World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:17, No:05, 2023

Investigation of Residual Stress Relief by in-situ Rolling Deposited Bead in Directed Laser Deposition

Authors : Ravi Raj, Louis Chiu, Deepak Marla, Aijun Huang

Abstract : Hybridization of the directed laser deposition (DLD) process using an in-situ micro-roller to impart a vertical compressive load on the deposited bead at elevated temperatures can relieve tensile residual stresses incurred in the process. To investigate this stress relief mechanism and its relationship with the in-situ rolling parameters, a fully coupled dynamic thermo-mechanical model is presented in this study. A single bead deposition of Ti-6Al-4V alloy with an in-situ roller made of mild steel moving at a constant speed with a fixed nominal bead reduction is simulated using the explicit solver of the finite element software, Abaqus. The thermal model includes laser heating during the deposition process and the heat transfer between the roller and the deposited bead. The laser heating is modeled using a moving heat source with a Gaussian distribution, applied along the pre-formed bead's surface using the VDFLUX Fortran subroutine. The bead's cross-section is assumed to be semi-elliptical. The interfacial heat transfer between the roller and the bead is considered in the model. Besides, the roller is cooled internally using axial water flow, considered in the model using convective heat transfer. The mechanical model for the bead and substrate includes the effects of rolling along with the deposition process, and their elastoplastic material behavior is captured using the J2 plasticity theory. The model accounts for strain, strain rate, and temperature effects on the yield stress based on Johnson-Cook's theory. Various aspects of this material behavior are captured in the FE software using the subroutines -VUMAT for elastoplastic behavior, VUHARD for yield stress, and VUEXPAN for thermal strain. The roller is assumed to be elastic and does not undergo any plastic deformation. Also, contact friction at the roller-bead interface is considered in the model. Based on the thermal results of the bead, the distance between the roller and the deposition nozzle (roller o set) can be determined to ensure rolling occurs around the beta-transus temperature for the Ti-6Al-4V alloy. It is identified that roller offset and the nominal bead height reduction are crucial parameters that influence the residual stresses in the hybrid process. The results obtained from a simulation at roller offset of 20 mm and nominal bead height reduction of 7% reveal that the tensile residual stresses decrease to about 52% due to in-situ rolling throughout the deposited bead. This model can be used to optimize the rolling parameters to minimize the residual stresses in the hybrid DLD process with in-situ micro-rolling.

Keywords : directed laser deposition, finite element analysis, hybrid in-situ rolling, thermo-mechanical model
Conference Title : ICLAM 2023 : International Conference on Laser Additive Manufacturing
Conference Location : Sydney, Australia
Conference Dates : May 11-12, 2023