Corrosion behavior and mechanical properties of duplex coating Ti6Al4V/TiAlBN

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ABSTRACT – Duplex coating of Ti6Al4V alloy was conducted with the aim of improving the corrosion resistance and mechanical properties of the alloy. In this study, plasma nitriding of Ti6Al4V was performed using a microwave plasma technique at 600ºC for 1 and 3 hours, then followed by deposition of TiAlBN for duplex coating purposes. Microstructural analysis revealed that the duplex coating process produces a relatively smooth and crack free modified surface layer which is believed able to inhibit the occurrence of corrosion process. The duplex surface obtained has superior surface hardness property, especially for samples with the longer nitriding time.

1. INTRODUCTION

Titanium and its alloys, especially Ti6Al4V has been used in many industries such as aerospace applications, chemistry, marine and automotive applications. Besides, Ti6Al4V alloy has begun to be used as a surgical implant material on account of their biocompatibility and mechanical compatibility [1]. However, wear and the resulting debris generated in total joint replacement was found to be a significant problem, which lead to the discontinuation of the use of Ti6Al4V for bearing surfaces and it is commonly believed due to the poor tribomechanical properties and corrosion resistance [2]. Since the corrosion resistance of titanium alloys depends very much on the properties of the surface layer, the surface modification process could provide a virtuous solution for surface properties enhancement. Therefore, much work has been done to improve the surface properties of Ti6Al4V including ion implantation techniques [3] plasma method [4] laser method [5], thermodiffusion treatment [6] and etc. Among these methods, laser treatment is promising and gaining much attention in the surface property improvement of medical implant. However, a work reveals that numerous surface cracks were formed in the surface of the laser- treated material, therefore a large corrosion current was expected [7]. Therefore, duplex coating concept was introduced. The duplex surface treatment has received considerable attention, since it improves considerably the adhesion between the coating and substrate [8]. The aim of this study, is to investigate the possibility of depositing TiAlBN coatings on Ti6Al4V alloy via a Duplex coating process as a corrosion resistance and mechanical properties enhancement for Ti6Al4V alloy.

2. METHODOLOGY

A commercial Ti6Al4V alloy was used as the substrate material. The plasma nitriding process is conducted using microwave equipment. The substrates are then heated to the required temperature (600ºC) and nitrogen along with argon gas is introduced into the microwave source to produce plasma. The flow rates of gas mixtures were set at 25% (Ar) : 75% (N_2). The nitriding time is performed for 1 hour and 3 hours. For the deposition of TiAlBN coating onto the plasma nitrided substrates is done using Radio Frequency (RF) magnetron sputtering system on the similar condition of process parameters in order to achieve the equivalent coating thickness of about 2 µm. The morphology of the coated samples was observed using Scanning Electron Microscope (SEM) and the surface hardness was determined using microhardness Vickers at load of 0.1kgs. For electrochemical test, the corrosion rate was determined using the Tafel extrapolation method in 2M NaCl solution. The collected data were analyzed using Gamry Instrument software to deduce the corrosion rate, corrosion current (I_{corr}) and corrosion potential (E_{corr}).

3. RESULTS AND DISCUSSION

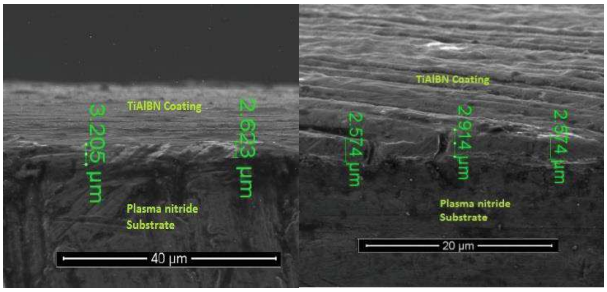
3.1 Microstructural Analysis

Figure 1 shows the thickness obtained for duplex coating TiAlBN on plasma nitride Ti6Al4V substrate at different plasma nitriding time. The thickness range of TiAlBN on substrate nitride at 600ºC 1hour is 2.623µm to 3.205µm while the thickness range of TiAlBN on substrate nitride at 600ºC 3 hours is 2.574 µm to 2.914 µm. It is also observed that utilizing the duplex coating technique produces a relatively smooth and crack free modified surface layer which is believed able to inhibit the occurrence of corrosion process and improve the surface mechanical properties [2].

3.2 Surface Hardness Analysis

The surface hardness of Duplex coating samples was found to be higher as compared to the Ti6Al4V untreated (Figure 2). The highest surface hardness (682.27 $HV_{0.1}$) is obtained in sample duplex coating

with plasma nitriding process for 3 hours. This means that major increment on the surface hardness is due to the deposition of TiAlBN and plasma nitriding process prior to the Ti6Al4V sample. Diffusion of nitrogen into Ti6Al4V samples believes to produce higher case depth which improves the load carrying capacity coating-substrate system and the overall hardness property of the system [8].



(a) (b)

Figure 1 SEM micrograph of the (a) TiAlBN duplex sample with 1 hour plasma nitriding treatment (b) TiAlBN duplex sample with 3 hours plasma nitriding treatment.

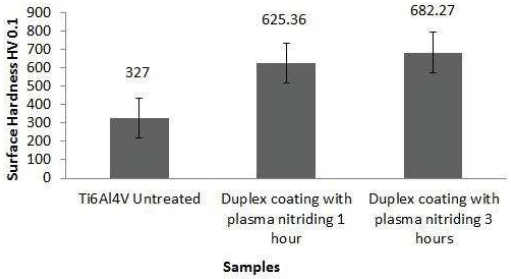


Figure 2 The surface hardness results of the Ti6Al4V untreated and Duplex coating samples at various plasma nitriding times.

3.3 Corrosion Rate Analysis

Table 1 shows the values of the corrosion rate, corrosion current (I_{corr}) and corrosion potential (E_{corr}) value of the various samples after the corrosion test by using the 2M NaCl solution. It was observed that the value of corrosion rate and corrosion current (I_{corr}) decreases for the sample of duplex coated. While, the value of corrosion rate for the untreated Ti6Al4V is the highest compared to the samples with the duplex treatment process. The result shows that by applying the duplex surface treatment on the Ti6Al4V improves the corrosion resistance of the alloy. It is also believed that the improvement in corrosion resistance was contributed by the TiAlBN nanocomposite coating [9].

4. CONCLUSION

It has been observed that the duplex coating process has a major influence on the corrosion resistance and mechanical properties of Ti6Al4V alloy. It is observed that the duplex coating process is able to produce a relatively smooth and crack free modified surface layer. Besides, the duplex coating process significantly improved the corrosion resistance and mechanical properties of titanium alloy. The improvement is considered to be primarily due to the TiAlBN precipitates acting as corrosion protection.

Table 1 The value of corrosion rate, I_{corr}, and E_{corr} for duplex samples and Ti6Al4V untreated.

Samples	**Duplex samples - Plasma Nitriding 1 hour**	**Duplex samples - Plasma Nitriding 3 hours**	**Ti6Al4V Untreated**
Corrosion rate (mpy)	1.436 x 10^{-6}	7.360 x 10^{-6}	7.919x10^{-3}
I_{corr} (mA/cm^2)	5.316 x 10^{-8}	8.285 x 10^{-9}	7.74x10^{-5}
E_{corr} (mV)	-0.240	-0.140	-0.906

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