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Additive Manufacturing in Production: a Study Case Applying Technical Requirements

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Abstract

Additive manufacturing (AM) is expanding the manufacturing capabilities. However, quality of AM produced parts is dependent on a number of machine, geometry and process parameters. The variability of these parameters affects the manufacturing drastically and therefore standardized processes and harmonized methodologies need to be developed to characterize the technology for end use applications and enable the technology for manufacturing.

This research proposes a composite methodology integrating Taguchi Design of Experiments, multi-objective optimization and statistical process control, to optimize the manufacturing process and fulfil multiple requirements imposed to an arbitrary geometry. The proposed methodology aims to characterize AM technology depending upon manufacturing process variables as well as to perform a comparative assessment of three AM technologies (Selective Laser Sintering, Laser Stereolithography and Polyjet).

Results indicate that only one machine, laser-based Stereolithography, was feasible to fulfil simultaneously macro and micro level geometrical requirements but mechanical properties were not at required level. Future research will study a single AM system at the time to characterize AM machine technical capabilities and stimulate pre-normative initiatives of the technology for end use applications.

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1. Introduction

The aim of this research is to explore an experimental methodology for pre-normative activities in Additive Manufacturing (AM) process characterization to be used at initial engineering design stages. The long-term vision of this work is to develop a standard methodology to characterize machine capabilities, such as dimensional repeatability and help engineering design and manufacturing community to use AM machines in end use applications. The background of this research is founded on evidences in which AM can potentially replace conventional methods to produce goods when production volumes are small (Campbell, et al., 2012). Current systems are capable to directly manufacture functional engineering components economically, especially suitable when production volumes are low and complexity of the geometry is high (Levy, et al., 2003). In addition, implementation of AM systems could potentially limit the fix cost in small series production, and therefore reduce cost and time-to-market during the product development of organizations (ElMaraghy, et al., 2013).

Over the past years, mechanical properties as well as the reliability and repeatability of AM processes have improved significantly (Wohlers, 2014). Hence, it is expected that AM systems will be used in the near future to produce parts for end use applications (Santos, et al., 2006); this process is defined as Rapid Manufacturing (Mellor, et al., 2014).

However, to drive manufacturing application the technology requires significant developments (Holmström, et al., 2014). AM machines have different architectures and material processing capabilities. The characterization and standardization of the technology is not yet mature and the part quality differences are substantial from machine to machine in terms of achievable mechanical and dimensional properties (Clemon, et al., 2013). Technical performance of the technology in manufacturing has not been standardized to penetrate in regulated industries (Gibson, et al., 2010). Hence, technology roadmaps emphasize that AM success in the future, is highly correlated to certification and standardization methods of the technology capabilities (Gausemeie, et al., 2013). Specially, in regulated high value product development industries, such as aerospace, automotive, defense, medical industry as well as consumer electronics.

Geometrical stability and material properties of AM produced part are strongly dependent on the manufacturing process planning and machines architecture (Hu and Kovacevic, 2003). Research has indicated that the part orientation, the part location of the geometry on the build tray as well as quality of the digital data has an effect on the achievable geometrical and topological quality. Hence, these parameters need to be studied further (D. Dimitrov, et al., 2006), (Brajlih, et al., 2010) and (Anand and Ratnadeep, 2011) in order to stimulate pre-normative activities towards AM certification and standardization.

Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Stereolithography (SLA) and Polyjet technology are some of the most common alternatives to produce engineering functional plastic parts, final quality of the produced parts changes are machine and process dependent (Pham and Gault, 1998) making its characterization more difficult. Research in the field has not presented a systematic experimental method to characterize AM machine capabilities, applying a harmonized experimental approach for quality assurance.

Additionally, in an AM process, produced parts have to fulfil simultaneously different types of mechanical and dimensional requirements. Frequently, due to the process dependencies of the additive method, the manufacturing set up imply trade-offs between micro and macro level geometrical requirements as well as mechanical requirements, due to the orthotropic behavior of the AM process. To address this issue, research community has used Design of Experiments (DOE) to optimize individual manufacturing parameters of the machines (Hsu and Lai, 2010), (Wang, et al., 2007) and (Rahmati, et al., 2007). However, selecting a combination of machine and process parameters to fulfil simultaneously multiple requirements has not been tackled. There is then a need to research a systematic experimental approach to fulfil multiple production requirements simultaneously and characterize manufacturing capabilities, as proposed in similar manufacturing context (Konda, et al., 1999).