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Hydrogen Embrittlement of Pre-Cathodically Hydrogen Charged Inconel 718 Fabricated via Selective Laser Melting: Fracture and Crack Propagation via 3D EBSD

Claudia-Tatiana Santos Maldonado[1*], Alfredo Zafra[2], Paul Sandmann[3], Emilio Martínez-Pañeda[2], Roberto Morana[4], Catrin Davis[3] and Minh-Son Pham[1]

[1.] Department of Materials, Royal School of Mines, Imperial College London, UK.
[2.] Department of Civil and Environmental Engineering, Imperial College London, UK.
[3.] Mechanical Engineering, Imperial College London, UK.
[4.] BP Exploration, Sunbury-on-Thames, London, UK.
*Corresponding author: c.santos-maldonado19@imperial.ac.uk

Additively manufactured (AM) Inconel 718 holds a great potential in aerospace, power generation and oil & gas applications due to its excellent mechanical properties [1,2,3]. In addition, laser powder bed fusion (LPBF) is one of the most widely used AM techniques to manufacture highly complex structures for safety-critical components [3]. However, several subcritical failures due to hydrogen embrittlement (HE) have been reported in conventional Inconel 718 [4-7] but only a few in AM [8-10]. In order to ensure the mechanical integrity and assist the development of next generations of 3D printed Ni-based alloys, this phenomenon should be thoroughly studied and understood.

In this work, new experimental techniques to measure the hydrogen diffusivity of AM Ni-based alloys and the understanding of the hydrogen embrittlement mechanisms of AM Inconel 718 is investigated. The work paid particular emphasis in the HE susceptibility for different scanning strategies and anisotropy. Solidification structures were analyzed using Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). Crystallographic texture was analyzed via Electron-backscattered Secondary Diffraction (EBSD) before H-charging. Specimens were electrochemically pre-charged in a 3 wt.% NaCl electrolyte at 90ºC – to facilitate the diffusivity- at different charging times. Slow strain rate tensile test was performed at a strain of 0.01mm/min (strain rate: 10^{-6} s^{-}) for both non-charge and H-charged samples. Fractography analysis via SEM and EBSD was followed to examine the microstructure evolution after deformation (Fig.1), as well as the reduction of area and the change in fracture mode (ductile-to-brittle). Electrochemical permeation tests and thermal desorption spectroscopy (TDS) were also employed to characterize hydrogen diffusion and trapping in these new microstructures.

Results show a significant reduction of the ductility and strength of the high hydrogen absorption samples – considered as the fully charged condition. Fracture was changed from intragranular to intergranular due to the hydrogen enhanced decohesion (HEDE) mechanism in conventional Inconel 718 (control sample) and cleavage-like fracture in AM Inconel 718 with diffusion of hydrogen into the cell dendrites (Fig.2). From the TDS results and diffusivity studies the most optimal charging condition were chosen, and electrolyte was changed to deuterium for characterization in Atom Probe Tomography (APT) to allow the mapping imaging and distribution of hydrogen in the sample. Complimentary, fracture and crack propagation was analyzed via 3D EBSD.

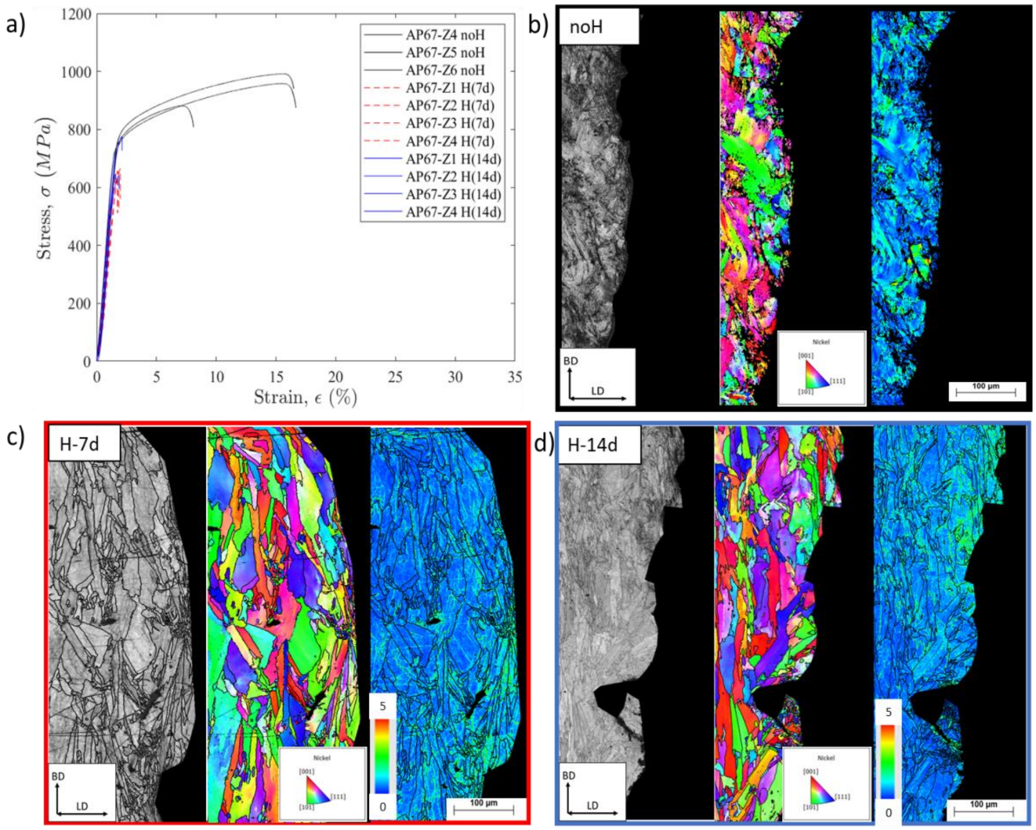

Figure 1. stress-strain results for AM Inconel 718 with scanning strategy meander 67º (a), fracture analysis of same material showing IQ map, IPF-Z map and Kernel map from EBSD results for non H-charged (b), H-charged for 7 days (c) and H-charged for 14 days (d)

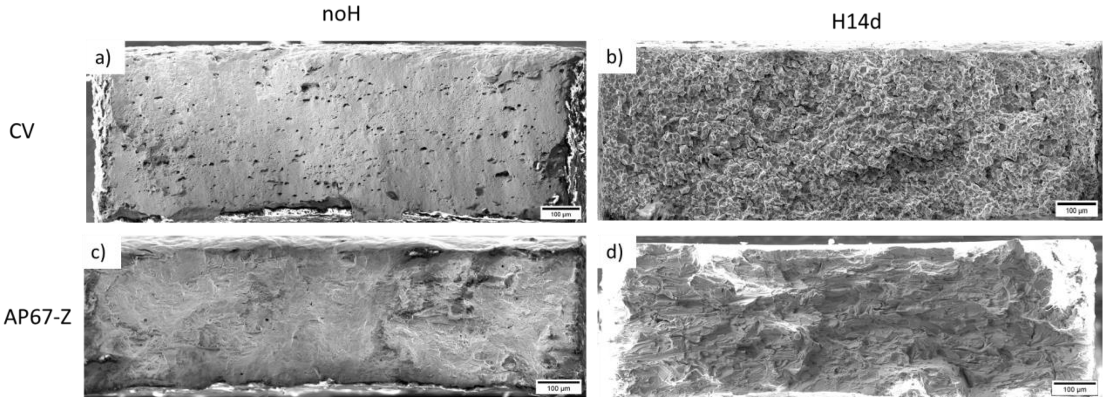

Figure 2. SEM fractography results for the conventional Inconel 718 non H-charged and 14days H-charged (a,b) and the AM Inconel 718 with scanning strategy meander 67º non H-charged and 14days H-charged (c,d)

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