and marine industries. In recent years, a great interest has been attracted to evaluate and improve the high temperature properties of TiAl alloy for application in aerospace and automotive components [12]. However, there are few literature available with respect to the corrosion and tribological behavior of TiAl alloy in sea water, which may be the requisite factor in an attempt towards employing them in a marine environment.

In addition, material wear in a corrosion environment is highly complex as it is resulting from the synergistic action of corrosion and mechanical wear, which is also highly dependent on material properties, tribo-chemistry and counterface selection [13–16]. An improved understanding of these issues and how they influence the wear of TiAl alloy in sea water are important to minimize material degradation and make sure the service safety of TiAl component.

Therefore, in this article, a Ti-46Al-2Cr-2Nb alloy is selected to investigate the corrosion resistance and tribological behavior in artificial sea water by sliding it against different couple balls involving SiC, GCr15 steel and Hastelloy C276 alloy. Simultaneously, surface tribo-chemistry during the sliding and the properties of counterface materials are evaluated and related to the tribological dissimilarities.

## 2. Experimental procedures

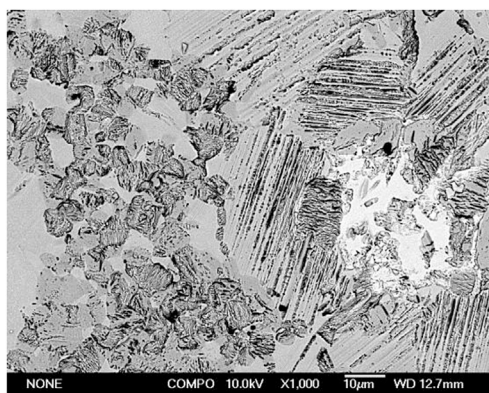
### 2.1. Material preparation

The Ti-46Al-2Cr-2Nb alloy usage has been prepared by powder metallurgy technique in our laboratory, the fabrication details have been described elsewhere [17]. In brief, this alloy contains a duplex structure and its mechanical properties are comparable to a vacuum casting Ti-41.7Al-8.3Nb-0.09Y alloy, as shown in Fig. 1. Before the electrochemical and tribological tests, the alloy samples were machined into the rectangle block with the size of 18.5 × 18.5 × 3 mm and then polished to

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Materials	Hardness (GPa)	Bending strength (MPa)	Compressive Strength (MPa)	Density (g/cm <sup>3</sup> )
Ti-46Al-2Cr-2Nb	3.65	563	1512	4.02
Ti-41.7Al-8.3Nb-0.09Y	3.85	565	1916	4.32

Fig. 1. Backscattered SEM image showing the microstructure of experimental Ti-46Al-2Cr-2Nb alloy and its mechanical properties compared to Ti-41.7Al-8.3Nb-0.09Y alloy [17].

the roughness of 0.2 µm.

### 2.2. Electrochemical characterization

The corrosion behavior of Ti-46Al-2Cr-2Nb alloy in artificial sea water at room temperature was evaluated utilizing the methods of the open circuit potential (OCP), electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization. The testes were performed on an electrochemical work station Reference 3000 (Gamry, American). Table 1 lists the composition (g/L) of the artificial sea water solution. The duration time of OCP measurement was 1 h starting from the test. After 60 min of stabilization time at OCP, EIS data acquisition involving Bode and Nyquist plots began to be conducted. The frequency ranged from 10<sup>5</sup> Hz to 0.01 Hz with 10 points per frequency decade and the amplitude AC voltage signal was 5 mV. Gamry echem analyst software was employed to analyze and fit the impedance data to equivalent electrical circuit by simplex method. The potentiodynamic polarization curve in the range from -6.32 V to 6.73 V was obtained with a scan rate of 0.5 mV/s. Tafel fit analyses of polarization curve were carried out to determine corrosion potential (E<sub>corr</sub>), corrosion current (i<sub>corr</sub>) and corrosion rate. For comparison purpose, electrochemical properties of a commercial Al 5083 alloy were characterized utilizing the same experimental parameters.

### 2.3. Tribological tests

Tribological behavior of the Ti-46Al-2Cr-2Nb alloy in sea water was investigated on a reciprocating tribo-meter with a ball-on-disc configuration. In order to evaluate the effect of the counterface materials, the couple balls were selected as SiC, GCr15 steel and Hastelloy C276 alloy, respectively. The Vickers hardness of the couple balls provided by the manufacturer was listed in Table 2. The sliding speed was fixed at 0.1 m/s and the applied load was increased from 20 N to 60 N. For the test time and sliding amplitude, the values were 30 min and 5 mm respectively. Before the tests, the samples and the couple balls were attached to the experimental instrument and the artificial sea water was poured into the experimental cell. The friction coefficient was recorded by the equipment during the tests. The wear rate was calculated as wear volume divided by applied load and sliding distance. The wear volume was the result of the area of wear scar multiplied by amplitude. The areas of wear scar (mm<sup>2</sup>) were measured by a contact profilometer using the integral method. To make sure the reliability of the data, each friction test was repeated three times and the average values were reported herein. After the tests, the

Table 1  
Composition of the artificial sea water solution (g/L).

Compound	MgCl <sub>2</sub>	CaCl <sub>2</sub>	SrCl <sub>2</sub>	KCl	NaHCO <sub>3</sub>	KBr	NaF	NaCl	Na <sub>2</sub> SO <sub>4</sub>	H <sub>3</sub> BO <sub>3</sub>
Concentration	5.200	1.160	0.025	0.695	0.201	0.101	0.003	24.530	4.090	0.027

worn surface morphologies and composition were examined on a scanning electron scope equipped with an energy dispersive spectrometer (JSM-6700F). The measurements of tribo-chemistry reactions were performed on an X-ray photoelectron spectroscopy (ESCALAB 250Xi). Also, the friction and wear tests of Al 5083 alloy were performed under the identical conditions.

## 3. Results and discussion

### 3.1. Electrochemical behavior of Ti-46Al-2Cr-2Nb alloy

Fig. 2 shows the open circuit potential (E<sub>OCP</sub>) as a function of time for Ti-46Al-2Cr-2Nb and Al 5083 alloys in sea water. From the Fig. 2a, an increase in the E<sub>OCP</sub> with the immersion time for Ti-46Al-2Cr-2Nb alloy may be the consequence of a protective, adherent and stable oxide film formed on the alloy surface [18,19]. Overall, the shift of E<sub>OCP</sub> in the positive direction is also evident for Al 5083 alloy (Fig. 2b). But there are some sudden and marked drops in the E<sub>OCP</sub> over the immerse time. This indicates that oxide (passive) film is formed on Al 5083 alloy surface, but which is thin, non-uniform, non-coherent and easily breaks down at specific points, resulting in the pits on the alloy surfaces [20].

Fig. 3 shows the potentiodynamic polarization curves for Ti-46Al-2Cr-2Nb and Al 5083 alloys in artificial sea water. The corrosion potential (E<sub>corr</sub>), corrosion current (i<sub>corr</sub>) and corrosion rate calculated from the polarization curves by Tafel analysis are listed in Table 3. Compared to Al 5083 marine product, Ti-46Al-2Cr-2Nb alloy exhibits the higher corrosion potential, about 20 times lower corrosion current and rate.

Fig. 4 shows the Nyquist and Bode diagrams of impedance spectra obtained in artificial sea water for Ti-46Al-2Cr-2Nb alloy and the corresponding fit results. According to references [21–23], the largest diameter of the semi-circle in the Nyquist plot reflects the highest corrosion resistance of the tested samples possibly. From this viewpoint, TiAl alloy has good corrosion resistance in artificial sea water (Fig. 4a). The high impedance module (Z<sub>mod</sub>) and the large phase angle in the Bode diagram (Fig. 4b) also confirm this point. In addition, the phase angle close to -85° over a low and middle frequency range illustrates the high capacitive behavior of Ti-46Al-2Cr-2Nb alloy and the formation of a compacted oxide film on the alloy surface.

Fig. 5 shows the equivalent electrical circuit model fitted to the EIS data for Ti-46Al-2Cr-2Nb alloy. It is seen that the impedance data for Ti-46Al-2Cr-2Nb alloy can be simulated adequately by a simple CPE couple on Gamry Echem Analyst software (Version 4.0) and the goodness of fit is 8.155 × 10<sup>-5</sup>. The equivalent electrical circuit is composed of electrolyte resistance (R<sub>u</sub>) in series with oxide film resistance (R<sub>p</sub>) and constant phase element (CPE), which is representative of the non-ideal capacitance of the oxide film [22]. It is noted that CPE involves two parameters such as admittance (Y<sub>0</sub>) and no unit (alpha). Table 4 lists the parameters of the fit results. Notably, the polarization resistance R<sub>p</sub> is as high as 6.19 MΩ cm<sup>2</sup>.

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