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Integrated Design For Additive Manufacturing based on Skin-Skeleton Approach

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Abstract

Additive Manufacturing can produce three dimensional complex products based on the virtual CAD model. This new manufacturing method brings new possibilities in design and manufacturing cycle by its new parameters and Design For Manufacturing approach can be used to consider these issues. Therefore, an integrated methodology of Design for Manufacturing approach is proposed for additive manufacturing in this paper. This methodology investigates the characteristics related to Additive Manufacturing in design stage. For this purpose, Skin-Skeleton approach is used to model the procedure from the first step to final one. This skin-skeleton model consists of usage and manufacturing model which are used to present the customer requirement, product specification and design trend by usage model as well as manufacturing procedure and its constraints by manufacturing model. For this purpose, Topological optimization and Power Crust algorithm are utilized as tools to present optimized usage skin and skeleton. Also, manufacturing model is presented due to AM characteristics. Therefore, this model helps us to identify usage and manufacturing attributes to provide an interface model to define the product model by analysis of different parameter related to design and manufacturing and their relations comprehensively. Therefore, this model permits to consider manufacturing constraints and attributes as soon as possible in design stage to provide a better solution as a final product model for design and manufacturing concurrently as an integrated approach. In order to validate this approach, a bag hook that produced by Fused Deposition Modelling which is a well-known additive manufacturing technique is used.

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Keywords: Additive Manufacturing; Design For Manufacturing; Skin-Skeleton approach; Topological Optimization; Power Crust Algorithm; Fused Deposition Modelling.

1. Introduction

Nowadays, Manufactures are encountered with producing different versions of products in different material and each level of complexity. Over three decades, Additive Manufacturing (AM) which is derived from Rapid Prototyping evolves manufacturing world by its advantages and capabilities. AM produces the products based on the CAD model and by layer by layer manufacturing process as its unique characteristics. The CAD model is converting to STL (Standard Tessellation Language) file format as a standard in order to adapt to different AM technologies [1,2]. According to ASTM International standard [3,4], AM is categorized as Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS), Selective Laser Melting (SLM), Electron Beam Melting (EBM), Streolithography (SLA), Multi-Jet Modelling (MJM), Binder Jetting (Indirect Inkjet Printing and 3DP), Laminated Object Manufacturing (LOM), Laser Engineered Net Shaping (LENS). For each kind of technology the process of fabricating the layers, printing ink and power source are different based on different materials and their characteristics. Thus, different properties and levels of quality are created [3].

The benefits including producing complexes geometries without any additional cost, accuracy, flexibility, positive impact on sustainability, less waste in material as well as, no

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additional tooling create a special status for AM between different manufacturing methods [5]. Despite these advantages, AM creates some difficulties for manufacturers like interdependency between material and physical process, limitation in material selection, low efficiency for serial production, longer design process than manufacturing process, capacity limitation and mechanical properties limitations. Furthermore, surface finishing problem and quality assurance and the problems for post process machining are assumed as disadvantages [5].

As mentioned, different issues are entered in manufacturing world by entering AM and its different technologies which disrupt design and manufacturing trends with new parameters. By using AM, designer is free in designing the product but it is necessary to investigate the manufacturing constraints and attributes as soon as possible to provide a better solution as a final product model for design and manufacturing simultaneously. So, Concurrent Engineering as a methodology of taking into account the needs of each different stages of product life cycle simultaneously can be used to consider these issues. It aims to integrate related activities together in parallel that in sequence and creates the iterations between activities will affect time and cost. Through optimizing the design stage, the total cost can be reduced up to 70% thereby the production. This matter shows the importance of design stage in total product development. Thus, integrated design as an important approach considering all aspects of product life cycle in its design as soon as possible can be helpful in product development. Moreover, the aspect of simultaneously is illustrated by overlapping stages of the design process and integration through the involvement of profession actors and stakeholders on each step. This design can be performed for some objectives as Design For X (DFX) approach which emphasizes the involvement of different expertise's profession in the product definition, but due to the importance of manufacturing processes, Design For Manufacturing (DFM) approach is used to handle the manufacturing problems in design stage to provide an efficient product model to improve time, cost and quality as important criteria in industrial world [4,6].

Overall, DFM as an integral methodology is utilized for simplifying the manufacturing process, optimizing product and process concept in design and increasing productivity and reliability in addition to minimization of cost, time and quality [7]. DFM activities consist of material and process selection in addition to manufacturability evaluation. It also includes verification, quantification and optimization in the levels of human, machines, tools, software and product [4].

In the last few years, there has been a growing interest in DFM approach for AM as a new concept of DFAM, but actually it is not a new approach, it must be considered that DFAM is just applying DFM approach for AM like other manufacturing processes [4]. Some of the researches [8–10] described DFM approach in some steps like specification analysis or requirement engineering, providing initial design, manufacturability evaluation, manufacturing and validation by using topological optimization and finite element analysis and multi criteria decision making [9], process-structure-property-behavior model [11] and structure optimization [10]. Furthermore, process selection and planning are considered in some of these approaches [11,12]. Manufacturing rules are also defined in DFM approach as a method to improve the manufacturing process [13]. Geometric analysis is also utilized due to manufacturing constraints as Geometric DFX [14]. Tool path optimization and part orientation, dimensional accuracy, light weight design and dimensional deviation are taken into account as other criteria in some research on DFM for AM [8]. Also, another approach on the axiomatic design method is provided based on mapping the customer needs on functions as functional requirements (FRs) and determination of design parameters was presented to indicate how the object can satisfy such FRs. Finally, process variables are described for manufacturing through zigzag decomposition [15].

Although several researches have proposed Design For Manufacturing for Additive Manufacturing, little attention has been paid to integration and studies on integration aspects are still lacking. Overall, a key limitation of this research is that there is no integrate and complete approach for DFM in AM that consider all criteria and constraints coming from it in order to provide an interoperable process with product development. All these methods use DFM approach applied to 3D model or a first sketching and thus have a too advanced process after product definition which is already considered like a first result. It is really necessary to integrate all use, design and manufacturing attributes inside the product definition to take into account the requirements in a complex system through Systems Engineering.

For this purpose, DFM-skin and skeleton approach which was applied for other traditional manufacturing process till now [6,16], can be helpful to present an integrated approach for AM. This approach is used to model AM and product concurrently due to product specification, manufacturing constraints and attributes. The aim is to generate an integrated model or a solution very soon in product life cycle with all product attributes (usage, design and manufacturing). But before using this model, it is necessary to determine initial definition of product. Firstly, design requirements and specification must be defined for product. Functional-structural model which is derived from Function-Behavior-Structure (FBS) Model of Gero [17] will be used to identify product function and requirements as well as, its initial structure. Also, it helps the designer to have a global view of the product. In this model, function can be defined as what the product should be able to achieve in terms of purpose, what it is for and structure must demonstrates who performs the functions, which components, and their relationships. It describes the internal composition of the product, what it physically is, but also how is its construction. Therefore, it is used to illustrate the functional surface and relation between support and material flow conduction in addition to force and mechanical performance. Moreover, this model is used to identify usage skin and usage skeleton and provide an initial volume space.