Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 36 (2015) 193 – 198

www.elsevier.com/locate/procedia

CIRP 25th Design Conference Innovative Product Creation

Redesign Optimization for Manufacturing Using Additive Layer Techniques

Konstantinos Salonitis*, Saeed Al Zarban

Manufacturing and Materials Department, Cranfield University, Cranfield, MK 10 7DX, UK

* Corresponding author. Tel.: +44 (0)1234 758347; fax: 44 (0) 1234 751172. *E-mail address:* k.salonitis@cranfield.ac.uk

Abstract

Improvements in additive manufacturing technologies have the potential to greatly provide value to designers that could also contribute towards improving the sustainability levels of products as well as the production of lightweight products. With these improvements, it is possible to eliminate the design restrictions previously faced by manufacturers. This study examines the principles of additive manufacturing, design guidelines, capabilities of the manufacturing processes and structural optimisation using topology optimisation. Furthermore, a redesign methodology is proposed and illustrated through a redesign case study of an existing bracket. The optimal design is selected using multi-criteria decision analysis method. The challenges for using additive manufacturing technologies are discussed.

Peer-review under responsibility of the scientific committee of the CIRP 25th Design Conference Innovative Product Creation

Keywords: Design for additive manufacturing; desing optimization; additive manufacturing; redesign

1. Introduction

The design process constantly balances the desire to remove material against the need to ensure that component stresses remain acceptable. Conventional manufacturing methods, such as turning and milling, impart limitations on the component geometries that can be produced. These limitations often result in structures that are inefficient, as many areas of a component have excess material that cannot be removed physically or cost effectively through conventional methods.

Additive Layer Manufacturing (ALM) techniques provide the opportunity to address the problem of inefficient structures. ALM enables components to be manufactured with material only where it is required. Components optimised to exploit the benefits provided by ALM can look very different from those designed to suit conventional production methods. It is challenging for engineers accustomed to designing components for conventional techniques to adapt their thinking to exploit the often organic shapes that ALM enables.

ALM technologies allow for the creation of intricate models and products comprise composite materials which can be customised. ALM consists of methods, which develop 3D object in sequence adding layers over each other. There have been enhancements both in materials and in the methods themselves during the last three decades; nevertheless all methods are based on the layer-by-layer concept.

The aim of the present study is the development of a framework for redesigning existing components in order to exploit the benefits of ALM. This framework is tested and validated through the redesign of an existing component, currently designed to be manufactured using conventional techniques. The objectives set were to present a lightweight design and to develop a component design that remains rugged enough to survive the shock loads applied.

2. Literature review

ALM manufacturing technologies allow for the creation of models and products that are intricate in nature and made of composite materials which can be customised. ALM can be defined as the processes in which physical objects are made through layer by layer selective fusion, polymerisation or

Peer-review under responsibility of the scientific committee of the CIRP 25th Design Conference Innovative Product Creation

doi:10.1016/j.procir.2015.01.058

sintering of materials. For every ALM process, the designers begin with 3D computer software and follow a number of general steps that are required to be undertaken for manufacturing a part (Fig. 1); these steps may vary with the technology used. Designers can take advantage of the processes capabilities in order to design complex designs by using unexplored regions of the design space.

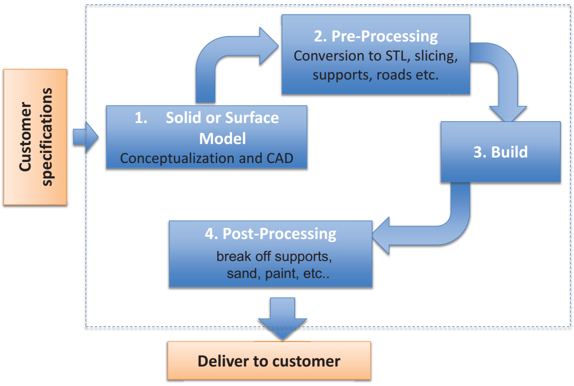

Fig. 1. ALM process steps for manufacturing.

ALM is stated to enhance design optimisation because of the designer's freedom and the fact that the design process is aided by a computer program, which allows layer by layer build-up of the model prototype [1]. Material complexity is another advantage, as ALM allows a wide range of materials to be used in the development of the product, which is not the case with traditional manufacturing.

Design methodologies that have been developed for manufacturing are attempting to constrain designer's imagination based on the manufacturing processes capabilities and limitations. For example limitations due to the use of tooling are no longer needed with ALM processes. A number of methodologies have been presented such as design for manufacturing and design for assembly with a number of variations for specific processes and industrial sectors.

Optimisation methods are also widely used for enhancing design; many different options exist such as multidisciplinary design optimisation (MDO), gradient methods, genetic algorithm optimisation (GA) to name few. Due to the high performance and affordable cost of computers, optimisation using commercial software is easy and reliable. Such software options present friendly interface, giving users the ability to identify variables of the design, constraints, objectives and optimisation results without performing any complicated algorithms or equations.

However, with regards the design frameworks for using ALM, there is a lack of studies. Only few have been published in the last five years. Some indicative studies include Rodrigue and Rivette [2] work on developing a design methodology based on design for assembly notion borrowing ideas from TRIZ analysis with regards the optimization of the alternative designs. Vayre et al. [3] presented a methodology composed of four steps for ALM of metallic components. Podshivalov et al. [4] documented a methodology for design tailored to medical applications. Ponche et al. [5] presented a methodology for design based on numerical chain taking into consideration the part orientation during building, the functional optimization and the optimization of the manufacturing paths. Adam and Zimmer [6] documented a number of design rules for additive manufacturing that can be integrated in a design framework.

3. Redesign methodology

According to literature review, the research gap identified is the lack of a framework for re-designing existing products for better use of ALM capabilities. A redesign methodology has been developed in order to fulfil the research gap. Fig. 2 presents the proposed methodology for redesigning an existing part designed for conventional manufacturing into an optimised part designed for ALM. The key objective is to take into account the manufacturing constraints, objectives and ALM technology capabilities.

The proposed methodology has five main steps. The first step is analysing the specifications, based on the collection of information about the part in terms of functional specifications, loading requirements, manufacturing process limitations and capabilities, and material to be used in ALM. Within the second step rough shapes (initial concepts) are designed that fulfil the redesign objectives (e.g. maximum strength, minimal weight, stiffness). This step starts with finite element analysis (FEA), which allows the definition of the design problem in terms of the loads applied on the surface of the existing part and prediction of where the maximum deflection and stress will occur.

This step also includes structure optimisation through topology optimisation to achieve the optimal load path rather than a conceptual design. The third step defines a list of manufacturing restrictions that are necessary for deciding the manufacturability. In addition to guidelines for proper fabrication using the chosen ALM machine, such as the minimum slice thickness for each layer and speed of nozzle, process distinctive restrictions, such as the need for support structures and the anisotropic nature of the part strength, should also be considered.

The fourth step evaluates the proposed designs while taking into account all restrictions and guidelines already discussed. Verification and validation of the models may also be part of this step to ensure that the designs meet the load and displacements requirements. Moreover, all final designs that have fulfilled the requirements should be a part of a multi-criteria decision analysis with pre-defined attributes to choose the most suitable optimised design. Each step is detailed in the following sections.

3.1. Analysis of specification

Before the drafting of concepts, a set of functional specifications for the existing part must be agreed with clients. Usually defined by the client, functional specifications are factors that designs must follow relating to how the product will be used and how it will look. These specifications should be considered in the drawing idea stage to ensure that all factors are considered. The specifications can