Fabrication route impact on H embrittlement susceptibility: conventional versus additively manufactured stainless steels

Frantz MARTIN [1*], Bojan ZAJEC [2], Bojan PODGORNIK [3], Mirjam BAJT LEBAN [2], Andraž LEGAT [2], Aurore HOLANDE [1], Irena PAULIN [3], Barbara ŠETINA BATIČ [3], Marko SEDLAČEK [3]

[1] Université Paris-Saclay, CEA, Service de recherche en Corrosion et Comportement des Matériaux, 91191, Gif-sur-Yvette, France (Corresponding author)*

[2] Slovenian National Building and Civil Engineering Institute (ZAG), Dimičeva 12, 1000 Ljubljana, Slovenia

[3] Institute of Metals and Technology (IMT), Lepi pot 11, 1000 Ljubljana, Slovenia

The growing interest and use of additive manufacturing (AM) in the steel industry requires the assessment of the produced materials their applications. In the specific case of hydrogen-containing environments, it is imperative to evaluate, and possibly avoid or mitigate hydrogen embrittlement (HE) risks. Laser-based AM processes generate in the final steel residual stresses, anisotropy, highly complex and hierarchical microstructures with high dislocation density, possible defects and chemical inhomogeneity. As these features can have a critical impact on HE susceptibility, a better understanding of the hydrogen distribution – redistribution with the different typical AM microstructures is needed, together with its effect on mechanical behaviour.

The present collaborative work focused on HE susceptibility of a low HE sensitive steel (AISI 304, austenitic), and of a more HE sensitive steel (AISI 420, martensitic), produced via three different routes: (i) conventionally, as a reference, (ii) AM-laser-powder-bed-fusion (LPBF) manufactured, and (iii) AM-LPBF with additional post heat-treatment. Hydrogen (or deuterium ^{2}H) was introduced in the specimens by cathodic charging in $NaO^{1}H$ ($NaO^{2}H$) solution at 65 °C for various durations.

The total absorbed ^{1}H (or ^{2}H) amount in the specimens was characterized by TDMS (Thermal Desorption Mass Spectrometry). Diffusivity of hydrogen was estimated by series of electrochemical permeation tests, for AISI 420 steel, and by means of GD-OES (Glow Discharge – Optical Emission Spectroscopy) for the AISI 304. The microstructure of each steel was finely characterized by means of SEM and EBSD. The mechanical properties were investigated by *ex situ* slow strain rate tests (10^{-5} s^{-1}), for different levels of hydrogen charging and each production route.

First of all, specific desorption (TDS) features were identified for all AM-LPBF specimens, in agreement with former literature results. Their origin will be discussed in relation with typical AM-promoted microstructural defects. Second, the AM-LPBF specimens showed a higher elasticity limit and a smaller ductility range, as compared to the conventional materials. However, the HE index seemed to be globally independent on the fabrication route. Nonetheless, the tensile test results were highly sensitive to specimen orientation vs. 3D-printing direction: the potential interplay of texture with hydrogen during charging and mechanical testing will be discussed. Analysis of surface crack arrests (for 304) suggest surface early brittle cracking in the hydrogen-rich area. Finally, the fine analysis of the fracture surfaces (SEM and EBSD on cross-sections) will be discussed in relation with local hydrogen concentration calculated with input data from GD-OES and TDMS. The relevance of proposing a local failure criterion involving a critical concentration of hydrogen will be discussed.