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Research paper

Microstructure and mechanical properties of open-cellular biomaterials prototypes for total knee replacement implants fabricated by electron beam melting

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ARTICLE INFO

Article history:
Received 11 February 2011
Received in revised form
14 April 2011
Accepted 6 May 2011
Published online 12 May 2011

ABSTRACT

Total knee replacement implants consisting of a Co–29Cr–6Mo alloy femoral component and a Ti–6Al–4V tibial component are the basis for the additive manufacturing of novel solid, mesh, and foam monoliths using electron beam melting (EBM). Ti–6Al–4V solid prototype microstructures were primarily α-phase acicular platelets while the mesh and foam structures were characterized by α'-martensite with some residual α. The Co–29Cr–6Mo containing 0.22% C formed columnar (directional) $Cr_{23}C_6$ carbides spaced $\sim$2 μm in the build direction, while HIP-annealed Co–Cr alloy exhibited an intrinsic stacking fault microstructure. A log–log plot of relative stiffness versus relative density for Ti–6Al–4V and Co–29Cr–6Mo open-cellular mesh and foams resulted in a fitted line with a nearly ideal slope, $n = 2.1$. A stress shielding design graph constructed from these data permitted mesh and foam implant prototypes to be fabricated for compatible bone stiffness.

1. Introduction

Bone implant materials, especially metals and alloys, have evolved over several millennia beginning with gold cranioplasty, Ni plated steel and related alloy evolution for fracture plates and a host of Ti alloy implants for a variety of skeletal repair joint replacements and dental restorations (Sanan and Haines, 1997). More recently, other metallic alloys have been employed especially as bone implant alloys, including austenitic stainless steels (especially 316L) and Co-base (Co–Cr) alloys (Park, 2000). Between about 1950 through to 1990, α and $(\alpha + \beta)$ Ti alloys with solid elastic (Young's) moduli of $\sim$110 GPa were developed, while more recently β-Ti alloys with lower elastic moduli (ranging from $\sim$50 to 90 GPa) have been developed (Niinomi, 2007). As bone implant materials, Ti and its alloys exhibit very suitable characteristics for biomedical applications because they exhibit high biocompatibility, strength, and often superior

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1751-6161/$ - see front matter
doi:10.1016/j.jmbbm.2011.05.010