

# Cell-Accelerated Corrosion (CAC) of Ti6Al4V Alloys in Hip Taper Junctions: Role of Microstructures

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**INTRODUCTION:** Hip replacement is a common procedure conducted in the United States. Between 2000 and 2019, total hip arthroplasties (THAs) in the U.S. increased by 177% [1]. Thus, efficacious and effective THAs are of paramount significance in orthopedic research. Aseptic loosening is one of the most common causes of chronic failure for THAs [2]. In fact, corrosion and wear of the THA metal components increase the risk of failure of the implants and of other side effects, such as adverse tissue reaction and toxicity from the wear products. There are many types of corrosion that are observed in implants. Recently, cell-accelerated corrosion (CAC) has been reported, particularly at hip modular junction [3]. From our group, we reported the CAC in CoCrMo alloy as a function of different microstructures. However, no systematic study on the Ti6Al4V alloy exists. Although the Ti6Al4V alloy is acceptable for its superior corrosion resistance, the alpha and beta phases in the microstructure determine the corrosion kinetics/mechanisms in a challenging joint environment. Therefore, the purpose of this study is to identify the role of titanium microstructures in simulated CAC conditions. In our research, six different microstructures of titanium-based samples were tested for corrosion with different media such as control media (CM), spent media (SM), and challenged media (CHM). The possible outcome of the study is to demonstrate how microstructure influences the cell-accelerated corrosion capacity of different Ti6Al4V surfaces.

**METHODS:** (i) **Materials:** For corrosion experiments, a potentiostat was used, along with a working electrode (connected to titanium surface(s)), graphite counter electrode, saturated calomel electrode (SCE) as a reference electrode, and 6 different Ti6Al4V-based microstructure samples (**Figure 1a**). The samples were polished to achieve a surface roughness of <50nm. (ii) **Solution:** control media (DMEM + 10% FBS + 1% antibiotic-antimycotic mix), spent media (control media incubated 24 hours with RAW 264.7 macrophage cells) and challenged media (CoCrMo particles added to media and incubated for 24 hours with RAW 264.7 macrophage cells) were created. The schematic of the electrochemical corrosion experiment with three different media is shown in **Figure 1b**. (iii) **Electrochemical corrosion testing:** A counter electrode (graphite), a reference saturated calomel electrode, and a working electrode (Ti6Al4V samples) were all connected to a potentiostat, and the corrosion experiments began. The electrodes were immersed in control, spent, or challenged media [4]. Open circuit potential (OCP), cyclic polarization (CP), and electrochemical impedance spectroscopy (EIS) were conducted. From the polarization curves, different parameters such as  $E_{corr}$  and  $I_{corr}$  were estimated and EIS data, Bode, and Nyquist plots were generated. An equivalent electrical circuit was used to determine polarization resistance ( $R_p$ ) and capacitance ( $C$ ). (iv) **Surface categorization:** Scanning electron microscopy (SEM), JEOL JSM-IT500HR FESEM with energy dispersive spectroscopy (EDS) (Oxford Instrument) was used to analyze the corroded surfaces (**Figure 3a-f**) [5].

**RESULTS:** The different microstructures and orientations of the samples (fine, coarse, bimodal, dendritic, lath-type, and needle-like) are shown in **Figure 1a**. The polarization curves for the tested media condition are shown in **Figure 2a-c**. The corrosion current ( $I_{corr}$ ) density of the different microstructure Ti6Al4V samples with the three different media (CM, SM, and CHM) are shown in **Figure 2d**. The corrosion current density of the samples with control media showed a higher value for sample C and a lower value for sample A. Similarly, when using spent media, sample F showed higher  $I_{corr}$  values and sample A showed lower  $I_{corr}$  values. In addition, the challenged media corrosion current indicated higher  $I_{corr}$  values for samples C and E and a lower  $I_{corr}$  value for sample F (**Figure 2d**). Interestingly, sample A and C showed higher  $I_{corr}$  value for challenged media compared to control media. However, other sample surfaces did not show significant changes in their  $I_{corr}$  values from control media to spent and challenged media. From the EIS data, polarization resistance and capacitance are presented in **Figure 2e-f**. Another exciting feature was observed. Lower resistance was observed for the control media group than for spent and challenged media, and the opposite was true for capacitance (**Figure 2f**). The SEM images of the corroded surfaces with challenged media are shown in **Figure 3a-f**. Samples C and F showed higher corrosion damage compared to other microstructures (**Figure 3a-f**).

**DISCUSSION:** The electrochemical corrosion experiments indicated the expected cell-accelerated corrosion behavior of Ti6Al4V alloys with different microstructures. In general, the trend in corrosion is not a definite pattern in different media as a function of the microstructures of Ti6Al4V alloy. Microstructures A and C exhibited relatively high  $I_{corr}$  values in challenged media (**Figure 2d**). In addition, microstructures A and C also exhibited markedly higher resistances and lower capacitance in the control media (**Figure 2e-f**). These sample microstructures (Samples A and C) were composed of more irregular

and coarse grain boundaries (**Figure 1a**). These surfaces exhibited higher  $I_{corr}$  values and lower  $E_{corr}$  values. Our findings demonstrate that challenged media potentially increases corrosion compared to spent media and control media. This is in line with our previously reported research, where challenged cells with particles may increase the chemical composition of the media [4]. This leads to a severe electrochemical reaction [3]. The findings also correlated with the SEM images (**Figure 3a-f**), which display the characteristic pattern of corrosion. SEM observation of samples A and C (**Figure 3a-f**) shows increased corrosion damage with irregular grain boundaries. This leads to a higher susceptibility to cell-accelerated corrosion. Such increased corrosion processes may pose a potential risk to the stability of the THA during *in vivo* conditions and a higher likelihood of implant failure. There are several limitations in this study, as it is a short-duration in-vitro simulation of CAC. Future investigations will be continued to compare implant retrievals and long-term testing conditions.

**SIGNIFICANCE:** Our findings exhibited increased cell-accelerated corrosion in the Ti6Al4V in specific microstructures in the challenged media with wear particles. In summary, Ti6Al4V alloy microstructures should be optimized to minimize the likelihood of cell-accelerated corrosion. Such microstructures of the Ti6Al4V alloy possibly help to generate a safer THA, working together with implant manufacturers.

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**REFERENCES:**[1] I Shichman *et al.*, 2023. [2] M Choi *et al.*, 2005 [3] A Di Laura *et al.*, 2017. [4] R A Ramachandran *et al.*, 2023. [5] J Manthe *et al.*, 2022.

**Major findings of the study include:** **Figure 1(a)** - Pictures of Ti6Al4V microstructures. **1(b)** Schematic of electrochemical corrosion experiments in different media, **Figure 2(a-c)** - Evolution of potentiodynamic curves. **2(d)** Bar diagram of  $I_{corr}$ . **2(e)** Bar diagram of resistance. **2(f)** Bar diagram of capacitance. **Figure 3(a-f)** - SEM images of Ti6Al4V alloy samples after the corrosion experiment.