Corrosion Behaviour of a Coated AZ31 Mg Alloy under Static and Cyclic Loading in Four Point Bending Tests

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Abstract. Modifying the surface of magnesium alloys can be an efficient method for managing their biodegradation behaviour and enhancing their biological characteristics. The coating of magnesium alloys has been the subject of significant research, with a particular focus on their initial protective ability and biological properties. This study investigates a phosphate and fluoride ceramic coating and its effect on corrosion fatigue and stress corrosion cracking of an AZ31 (Mg–3Al–1Zn–0.3Mn %wt) magnesium alloy in a corrosive environment using X-ray Computed Tomography and scanning electron microscopy combined with Digital Image Correlation (DIC) at nanoscale. These tests have been performed via static and cyclic loading four point bending tests.

Introduction

Biodegradable materials are expected to show mechanical strength in the initial and reparative phase of implantation [1]. Tissue healing should be achieved without losing the integrity of the implant while the implant is slowly absorbed by the body. However, the applied stress and the corrosion behaviour of the material make degradation difficult to predict. Mg alloys are promising candidates for bioimplants due to their good mechanical properties and bio-degradability in vivo [2]. However, their high corrosion rate, stress corrosion cracking (SCC), and corrosion fatigue (CF) lead to premature failure. The oxide layer formed on the magnesium is not a good passivating layer, and magnesium hydroxide formed on the magnesium implants reduces the Mg ion transfer to the fluid. However, the chloride ions in body fluid dissolve the hydroxide layer, and the corrosion is increased. The implants inserted into a living body undergoes cyclic loading during the patient's daily activities and the body's natural environment contains various salts and proteins that may affect the corrosion process. The combined effects of cyclic loading and corrosive body fluids leads to excessive corrosion and abrupt failure of the implant due to CF or SCC.

Recently, various coatings have been developed to reduce the corrosion rate of Mg alloys [3]. In this study, AZ31 Mg samples are coated by electrochemical oxidation producing ceramic surfaces composed of Phosphate and Fluoride coating. Here, we perform static loading and cyclic loading in four point bending (FPB) tests to monitor the corrosion of the coated/noncoated AZ31 within Hank's Balanced Salt Solution (HBSS). CF and SCC of the rods were measured using X-ray Computed Tomography (XCT). The effect of the environment on the surface coating was assessed by scanning electron microscopy (SEM) and the strain on the coating surface monitored by SEM imaging combined with DIC.

Experiment

In the study, the effect of the coating on the CF and SCC of an AZ31 (Mg–3Al–1Zn–0.3Mn %wt) Mg alloy have been investigated within corrosion environment. 3 mm diameter rods of AZ31 was used for all experiments. The rods were coated by electrochemical oxidation to produce a Phosphate and Fluoride ceramic coating. The coated rods were cut with a nominal length of 30 mm. Interrupted *in situ* four point bending (FPB) tests, static loading FPB test in Hanks' Balanced Salt Solution (HBSS), and cyclic loading FPB tests in HBSS were performed. Interrupted *in situ* FPB tests were performed in the tension/compression Deben CT5000 rig, and the sample was scanned via XCT at 0, 100, 200, and 300 N load. For static loading FPB tests, a test rig was designed that did not contain any material which caused galvanic corrosion. The load was applied by a screw and measured by a load cell. The cyclic loading FPB tests were also performed in a similar environment to the static FPB test via BOSE tensile/compression instrument. For the static and cyclic loading FPB tests, all the samples were scanned via XCT before and after the tests. For both static loading and at various time points during cyclic loading the coating was examined in the SEM and strain on the surface measured using DIC.

Results

FPB tests performed on the coated sample up to 300 MPa (beyond yielding) in air showed that the cracks are formed in the coating transverse to the longitudinal axis of the rod (Fig. 1) and generally follow pores in the coating. Cross section of the sample shows that the coating does not undergo any detachment from the substrate. These cracks are related to the strain patterns that form on the coating surface during loading.

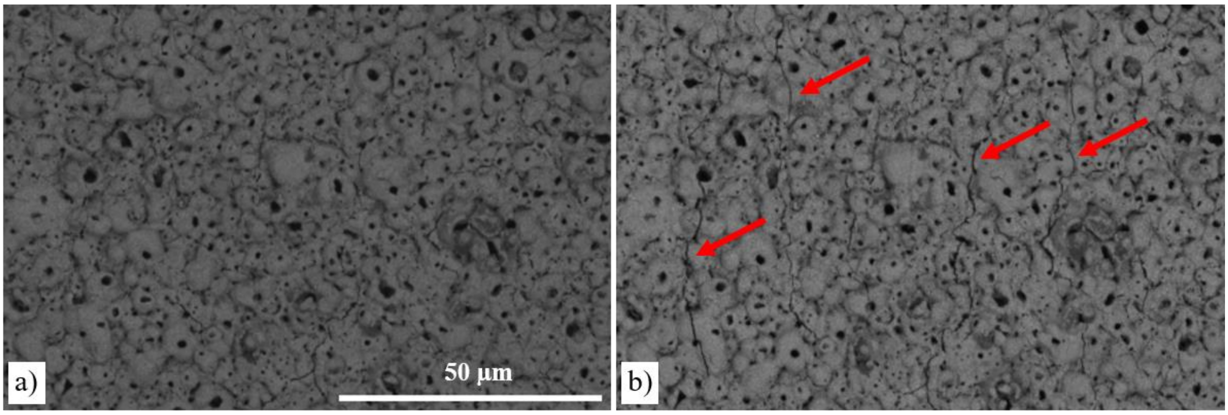

Figure 1 Backscattered electron images of the coated AZ31 Mg alloy in the tension region (a) before and (b) after deformation. Cracks are showed by red arrows.

Conclusion

This study investigates the effect of a Phosphate and Fluoride ceramic coating on mechanical behaviour of AZ31 Mg alloy due to static and cyclic loading FPB in corrosion environment. The coating makes the AZ31 Mg alloy more suitable for clinical application due to a decreasing degradation rate of the alloy which leads into an improvement in the mechanical performance under corrosive environment. Even beyond the yield with relatively high strains on the surface the coating remains attached to the alloy.

References

[1] Y. Koo, Y. Jang, and Y. Yun: Mater. Sci. Eng. B Solid-State Mater. Adv. Technol. (2017), vol. 219, pp. 45–54
[2] P. Das, T. S. S. Kumar, K. K. Sahu, and S. Gollapudi: Corros. Rev., vol. 40 (2022), pp. 289–333
[3] P. Amaravathy, S. Sathyanarayanan, S. Sowndarya, and N. Rajendran: Ceram. Int., vol. 40 (2014), pp. 6617–6630