Sintesi della tesi: Study and development of an innovative L-PBF demonstrator and an anti-ice solution based on trabecular structures

Dottorando: Sara Varetti

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The work presented in this thesis regards two separate research topics about Laser Powder Bed Fusion (L-PBF) technology, carried out simultaneously over the Ph.D course. The first topic concerns the experimental characterization of samples produced with an innovative L-PBF prototype. The second topic is related to the mechanical and thermal characterization of a real case-study produced with a L-PBF commercial machine.

In the first topic an innovative L-PBF demonstrator, able to process very large components with a higher production rate, is presented. The machine was built in the frame of the regional project STAMP by the innovative start-up 3D New Technologies S.r.l.. A set of tests was conducted to evaluate the powders to be used for the production and the optimization of the process parameters of the machine. Initially the samples produced by the machine were made of Stainless Steel 316L powders, because 316L material is simple to produce. The goal is to turn to more complex materials whose production can take advantage of machine innovations, such as aluminium alloys. The L-PBF technology market is carefully analyzed, in order to justify the technical choices that have characterized the innovations of the machine, named LLA400. The LLA400 machine tries to respond to the demand for larger and faster L-PBF machines, with greater automation and closer to the concept of industrialization. The innovative solutions adopted for the demonstrator were tested, and the functioning of some components, such as inert gas blowing, were evaluated. Furthermore, the characteristics of two powders for L-PBF were considered: i) AlSi10Mg powders made with different atomization techniques and ii) 316L commercial powders of LPW. The 316L powders were used for the specimens produced with the machine in the first trials; Al powders will be used for future jobs. Finally, the first 316L samples, consisting in single layers, were produced by the machine and characterised. The fusion defects were analyzed thanks to Optical Microscope and comparison with literature data. After the first tests, the research activity for the optimal process parameters was directed towards energy densities between 80 and 130 J/mm^3, but a lot of tests are necessary before it can be completed. In conclusion, for the LLA400 machine of the STAMP project the innovations introduced such as preheating and increased productivity have been verified. 316L single layers were produced and some process parameters that allow obtaining a homogeneous melting were identified. For the future it is necessary to produce larger pieces and to observe the effects of innovations on the quality of the final component. This operation will be performed on all other materials. This will allow to obtain an optimal set of parameters for each type of material processed.

The second topic concerns the characterization of an anti-ice system patented by Politecnico di Torino. The system for the leading edge of the aircraft wings consists of a sandwich panel with a core made of trabecular structure. The entire panel is made with L-PBF technology. The anti-ice system produced is a hot air system: it uses the hot air tapped from the engine to maintain the wing surface at a temperature higher than the water freezing point. The characterization of the system was founded by Politecnico di Torino with a Proof of Concept (PoC), that had the goal of carrying the patent from a TRL 1 to a TRL 5, with a prototype. The prototype must demonstrate the functioning of the system and its feasibility with the L-PBF technology. In order to choose the design of the final mock-up, different mechanical and thermal tests on AlSi10Mg and Ti6Al4V specimens were carried out. The specimens were produced with six different cell shapes (Bccz, Rhombic dodecahedron, Octet-truss, Auxetic, Schwartz diamond and Gyroid), three cell sizes and three values of solid volume fraction. The first mechanical test is the uniaxial compression test of trabecular specimens in AlSi10Mg and Ti6Al4V. On the base of the results obtained from this test, the characteristics of the specimens for the following tests were chosen. The second test set is the uniaxial compression test on AlSi10Mg sandwich panels with trabecular core, followed by the 3-point bending tests. The last mechanical test carried out is the fatigue test on some selected specimens. An example of the specimens for all mechanical tests is illustrate in Figure 1.

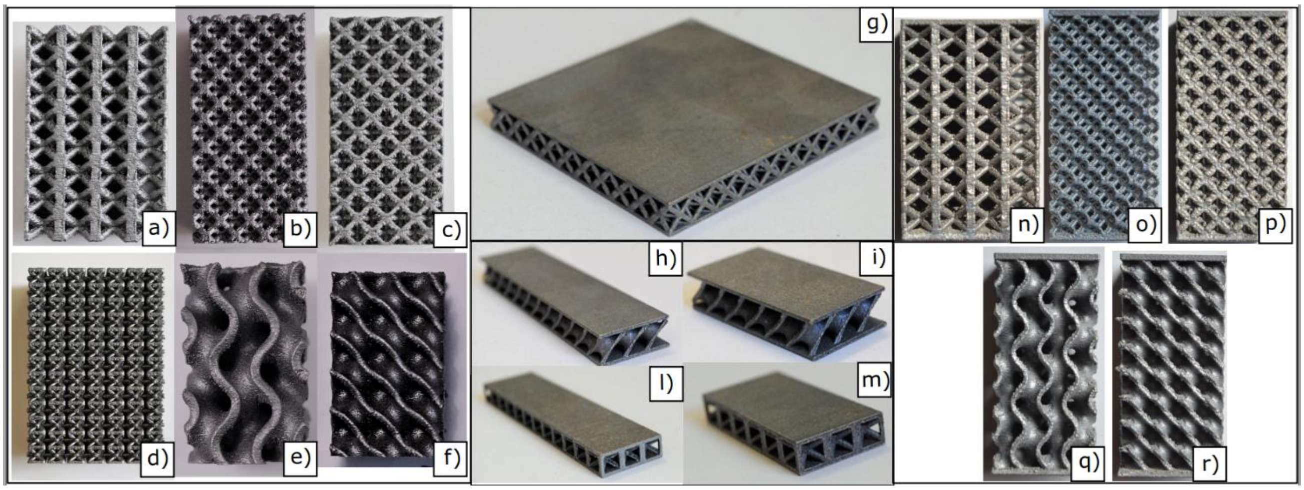

Figure 1: AlSi10Mg specimens produced for different mechanical tests. At the left six images show the specimens for uniaxial compression test with a) bccz, b) rhombic, c) octet, d) auxetic, e) gyroid and f) schwarz geometry. In the middle, g) a sandwich panel for compression test with octet structure, and four sandwich panels for bending tests with h) schwarz cell - long design, i) schwarz cell - short design, l) bccz cell - long design and m) bccz cell - short design. At the right side five specimens for fatigue tests with n) bccz, o) rhombic, p) octet, q) gyroid and r) schwarz.

Finally, thermal tests were carried out on the Bccz and Rhombic panels, to verify the goodness of the heat exchange between the hot air and the panel. Furthermore, thanks to the Optical Microscope images of the specimens, it was possible to analyze the results of the production process with AlSi10Mg and Ti6Al4V materials. For denser cell, such as 3 mm, in particular in the case of samples made by AlSi10Mg, the difficult heat dissipation during the process causes an excessive enlargement of the structure, making these cells not suitable for the final application.
In conclusion, the mechanical and thermal tests allowed to identify the best types of cells to be used as sandwich cores in aerospace use. The best cells shapes are the Schwartz diamond for the mechanical performances and the Bccz for mechanical and thermal behavior, while the best cell size is 7 mm, that allows a good passage of the air. The bending tests showed the goodness of the connection between core and skins as delamination never occurs. Fatigue tests revealed that Bccz have a different failure mechanism compared to the uniaxial compression test. Moreover, the results suggest that the Bccz structures have higher fatigue life than Octet and Rhombic cells, while Octet cells is better than the Rhombic ones.