Tribological and Corrosion Characteristics of Ti6Al4V Coatings Cold Sprayed with Nitrogen and Helium Propellant Gases

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Abstract. The tribological and corrosion characteristics of Ti6Al4V coatings on Ti6Al4V substrates with nitrogen (N₂) and helium (He) propellant gases cold sprayed via a high pressure cold spray process were investigated because different masses of the N₂ and He working gases could affect the velocities of Ti6Al4V particles during the cold spraying and consequently the properties of the coatings. The more uniform and denser structure of the Ti6Al4V coatings with a lower porosity level was achieved with He working gas. As a result, the Ti6Al4V coatings deposited with the He working gas had a higher hardness than those deposited with the N₂ working gas. The tribological results showed that the use of He gas during the cold spraying produced the more wear resistant Ti6Al4V coatings associated with their higher hardness. The denser Ti6Al4V coatings deposited with the He gas had a lower anodic current density in a NaCl solution than those deposited with the N₂ working gas. It is clear that the wear and corrosion resistances of the Ti6Al4V coatings were significantly influenced by the propellant gases during the cold spray deposition.

Introduction

Ti6Al4V alloy is the most widely used titanium alloy for aerospace applications due to its light weight and high strength [1]. The cold spray process is a newly developed coating technique which accelerates powder particles to supersonic speeds in a carrier gas such as nitrogen or helium. Upon impact with a target substrate, the particles plastically deform and adhere to the surface. Subsequent layers are then deposited to build up a coating [2].

Traditionally, thermal spray and welding have been widely used to repair damaged aerospace components. However, many metallic materials are very prone to oxidation, many substrate materials cannot tolerate high temperatures, and many thermal sprayed coatings are subject to high thermal stresses and contain high levels of porosities [3-5]. Thanks to low temperature input during cold spray process, the cold sprayed coatings are free from phase transition, oxides, inclusions and thermal residual stress [6].

The tribological and corrosion properties of the cold sprayed coating were influenced by cold spray process parameters, such as the carrier gas used. In this study, cold sprayed Ti6Al4V coatings were deposited by N₂ and Helium carrier gas. Their tribological and corrosion behaviors were investigated.
Experimental Details

Preparation of Samples

The powder used for this study was Ti6Al4V with a size distribution of 0~45 µm, which was produced via plasma atomization (AP&C, Canada). The substrates used for this study was Ti6Al4V bulk material. The PCS-1000 cold spray system was used for the cold spray deposition by using He and N2 carrier gas at 950 °C and 5MPa.

Coating Characterization

The microstructure of the samples was observed by AXIOSKOP 2 MAT optical microscope equipment. Image J software was used to analyze the porosity levels of the cold sprayed Ti6Al4V coatings. Micro-hardness tester (FM 300e) was used to measure the surface hardness of Ti6Al4V coatings under a load of 200g. Each sample was measured at ten random locations to get the average value.

Tribology Testing

The cold sprayed Ti6Al4V coatings using He and N2 as working gas were used for tribology test. The samples were polished and ultrasonically rinsed with in ethanol. The CSM tribometer was used to test the friction coefficient and specific wear rate of the Ti6Al4V coatings. A diameter of 6mm ceramic ball was used as the counter face materials under a normal load of 1N. The linear speed of the rotating ball was 4cm/s with a radius of 1 mm. The wear test was terminated after 30000 laps. After wear test, the wear tracks were measured by surface profilometry (Talyscan 150).

Corrosion Testing

The cold sprayed Ti6Al4V coatings using He and N2 as working gas were also used for corrosion test. The samples were cut into square shaped and polished. The samples will be mounted onto the exposed area of the flat cell where the surface of the sample will be exposed to the corroding solution. GAMRY (Interface 1000) workstation was used to carry out the measurement of potentiodynamic polarization. A flat cell kit was setup with three electrodes, namely platinum mesh as counter electrode, Ag/AgCl as the reference electrode and a working electrode. Open Circuit Potential and Potential Dynamic were performed for both cold spray N2 and He working gas samples. The corroding solution was NaCl solution with a concentration of 0.6 molarity.

Results and Discussions

Figure 1a and Figure 1b show the microstructures of cold spray coating with He working gas and N2 working gas, respectively. It can be clearly seen that the coating deposited by using He working gas is much denser and with less micropores than the coating deposited by using N2 working gas. By using the Image J software, the porosity of Ti6Al4V coating deposited by using N2 was 11.48% which was much higher than the porosity level of Ti6Al4V coating deposited by using He (4.86%). Besides, there was no sign of decimation between substrate and coating by using He as working gas, which indicated that the bonding between coating and substrate was high. However, there were continuous micropores at the interface between substrate and coating by using N2 as working gas which hinted that the bonding between coating and substrate was poor.

Figure 2a shows the microhardnesses of Ti6Al4V coatings sprayed by using He gas and N2 gas. It can be clearly seen that the Ti6Al4V coating sprayed by using He gas obtain higher microhardness (394.7±20 HV) than the Ti6Al4V coating sprayed by using N2 gas. Figure 2b shows the graph of friction coefficients of the Ti6Al4V coatings sprayed by using He gas and N2 gas. The Ti6Al4V coating deposited by He working gas has lower friction coefficient and higher wear resistance due to its high hardness [7-9]. Both graphs in Figure 2b showed a stable friction during the process of sliding and this is due to their stable wear.
Figure 1. Microstructures of Ti6Al4V coatings deposited by using: (a) He working gas and (b) N2 working gas.

Figure 2. Microhardnesses (a) and friction coefficients (b) of the Ti6Al4V coatings sprayed by using He gas and N2 gas.

Figure 3 shows the surface topologies of the wear tracks of Ti6Al4V coatings using He and N2 working gas. The volume removed from the Ti6Al4V coatings for both He and N2 gases are $7.23 \times 10^{-12}$ m$^3$ and $8.77 \times 10^{-12}$ m$^3$. By calculation, we can get the specific wear rate of Ti6Al4V coatings sprayed with He and N2 working gases is $103 \times 10^{-14}$ m$^3$/Nm and $122 \times 10^{-14}$ m$^3$/Nm respectively, which indicated that the Ti6Al4V coatings sprayed with He has higher wear resistance than Ti6Al4V coatings sprayed with N2 due to its lower friction.

Figure 4 shows the potentiodynamic polarization curves of the Ti6Al4V coatings using He and N2 working gas. To compare between both Ti6Al4V coatings with He and N2 working gas, Ti6Al4V coating deposited by N2 working gas has higher $i_{corr}$ than Ti6Al4V coating deposited by He working gas. The reason is because Ti6Al4V coating deposited by N2 working gas has more pores which will have larger exposed area and higher anodic dissolution in NaCl solution [10].
Another evident that can be determined on the anodic dissolution rate of the Ti6Al4V coatings by observing the steepness of the polarization curve under anodic region [11]. Through estimation, the gradients of the polarization curve dissolution rate of the Ti6Al4V coatings with He and N2 working gas are $3.8 \times 10^{-6}$ and $1.7 \times 10^{4}$ respectively, which can be deduced that Ti6Al4V coating deposited by N2 working gas has lower anodic dissolution.

![Figure 4. Potentiodynamic polarization curves of the Ti6Al4V coatings using He and N2 working gas.](image)

**Conclusions**

The Ti6Al4V coatings were successfully deposited onto Ti6Al4V substrates by using He and N2 working gas. Microstructures of Ti6Al4V coatings were observed by optical microscope. The Ti6Al4V coating deposited by N2 working gas displays higher porosity and lower bonding strength compared with Ti6Al4V coating deposited by He working gas. The tribological results showed that the use of He gas during the cold spraying produced the more wear resistant Ti6Al4V coatings associated with their higher hardness. The denser Ti6Al4V coatings deposited with the He gas had a lower anodic current density in a NaCl solution than those deposited with the N2 working gas. It is clear that the wear and corrosion resistances of the Ti6Al4V coatings were significantly influenced by the propellant gases during the cold spray deposition.

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