MICROSTRUCTURE AND CORROSION RESISTANCE OF NITRIDED TITANIUM ALLOY FABRICATED BY SELECTIVE LASER MELTING

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The present study explores the potential of gas nitriding as a method to enhance the wear and corrosion resistance of 3D-printed titanium alloys for improving the durability and performance of these materials in various applications. 3D-printed titanium alloy (Ti6Al4V) via the selective laser melting (SLM) method, was selected for this purpose. Gas nitriding was carried out at temperatures ranging 650...800°C for 10 hours under atmospheric pressure. It has been shown that a hardened surface layer is formed when nitrogen interacts with a titanium alloy during gas nitriding. This layer consists of an upper compound layer of TiN and Ti_2N, and an underlying diffusion zone. As the treatment temperature increases, both the surface microhardness and the depth of the hardened nitride layer increase. And finally, such hardened nitride layers allow for several times improvement in the corrosion resistance of SLM titanium alloy.

Keywords: titanium alloy, 3D-printing, selective laser melting, nitriding, corrosion resistance

The use of additive manufacturing (AM) to produce titanium alloys, particularly Ti-6Al-4V, is becoming increasingly popular. This is due to its ability to significantly improve the buy-sell (buy-to-fly) ratio, reduce material waste and lower the cost of producing complex geometries, as well as enabling rapid design iteration. Advantages of AM over traditional forging include minimal waste (AM powder can be reused), the production of complex internal structures and shorter lead times for small production runs. AM also enables the fabrication of metal matrix composites and graded structures. However, AM of Ti-6Al-4V typically exhibits microstructural features and defects that can reduce its corrosion resistance compared to conventional forging. These include a martensitic α′-microstructure resulting from rapid solidification, as well as residual stresses, anisotropy, porosity, interconnected defects and surface roughness. Post-structural treatment is therefore recommended to transform the metastable α′ microstructure into a more stable α+β microstructure, relieve residual stresses, close pores, and improve corrosion characteristics. This study proposes performing gas nitriding as a post-treatment, which will have a dual effect. Firstly, a corrosion-resistant surface nitride layer will be formed. Secondly, the metastable structure of the alloy matrix will be transformed due to thermal effect.

The study aims to quantitatively assess the effect of different temperature regimes on surface hardening and microstructure levels, and to examine the impact of these changes on the corrosion resistance of AM Ti-6Al-4V alloy.

Methods. The AM Ti6Al4V (Ti64) alloy was purchased from 3D Metal Tech LLC (Ukraine). The AM was conducted using the selective laser melting (SLM) method. A gas nitriding was carried out on a furnace developed and manufactured at the Karpenko Physico-Mechanical Institute of the NAS of Ukraine. Two conventional nitriding regimes were selected for investigation: isothermal low-temperature (650°C) and high-temperature (800°C) gas nitriding for 10 hours.

Results and discussion. XRD analysis shows that a nitride compound layer consisting of the lower valence nitride Ti_2N and the mononitride TiN is formed on the surface of the titanium alloy, regardless of the manufacturing technology. As the temperature increases from 650°C to 800°C, the intensity of the nitride phase lines increases. Metallographic analysis has shown that the thickness of the nitride layer increases from 1 to 5 µm as the temperature rises. The intensity of the nitriding, including the formation of nitrides and gas saturation, also affects the level of surface hardening, depending on the temperature regime, as confirmed by durometric analysis. The surface microhardness of the alloy is set at ~4.0 GPa prior to nitriding, regardless of the structural state. After nitriding, the surface microhardness increases by approximately 1.5–3 times. The greatest increase in surface microhardness was observed in the alloy following high-temperature nitriding (~13 GPa).

Gravimetric (immersion) tests have shown that forming a nitride layer on the surface of titanium alloys significantly improves their corrosion resistance. Increasing the nitriding temperature tends to improve corrosion resistance, as this results in a thicker nitride layer forming. It should be noted that nitriding can reduce the corrosion rate of the AM alloy by several orders of magnitude. For instance, high-temperature nitriding decreases the corrosion rate of the AM alloy by approximately one order of magnitude (from 20 to 3 $g/cm^2 \cdot h$).

Conclusions. Thus, nitriding is an effective method of improving the corrosion resistance of 3D-printed titanium alloys. Compared to post-heat treatment, which brings the corrosion resistance of 3D-printed alloys closer to that of wrought alloys, nitriding improves corrosion resistance by an order of magnitude, that significantly expanding the range of applications for these alloys.

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1. *Srivastava M., Jayakumar V., Udayan Y., Sathishkumar M., Muthu S.M., Gautam P., Nag A., Additive manufacturing of titanium alloy for aerospace applications: Insights into the process, microstructure, and mechanical properties // Appl. Mater. Today. – 2024. – 41. – №102581.* https://doi.org/10.1016/j.apmt.2024.102481