Investigation of electrochemical biocompatibilities of beta-type Ti-Nb-Ta-Zr and Co-Cr-Mo alloys through microstructural refinement

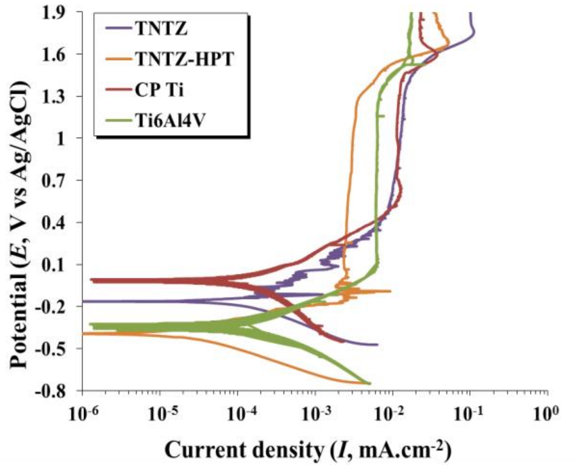
We aimed to investigate the electrochemical behaviours of *β* type Ti-Nb-Ta-Zr (TNTZ) and Co-Cr-Mo (CCM) alloys in this collaboration. *In-vitro* corrosion susceptibilities of the alloys were compared with traditional implant materials such as Ti-6Al-4V and CP Ti in this study. Also, the effect of high-pressure torsion (HPT) on the corrosion susceptibilities of the alloys was investigated in simulated body fluid.

Metallic materials are used as biomedical implants for various parts of the human body for many decades. The physiological environment (body fluid) is considered extremely corrosive to metallic surfaces and corrosion is one of the major problems to the widespread use of the metallic materials in the human body because the corrosion products can cause infections, local pain, swelling, and loosening of the implants.

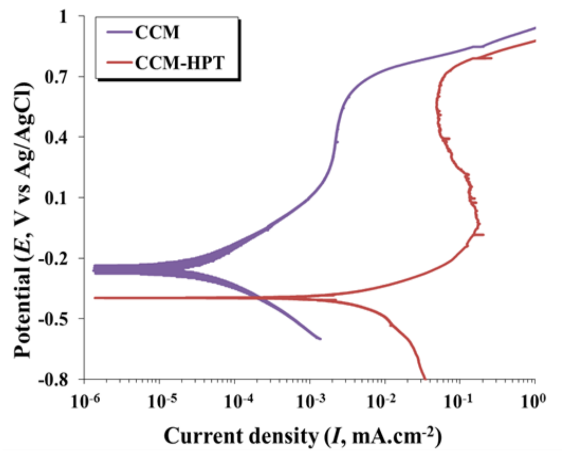
Recently, the most common corrosion resistant metallic biomaterials are made of stainless steels, titanium (Ti) and its alloys and cobalt (Co)-chromium (Cr)-molybdenum (Mo) alloys. Ti and Co alloys are the most common biomaterials because of their well chemical, mechanical and biocompatibility characteristics. Ti alloys are known for its high corrosion resistant due to instant formation of an inert oxide layer on its surface and chromium oxides increase the corrosion resistance of Co-Cr-Mo alloys.

During the visiting period, in-vitro corrosion susceptibilities of β-type Ti-Nb-Ta-Zr (TNTZ) and Co-Cr-Mo (CCM) alloys were compared with commercial implant materials such as Ti-6A-4V, and commercially pure Ti (CP Ti). The high-pressure torsion (HPT) processing is a well-proved technique for metallic materials to form ultrafine grained or/and nanostructures [1-2]. Therefore, the effect of HPT on the corrosion susceptibilities of TNTZ and CCM alloys were also investigated under *in-vitro* conditions at body temperature.

Potentiodynamic scanning (PDS) plots for the studied samples in Ringer's solution are shown in Fig. 1. The PDS profiles of the samples are quite similar each other and, all samples reach their respective stable passive current densities as the potential increases. The passive current densities remain almost unchanged inside their wide passive regions, indicating that their corrosion rates are in steady state and the passive films formed on the surfaces are stable.



(a) Ti alloys



(b) Co alloys

Fig. 1 Potentiodynamic polarization curves of (a) Ti alloys and (b) Co alloys

These results indicate that the severely strained TNTZ (TNTZ-HPT) is more resistant to corrosion than the other Ti counterparts in Ringer's solution. In addition, TNTZ-HPT shows lower E_{pp} (passivation potential) value and a wider passivation range as compared to the others. Since the supersaturated solid solution decomposes completely and reaches the equilibrium state after the HPT. Therefore, the protective oxide layer on the surface of TNTZ-HPT is less complex or better when compared with the others. This behavior is related to its small current density and width passive area as shown in Fig. 1. (a). It can be concluded from above results that the HPT can be considered to give a balance between deformation-induced disordering and deformation-accelerated diffusion towards the equilibrium state in the Ti based alloys.

As seen from Fig. 1 (b), the corrosion potential (E_{corr}) of the CCM sample is more noble than CCM-HPT. This is in contradiction with the obtained results for Ti based alloys (Fig. 1 (a)) in this study. In other words, the electrochemical behavior of the CCM alloys is different from that of Ti alloys. The behavior may be related to increasing crystal defects, high dislocation density, grain size and crystal orientation, and residual stress after the HPT in the sample. In addition, this relates to passive film formed on their surfaces. Since the stability of passive oxide film of the TNTZ alloys is higher than that of the CCM alloys.

It is well known that protective surface films the surfaces of the alloys play key role in corrosion of the metallic implants [3-5]. TNTZ alloys have a large potential range, nobler positive potentials and lower current density values than CCM alloys due to both transpasivation and oxygen evolution reaction. It can be said that oxide layer formed on the TNTZ alloys is more stable, less soluble and more biocompatible compared to chromium oxide based layer formed on the CCM alloys.

In the view of the HPT, there is no general rule for corrosion resistance of the alloys. That they may corrode either very quickly (for CCM) or extremely slowly (for TNTZ) is mainly related to its thermo-mechanical past and medium characteristics.

Clearly, the results of the mechanical and corrosion behaviors show that there is a strong connection between corrosion resistance and microstructural features of the metallic materials, including grain diameter and states of grain boundary and secondary phases. However, further systematic approach is needed to using in human bodies of the severe deformed structure.

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