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THE FEATURES OF HYDROGEN EMBRITTLEMENT OF ELECTRON BEAM ADDITIVE MANUFACTURED AUSTENITIC STEEL

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We study the effect of hydrogen-charging on mechanical properties and fracture mechanisms of wire-feed electron beam additive manufactured (EBAM) austenitic steel. Austenitic stainless steel wire (1 mm) with the chemical composition: Fe-17.7Cr-9.7Ni-1.2Mn-0.86Ti-0.57Si-0.19Cu (wt. %) was used for additive manufacturing. The EBAM process was carried out with the following parameters: accelerating voltage U = 30 kV, beam current I = 16.5 mA, wire feed rate V_W = 200 mm/min, V_b = 180 mm/min – beam movement speed, and ellipse scan (4.5 × 4.5 mm). The entire additive manufacturing process was conducted in a vacuum using austenitic stainless steel plate as the substrate material. The steel billet grown by the EBAM method were obtained by sequential deposition of same thickness layers (55 layers) onto a substrate. Conventional cast AISI 321 steel was used as a reference material. An electrochemical hydrogen (H)-charging of cast and EBAM steel specimens was conducted in a 3 % NaCl water-solution at a current density of 50 mA/cm^2 for 50 h. Tensile tests of the specimens were carried out at room temperature and at strain rate of 5×10^{-4}s^{-1}.

Cast steel had a uniform coarse-grained austenitic structure with a grain size of 20-30 μm. EBAM steel possessed a non-uniform heterophase structure typical of additive-produced austenitic steel (γ-phase matrix with a predominantly vermicular and lathy δ-ferrite). According to EBSD analysis, the steel has a coarse columnar grain structure, the austenite grains are elongated along the growth direction of the steel billet, which is due to the maximum temperature gradient in this direction during the deposition process.

Before H-charging, steels have similar flow curves, but plasticity and yield strength are lower for EBAM-produced steel: δ = 79 % and δ = 64 %, $\sigma_{0.2}$ =310 MPa and $\sigma_{0.2}$ =220 MPa for cast and EBAM steel specimens, respectively. This is attributed to the complex anisotropic structure of the additively produced steel. H-charging leads to embrittlement of both steels but has a stronger effect on EBAM specimens. The hydrogen embrittlement index I_H, which characterizes the loss of ductility caused by hydrogen, is I_H = 20 % for cast steel, I_H = 37 % for additive-produced steel.

Study of the fracture surface and lateral surface of H-free and H-charged fractured specimens using a scanning electron microscope (SEM) showed that H-free specimens are fractured by a viscous transgranular mechanism. Strong cracking was observed on the lateral surfaces of the fractured H-charged specimens of both steels. H-charged cast steel is characterized predominantly by transgranular cracks, in contrast to EBAM-produced steel, where the nucleation and propagation of cracks occurs at the interphase (ferrite/austenite) boundaries. SEM investigation of fracture surfaces revealed that H-charging leads to the formation of a brittle hydrogen-induced layer with a thickness of about 20 μm for cast specimens and about 60 μm for additive-produced specimens, which correlates with tensile test data.

Thus, the dual-phase (austenite/ferrite) structure of EBAM-produced steel promotes faster diffusion of hydrogen atoms deep into the specimens than in cast steel. This is associated both with high volume fraction of δ-ferrite in the microstructure and its dendritic morphology. These factors assist formation of wider hydrogen-induced brittle surface layers in EBAM-produced specimens and therefore are more susceptible to hydrogen embrittlement as compared to the cast steel with fully austenitic microstructure.

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