Feasibility studies on Laser Powder Bed Fusion of powders mixtures based on Aluminium alloys or High Entropy Alloys

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Abstract

Laser Powder Bed Fusion (LPBF) is an advanced metal additive manufacturing process, which allows to fabricate components with sophisticated shapes by locally melting subsequent layers of powders with a computer-controlled laser beam. Over the last years, LPBF has gained much interest not only for its inherent advantages related to the high design freedom but also for its opportunities from a material point of view. During LPBF process, in fact, the highly focused laser beam creates a small and highly dynamic melt pool in which the alloy rapidly solidifies and undergoes complex thermal cycles with kinetics significantly different from that occurring in conventional manufacturing processes, i.e. casting. This contributes in creating new materials with different microstructures and unique properties.

Recently, broad material research opportunities for LPBF have been perceived in the exploitation of the metallurgical effects associated to the rapid solidification conditions during the process, namely the refinement of the segregation scale, the formation of supersatured solid solutions and metastable phases as well as the retention of disordered crystalline phases. These effects have been considered promising both for heading *ad-hoc* alloying strategies aimed to develop novel aluminium alloys with high strength and for boosting maturity of recently discovered High Entropy Alloys (HEAs), which are alloy systems composed by more than four elements in equi- or near equi-atomic concentration, preferably forming disordered crystalline structures. Nevertheless, to date, major obstacles to the development of novel alloys by LPBF come from the high-cost, poor availability and large size of purchased batches of the gas-atomized powders. Novel, economically affordable as well as stimulating material research opportunities for LPBF could come both from the *in-situ* synthesis of alloys from mixtures of different powders and from the use of alloy powders synthesized by other alloying techniques than atomization, i.e. mechanical alloying. The present thesis investigated both the scenarios, according also to the compositional complexity of the alloy system. Novel Al-Si-Ni and Al-Si-Ni-Cr-Fe aluminium alloys and two HEA systems were studied in the present thesis.

The first study investigated the consolidation, the alloying behavior as well as the microstructure and the mechanical properties of an Al-Si-Ni alloy *in-situ* synthesized from a powder mixture constituted by AlSi10Mg and pure Ni powders. By properly tailoring the alloy composition, it was possible to manufacture nearly full dense and crack free samples. The physical phenomena occurring within the melt pool during LPBF together with the continuous heating/melting of the material during the building were effective in mixing the starting powders. The material microstructure consisted of wide regions with composition close to that of the powder mixture alternated to coarse and randomly distributed Ni-rich precipitates, globally designating a heterogeneous microstructure. Notwithstanding this, the addition of Ni was effective in producing an alloy with high hardness due to the precipitation of sub-micrometric strengthening Al_3Ni phase.

The second study investigated an Al-Si-Ni-Cr-Fe aluminium alloy synthesized starting from a powders system by far more complex than the previous one, constituted by a mixture of AlSi10Mg and Hastelloy X nickel-base superalloy powders. The consolidated samples were porous due to adoption of a powder layer thickness not appropriated with respect to the other processing parameters. Nevertheless, the alloy composition synthesized was promising due to the absence of composition-

related defects, such as cracks. The scanning speed during LPBF controlled the extent of the reaction between the starting powders, the alloying process and the fraction of product phases formed as well as the mechanical properties of the synthesized alloy. Alloying with Hastelloy X resulted into an enhancement of the microhardness up to 50% with respect to AlSi10Mg but major concerns were found in the capability of LPBF of effectively *in-situ* mixing a powder system constituted by many species from different alloy powders having a large mean particle size.

The third study adopted a single scan track (SST) technique for preliminarily investigating the processability and the alloying behaviour of compositionally complex AlTiCuNb and AlTiVNb HEAs powder compositions by using both mixture of the constitutive elemental powders and alloy powder synthesized by mechanical alloying. The characterization of the SSTs revealed that the microstructure homogeneity as well as the chemical composition accuracy within the melt pool were enhanced when using alloy powders synthesized by mechanical alloying in place of complex mixtures of the elemental powders. The broad ranges into the physical as well as powder properties in the elemental powders mixtures and the high melting point of some of its constitutive elements contributed in creating inhomogeneous distribution of the elements as well as residual unmelted particles within the melt pool. In addition, the SST technique revealed major issues in the deposition of a powder layer with equiatomic composition starting from a complex powder mixture constituted by many different species. On the other hand, SSTs of chemically and morphologically homogenous HEAs powders synthesized by mechanical alloying could represent a fast and cost-effective technique for preliminarily assessing the behaviour of novel HEAs powders during LPBF.