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Preliminary Results of Surface Hardening of Ti-6Al-4V via DC Plasma Nitriding Using PECVD: Implications for Medical Implants

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ABSTRACT

Introduction: Increasing demand for high-performance materials in the medical field, particularly for implants, has prompted significant advancements in surface engineering techniques. Among the various materials used for medical implants, titanium alloys, especially Ti-6Al-4V, have garnered widespread attention due to their excellent mechanical properties, corrosion resistance, and biocompatibility. However, the wear resistance and fatigue strength of Ti-6Al-4V can be limited under certain conditions, particularly in demanding applications such as joint replacements and dental implants. Plasma nitriding, a surface modification technique, has emerged as a promising method to enhance the surface properties of titanium alloys. This technique involves the introduction of nitrogen ions into the material's surface under a controlled plasma environment, resulting in the formation of a hard, wear-resistant nitrided layer. Plasma nitriding not only improves the mechanical performance of Ti-6Al-4V but can also modify its surface chemistry and microstructure to better suit the requirements of medical implants, where long-term durability and bioactivity are crucial. This paper investigates the effect of plasma nitriding on the surface characteristics of Ti-6Al-4V, focusing on the enhancement of hardness which is a critical factor for the performance of medical implants.

Materials and Methods: Commercially available Ti-6Al-4V alloy (grade 5) samples were used as the substrate material. The samples were cut into $20 \times 20 \times 3$ mm, and then each of them was ground using 800, 1000, 1200, and 2500-grit SiC paper carefully and then polished by using $1 \mu\text{m}$ Al₂O₃ pastes before nitriding. Prior to plasma nitriding, all samples were ultrasonically cleaned in acetone, ethanol, and deionized water to remove surface contaminants.

Results and Discussion: Results demonstrated that plasma nitriding using PECVD effectively enhances the surface properties of Ti-6Al-4V alloy by forming a hard titanium nitride. The formation of TiN and Ti₂N phases is crucial for improving mechanical properties, as these nitrides exhibit high hardness and chemical stability. The increased surface hardness translates to better wear performance, reducing implant wear debris generation—a key factor in implant longevity and biocompatibility. These improvements suggest plasma nitriding by PECVD is a promising surface treatment for enhancing the service life of Ti-6Al-4V biomedical implants. Future studies could focus on optimizing process parameters further, evaluating fatigue performance, wear resistance and conducting in vitro/in vivo biocompatibility assessments to fully establish the clinical potential of nitrided Ti-6Al-4V.

Conclusion: Plasma nitriding of Ti-6Al-4V alloy using a PECVD system significantly enhances the surface hardness by forming a uniform, hard titanium nitride layer without compromising corrosion resistance. The formation of TiN and Ti₂N phases and a well-developed diffusion zone contribute to the improved mechanical and tribological properties essential for medical implant applications. This surface modification method shows great promise for extending the lifespan and reliability of Ti-6Al-4V-based biomedical devices. Further research into optimizing nitriding parameters and comprehensive biocompatibility testing is recommended to advance clinical adoption.



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Keywords: ¹³¹Cs balloon brachytherapy, Cold atmospheric plasma, COMSOL multiphysics, GBM, MCNPx simulation, Plasma-based radiosensitization

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