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Additive manufacturing of titanium alloy for aircraft components

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Abstract

Selective Laser melting (SLM) is an additive manufacturing technology that uses laser as a power source to sinter powdered metals to produce solid structures. The application of SLM permits engineers to develop and implement components with topologically optimized designs and resultant material properties in comparison to conventionally produced casting parts. Current aviation programs as ACARE 2020 (Advisory Council for Aviation Research and Innovation in the EU) and Flightpath 2050 request a reduction of fuel consumption as well as CO_2 and NOx emissions in the next years. To meet these requirements there is a clear trend to produce light-weight components for engines and structural parts of aircrafts through SLM. Since SLM process is a key technology for aeronautical application, this paper focusses on the qualification of a high performance titanium alloy as well as on the investigation of optimized process parameters and positioning strategies of the structures produced in the SLM machine.

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Keywords: additive manufacturing, titanium alloy, light-weight components, aircraft

1. Introduction

In the field of commercial aviation, a demand for more than 28,000 new large commercial aircraft on the global market is expected for the period of 2012-2031. Approximately 10,000 of the old aircraft will have to be replaced. A global growth of 4.7 % per year in air traffic, measured in passenger kilometers (RPK), is also estimated [1]. Embraer forecasts a requirement for more than 5,000 new jets in the 30 to 120-seat capacity segment over the next 15 years, with a total market value estimated up to US$ 200 billion [2]. In addition, aviation programs ACARE 2020 (Advisory Council for Aviation Research and Innovation in the EU) and Flightpath 2050 request a reduction of fuel consumption as well as CO_2 and NOx emissions over the course of the next years for aircrafts [3,4].

These framework conditions represent a challenge for the producers of structural parts and engines for aircrafts. In order to fulfill current and future requirement, the aircraft industry must undergo considerable technological developments concerning innovative materials and design techniques as well as new fabrication processes. An interesting additive manufacturing technology for the fabrication of components with innovative designs and also topological optimized geometries is the selective Laser melting (SLM). SLM allows a layer by layer production of complex components directly out of metal powder based on CAD-Data. An exceptional advantage of SLM is the possibility to manufacture complex lightweight structures that cannot be produced using conventional processes. Lightweight structures can contribute to the increase of efficiency and also to reduce the fuel consumption and the emission levels of gases by aircrafts.

Embraer is working in cooperation with Fraunhofer IPK to investigate the characteristics and mechanical properties of a titanium parts made by Selective Laser Melting for a structural aerospace application. In order to achieve advanced

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knowledge regarding these produced parts it is essential to analyze the process and the resultant parts. To attain this target, test geometries of Titanium alloys were built and different properties such as density, micro hardness, surface roughness, tensile and fatigue properties were examined. As the final result structural metal parts were produced by the SLM process to evaluate the achieved results.

2. Selective Laser Melting (SLM) of titanium alloy

2.1. SLM Process

Selective Laser Melting (SLM) allows the processing of several metal materials and is especially appealing for individual parts with complex geometries. Using SLM, designers can integrate functions as cooling channels, rear slices and build lightweight structures directly into the component and manufacture this component in one single process step. The iterative process flow is shown in Figure 1.

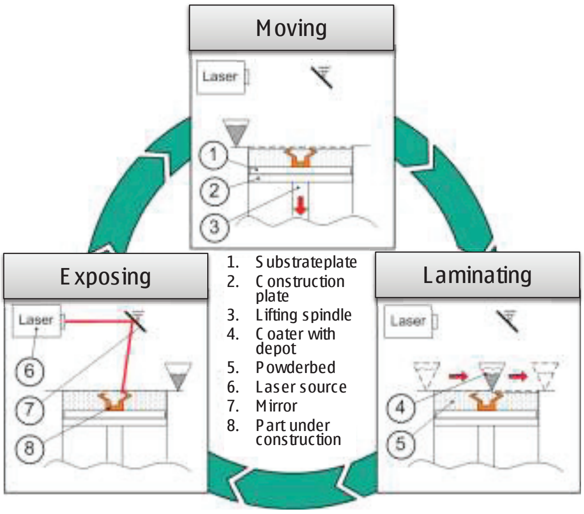

Fig. 1. SLM-process flow [5].

The substrate plate is lowered to one layer thickness and the powder is evenly distributed by the coater over the platform. Then the material is selectively melted. These three steps repeat until a whole part is built up, layer by layer. During the process the whole process chamber is flooded with an inert gas such as Argon to avoid oxidation of the metal powder. The powder that has not been used in the process is sieved and reused for the next process. The features that concern the selection of the layer thickness are shown in Table 1. In order to achieve high process stability, velocity and low material costs, and still being able to build a part with an acceptable resolution and surface quality, a layer thickness of 50 µm is used in this paper.

Table 1. Selection of layer thickness [6].

Feature	Thin 10 – 30 µm	Thin 30 – 100 µm
Part resolution	high	ok
Surface quality	high	ok
Process stability	ok	high
Process velocity	low	high
Material costs	high	ok

2.2. Titanium alloy TiAl6V4

TiAl6V4 is counted among the (α+β)-alloys and it is today's most common used titanium alloy. It covers 50 % of the whole production of titanium alloys. It is also the most explored and tested titanium alloy with very balanced properties, such as low density, ductility, good corrosion and oxidation resistance. It is used in high operating temperatures and high stresses, for example in the building of gas turbines. The properties of the titanium-alloy depend on the microstructure, the size and arrangement of the α- and β-phase. The microstructure is depending on the cooling process. The both extreme forms are the lamellar and the globular microstructure. Simple cooling from the β-phase leads to a lamellar microstructure, the lamellas are coarsed with decreasing temperature. Fast quenching leads to a martensitic transformation of the ß-phase with a fine-spitted structure. Globular microstructure is the result of recrystallization. Both forms of microstructures can exist in fine and coarse distribution [7]. Several researches on the field of titanium alloy manufacturing by SLM are been carried out and are showing a high potential for its application [8,9,10].

3. Analysis of used powder material for SLM

3.1. Chemical composition

The chemical composition of the powder material used for SLM was identified by an Energy Dispersive X-Ray Analysis (EDX) with the Scanning Electron Microscope LEO 1455 VP. The chemical composition shall compare the status quo with a desired status. The manufacturer values correspond to the material values of DIN 5832-2 [11]. The detected values of the delivered powder are comparable too, see Table 2. The chemical composition of the powder material is suitable for further SLM.

Table 2. Chemical composition of the powder material.

Element	Determined Values EDX-Analyses (wt. %)
Titanium (Ti)	91.23
Aluminum (Al)	5.21
Vanadium (V)	3.47
Iron (Fe)	0.10