THREE-DIMENSIONAL CRACK PROPAGATION BEHAVIOR IN HYDROGEN-RELATED FRACTURE OF HIGH-STRENGTH MARTENSITIC STEEL

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Intergranular and quasi-cleavage are typical fracture modes in hydrogen-embrittlement. Basically, increasing the hydrogen content changes the fracture mode from quasi-cleavage to intergranular, and the transition to intergranular leads to severer brittle behavior. Although the martensite structure involves several types of high-angle boundaries, hydrogen-related intergranular fractures mainly occur on the prior austenite grain boundaries. Because of nucleation as well as impingement of several martensite variants at austenite grain boundaries, a given austenite grain boundary is divided into several grain boundary segments (hereinafter, PAGB segments) by martensitic transformation. The PAGB segments formed at each austenite grain boundary have identical spatial boundary plane but exhibit different crystallographic features. Conventional 2D observation using SEM is a general method for statistical analysis on crack propagation behavior. However, it has some difficulties for analysis on crack arrestability, because critical factors for the crack arrest do not necessarily exist on the analyzed section. On the other hand, 3D techniques can analyze the controlling factors for crack arrestability. The present study utilized 3D characterization techniques, namely, X-ray CT and FIB-SEM serial sectioning to elucidate the critical factors for local crack-arrestability of hydrogen-related intergranular fracture in high-strength martensitic steel. We found from the fracture toughness tests that the crack-growth resistance decreased with increasing hydrogen content [1]. However, the hydrogen-related intergranular cracks propagated in a stable manner even when the hydrogen content was large (up to 4 wt. ppm). The X-ray CT results indicated that the fracture propagated discontinuously with a certain area of un-cracked ligaments (isolated non-crack regions) [2]. The crack propagation tended to be more continuous with increasing hydrogen content. Accordingly, we can propose that the macroscopic continuous crack propagation with increasing hydrogen content resulted in the decrease of crack-growth resistance. The microscopic 3D analysis using FIB-SEM serial sectioning revealed that the intergranular crack propagation was arrested locally at low-angle PAGB segments. The formation of un-cracked ligaments was often accompanied by quasi-cleavage crack propagation. Therefore, we can propose that the local crack-arrestability depends on the crystallographic feature of each PAGB segment, and low-angle PAGB segments can act as obstacles to crack propagation.

References

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