Progress in the development of a novel Ta-Nb-Ti multi-component alloy for biomedical applications

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The modern material class of equiatomic multi-component alloys, especially high-entropy alloys (HEAs) gained tremendous attention in the scientific community over recent years, which can be attributed to two main reasons: Firstly, the new concept of combining several elements (at least 5 principal elements with concentrations between 5 and 35 at. % [1]) in contrast to conventional alloys, mostly containing only two or three elements in addition to the main alloy constituent. This results in a broad variety of possible combinations thus leading to completely novel alloys with exceptional properties. Secondly, recently developed refractory metal based high-entropy alloys (RHEAs) have shown properties that are superior to the ones of current state-of-the-art alloys, which are attributed to several unique thermodynamic effects [2,3]. However, besides the outstanding mechanical properties, abrasion resistance and thermal resistance, a vast variety of chemical elements used in RHEAs also belong to the category of biocompatible elements, hence leading to potentially new biomedical materials.

To meet the demands for biomedical applications, specifically for implant materials, three main criteria must be fulfilled: Excellent mechanical properties (regarding the force transmission between implant and bone), corrosion resistance (prevention of corrosive damage to the implant) and biocompatibility (no tissue damage by the implant material or by corrosive/ abrasive particles) [1]. The present study meets these targets on the basis of previous investigations regarding Mo-Nb-V-W-Ti high-entropy alloys [2], which have confirmed promising mechanical properties. Furthermore, the works of Shi et al. [3], Shittu et al. [4] and Yuan et al. [5], concerning the corrosive capabilities and degradation resistance, as well as the biocompatibility of HEAs, are considered to support our theories. However, in consideration of this background and due to the excellent biocompatibility of the constituents [6], an equiatomic composition of Ta, Nb and Ti as multi-component base alloy was chosen for the experiments.

The alloy examined was produced using an arc melting furnace under Ar atmosphere, metallographically prepared and investigated respectively. Scanning electron microscopy (SEM) analysis revealed the presence of a dendritic microstructure, with an enrichment of high-melting elements in the dendrites, as well as Ti in the interdendritic regions (verified by means of EDS mappings). Microstructure analysis by means of X-ray diffraction (XRD) showed, that there are two types of body-centered cubic (bcc) crystal structures (Im-3m I: a = 3.287 Å; Im-3m: a = 3.291 Å) present in the as-cast state. To get a better understanding of the microstructure evolution, heat-treatment experiments regarding different temperatures and times were performed. Furthermore, the alloy produced, as well as samples of elemental Ta, Nb, alloy Co-28Cr-6Mo and alloy Ti-6Al-4V, were prepared to a defined surface grade. The topography of the surfaces was evaluated using confocal microscopy and contact angle measurements subsequently. Afterwards, the biocompatibility of the novel alloy Ta-Nb-Ti was evaluated by means of cell (osteoblasts) attachment, as well as monocyte inflammatory response analysis. First results indicate competitive osteoblast attachment, as well as comparable expressions of fibrosis markers in comparison to conventionally used biomedical materials. In addition, the Ta-Nb-Ti alloy showed a markedly reduced inflammatory capacity, indicating a high potential for use as prospective biomedical material.

References

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