

Development and characterisation of Al-based alloys processed by PBF-LB/M

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Development and characterisation of Al-based alloys processed by PBF-LB/M / Martucci, Alessandra. - (2023 Feb 27), pp. 1-155.

*Availability:*

This version is available at: 11583/2976598 since: 2023-03-06T10:44:09Z

*Publisher:*

Politecnico di Torino

*Published*

DOI:

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In recent decades, the Laser-based Power Bed Fusion (PBF-LB/M) process has attracted huge interest from the industry and academia as one of the most performing additive manufacturing technologies for metals. With this promising process, complex-shaped functional components with good surface quality, excellent dimensional tolerance and unprecedented mechanical properties can be produced with a limited number of post-processing operations. Among the alloys currently available in the PBF-LB/M material portfolio, Al-based alloys stand out for their excellent strength-to-weight ratio, attracting increasing interest from the automotive and aerospace industries. The production of commercial Al-based alloys and the development of novel Al-based compositions tailored for the PBF-LB/M process are growing areas; however, they present a fair share of challenges to be solved. This thesis aims to explore the major challenges in the PBF-LB/M processing of Al-based alloys, critically analyse some solutions already attempted in the literature and propose new and unexplored ones. With this purpose, the main steps in the development and characterisation of this promising alloy category were discussed. As a first aspect, the Al-based powder properties required for the PBF-LB/M process, the characterisation procedures and the effect of reuse were analysed. The latter point is of particular interest from a sustainability perspective and was the scope of a study carried out in cooperation with Chalmers University in Gothenburg, Sweden. The work focused on the reuse impact on the particle surface oxidation of Scalmalloy, a high-performing Al-Mg-Sc-Zr alloy patented by APWorks. Subsequently, the discussion turned to the different optimisation strategies that can be undertaken with commercial alloys or non-standard compositions. As an example of the first category, the low-power optimisation work performed on the Scalmalloy produced by a lab-scale PBF-LB/M machine was reported. When optimising the process parameters of a non-standard composition not available in the literature, a time- and effort-saving option may be to start with the single scan track (SST) method. This method allows a wide range of power-scan speed (P-v) combinations to be analysed without the time-consuming production of bulk samples. To further speed up the SST analysis procedure and make it reliable and robust, a computer-aided method exclusively based on on-top images was developed. Once a minimal number of P-v combinations suitable for mass production have been obtained and the optimal hatch distance (hd) values have been calculated based on the SST width and desired overlapping, the other process parameters can be optimised by bulk sample production. This procedure was followed in the work conducted on an innovative composition, AlSi10Cu4Mg. Unfortunately, this linear procedure is sometimes not suitable for alloys with a high sensitivity to cracking. Indeed, the SST method is not able to predict the residual stresses that can be generated due to the layer-by-layer process. In these cases, the optimisation process becomes more complex, and although the literature offers possible solutions, a standard procedure is still unknown. To fill this gap, a study was conducted on a highly crack-sensitive alloy, AlSi10Cu8Mg, in which various strategies were systematically explored. This study revealed that the synergetic use of low scan speeds and support structures might easily result in fully densified and crack-free specimens without building platform heating. This efficient methodology used to quickly define process conditions without crack and delamination formation can be extended to all new compositions affected by cracking tendency, establishing an important new target in expanding the materials portfolio of the PBF-LB/M process. Developing new compositions to expand the PBF-LB/M material portfolio is one of the most heartfelt goals in this area. The design of new alloys often occurs with the aim of improving one or more strengthening mechanisms: by grain refining, by solid solution and/or by precipitation. During the work carried out at Chalmers University, a novel Al-Mn-Cr-Zr system was developed and characterised. This composition was designed in order to obtain a supersaturated

solid solution in the as-built state and exploit the strengthening by precipitation after heat treatment. As part of a comprehensive characterisation work conducted on this promising alloy, the influence of the PBF-LB/M process parameters on the supersaturated solid solution condition and the formation of Al-Mn enriched nano-precipitates was investigated. The results revealed a very stable system over the range of process parameters tested. All samples exhibited a low level of nanometre phase enriched in Al-Mn precipitation, thus allowing a supersaturated state to be established under all process conditions. This condition is highly advantageous for the mechanical behaviour of the alloy in the as-built state but also after heat treatment. Starting from this condition, in fact, and heat-treating the alloy, the formation of fine and uniformly dispersed strengthening precipitates can be obtained, significantly increasing the mechanical performance.