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Optimized and Cost-Efficient Compression Molds Manufactured by Selective Laser Melting for the Production of Thermoset Fiber Reinforced Plastic Aircraft Components

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Abstract

Today, innovative lightweight constructions and highly complex parts for aircraft can be realized by Additive Layer Manufacturing (ALM), also called 3D-printing, in a time-saving and cost-efficient way. However, these new production technologies are not only considered for lightweight components but also for the manufacturing of molds, tools and jigs. In this context the additive manufacturing of heated compression molds for the production of thermoset composites by using a Selective Laser Melting (SLM) or also called Laser Beam Melting (LBM) process is particularly promising. In comparison to conventional machining the additive tool manufacturing obtains shortened time for development, simplified of the production due to less process steps, reduced production lead time and a general cost reduction. By the way, less energy consumption and improved material usage for the manufacturing of composite molds are further benefits, which cause an additional increase of the cost efficiency and economical sustainability. Moreover, an optimization of the fiber reinforced plastics (FRP) part quality, an improvement of the reproducibility of manufacturing processes and a higher freedom of the part design can be realized due to a higher complexity of the mold geometry, an increased functional integration, new design approaches of heating channel systems and an improved temperature distribution of the additive manufactured compression molds. Consequently, these new composite tool manufacturing opportunities promise enormous potentials, but also several challenges for the future production of aircraft components.
This paper deals with a first feasibility analysis of the Additive Layer Manufacturing of heated composite molds, jigs and tools for aerospace industries. Furthermore, the additive manufacturing of a heated research mold for a Sheet Molding Compound (SMC) aircraft component and first investigation findings of the influences on the manufacturing process parameters by using this research mold are further key aspects of the present work.

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Keywords: Additive Layer Manufacturing; 3D-Printing; Mold; SMC; FRP; Composite Tooling

1. Introduction and motivation

The technologies of heated tools and jigs for aerospace composite parts are mainly dominated by traditional manufacturing methods. The auspicious and innovative SLM process of metals provides a more cost-efficient, simpler and faster opportunity to produce small and complex heated molds for FRP components. The traditional ways of building tools for the production of thermoset composite or plastic parts show a major problem in adding change requests during the development process, manufacturing progress and also in the integration of tempering channel systems. Therefore new methods must be considered to improve the tooling and to make it more flexible regarding spontaneous demands, accelerated development processes and shorter manufacturing cycle times. These facts are important for an effective and cost-saving production of molds for FRP parts with a complex

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shape and high requirements on quality and reproducibility. With this background and the high rate of variant diversity in components ALM technologies are of great relevance for aerospace industries, also for tool and jig manufacturing. Furthermore additive manufacturing provides higher complexity of the mold shape and an increased functional integration due to new design opportunities and a maximum freedom of design. Consequently, the quality of the composite part and the process reproducibility can be improved due to surface compliant heating channels and an optimized heat conduction. Besides, less material is used due to the additive production process in comparison to subtractive manufacturing technologies. The material usage can be optimized up to 95 percent. Therefore and regarding to less energy consumption and a decreased carbon footprint for the fabrication of heated molds the energy consumption, the resource efficiency and the ecological sustainability of the production of aircraft parts can be improved. [1,2]

The focus of this work is the development of an isothermally heated compression mold for SMC manufactured by laser beam powder bed melting for a test component of the aircraft primary structure. In this context a systematic approach for the development and manufacturing of FRP tools and molds build by SLM will be shown. Further focal points are first research findings regarding the manufactured tool, pressing tests and the SMC processing. Finally the current potentials and limitations of the composite tools manufactured by SLM for the aerospace industry will be analyzed.

Nomenclature

ALM	Additive Layer Manufacturing
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CFRP	Carbon Fiber Reinforced Plastics
FEM	Finite Element Method
FMEA	Failure Mode and Effects Analysis
FRP	Fiber Reinforced Plastics
EBM	Electron Beam Melting
EDM	Electrical Discharge Machining
GFRP	Glass Fiber Reinforced Plastics
LBM	Laser Beam Melting
QFD	Quality Function Deployment
SLM	Selective Laser Melting
SMC	Sheet Molding Compound

2. State of the Art

2.1. Selective Laser Melting Process

Nowadays manufacturing conventional tools with complex geometries or built-in functions are connected with high development and process costs. Different steps in the production such as multiple drilling and milling processes or the usage of EDM increases the costs and production time significantly. Therefore layered freeform fabrication and ALM processes are gaining more attention and are growing to be a promising alternative for the production of complex tools and molds with integrated heating channel systems. A possible solution in tool manufacturing is the SLM process, illustrated in Fig. 1. This additive manufacturing process uses 3D CAD data as a digital information source and energy in the form of a high powered laser beam to create three-dimensional metal parts by fusing fine metallic powders together. 3D objects are built by applying very thin layers of powdered building material leveled over the build platform. This metallic material is melted due to the thermal treatment and influences of a laser beam. Due to the statistical distribution of size of the metallic powder particles each layer has a thickness of at least 20µm to 50µm. [1,2,3]

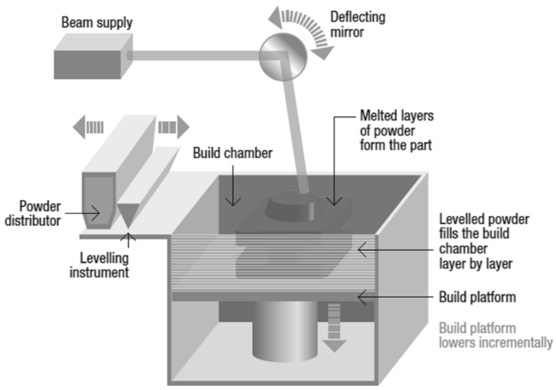

Fig. 1. Principle of the SLM process [2].

The powder which is not melted remains in place to support features further up the object that hang from the main structure. The build platform moves down incrementally to print the subsequent layers. Once finished the remaining unmelted metallic powder is removed and recycled. The SLM fully fuses the metal powder into a solid homogeneous form which saves the additional heating procedure of the sintering process. Hence numerous parameters take effect on this complex manufacturing procedure. The most dominant influence parameters are shown in Fig. 2. Benefits of this production process are cost reduction of complex geometries, functional integration (e.g. heating or cooling channels) and reduction of development and production time. Currently the disadvantages are high acquisition costs and limited operating space. Due to the shrink characteristics and the resulting surface roughness caused by the melting process a further mechanical editing of the final 3D printed model is required. A similar process is EBM, which uses an electron beam instead of the laser as an energy source. The metallic powder can consist of different metals or metal alloys such as steel, aluminum and titanium. [1,3,4,5]