Engineering of a Novel Spark Plasma Sintered Ti–Zr–Fe Alloy as a Safer Biomedical Implant Alloy

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Titanium alloys are widely used in biomedical implants due to their high strength-to-weight ratio, corrosion resistance, and biocompatibility. However, the standard Ti–6Al–4V alloy contains aluminum and vanadium, which present cytotoxic risks during long-term implantation. This study investigates a safer, economical titanium alloy by substituting these toxic elements with biocompatible zirconium and cost-effective ß-stabilizing iron. A novel Ti–2Zr–1.5Fe alloy was designed using the CALPHAD approach. Experimental procedures included high-energy ball milling for 6 hours, consolidation via Spark Plasma Sintering (SPS) at 900 °C and 1000 °C, followed by microstructural, mechanical, and biological evaluations. XRD verified that ball milling induced solid-solution formation matching the CALPHAD-optimized composition prior to SPS. Increasing the sintering temperature enhanced densification, achieving ~99% theoretical density at 1000 °C compared to ~95% at 900 °C. Microstructural examination of the 1000 °C sample revealed a homogeneous a+ß dual-phase structure with complete elemental diffusion, agreeing with CALPHAD predictions, whereas 900 °C caused zirconium segregation. The 1000 °C alloy achieved a hardness of ~520 HV, exceeding Ti–6Al–4V (~450 HV) via solid-solution strengthening. Biological testing confirmed acceptable cytocompatibility (cell viability >70%, ISO 10993-5) and demonstrated P. aeruginosa growth inhibition. Integrating CALPHAD-guided design with SPS provides a viable pathway via improved mechanical performance, antibacterial activity, strong cytocompatibility, and a ~28% raw-material cost reduction. Ti–2Zr–1.5Fe is a promising candidate for next-generation biomedical implants due to its optimal balance of safety, superior hardness, and economic viability.

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