Influence of processing-induced changes on the performance of Ti-based alloy in biological systems

Uticaj promena izazvanih procesnim postupcima na performanse Ti-legure u biološkim sistemima

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Abstract

This work explores the impact of high-pressure torsion (HPT) and laser surface modification on the microstructure, surface features, mechanical properties, corrosion resistance, and biological response of the Ti-45Nb (mass%) alloy, considering its potential for biomedical application. HPT processing resulted in significant grain refinement, producing an ultrafine-grained alloy. Microstructural characterization revealed two phases, β-Ti and Ti_4Nb, present in both the coarse- and ultrafine-grained alloy microstructures, consistent with theoretical investigations. Subsequently, laser scanning of the Ti-45Nb alloy in both microstructural states produced uniform linear surface micropatterns accompanied by changes in surface chemistry (increased oxygen content and oxide layer formation) and surface topography (increased surface roughness). Mechanical testing showed that the elastic modulus, hardness, and plasticity increased in both microstructural variants after laser surface modification, with higher values observed in the ultrafine-grained alloy. Additionally, theoretical investigations confirmed these findings and highlighted the impact of both structural and surface modifications on the alloy's mechanical behavior. Furthermore, corrosion testing demonstrated that all alloy samples exhibited high corrosion resistance, which was attributed to the formation of a dual-layer oxide film. The ultrafine-grained alloy developed a thicker inner barrier layer, whereas the coarse-grained alloy exhibited a thicker outer porous layer. Specifically, the best corrosion resistance was observed in the coarse-grained alloy prior to laser modification and in the ultrafine-grained alloy following laser modification. Finally, biological tests confirmed excellent cytocompatibility of the alloy in both microstructural states, before and after surface modification. In vitro tests further showed that laser surface modification enhances the attachment, adhesion, and proliferation of fibroblast cells on all alloy sample surfaces, indicating excellent biocompatibility, especially pronounced in the ultrafine-grained alloy. Overall, the combined influence of microstructural and surface modifications significantly enhanced the Ti-45Nb alloy's performance, highlighting its strong potential for application in biological systems.

Keywords: *Ti-45Nb alloy; high-pressure torsion; laser surface modification; mechanical properties; corrosion resistance; biocompatibility*

Izvod

Ovaj rad istražuje uticaj postupka uvijanjanja pod visokim pritiskom (HPT) i laserske površinske modifikacije na njenu mikrostrukturu, površinske karakteristike, mehanička svojstva, otpornost prema koroziji i biološki odgovor Ti-45Nb (mas.%) legure, uzimajući u obzir njen potencijal za

primenu u biomedicini. Primena HPT procesa rezultirala je značajnom rafinacijom zrna, pri čemu je formirana sitnozrna legura. Mikrostrukturna karakterizacija otkrila je prisustvo dve faze, β-Ti i Ti_4Nb, u mikrostrukturama krupnozrne i sitnozrne legure, u skladu s teorijskim istraživanjima. Nakon toga, lasersko skeniranje Ti-45Nb legure u oba mikrostrukturna stanja proizvelo je uniformne linearne površinske mikroobrazce, uz promene u hemijskom sastavu površine (povećan sadržaj kiseonika i formiranje oksidnog sloja) i topografiji površine (povećana hrapavost). Mehanička ispitivanja pokazala su da su se vrednosti modula elastičnosti, tvrdoće i plastičnosti povećale kod obe mikrostrukturne varijante nakon laserske površinske modifikacije, pri čemu su veće vrednosti zabeležene kod sitnozrne legure. Takođe, teorijsko istraživanje potvrdilo je ove rezultate, ukazujući na uticaj i strukturnih i površinskih modifikacija na mehaničko ponašanje legure. Pored toga, ispitivanja korozije pokazala su da se svi uzorci legure odlikuju visokom otpornošću prema koroziji, što se pripisuje formiranju dvoslojnog oksidnog filma. Sitnozrna legura se odlikuje debljim unutrašnjim barijernim slojem, dok je krupnozrna legura pokazala deblji spoljašnji porozni sloj. Konkretno, najveća otpornost prema koroziji primećena je kod krupnozrne legure pre laserske modifikacije, odnosno kod sitnozrne legure nakon laserske modifikacije. Na kraju, biološki testovi potvrdili su odličnu citokompatibilnost legure u oba mikrostrukturna stanja i pre i nakon površinske modifikacije. In vitro ispitivanja su dodatno pokazala da laserska modifikacija površine poboljšava vezivanje, adheziju i proliferaciju fibroblastnih ćelija na površinama svih uzoraka legure, što ukazuje na izvanrednu biokompatibilnost, pri čemu je ovaj efekat najizraženiji kod sitnozrne legure. U celini, kombinovani uticaj mikrostrukturne i površinske modifikacije značajno je poboljšao ponašanje Ti-45Nb legure, ističući njen veliki potencijal za primenu u biološkim sistemima.

Ključne reči: *Ti-45Nb legura; uvijanje pod visokim pritiskom; laserska modifikacija površine; mehanička svojstva; otpornost prema koroziji; biokompatibilnost*

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