Abstract

This research is mainly focused on the study of microstructural, mechanical, electrochemical, and cytocompatible behavior of porous Ti-6Al-xMo alloy with varying porosity and Mo wt.%. This study attempts to make dense and porous Ti-Al-Mo alloys through powder metallurgy route using space holder technique. Ammonium bicarbonate is used as a space holder to generate a porosity in samples. The mixed powders were compressed in die which is cylindrical in shape and compaction pressure was kept at 400 MPa. Green pellets were heated at 150 ˚C for 4 hrs to take out the space holder from the material. After drying, step sintering has been performed on the samples to diffuse the particle and enhance the strength of the material in a high vacuum furnace. Porosity, macropores and pore wall thickness of the samples were calculated from micro computed tomography and Archimedes method. The microstructure and morphology of the samples were investigated through FE-SEM, EDS, EBSP and TEM. Phase analysis was done through XRD pattern. Energy absorption, densification strain, compressive strength, and elastic modulus, were calculated from the uniaxial compression test. Ion release properties of samples were checked from the Inductively coupled plasma microscope and weight loss method. The proposed fabrication method is useful for designing porous Ti6Al(3-15)Mo alloy with desired macro pore size and relative density using ammonium hydrogen carbonate as a space holder. Interconnected and uniformly distributed macropores as obtained in developed samples are helpful for obtaining good mechanical properties as well as transportation of body fluid. It is helpful in promoting biological fixation between implant and bone. With increase in Mo content in Ti6Al(3-15)Mo, Kirkendall pores increase which is helpful for fixing the bone tissues in the implants. The porous Ti6Al(3-15)Mo alloys are composed of α, α_2 and β phases. β phase stability increases and, α and α_2 phase stability decreases with Mo content. Porous Ti6Al(3-15)Mo alloys with density in the range of 1.33 to 2.75 g/cm^3 can be used as cortical bone.

On the other hand, Ti6Al15Mo alloy with a density of 1.17 g/cm^3 is suitable for replacing the cancellous bone. With increase in Mo content in the Ti6Al(3-15)Mo alloys, Mo ion releases at a faster rate compared to Ti and Al in SBF solution. The maximum amount of released Ti, Al and Mo ions from the porous Ti6Al(3-15)Mo alloys are 99.79 %, 99.96 % and 28.47 %, respectively, less than the permissible limits. When compared to stainless steel, CoCr alloy, and CP Ti, the strength and modulus of porous Ti6Al(3-15)Mo alloys exhibit enhanced characteristics for replacement in implant applications.

Further study is focused to enhance the microstructural, electrochemical and mechanical characteristics of Ti6Al15Mo ternary alloy porous samples. The effect of strain rate on mechanical properties were also studied. In addition, potentiodynamic polarization, fatigue and cytocompatibility tests were conducted to further analyze the properties of the alloy for load bearing applications. Ti6Al15Mo ternary alloy porous samples were fabricated with a range of space holder content (40 to 70 vol.%) and sintered using four different sintering cycles. Ti6Al15Mo alloy consist of α, α_2, and β phase. The volume percentage of β phase increases and residual porosities decrease with increase of soaking time in the samples. Equiaxed grain size also increased with an increase in soaking time. The plateau stress of porous samples increased with an increase in compression speed and soaking time. Elastic modulus slightly increased with soaking time and strain rates, but decreased with an increase in porosity which is helpful for reducing the stress shielding effect. Densification strain and plateau stress of the porous samples increased with an increase in soaking time, providing higher longevity for Ti6Al15Mo porous sample-based implants. Strain rate sensitivity exponents and energy absorption efficiency were sensitive to relative density, soaking time, and strain rate. The efficiency of energy absorption and energy absorption capacity increased with an increase in soaking time, strain rate, and porosity. Specific strength and specific energy absorption were superior compared to reported materials. Elastic modulus and plateau stress of Ti6Al15Mo porous alloy having porosity 47% to 69% are in the range of 3±0.5 to 24±1.5 GPa and 69±6.72 to 174±6.52 MPa, respectively, which are similar to the properties of natural bone. Porous Ti6Al15Mo alloy samples having porosity from 47% to 69% were able to withstand fatigue without failing up to a practical limit of 10^6 cycles and under a maximum applied stress of 0.7 times of the maximum stress of the material. The ion release limit of Ti, Mo, and Al in 4hr sintered and 70% space holder content Ti6Al15Mo porous samples was well below the safe limit in human bone. Compared to the Ti6Al4V alloy, the Ti6Al15Mo alloy sample exhibited superior cell viability characteristics. Moreover, the Ti6Al15Mo porous alloy sample was found to be non-cytotoxic, and the interconnected macropores provided a conducive environment for cell adhesion and growth.

At optimized sintering cycle, dense Ti-6Al-xMo alloy samples were fabricated through powder metallurgy with varying Mo wt%. To observe the deformation behavior, compressive test was done, and compressive stress-strain curves were computed. The compression test revealed shear failure at 45° to the load axis. The fractured surface of each Ti6AlxMo alloy exhibits a different morphology. Microhardness and nano hardness results demonstrated that all the studied alloys have higher microhardness, nano hardness, wear-resistance and anti-wearability compared to the CP Ti and Ti6Al4V alloy. Elastic energy, plastic energy, elastic recovery, and plastic index were studied through nanoindentation tests. The Ti6Al6Mo alloy exhibits the highest yield strength, microhardness and nano hardness compared to all the studied alloys due to the presence of alpha and beta colonies with low interlayer distance in the microstructure. Some examples of biomedical applications where strength and wear resistance of alloys are more important than modulus value include: dental, cardiovascular implants and surgical instruments. Therefore, Ti6Al6Mo alloy samples are suitable for these applications. Ti6Al15Mo alloy exhibits elongated dimples ascribed to the existence of β phase. This alloy exhibits higher yield strength, lower modulus, and higher ductility compared to other reported materials, including CP Ti, Ti6Al4V, Ti6Al7Nb, Ti5Al2.5Fe, and Ti3Al2.5V, commonly used for implants. Nano hardness test results revealed that designed alloys exhibited elastic recovery values in the range of 25.4% - 33.7% and Ti6Al15Mo alloy exhibited highest elastic recovery among the presently designed alloys and CP-Ti therefore it has good impact resistance properties. Ti6Al15Mo alloy is the most advantageous alloy for load bearing implant applications.