Processing-Structure-Properties

in Metals Additive Manufacturing (MAM)

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Metals Additive Manufacturing *Creep Properties* *Process Window*

Abstract Metals additive manufacturing (MAM) has opened up a wide range of applications both new and old. High cooling rates are enabling new compositions to be explored and used to manufacture real parts. The substantial jump in geometrical flexibility is also enabling new approaches to design and, crucially, co-design where processing and function advance synergistically. An example of co-design will be discussed where LPBF has enabled high efficiency high-temperature and high-pressure heat exchangers [1]. The joint research between Carnegie Mellon University and the University of California at Davis resulted in successful printing, Fig. 1a, and testing of a heat exchanger rated at 55 kW, Fig. 1b. The underlying science of melting, re-solidification and microstructural evolution has benefited from the national investment in user facilities such as x-ray synchrotrons that enable ultra-high speed visualization and diffraction experiments to probe microstructural evolution. They have also enabled defect formation to be quantified which is crucial for fatigue-sensitive parts. A multi-institution NASA-supported project implemented a thorough study of fatigue as a function of LPBF parameters in Ti-6Al-4V and determined that there is the process window determined by defect (pore) content corresponds closely to the fatigue-defined window [2]. The process window has a locus of minimum pore content that can be rationalized on the basis of competing defect formation mechanisms. For qualification and certification (Q&C) purposes, the key process variables include power, spot size, scan speed, hatch spacing and layer thickness along with many other secondary variables. Many of the process outcomes can be calculated, i.e., predicted albeit with substantial computational effort. For everyday use, machine learning (ML) is providing numerical models that deliver results fast enough to be used for Q&C. ML approaches call for new approaches to verification and validation. These considerations motivate the development of a digital twin for MAM that connects together all the stages of feedstock, printing, post-processing and properties.

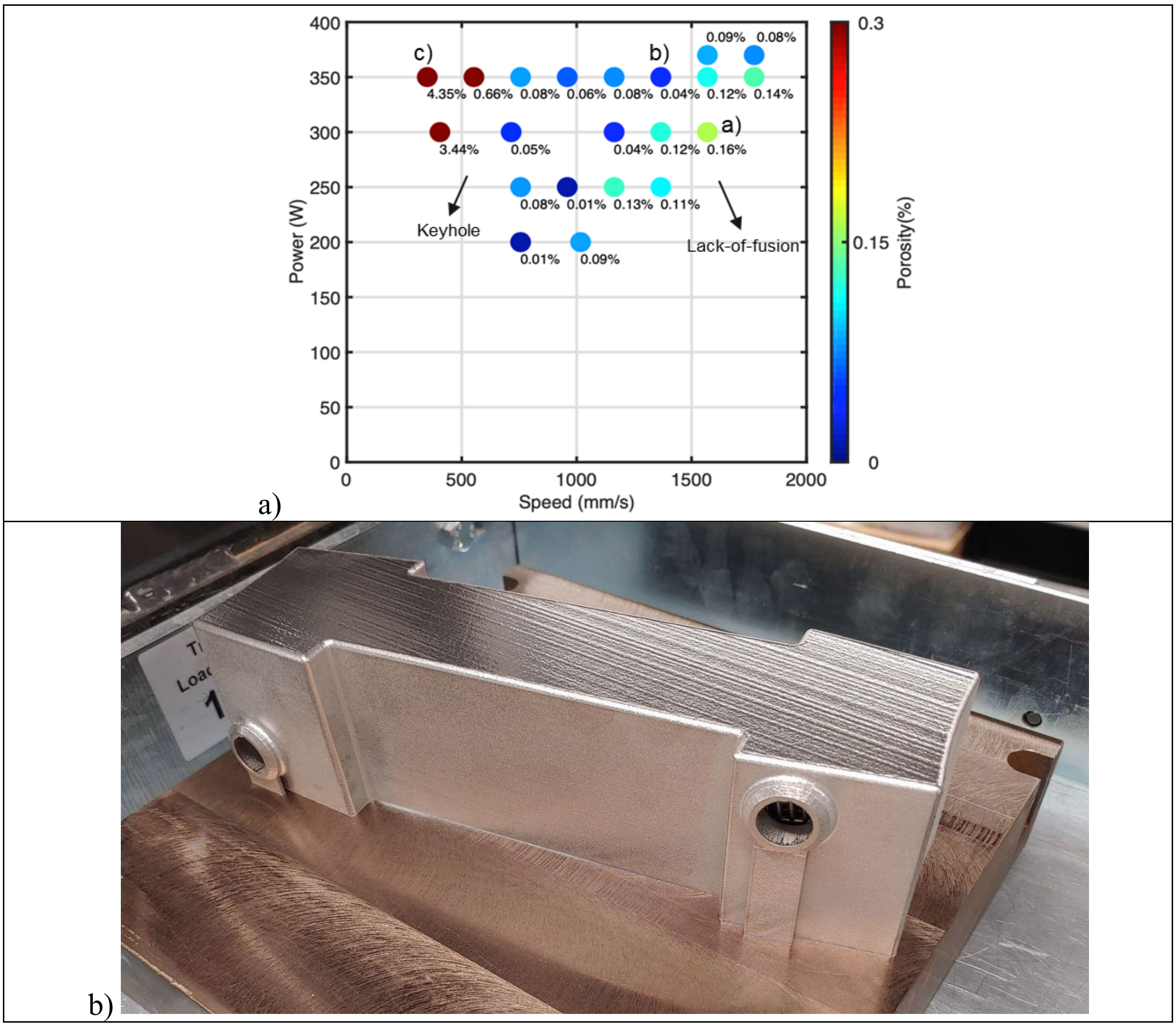

***Figure 1** – a) Process window for Haynes 282 printed in an EOS M290, showing the variation in porosity with power and scan speed; b) photograph of a high temperature, high pressure heat exchanger rated at 55 kW, printed in Haynes 282 and tested at 800 °C and 200 atmospheres.*

References

[1] "Design and techno-economic optimization of an additively manufactured compact heat exchanger for high-temperature and high-pressure applications", Sreedev Das, Erfan Rasouli, Tracey Ziev, Nicholas Lamprinakos, Junwon Seo, Parth Vaishnav, Anthony D. Rollett, Vinod Narayanan, *Applied Thermal Engineering* **245** 122778 (2024)

[2] "Fatigue-based process window for laser beam powder bed fusion additive manufacturing", Tharun Reddy, Austin Ngo, Justin P. Miner, Christian Gobert, Jack L. Beuth, Anthony D. Rollett, John J. Lewandowski, Sneha P. Narra, *International Journal of Fatigue* **187** 108428 (2024).