Evaluation of Corrosion Fatigue Behaviour of Laser-welded NiTi Alloys using Bending Rotation Fatigue Test in Simulated Body Fluid


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Corrosion fatigue is a process which is a consequence of synergistic interactions among the material microstructure, environment and cyclic loads/stains. This study reveals a comparison of corrosion fatigue behaviour of laser-welded and bare NiTi wires using bending rotation fatigue (BRF) test coupled with a specifically designed corrosion cell. The testing environment was Hanks’ solution (simulated body fluid) at 37.5°C. Electrochemical impedance spectroscopic (EIS) measurement was carried out to monitor the change of corrosion resistance of sample during the BRF test at different periods of time. Experiments indicate that the laser-welded NiTi wire would be more susceptible to corrosion fatigue attack than the bare NiTi wire. This study can serve as a benchmark for the product designers and engineers to understand the corrosion fatigue behaviour of the NiTi laser weld joint and determine the fatigue life safety factor for the NiTi medical implants which involve laser welding in the fabrication process.

Introduction

Shape memory NiTi alloys have been extensively used for medical device applications on account of their unique shape memory effect (SME) and super-elasticity (SE), as well as good biocompatibility. Laser welding is one of the effective methods to fabricate medical implants which involve complex-shaped NiTi components. It is postulate that NiTi laser-weld joint is susceptible to corrosion fatigue attack in human body given the presence of thermally-induced defects. However, a specific study on investigating the corrosion fatigue behaviour of the NiTi laser-weld joint is still lacking in literature, and accordingly this becomes the motivation of this study.

Methodology

Fibre Laser Welding

Material used was commercial Ti-55.91 wt% NiTi wire with diameter 0.5 mm (procured form Johnson Matthey Noble Metals). The laser-welded sample was prepared by laser joining two NiTi wires using a 100 Watt CW fibre laser (Model SP-100C-0013, output wavelength 1091 nm, in-focus spot size 46 μm).

Corrosion Fatigue Testing

Fatigue life of the sample was measured by using a specifically designed test rig based on the concept of bending rotation fatigue (BRF) test [2, 3]. In the BRF test, the wire sample was bent into a semicircle (R = 60 mm) and rotated with a selected rotational speed (100 rpm or 1.67 Hz). The surface strain at the outer surface of the mid-point was given by ε = dR/2, where d is the wire diameter and R is the radius of the semicircle. The ε was 0.42 % in the BRF test.

To mimic the human body conditions, the sample was immersed in a corrosion cell (Fig. 1). The corrosion cell was connected with the PAR 273A potentiostat for the circuit potential (OCP) at 37.5°C throughout the BRF test. The surface area exposed to Hanks’ solution was 37.5 cm². The impedance spectra were acquired in the frequency range from 100 kHz to 1 mHz.

Results and Discussion

Fatigue Life Measurement

Both the bare and laser-welded samples showed reduction in the fatigue life when testing in Hanks’ solution. However, the laser-welded sample showed a more significant degradation (42 % reduction) as compared to that of the bare sample (18 % reduction).

EIS Measurement

Diameter of semicircle arc in the Nyquist plots indicates the polarization resistance (Rp), i.e. the higher the diameter, the higher is the Rp. The Rp of laser-welded sample noticeably decreased with increasing testing time, whilst the decrease of Rp was also observed in the bare sample, but the magnitude was much smaller.

Presence of a single peak in the Bode plots suggests that the passive films on both the bare and laser-welded samples exhibited one relaxation time constant.

SEM Fractography

Fatigue striations, a typical feature of fatigue damage, can be observed on the fracture surface of the laser-welded sample. Fracture occurred in the weld zone (WZ). Clear micro-cracks appeared on the fracture surface. Such micro-cracks were believed to be associating with hydrogen embrittlement, as there is no signs of anodic dissolution.

Hydrogen Effect

In aqueous media, hydrogen can be introduced into the WZ by dissociation of hydrogen molecules into atomic hydrogen, resulting damage to the mechanical properties of the WZ, i.e. by decohesion of atomic bonds or generation of large internal pressure.

Conclusion

Experimental results in this study showed that the NiTi weld joint was susceptible to hydrogen attack in Hanks’ solution at OCP at 37.5°C, resulting in noticeable reduction in fatigue life. Fatigue life occurred in the weld zone (WZ), possibly due to presence of weld defects and imperfections which act as hydrogen trapping sites.