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Composites Part Production with Additive Manufacturing Technologies

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Abstract

Additive Manufacturing (AM) is of particular interest in the context of composite part production as AM promises the production of integrated, complex structures with low lead times. Currently, AM is used for tooling and sandwich cores with added functionalities. This paper presents four design principles that improve the production of composites parts during layup, handling, curing and post processing in the layup process. Design principles are applied to a hat-stiffener, a highly integrated aircraft instrument panel and a novel insert eliminating drilling operations. Results show that AM can reduce the part count, assembly steps and deformations during curing.

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1. Introduction

Recent advances in the field of Additive Manufacturing (AM) have generated increased interest in the context of Fiber-Reinforced Polymers (FRP) part production [1]. This is owing to the possibility of AM to directly produce geometrically complex structures at constant manufacturing effort. Current applications combining AM with FRP include layup tooling [2, 3, 4] and structural lightweight AM elements with added functionalities, such as AM honeycomb cores in Sandwich structures [5].

Lots of effort is observed in the development of thermally stable materials for the production of in-autoclave tooling with Fused Deposition Modeling (FDM) [6]. Stratasys published design guidelines for the design for FDM tooling and washout tools considering thermal expansion, accuracy and tool life [7]. Studies exist on the effect of thermal stresses for ULTEM 9085 by FDM at 121 °C and vacuum pressure [8]. For ULTEM 1010 by FDM, at 120 °C and bar pressure a minimal wall thickness of 12 mm is reported to keep tool deformations small [9]. These studies represent very important research towards the full understanding of FDM in the context of composite tooling. Most studies focus on the development of materials and their suitability under curing conditions.

Although curing is an important step in the manufacturing of FRP parts, AM can yield benefits along the whole processing route. To the best of our knowledge, there is no study systematically exploring AM design opportunities in tooling, layup, curing and post-processing of FRP parts.

This paper investigates how through *design*, AM can add value in the FRP layup process. Selective Laser Sintering (SLS) and Selective Laser Melting (SLM) are combined with a FRP layup process to produce highly integrated lightweight composite parts (Section 2). Four major AM design principles that could favorably impact the composite part production are presented and assigned along the main processing steps (section 3). Considerations relevant to the successful implementation of such design principles are presented. Case studies exemplify the embodiment of selected design principles and quantify the benefits of using AM in the processing of FRP (section 4). Section 5 concludes.

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2. Background information

2.1. Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) is a powder bed fusion process where a laser is directed onto the powder bed and thermally fuses the powder layer to form the cross section of the part. The building platform is lowered and a new layer of powder is applied by roller. The process is repeated until the 3D part is built [10]. SLS shows high technological readiness and is considered to be the most favorable production technique for functional polymeric materials [11]. SLS doesn't require support structures and therefore allows the direct production of very complex geometries such as overhangs, internal channels and functional elements. The most common materials for SLS are polyamide 12 (PA12) and dry blends of PA12 accounting for approximately 90% of the industrial production [12].

2.2. Selective Laser Melting (SLM)

Selective Laser Melting (SLM) is a powder bed fusion process using a similar principle to SLS. A laser thermally melts the metal powder which then changes to a solid phase as it cools and forms the cross section of the part. The high melting point of metal powders leads to high thermal gradients and thermal stresses can result warping. Therefore SLM requires support structures for overhangs and anchors are used to attach the parts to the build plate. Typical materials are among others stainless steel, titanium and aluminum alloys [13].

2.3. Composite hand layup process

Fiber-Reinforced Polymers (FRP) consist of aligned, continuous fiber reinforcements that are embedded in a polymeric resin. For many high performance applications PREimPREGnated (prepreg) fibers are used. The autoclave prepreg layup process is a well-established and robust manufacturing route for the production of high performance lightweight structures. In this process prepregs are cut and laid down in the desired fiber direction on a tool. The layup is vacuum bagged and put in the autoclave where defined temperatures and pressures are applied for curing and consolidation of the part [14]. Figure 1 shows an adapted prerpeg layup process where complex elements made by AM are inserted during the layup. These elements can be tooling, structural cores or inserts made from polymers or metals. This approach enables the production of highly integrated, complex parts made of AM and FRP.

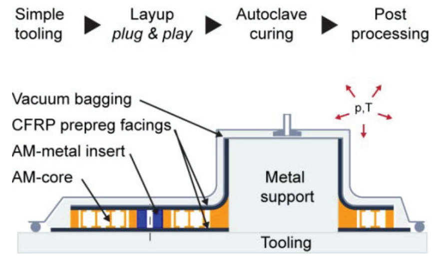

Fig. 1. Hand layup process route combining additive manufacturing and FRP.

3. AM design principles for the composite part production

This section introduces four major design principles that support the processing of FRP parts. They are based on two fundamental characteristics of additive manufacturing: The first one, is the possibility to design very complex geometries, often referred to as *complexity for free*. From this follows the second advantage, that is the integration of various functions into one single part.

3.1. Positioning and fixation elements (pre-assembly)

In the manufacturing of composite parts reinforcement plies, inserts for load introductions, attachment points or structural cores are subsequently added to form the part. The positioning and fixation of such elements is crucial to meet design tolerances for the attachment of further components (e.g. instruments) or the integration of the part in a superior assembly.

In honeycomb sandwich structures the positioning and fixation of inserts is effortful and requires many process steps. The installation of a molded-in fastener into a conventional honeycomb structure requires the following steps: First, a hole is drilled into the honeycomb, then a potting resin is applied. The insert is placed in the hole and a temporary tab is used to hold and fix the fastener during the potting process [15].

With AM, *positioning and fixation elements* can directly be integrated into the additive core or tooling (Fig 2). Design embodiments of such elements can broadly be divided to:

- Connection elements: snap fit, puzzle joints, etc
- Positioning elements: pockets with form fits, spacing elements (e.g. defined bonding gaps)

The integration of such elements potentially reduces the number of assembly steps and thereby the assembly time. In sandwich structures, this allows for a quick pre-assembly of structural elements including AM core elements and inserts (e.g AM cores, inserts) before going on to the layup of the facings. AM tooling could include such elements for the positioning and fixation of conventional honeycombs and inserts. However, a few considerations must be accounted for: On one hand, tolerances are crucial in the design of AM positioning elements. For AM, dimensional tolerances vary depending on the process and the building orientation. Due to the mechanical anisotropy of AM [16], material and building orientation of load bearing connection elements such as snap fit joints should be considered [17].