Simulation of the Pre-Heating Stage in Electron Beam Additive Manufacturing

E. Landau[1,3], E.Tiferet[2,3], Y.Ganor[2,3], M.Chonin[2], M.Ezra[2], G.Ziskind[1]

[1] Dept. of Mechanical Engineering, Ben Gurion University of the negev
P.O.B. 653 Beer-Sheva 8410501 Israel
E-mail: landaue@post.bgu.ac.il , web page: http://www.bgu.ac.il

[2] AM Center, Rotem Industries LTD
Mishor Yamin D.N. Arava 86800 Israel
E-mail: ganory@Rotemi.co.il , web page: http://www.rotemi.co.il

[3] Nuclear Research Center Negev (NRCN), Israel

ABSTRACT

In this work, we investigate the EBAM thermal management required during pre-heating in the ARCAM Q20+ EBAM machine. Generally, in electron beam additive manufacturing of Ti6Al4, the powder bed is pre-heated to ~0.5T_m (where T_m is the homological temperature of the material). This is usually followed by a second pre-heating to a higher temperature (~0.8T_m) before applying selective melting. Pre-heating the powder is essential for the EB energy deposition, but it is also known to result in lower residual (thermal) stresses in the build due to the smaller thermal gradients during melting. While it is still (nominally) well below melting temperatures, several significant effects are evident in the powder material properties and the thermal behavior of the build as a result of the pre-heating stages (e.g. powder partial sintering)[1][2]. Furthermore, obtaining a uniform and desired pre-heating temperature may become difficult in advanced build stages (with significant variations in the thermal properties of the underlying layers and changes in the build chamber thermal boundary conditions) and can affect the build quality. In order to study the effects of EBAM pre-heating as a preliminary stage to obtaining a full transient part-scale thermal (and mechanical) simulation, a numerical model of the pre-heating process was developed and tested over several levels of scaling. The model is implemented using the ABAQUS © heat transfer FEM solver with several tailored user subroutines, developed for thermal management of the electron beam scan path (per pre-heating configuration) and the scaling of the energy deposition from moving heat source to line "heat blasts" to modified uniform heat generation of the active layer. Scaling the heat source (EB) is essential in order to estimate the integrated temperature-history per volume cell (representing a small cluster of powder) to include localized temperature peaks caused by direct crossing of the electron beam over the cell (these peaks may significantly exceed the designated pre-heating temperature for a short fraction of time). In addition, the Q20+ build chamber thermal boundary conditions change during the transient process, and may not be entirely homogeneous. These boundary conditions, often approximated by a simplified radiation-to-ambient interaction, may have a significant effect in advanced build stages, and are therefore considered in a dedicated sub-model for the process. Validation is obtained through dedicated build plate and powder pre-heating experiments, which are also used for thermal characterization of the Q20+ build chamber. The experiments are initially performed by testing several pre-heating schemes on a solid steel plate with 9 thermocouples drilled in a symmetric configuration to about 2mm from the active surface. In addition, a set of 8 additional thermocouples are positioned over the heat shield and the bottom stage to estimate the heat removal conditions. A dedicated thermal IR camera is installed using a specially designed mount and mirror configuration, to provide transient temperature contour estimations of the top build surface. The nominal and local temperature-history results that are obtained for different pre-heating schemes serve as an important basis for future research of pre-heated powder thermal properties and modelling of the selective melting and additive stages of the process.

REFERENCES

[1] N. Shen and K. Chou. "Numerical thermal analysis in electron beam additive manufacturing with preheating effects", *Proceedings of the 23rd Annual International Solid Freeform Fabrication Symposium - An Additive Manufacturing Conference*, The University of Texas in Austin, August 6-8, 2012.

[2] C.J. Smith, S. Tammas-Williams, E. Hernandez-Nava and I. Todd, "Tailoring the thermal conductivity of the powder bed in Electron Beam Melting (EBM) Additive Manufacturing", Scientific Reports **7**, 10514, (2017).