DESIGN FOR ADDITIVE MANUFACTURING TO PRODUCE COMPLEX METAL PARTS

COSMIN COSMA[1], BOGDAN ZAHARIA[2], PETRU BERCE[1], NICOLAE BALC[1*]

Abstract. This paper presents a practical example of how an existing industrial metallic component should be redesigned to exploit the benefits of selective laser melting (SLM) manufacturing. The main challenges are: the component design in order to avoid the support structures, which typically anchor the surfaces, and to develop a special shape for internal channels that does not need support structure, because they are difficult or impossible to remove at the end of SLM manufacturing. The principles taken into account were the surface angles and the "raindrop" shape for the channels and holes. To test and validate the proposed method, the model was directly SLM processed from stainless steel (316L) powder. Combining principals of design for additive manufacturing and SLM process can be an efficient tool to obtain real industrial parts, while avoiding the support structures by integrating them into the surfaces. Respectively, developing new concepts of holes maintaining the same area of them as in the conventional approach.

Key words: industrial component, redesign, selective laser melting, steel powder.

1. INTRODUCTION

The use of Additive Manufacturing (AM) provides an increasingly popular industrial approach for producing complex mechanical parts when conventional technologies are not suitable [1]. The advantage of AM process is the freedom they give to design engineers [2, 3]. Various examples have proven how AM is the only available way for highly complex and intricate geometries [4–6].

In general, the concept of Design for AM is a method or tool whereby functional performance and other key product life-cycle considerations such as manufacturability, reliability and cost can be optimized subjected to the capabilities of AM technologies [7]. To develop a topological optimization of parts, the Redesign for Additive Manufacturing tools can be used to simulate structures with complex shapes which exactly meet the mechanical constraints while requiring as little material as possible [8, 9]. Figure 1 presents the main steps to redesign an existing part which was designed for conventional manufacturing.

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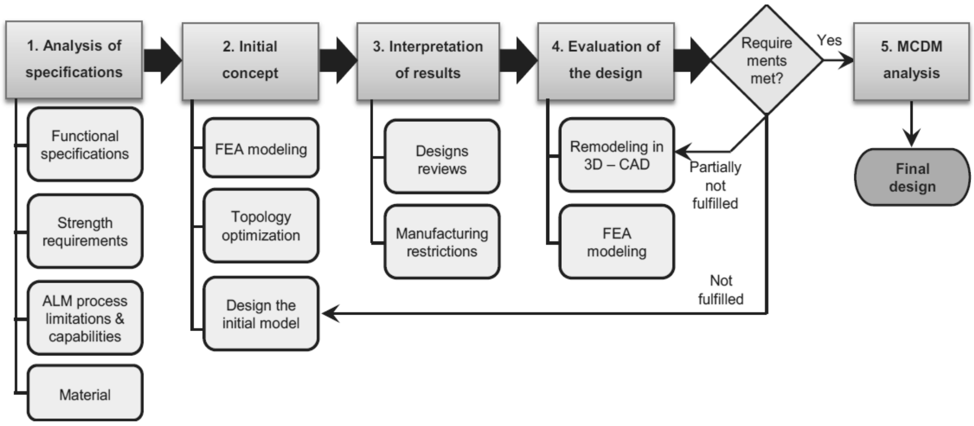
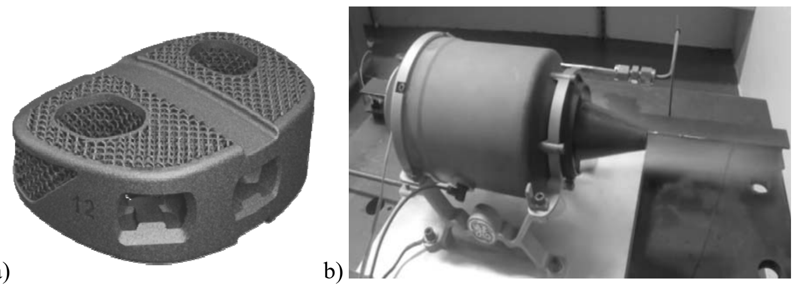


Fig. 1 – Methodology to Redesigning for AM [8].

Combining the Design for AM method and Selective Laser Melting (SLM) process could be a promising approach to obtain optimized shapes and mechanical structures, integrated into metallic industrial parts. Recently, a number of front running companies have made major headlines in the use of metal AM for direct production of parts in medical, automotive, or aerospace applications [10]. Emerging Implant Technologies, a German medical device maker focused exclusively on spinal applications (Fig. 2a), reports that it has received full approval from the US Food and Drug Administration for its metal AM spinal cages made of titanium macro-porous scaffolds [11]. Most notable development in aerospace was done by General Electric [12], who have included functional metallic AM parts in their latest GEnx jet engine for Boeing 747s (Fig. 2a). In motor-sport, metallic AM components designed and fabricated by Sauber were integrated in Formula 1 race car [11]. They include exhaust components, the roll hoop with complex internal structures to protect the driver in accidents, radiator inlets and large components to increase the level of wind-tunnel performance (Fig.3).



a) b)

Fig. 2 – AM parts: a) spine cage made of porous titanium structures used to treat 10,000 cases in Germany, France, Australia, Korea and Netherlands www.eit-spine.de; b) junctional metallic components in GE jet engine, www.geaviation.com.

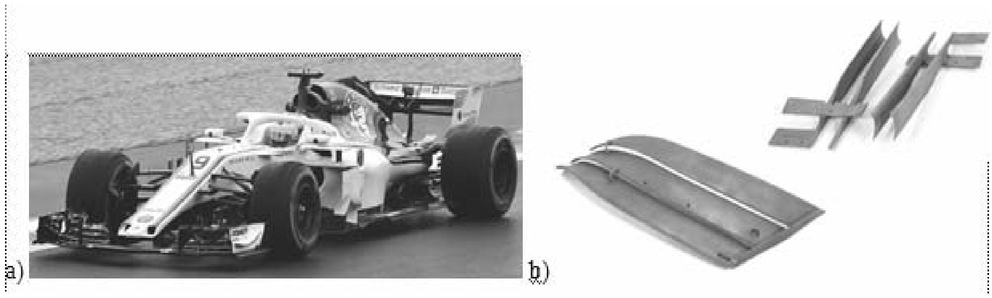


Fig. 3 – Motor-sport AM processed components: a) Alfa Romeo Sauber F1 Team race car C37 2018; b) wind-tunnel made of AlSi10Mg [11].

Another example was developed by Bombardier and Airbus and is presented in Fig. 4, being focused on an engine nacelle hinge, type V2500. Moreover, the mechanical behaviour of redesigned parts could be predicted via finite element analyses [13]. Figure 5 presents the main steps undertaken by Fraunhofer ILT researchers focused on developing a stub axle for Formula Student team Running Snails. Compared to conventional model, this redesigned part is with approx. 20 % lighter. From topological optimization point of view, commercial softwares can offer some perspectives in this direction (e.g. Generative Design in Solid Edge software (Fig. 6). However, forming principles of SLM differ from those of traditional methods, such as casting or cutting technologies [14–17]. Also, adapted design for AM rules are demanded in order to avoid supplemental support structures during SLM processing.

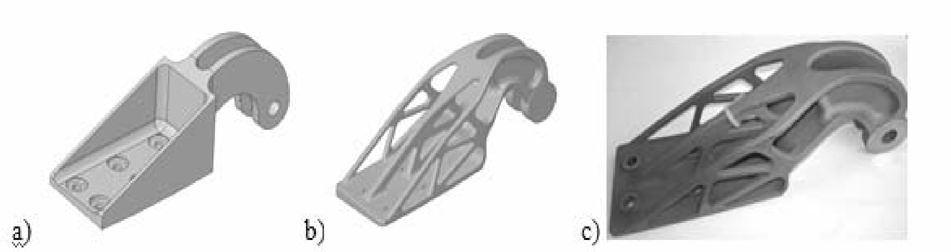


Fig. 4 – Engine nacelle hinge from Airbus: a) conventional design; b) redesigned for AM; c) SLM-manufactured [18].

The aim of this case study is to present a practical example of how an existing industrial metallic component should be redesigned and manufactured in order to exploit the advantages of SLM process and to avoid the need of support structures. The part redesigned was provided by Michelin, an international manufacturer of tires for automotive industry with one factory located in Zalau (Romania). This company is the second largest tire maker in the world after Bridgestone, and larger than both Goodyear and Continental [20].

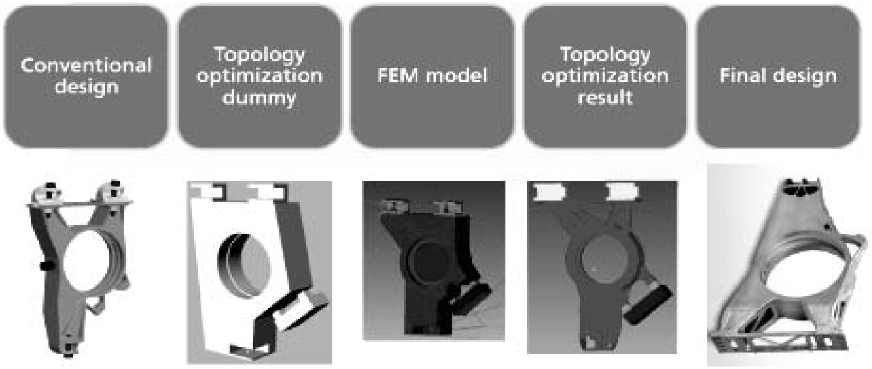


Fig. 5 – Resigned automotive component SLM manufactured from AlMgSc powder [19].

Fig. 6 – Topological optimization of a virtual model, www.solidedge.siemens.com.

2. CASE OVERVIEW

It is known that re-manufacturing a damaged component of an industrial equipment it could be difficult because sometimes there is no technical documentation for the part, as it could be just a prototype or it could come from an old model that is not manufactured any more, or if the amount of time that is needed for the new part to be build is not satisfactory because of the urgency to change the part as soon as possible to restart the production [21]. Using SLM process and Reverse Engineering techniques is possible to re-manufacture rapidly a damaged part, for which no documentation is available. For this reason, the present paper is focused on a real component used in industrial production.

The present industrial metallic component is used in tires manufacturing by Michelin Romania, and it is a part of a collapsible rotating drum, which holds the rubber raw materials. In this manufacturing phase illustrated in Fig. 7a, the building machine starts processing a “green tire” by wrapping the rubber-covered fabric plies of the body around the machine drum. The main functionality of the present industrial metallic component is to create the shaped of the pneumatic tire by inflating with air the central section of drum (Fig. 7b).

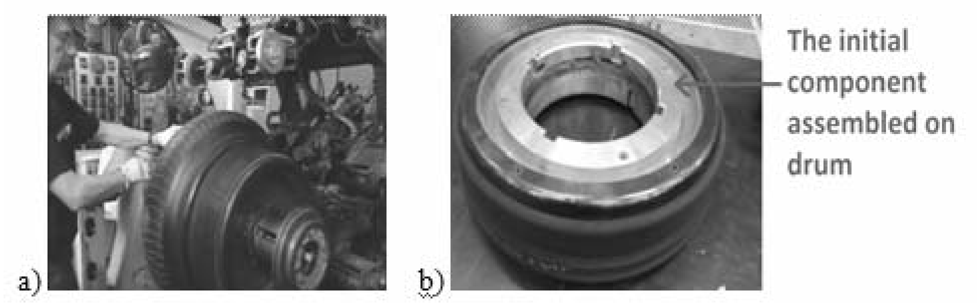


Fig. 7 – Tyres manufacturing process: a) wrapping the rubber-covered fabric plies; b) the metallic part mounted on drum, www.michelin.com.

3. MATERIAL AND METHODS

The material used for SLM manufacturing was stainless steel 316L powder provided by MCP HEK Tooling (Germany). Information about particles shape and size are essential in controlling many powder-based additive manufacturing processes. In this study, the 316L powder has spherical grains with a mean diameter of around 50 µm. The chemical composition of this stainless steel is exposed in Table 1. The SLM equipment used to manufacture the part was Realizer II SLM 250 (Germany). The equipment has incorporated a solid-state laser type Nd:YAG with 200 W maximum laser beam power. This complex process can manufacture metallic parts layer-by-layer, under an inert atmosphere (Argon or Nitrogen). We used REditor software to configure the process parameters for SLM manufacturing. Based on our know-how and previous studies focused on optimizing the SLM process [22, 23], we set up the main process parameters: 160 W laser power, 1000 mm/s scanning speed of laser and 45 µm layer thickness of powder. These SLM parameters lead to a relatively stable manufacturing, avoiding defects. In general, defects are generated by high internal stress and they could lead to micro-cracks, severe warping, distortion and de-lamination [24].

Table 1

Chemical composition of 316L powder

Chemical element	C	Mn	Si	P	S	Cr	Mo	Ni	N	Fe
Maximum weight (%)	0.03	2	0.75	0.045	0.03	18	3	14	0.1	66

The CAD software used to design the part was CATIA. To simulate the SLM manufacturing we used Realizer and RDesigner. The design rules taken into account are specific to laser beam melting technologies.

4. RESULTS AND DISCUSSIONS

4.1. REDESIGNING THE PART

In general, the support structures are required to sustain the parts during SLM manufacturing. Figure 8 shows how many support structures are needed to manufacture the initial design of part.

However, surface angles of parts higher than 45° are possible to be build without supports structures according to German Standard VDI 3405 [25]. A sketch of this principal is illustrated in Fig. 9 where is presented a cross-section of a profile which has different δ angles between the surfaces and the SLM plate. This sketch demonstrates the importance of building orientation on SLM plate and how we can improve the design of parts. Moreover, analysing the evolution of internal channels from conventional design to simple or complex optimization [26, 27], we find an opportunity in this field which is exposed in Fig. 10.

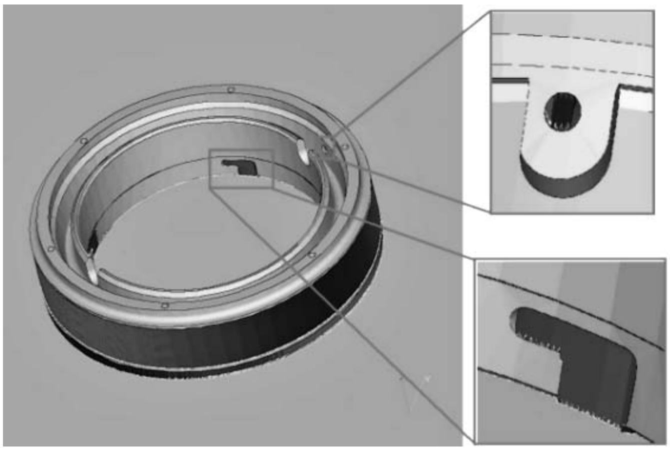


Fig. 8 – Initial design of part which requires supports structures to sustain the external surfaces, holes and channels during SLM manufacturing. The required support structures are indicated with red.

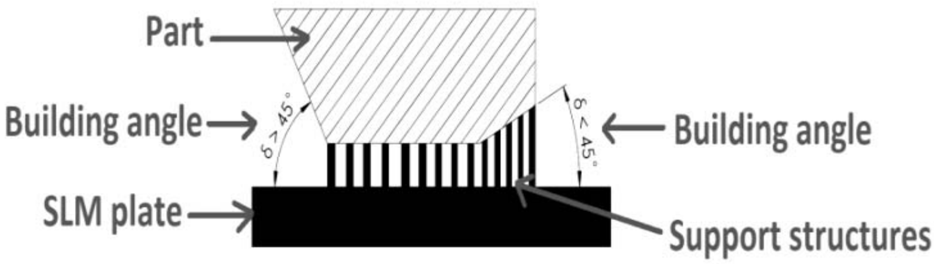


Fig. 9 – The redesign principal applied on outer-boundary surfaces.

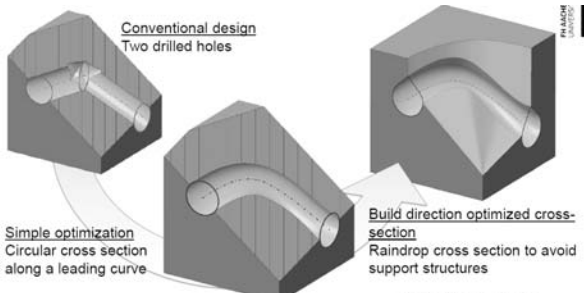


Fig. 10 – Evolution of internal channels: conventional design, simple optimization and complex optimization in concordance with build direction of part [26].

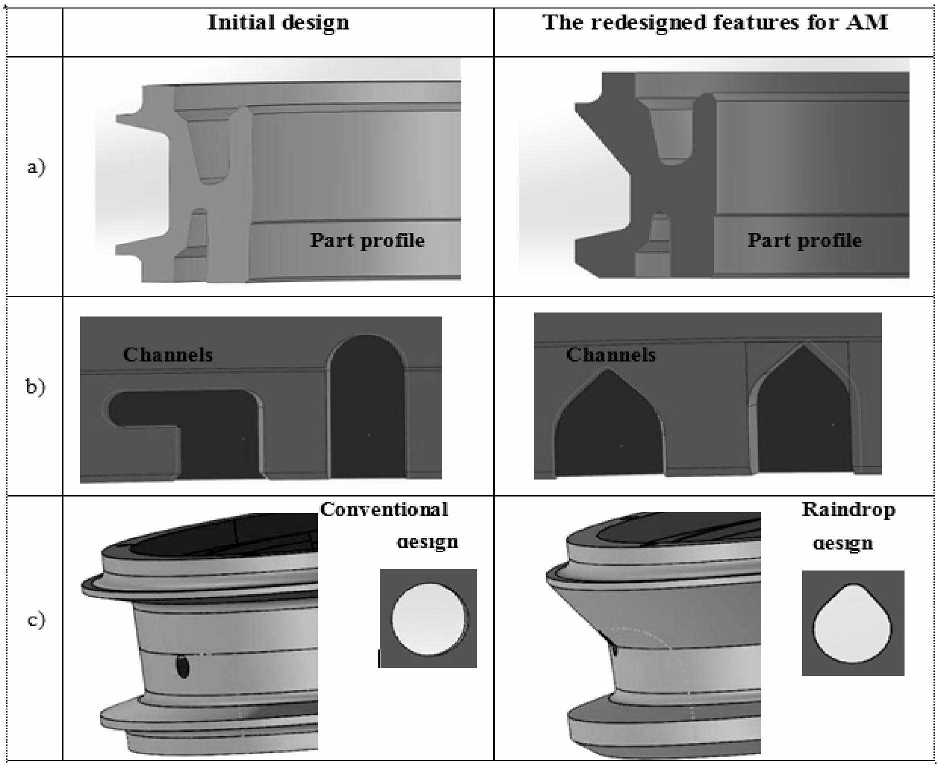


Fig. 11 – Conventional design vs. Redesign for AM: a) the profile of part – external walls; b) channels; c) holes with the same area and their trajectories – dotted lines with blue.

These design rules were applied to generate the following features of the metallic part in concordance with building angle: the profile (external walls), channels, holes and trajectory of holes (see Fig. 11). The channels were redesigned similar to a "raindrop", while maintaining the same area comparing with the initial design because these channels conduct a specific air pressure (Fig. 11c). Moreover, the trajectory of them was curved.

The main benefits of applying redesigning for AM rules are: 1) it allows us to improve the shape of part in order to avoid the supports structures which normally are needed to anchor the external surfaces; 2) we can adapted the trajectory of internal channels for optimal flow avoiding the support structures inside which are difficult/impossible to removed; 3) we can maintain the same area of the air channels comparative with initial design (51 mm^2); 4) we can validate the proposed redesign, manufacturing the part via SLM, to suit customer's needs.

4.2. SLM MANUFACTURING

To test and validate the redesign of part without any support structures, this was fabricated directly on SLM plate (see Fig. 12 and Fig. 13). The manufactured part was rescaled at 1/4 and it was made of 316L powder. The dimensional deviations obtained were ± 0.07 mm. Because the surface roughness of SLM part affect the functionality of it, the evaluation of surface texture is demanded, [28].

Further post-processing, such as CNC turning, are needed to obtain the required profile of the SLM manufactured part (e.g. initial exterior profile – Fig. 11a and SLM manufactured exterior profile – Fig. 13a) and CNC milling of fixing channels (e.g. initial shape of channels Fig. 11b *vs*. the SLM-manufactured channel, Fig. 13b. Depending on the surface roughness requirements, the part could be finished via grinding or by other conventional technologies in order to ensure a proper surface quality and accuracy [29–32]. In order to be used by the industry, the mechanical and tribological properties of this SLM part should be investigated because it is possible that at micro-structure level some micro-pores can appear and they could change these properties [33, 34].

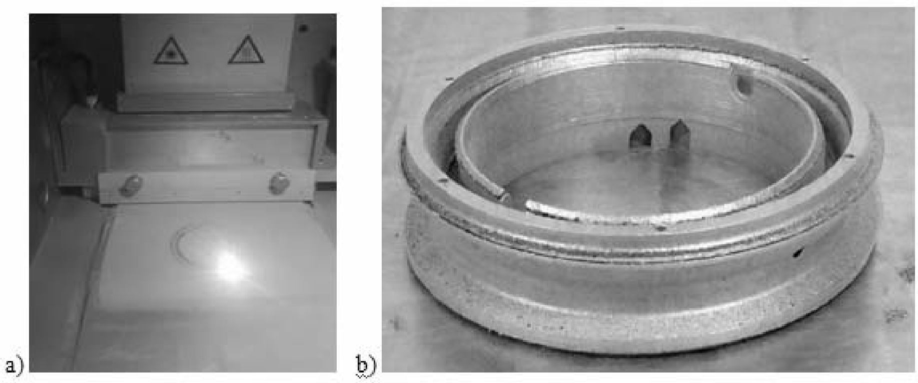


Fig. 12 – The redesigned part processed proper without support structures: a) SLM manufacturing using 316L powder; b) isometric view of part.

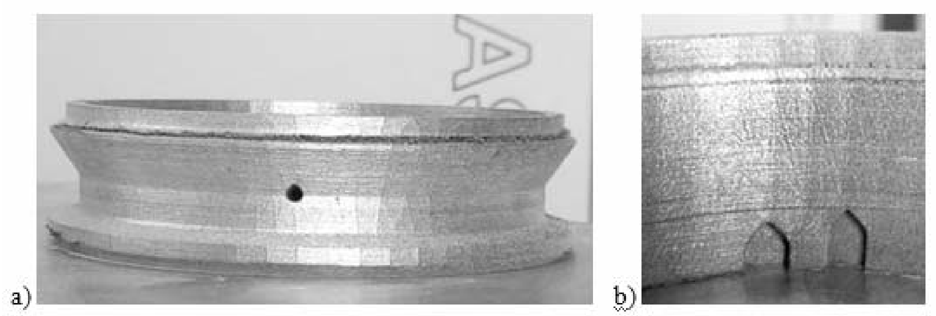


Fig. 13 – Redesigned part SLM-processed: a) external profile walls; b) fixing channels for assembling this part into tyres drum.

Designers today are challenged with a lack of understanding of AM capabilities, process-related constraints and their effects on the final product [35–38]. Combining design for AM principals presented with SLM manufacturing, it can be an efficient tool for obtaining real industrial parts, avoiding the support structures, or integrating them into parts shapes.

5. CONCLUSIONS

The presented case study was focused on design for Additive Manufacturing of a real metallic component, demonstrating the high potential of SLM process. This paper contributes on the following topics:

– Developing new industrial application via SLM process, part of Rapid Tooling concept, and suggests about improving the SLM manufacturing;

– Design for Additive Manufacturing an industrial product to be easier and cost effective to be made by SLM, while improving the shape of part in order to avoid the supports structures and developing new design forms of channels and holes, which can be manufactured without support structures (“raindrop form”);

– Testing and evaluating the proposal redesign of product by manufacturing them via SLM, demonstrating the viability of design for AM concept.

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