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A direct material reuse approach based on additive and subtractive manufacturing technologies for manufacture of parts from existing components

Van Thao Le*, Henri Paris, Guillaume Mandil, Daniel Brissaud

Univ. Grenoble-Alpes, CNRS, G-SCOP, 38000 Grenoble, France

* Corresponding author. *E-mail address:* Van-Thao.Le@grenoble-inp.fr

Abstract

This paper presents a direct material reuse approach. The approach consists in producing new parts directly from existing components avoiding the material recycling stage, using a combination of additive and subtractive technologies. The proposed approach seems able to reduce resources consumption and waste during the manufacturing process. The major steps of the approach are presented. The process planning for combined additive and subtractive processes is particularly discussed. The process planning is designed through the feature concept, based on the knowledge of individual processes, technological requirements, and available resources. Finally, the feasibility of proposed approach is validated through a case study.

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Keywords: Direct material reuse; Process planning; Additive manufacturing; Machining; End-of-life product.

1. Introduction

Today environmental issues of manufactured products receive a significant attention from most countries in the world. Environmental policies and regulations [1] push manufacturing companies to produce their products in a cleaner and greener manner. The production process must be balanced from economic and social points of view by using resources efficiently and reducing environment impacts [2]. Moreover, the increase of end-of-life (EoL) products has also become an unavoidable social issue due to the increase of product demand. This causes an increase of environmental impacts, and contribute to reach the limits of landfill facilities. To solve this problem, the researchers and manufacturers are looking for efficient strategies to recover EoL products while taking into consideration the environmental benefits [3].

Until recently, there were two possibilities to recover EoL products. The first scenario consists in recycling the material of EoL products, and then using produced material in a new production cycle. However, the energy consumption of recycling systems remains important [4]. In addition, added value, functionality and built-in energy of original products are generally lost during the recycling process [1]. On the other hand, in the second scenario EoL products are recovered via repairing or remanufacturing processes [4]. Remanufacturing is an industrial process, which allows the conversion of EoL products into products in a like-new condition one. This strategy can extend the life-time of products, reducing manufacturing cost, and waste, as well as environmental impacts [1]. Hence, the remanufacturing is today considered as an alternative solution for the recycling.

In the past three decades, additive manufacturing (AM) has attracted an increasing attention of researchers both in the academic and industrial sectors. AM offers a special ability to build complex parts without using cutting tools, cooling fluid and fixture systems. This technique has been identified as having the potential to provide a number of sustainability advantages [5]. First, AM provides the capability of freeform production that removes the limitations of conventional manufacturing and opens new prospects for the design of innovative and lightweight parts [6]. This will reduce material and energy consumption in manufacturing. Secondly, the

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adoption of AM offers shorter and simpler supply chains, and more localized production [7]. Finally, AM also provides a huge potential to reduce environmental impacts and offers a significant sustainability benefits [8].

Taking into account these benefits and performances of AM, this article presents a direct material reuse approach based on combined additive and subtractive technologies. The approach aims to reuse EoL components or existing components directly to produce new parts, avoiding the recycling phase. The obtained parts are then intended for another product. This is totally different from other strategies, such as repairing and remanufacturing of components.

2. Related works

A number of studies have reported the possibility of AM for remanufacturing applications. Cottam et al. [9] used the laser cladding to build Ti-6Al-4V entities on Ti-6Al-4V substrate. By observing microstructures and microhardness of built samples in the function of cladding parameters, the authors could determine what parameters that can be used for repairing components. Terrazas et al. [10] presented a method, which allows the manufacture of multi-material parts using discrete runs of electron beam melting (EBM) system. The authors successfully built a copper entity on the top of an existing titanium part. Their results demonstrated the feasibility of EBM for remanufacturing. Dutta et al. [11] stated that directed material deposition (DMD) technology offers the particular benefit of a minimum heat affected zone that enables a high-quality repaired part to be achieved. In fact, these works focused on investigating microstructures of the samples to observe the phase transformation traversing the heat affected zone. This could predict the mechanical bonding between the AM-built zone and the substrate zone. However, this prediction has not yet validated by the tests on mechanical properties, such as the tensile testing. To fill this gap, Mandil et al. [12] carried out a study to confirm the feasibility of EBM for the build of new entities on existing parts. In their work, both the observation of microstructures and the tensile testing go to the conclusion of the existence of strong bond between the EBM-built entities and the existing part.

Literature shows that the use of directed energy deposition (DED) techniques (e.g., DMD) have a significant efficiency in the remanufacturing of worn-out or damaged components, particularly for high value components, such as turbine blades, molds and dies. Wilson et al. [13] stated that laser direct deposition was efficient for remanufacturing turbine blades. Rickli et al. [14] also presented a framework for a remanufacturing system using DMD technique, which was able to restore high value EoL cores to original specifications and ensure their quality. However, these works only aim to return EoL components in a like-new condition, and extending their lifetime. In comparison with DED processes, the powder bed fusion (PBF) processes have some limitations for remanufacturing applications due to the limited build envelope and the deposition of material that is only conducted on horizontal flat surfaces. However, there are numerous components, which can be remanufactured by these processes. For example, Navrotsky et al. [15] used selective metal melting (SLM) to repair gas turbine burner tips. This research also demonstrated the potential of SLM technique for building new features on existing components.

Recently, Newman et al. [16] proposed a framework, entitled 'iAtractive', which can generate different strategies for manufacture of parts based on existing components. The development of such strategies is presented in [17]. These strategies use CNC machining, AM process (i.e., fused filament fabrication, FFF), and inspection process interchangeably. However, the strategy is only efficient for producing prismatic plastic parts. In some cases, the strategy is not time-effective and reduces the tensile strength of the produced parts.

3. Direct material reuse approach

3.1. Approach overview

In this work, taking into account the performance of AM techniques a direct material reuse approach is proposed. This approach can give a new life to existing components by transforming them into new parts intended for another product [18]. The existing components could be extracted from EoL products. In comparison with the approach proposed in [16] and [17], the proposed approach is extended to metallic components. For this purpose, the current study focuses on metal-based AM techniques, namely DED processes (e.g., DMD and CLAD - construction laser additive deposition) and PBF processes (e.g., SLM and EBM). The approach consists in reusing the existing parts directly to produce the final parts, using a combined subtractive and additive manufacturing, and inspection processes. This combination takes the advantages and performance of AM and CNC machining techniques while minimizing their disadvantages.

The general manufacturing process of parts based on existing components is described in Fig. 1. This process consists of three major stages: the pre-processing stage, the processing stage and the post-processing stage.

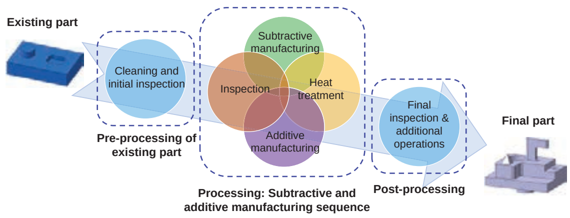

Fig. 1. Major stages of manufacturing process of parts from EoL components.

- *Pre-processing stage*. First, the existing part or component extracted from EoL products is cleaned and evaluated. Its actual geometry and shape are then achieved by a system of measurement and scanning to generate the CAD model. The information and the CAD models of the existing part and the final part are used for the processing stage.
- *Processing stage*. This stage refers to design a manufacturing sequence containing subtractive, additive, and