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A COMPARATIVE STUDY OF THE MACROSCOPICAL AND MICROSCOPICAL FRACTURE MECHANISMS IN CAST AND ADDITIVELY MANUFACTURED AUSTENITIC STAINLESS STEELS

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Using light microscopy and scanning electron microscopy we investigated the peculiarities of tensile fracture mechanisms of industrially cast and wire-feed electron beam additively manufactured austenitic stainless steel specimens. The electron beam wire-feed additive manufacturing (EBAM) method was used to build a wall of AISI 304-type stainless steel on carbon steel plate substrate. AISI 304 stainless steel wire of 1 mm diameter with following chemical composition Fe-19.1Cr-9.1Ni-0.95Si-0.2Mo-0.2Co-0.2Cu-0.15Nb-0.1V-0.12C (wt.%) was used for EBAM processing. The wall freeform fabrication was performed in layer by layer strategy under vacuum condition. Commercially produced cast bars of AISI 321 stainless steel with following chemical composition Fe-17.4Cr-8.8Ni-1.1Mn-0.4Si-0.1Mo-0.2Cu-0.5Ti-0.1V-0.07C (wt.%) was used as a reference material. For the tensile tests, the dumb-bell shaped flat specimens with nominal dimensions of 12×3×1.5 mm (thickness) were cut from the cast billets and from the EBAM-built wall in longitudinal and transverse directions relative to layer growth. Tensile tests to failure were performed for all steel specimens at room temperature and an initial strain rate of 5×10^{-4} s^{-1}.

Solution-treated cast AISI 321 specimens had a homogeneous coarse-grained austenitic structure with an average grain size of 20 μm. The microstructure of EBAM as-built specimens was inhomogeneous and consisted of mainly austenitic phase with δ-ferrite vermicular dendrites. EBAM-built specimens were characterized by columnar coarse-grained structure, which is inherent for additively manufactured alloys. Average grain size of austenite increases with the distance from the substrate from about 100 μm at the bottom part of the as-built wall (near substrate) to about 130 μm at the top part of the wall. Additionally to microscopical inhomogeneities in grain structure, a macroscopically layered structure was revealed, which follows the sequence of layer-by-layer EBAM growth of the wall. The anisotropy of the structure in different scales correlates well with the anisotropy of the mechanical properties and fracture mechanisms of longitudinal and transverse EBAM-built AISI 304 steel specimens.

Regardless of the method of manufacturing – additively grown or cast – steels are characterized by the neck formation in the fracture area of the specimens. Fracture for both cast and EBAM specimens occur in a ductile transgranular regime with dimple ruptures on the fracture surfaces. The main differences in deformation and fracture mode between cast and EBAM-built steels were observed on the side surfaces of the specimens. For the cast specimens, a uniform elongation of the grains occurs and a relief with traces of multiple slip (twinning) is observed. Additively manufactured transverse and longitudinal specimens are characterized by complex relief in the lateral surfaces. After fracture, a system of macroscopical bands oriented along the tensile axis is observed on the surfaces of transverse EBAM-built specimens. Inside of these bands, the microbands are located perpendicular to the tensile axis. Microcracks propagate in shear microbands, and fracture of the specimens occurs along them. Deformation of longitudinal EBAM-built specimens occurs more non-uniformly. The system of macroscopical bands oriented along the tensile axis also presents in them, but they are less homogeneous and pronounced as compared with the lateral surface of transverse specimens. Wide microbands oriented perpendicular to the tensile axis were observed. Along them, numerous microcracks propagate close to the area of fracture. Unlike transverse specimens, the microscopical localization of deformation is more developed in all longitudinal specimens. These features are associated with the formation of anisotropic austenitic structure with coarse grains and δ-ferrite dendrites formed during EBAM-processing of austenitic stainless steel.

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