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Rapid manufacture of integrated self-powered sensing systems using additive manufacturing for critical structure health monitoring

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Overview

Military assets and equipment may be subject to harsh operational and environmental conditions. In particular, aerospace and marine structures, such as naval airframe and platforms, ships and storage tanks, suffer continued degradation from both marine and atmospheric corrosion. Ultimately, the integrity of these structures can be critically affected. Pitting and crevice corrosion of structural materials is perhaps the most significant threat to the integrity of complex engineered systems, since both are extremely difficult to detect due to their localised nature and limited access to the affected area, such as bolted and lock-tight joints.

Recent advances of *in situ* structural health monitoring (SHM) technologies provide promising solutions to tackle these challenges by effectively detecting, locating, and quantifying the corrosion-induced damage as well as providing real-time structural integrity information for condition based maintenance programme. Therefore, integration of self-powered corrosion sensing systems into a critical engineering structure for *in situ* SHM using additive manufacturing technologies (AM) was proposed.

Objective of this project

To assess the feasibility of using AM technologies to rapidly manufacture integrated corrosion monitoring systems.

Strategies for *in situ* SHM

- Integration of a corrosion sensing system into a structure would achieve the combined targets of *in situ* health and integrity monitoring.
- AM technologies provide the opportunity to directly produce complex engineering structures with an integrated sensing device.

Main Challenges

- Compatibility of sensing materials with AM technologies.
- Innovative AM manufacturing approaches for the integration of sensing materials into complex engineered structures.

Identification of sensing systems for corrosion monitoring and integration

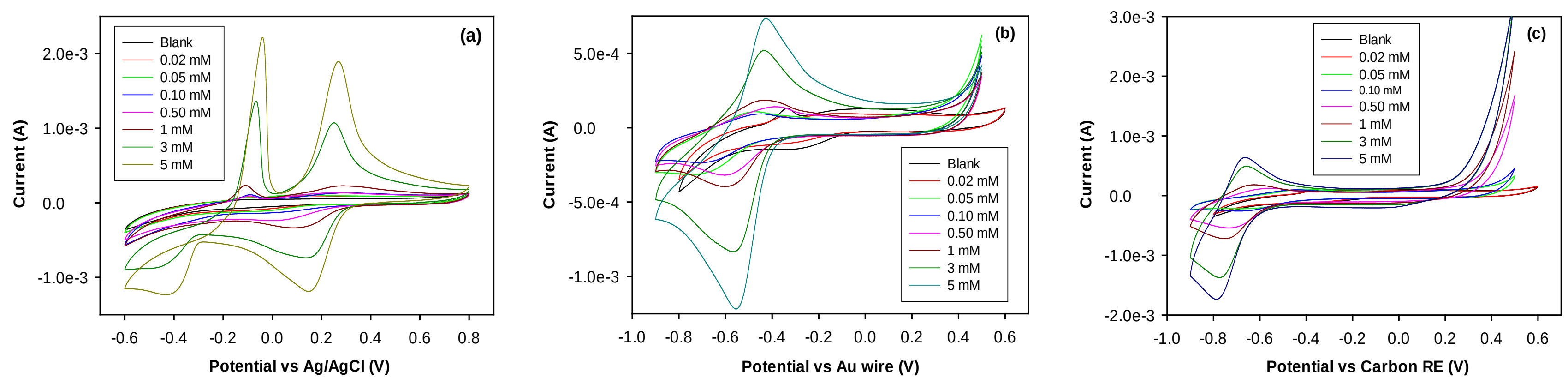

Figure 1. Cyclic voltammograms (CV) of $CuCl_2$ at different concentrations in a 3.5% NaCl solution on carbon working electrodes of 3 mm diameter against: **(a)** Ag/AgCl, **(b)** Au wire and **(c)** carbon reference electrodes.

Demonstrated the feasibility of using a carbon-based multi-electrode system for crevice corrosion sensing of copper-based alloys in marine environments with electrochemical techniques.

Corrosion and mechanical performances of AM structures

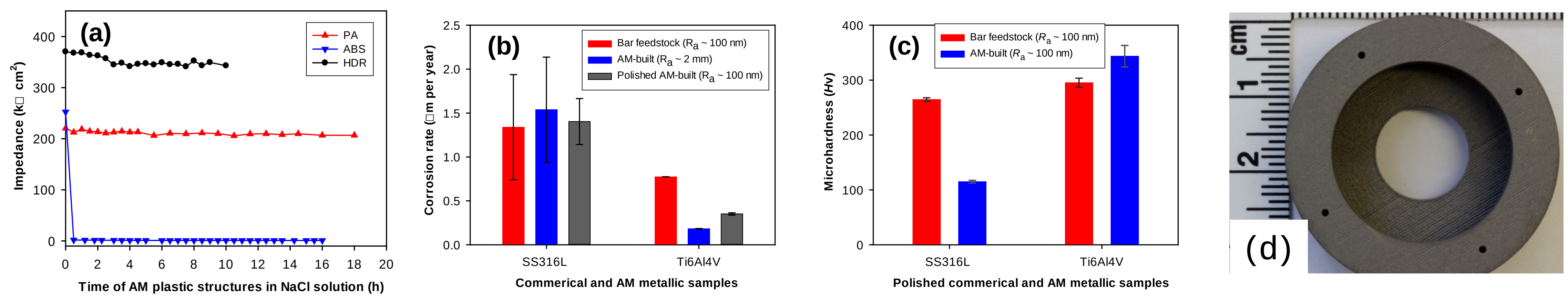

Figure 2. (a) Impedance changes of the AM plastic crevice former *vs.* time and **(b)** the corrosion rates of both the AM-built and commercial feedstock metallic samples in a 3.5% NaCl test solution. **(c)** Microhardness of commercial feedstock and AM-built metallic samples. **(d)** Direct metal laser sintering-built Ti6Al4V crevice corrosion former model.

- **Three plastic and two metallic crevice former models built using different AM technologies.**
- **Corrosion performance of AM-built materials electrochemically assessed in a 3.5% NaCl solution.**
- **AM plastic models showed varied impedance behaviour (HDR performed best, ABS worst).**
- **Corrosion and mechanical performances enhanced for AM-Ti6Al4V, but deteriorated for AM-SS316L in comparison with bar feedstock samples.**

Corrosion monitoring function of sensors integrated within AM structures

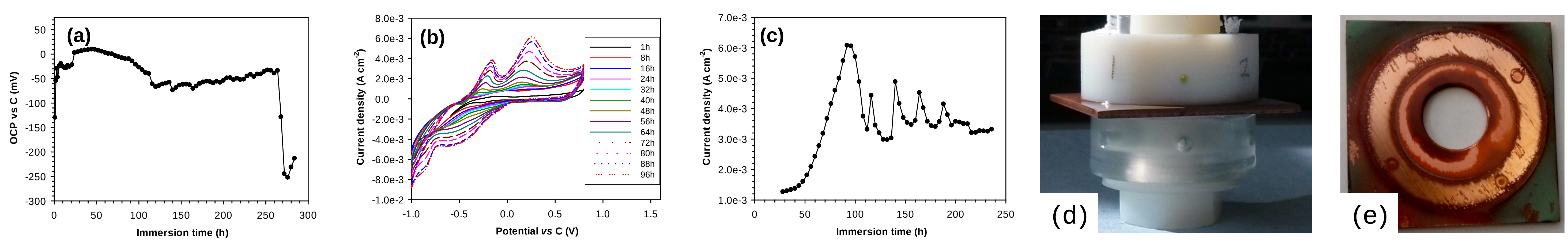

Figure 3. Carbon multi-electrodes embedded in an AM-built HDR crevice former structure: **(a)** Open-circuit potential, **(b)** CVs and **(c)** copper stripping peak current density *vs.* time when immersed in 3.5% NaCl test solution. The crevice corrosion assembly **(d)** with an AM–built HDR structure and embedded sensors (top white part) and corroded copper plate **(e)** after a 300 h immersion.

All-carbon sensor systems embedded into an AM-built HDR structure effectively detected and quantified cupric ions in the crevice corrosion chemistry micro-environment using electrochemical methods, especially when utilising the voltammetric technique.

Summary

- **The feasibility of using a carbon-based multi-electrode system has been demonstrated for corrosion sensing of copper-based alloys.**
- **Model crevice former structures of five different materials have been successfully built via different AM technologies and their corrosion performances assessed in a 3.5% NaCl test solution.**
- **A prototype functional structure was demonstrated - an AM-built HDR model crevice structure with the embedded multiple carbon-based sensor system for crevice corrosion of in a 3.5% NaCl solution.**

Future work

- **Identification of corrosion energy harvesting technologies.**
- **Rapid manufacture and performance evaluation of corrosion energy harvesting systems.**
- **Integration of energy harvesting and sensing systems for corrosion monitoring.**
- **Integration of a self-powered wireless sensor network into critical structural locations for *in situ* integrity monitoring.**

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