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Interlayer-Mechanical Working: Effective Strategy to Mitigate Solidification Cracking in Wire-Arc Additive Manufacturing (WAAM) of Fe-based Shape Memory Alloy

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Abstract : In recent years, iron-based shape-memory alloys have been emerging as an inexpensive alternative to costly Ni-Ti alloy and thus considered suitable for many different applications in civil structures. Fe-17Mn-10Cr-5Si-4Ni-0.5V-0.5C alloy contains 37 wt.% of total solute elements. Such complex multi-component metallurgical system often leads to severe solute segregation and solidification cracking. Wire-arc additive manufacturing (WAAM) of Fe-17Mn-10Cr-5Si-4Ni-0.5V-0.5C alloy was attempted using a cold-wire fed plasma arc torch attached to a 6-axis robot. Self-standing walls were manufactured. However, multiple vertical cracks were observed after deposition of around 15 layers. Microstructural characterization revealed open surfaces of dendrites inside the crack, confirming these cracks as solidification cracks. Machine hammer peening (MHP) process was adopted on each layer to cold work the newly deposited alloy. Effect of MHP traverse speed were varied systematically to attain a window of operation where cracking was completely stopped. Microstructural and textural analysis were carried out further to correlate the peening process to microstructure.MHP helped in many ways. Firstly, a compressive residual stress was induced on each layer which countered the tensile residual stress evolved from solidification process; thus, reducing net tensile stress on the wall along its length. Secondly, significant local plastic deformation from MHP followed by the thermal cycle induced by deposition of next layer resulted into a recovered and recrystallized equiaxed microstructure instead of long columnar grains along the vertical direction. This microstructural change increased the total crack propagation length and thus, the overall toughness. Thirdly, the inter-layer peening significantly reduced the strong cubic {001} crystallographic texture formed along the build direction. Cubic {001} texture promotes easy separation of planes and easy crack propagation. Thus reduction of cubic texture alleviates the chance of cracking.

Keywords : Iron-based shape-memory alloy, wire-arc additive manufacturing, solidification cracking, inter-layer cold working, machine hammer peening
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