Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

Hydrogen Embrittlement of Additively Manufactured AlCoCrFeMo and as-Cast CoCrNi High/Medium Entropy Alloys

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ABSTRACT

Hydrogen energy is a promising alternative for fuel cells, power generation, and transportation; however, hydrogen embrittlement (HE) is a major challenge as it reduces the ductility, toughness, and fatigue life of metals in hydrogen-rich environments. Addressing HE is essential for ensuring material reliability and advancing the hydrogen economy in nuclear reactors, aerospace, and hydrogen storage systems.

In this work, we investigate the HE behavior of high- and medium-entropy alloys (HEAs and MEAs) produced through suction casting and laser additive manufacturing (AM), examining how these fabrication methods influence microstructure and mechanical performance. Understanding these effects is essential for optimizing the reliability of HEAs and MEAs in hydrogen applications. Microstructural features play a critical role in hydrogen diffusion and embrittlement susceptibility. The AM-fabricated HEA exhibits a characteristic cellular structure formed due to rapid solidification, leading to high dislocation densities and compositional segregation along cell boundaries. These features influence hydrogen trapping and diffusion. The as-cast MEA, with its refined microstructure and reduced segregation, provides a different pathway for hydrogen transport. By investigating these two fabrication methods, this work highlights the influence of different microstructural heterogeneities on hydrogen embrittlement in HEA/MEAs.

In this study, an as-cast CoCrNi MEA with a heterogeneous microstructure consisting of 50% equiaxed, 15% lamellar, and 35% dendritic regions produced via suction casting and an AM AlCoCrFeMo HEA with a cellular microstructure produced via powder deb fusion were investigated in this study. The CoCrNi alloy exhibited a Vickers hardness of 192 HV, which is 28% higher than stainless steel. Microindentation was used to evaluate the contributions of these microstructural features to mechanical properties after hydrogen charging. Grain boundaries, as critical sites for hydrogen accumulation, play a key role in determining mechanical response. In the suction-cast alloy, EBSD results showed large grains (~300 μm), while optical microscopy revealed finer substructures (~12 μm), indicating a high density of low-angle grain boundaries (LAGBs). Microindentation provides valuable insights into how these LAGBs influence hydrogen embrittlement in HEAs and MEAs by analyzing each microstructural region separately. This helps to identify mechanisms of degradation and potential strengthening strategies. These findings contribute to the development of more resilient materials for hydrogen-based applications, ensuring improved performance and reliability in hydrogen-rich environments.