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THE EFFECT OF HYDROGEN-CHARGING ON MECHANICAL PROPERTIES AND FRACTURE MECHANISMS OF WIRE-FEED ELECTRON BEAM ADDITIVE MANUFACTURED AUSTENITIC STEEL

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The effect of hydrogen-charging on mechanical properties and fracture mechanisms of wire-feed electron beam additive manufactured (EBAM) austenitic steel alloyed with niobium was investigated. For EBAM processing, a 1 mm-thick austenitic steel wire with a chemical composition of Fe-18.7Cr-9.5Ni-0.7Si-0.5Al-1.5Nb-0.12C (wt %) was used. The EBAM-processing was conducted in vacuum chamber under the following parameters: beam acceleration voltage 30 kV, wire-feed rate 200 mm/min, scanning frequency 1 kHz, beam current 16.5 mA, and ellipse scan 4 × 4 mm. An electrochemical hydrogen (H)-charging of as-built steel specimens was carried out in a 3 % NaCl water-solution at a current density of 50 mA/cm^2 for 50 h. Tensile tests of the H-free and H-charged as-built specimens were carried out at room temperature and at strain rate of $5\times10^{-4}s^{-1}$.

The as-built steel wall possesses a macroscopically layered structure and microscopically inhomogeneous dendritic microstructure typical for the EBAM deposition method. According to electron back scattered diffraction (EBSD) analysis, the grain structure of the main austenitic phase in the EBAM steel billet possesses strong anisotropy and is characterized by large columnar grains that are elongated along the building direction. In scanning electron microscopical (SEM) and light microscopical (LM) images there are no visible differences in morphology of dendrites in the microscopical layers and interlayer boundaries. Energy dispersive X-rays (EDS) analysis clearly shows that the microstructure of the EBAM steel consists of a fine vermicular and lathy morphologies of δ-ferrite within austenite matrix. For as-build state, a volume fraction of δ-ferrite was 5.5 % and a quite inhomogeneous distribution of δ-ferrite vs. distance from the substrate was identified. The presence of a high content of niobium in the initial wire composition promotes to the formation of Nb-reached phases (σ-phase and Laves-phase) during the EBAM processing. These precipitates possess irregular shape and their size varies from units to tens of micrometers. EDS analysis shows that such precipitates are enriched by iron and niobium and they are mainly located along intergranular and interphase (austenite/δ-ferrite) boundaries.

The tensile tests of H-free as-built EBAM steel specimens show typical for conventional austenitic stainless steels behavior in plastic flow regime. The EBAM steel has a yield strength of 230±10 MPa and total elongation 50±2 %. Deformation of H-free specimens of EBAM Nb-alloyed steel promotes a formation of plenty of microscopic holes or cracks on grain boundaries (predominantly at the interfaces of austenite and Nb-reached phases). Surface microcracking occurs in transgranular regime in the stage of well-developed plastic deformation (near the neck zone). H-charging causes a change in the mechanical properties of the specimens: the yield strength of specimens increases in comparison with as-built state. H-charging promotes to the formation of thick H-assisted brittle surface layer on the side surfaces of the EBAM-produced specimens. Fracture mechanism in them has mixed characteristics: brittle transgranular and intergranular modes. Hydrogen embrittlement index I_H, which characterizes H-assisted loss in elongation, varies in the rather large range 15-25 %. The δ-ferrite, σ-phase and Laves-phase in the microstructure of the EBAM steel provide fast transport of hydrogen atoms into the specimens during H-charging as compared to conventional stainless steels with fully austenitic structure.

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