Experimental analysis of hardening mechanisms in an aluminum alloy manufactured by the L-PBF process

Louise Toualbi*†[1], Yann Le Bouar‡ , Frédéric Fossard , Jean Sébastien Merot , Pauline Stricot[2,3], Simon Fritz[4,5], Eric Grevin , Agnès Bachelier-Locq , Nicolas Horezan[6], Quentin Barres[7], and Yves Renollet[8]

[1]DMAS, ONERA, Université Paris Saclay [Châtillon] – ONERA – France
[2]DMAS, ONERA, Université Paris Saclay [Châtillon] – DMAS ONERA – France
[3]Mines Paris - PSL (École nationale supérieure des mines de Paris) – Université Paris sciences et lettres – France
[4]Ingénierie des Matériaux Polymères – Institut National des Sciences Appliquées de Lyon – 17, Av. Jean Capelle 69621 Villeurbanne Cedex, France
[5]Matériaux, ingénierie et science [Villeurbanne] – Univ Lyon, INSA Lyon, Univ Claude Bernard Lyon 1, CNRS UMR 5510, MATEIS Laboratory, F-69621, VILLEURBANNE, France – Bâtiment Blaise Pascal 7, avenue Jean Capelle 69621 VILLEURBANNE CEDEX, France
[6]ONERA – DMAS ONERA – France
[7]DMAS, ONERA, Université Paris Saclay – DMAS ONERA – France
[8]DMAS, ONERA, Université Paris Saclay [Châtillon] – ONERA, Université Paris-Saclay – France

Abstract

The development of Additive Manufacturing (AM) processes in recent years has enabled the production of complex geometry parts that are challenging to produce using conventional manufacturing methods. However, AM results in microstructures and metallurgical states that differ from those achieved with traditional processes. The aerospace industry is currently focusing on the use of traditional aerospace materials and applying post-processing homogenization heat treatments to ensure that the mechanical properties are comparable to those obtained through conventional methods. However, the development of new alloy grades specifically for AM can exploit the unique characteristics of these manufacturing processes. In the case of the Al-Fe binary system, Laser-Powder Bed Fusion manufacturing induces the precipitation of strengthening phases and the formation of dislocations due to thermal hardening. Indeed, L-PBF process involves successive melting of layers of powder material via a laser, which induces very short interactions between the raw powder and the laser, resulting in rapid solidification and cooling rates. As a result, the as-built material exhibits remarkable hardening, which raises questions about the thermal stability of this as-built microstructure, especially when considering the potential for using these new alloy grades for applications such as repairing components using AM processes.

Aim is to improve understanding of metallurgic and thermal mechanisms related to rapid

---

*Speaker

†Corresponding author: louise.toualbi@onera.fr

‡Corresponding author: yann.lebouar@cnrs.fr

solidification and cooling rates that are characteristic of L-PBF production and lead to structural strengthening of alloy in service. To achieve this, samples produced using different manufacturing parameters were subjected to detailed characterisation using Transmission and Scanning Electron Microscopy and X-Ray Diffraction. The results showed that the as-built microstructure produced is characterised by a remarkable hardening, which can be modulated by adjusting the manufacturing parameters (essentially the laser scanning speed and the temperature of the manufacturing plate). The impact of the manufacturing parameters on the microstructure is highlighted, particularly on the size of the solidification cells which largely controls the mechanical behaviour. The results also reveal the correlation between the Fe distribution in the microstructure and the local hardness of the material.

The differences in mechanical behavior related to microstructural organization are highlighted by conducting in-situ SEM tensile tests, allowing for visualization of more ductile zones along the edges of the melt pools. Additionally, microstructural characterizations carried out using Atom Probe Tomography (at GPM UMR 6634, Rouen, as part of a METSA grand) and Transmission Electron Microscopy have revealed a significant amount of Fe in solid solution, which could potentially further harden the material in the form of nanometric precipitates. This finding underscores the value of exploring the application of a post-fabrication heat treatment, both to fully harness the available hardening potential in the alloy and to reduce the local behavior gradient in the as-built microstructure.
The results demonstrate the impact of heat treatments on material hardening in terms of microstructural evolution, changes in local micro-hardness levels, and focus particularly on describing hardening mechanisms at the scale of solidification cells.