IMPACT OF RAW MATERIAL COMMODITIZATION ON SUPPLY CHAINS

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Abstract

In this research we analyze the impact of a less cost intensive raw material supply chain on the utilization of additive manufacturing (AM) and its implications for the whole production supply chain. Utilizing the case data and scenario modeling we compared the competitiveness of additive manufacturing in comparison to conventional methods such as machining and casting. Results illustrated the increased production competitiveness with regard to both conventional methods. Moreover, we found simplicity and swiftness of supply chain as the two significant changes that occur as the result of a new raw material supply. One of the major limitations of this research was due to the secrecy of the companies which are currently utilizing the technology and their reluctance to share their perceived competitive advantage for the analysis. Therefore, the data extracted from our own case simulations which then were analyzed to compare the supply chains. Future research should expand the number of cases and utilize more suitable AM machines.

Keywords: Additive manufacturing, raw material commoditization, supply chain.

Introduction

Additive Manufacturing (AM), a novel production technology that recently started to be used for the production of metal final parts in larger volumes (GE), still struggles with a number of shortcomings [3]. The cost and availability of raw material is one of the issues especially for the metal parts production. This makes the utilization of AM for final parts in a supply chain, risky. However, the benefits gained from the use of three-dimensional printing in some cases outweigh the uncertainty and difficulties. For instance in case of GE fuel injectors for the jet engines, the parts consolidations and performance improvements due to complex geometries were the important selection criteria. Another beneficial aspect of implementing AM can be the possibility of production decentralization [3], which significantly reduces the delivery time while increasing supply chain flexibility. Higher level of availability for an AM grade powder with an economical cost can unlock these benefits for more applications.

Metalysis, is a novel process of titanium raw material production which promises much cheaper raw material in powder form factor, can change the current supply chains [9]. The fact that Metlysis yields a raw material which undercuts current titanium purification methods (e.g.: Kroll) by a wide margin, makes it a candidate not only for AM but also conventional manufacturing (CM) methods such as casting and CNC machining. Therefore, it is essential to know the actual impact on the production cost as well as the supply chain effect. In this paper we aim to answer that question.

The remainder of this paper is organized as follows: Section 2 presents a literature review; Section 3 explains the research methodology; and Section 4 presents the findings and results of our analysis. This paper ends with conclusions summarizing the research outcomes, and suggestions for future investigation are provided.

Literature review

In this section we briefly review the literature on the two main subjects of this paper which are additive manufacturing supply chain and Metalysis process.

Additive manufacturing and its supply chain

ASTM Standard defines Additive Manufacturing (AM) as "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining". The literature for this technology is rife with synonyms, including additive processes, additive fabrication (AF), additive layer manufacturing (ALM), layered manufacturing, and solid freeform fabrication (SFF), 3D-printing (3DP) and rapid manufacturing (RM).

In Figure 1, the AM process is explained. Process begins with development of a three-dimensional CAD model of the object with all its details and dimensions. This CAD file is then converted to stl-file, which most AM-machines understand. Next the 3D file is sliced into very thin two-dimensional (2D) cross sections (layers) by a computer program. The machine produces each layer on top of the previous one, completing the object in question, utilizing different solidification methods of raw material in its production chamber. The process takes from a few hours to a few days to produce an object, depending on its size and needed accuracy. After the object has been removed from the machine and cleaned, it can be post-processed. The post-processing methods vary according to the AM process, but they can include removal of support material, infiltration of pores, surface finishing (peening, blasting or tumbling), annealing, and cleaning and machining [8].

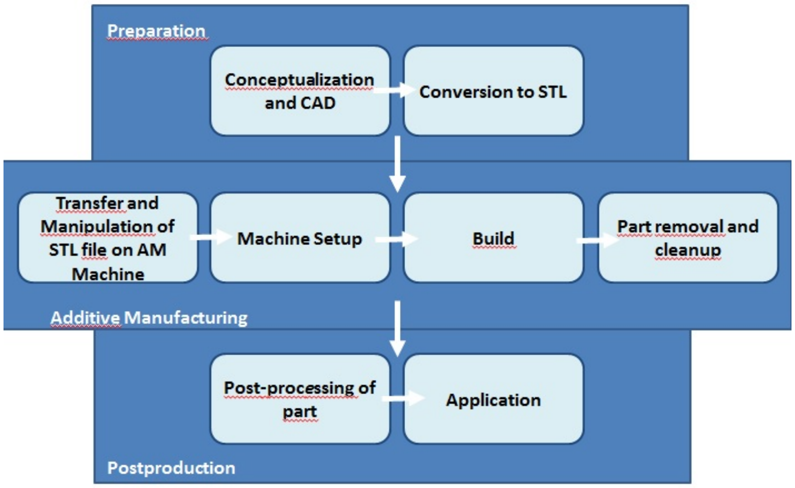

Fig.1. Additive manufacturing process

AM has long history in conceptual and functional prototyping but now the step toward directly manufacturing of final parts and products has been made. The methods are reaching the suitable precision and quality necessary to be used as final functional parts for special applications, such as in aerospace, defense and other highly-engineered systems [10].

The reason AM technologies have been gathering momentum is certain benefits over the conventional manufacturing methods. According to Holmsröm et al. [5] the most important ones are toollessness, production for performance and potential for simpler supply chains. Additionally Khajavi et al. [3] suggested that using AM methods could reduce material waste (by as much as 90%).

Figure 2 is a simplified illustration of production process flow while utilizing traditional manufacturing methods in contrast to the AM method. Utilization of AM alleviates the supply chain complexity while reducing production steps and enables a far more flexible decentralized supply chain [3].

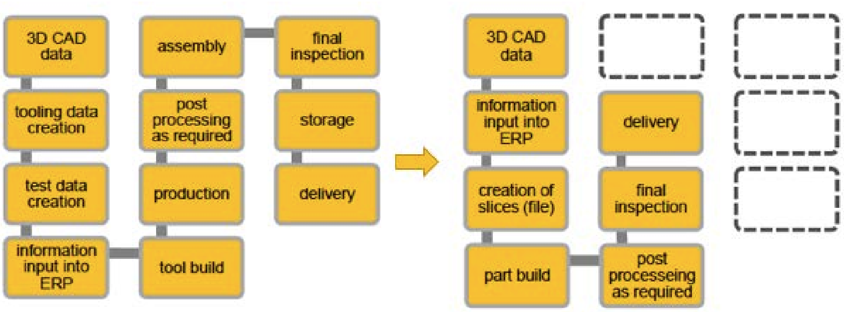

Fig.2. Change from conventional process flow to AM process flow (Rommel and Fischer, 2013)

Metalysis process

Metalysis Process is a new method for purification of titanium which yields metal powder. As it is essentially one step process, it is possible to reduce cost of the production considerably perhaps even up to 75%. Titanium oxide (sintered rutile sand) serves as cathode and carbon as anode. Both anode and cathode are placed in a bath of calcium chlorine salts at 800°C-1000°C temperatures. Salts acts as an electrolyte allowing current (metal ions) to travel from cathode to anode. In anode, ions react with carbon and forms carbon dioxide gas. Meanwhile the cathode transforms into metal [2,9].

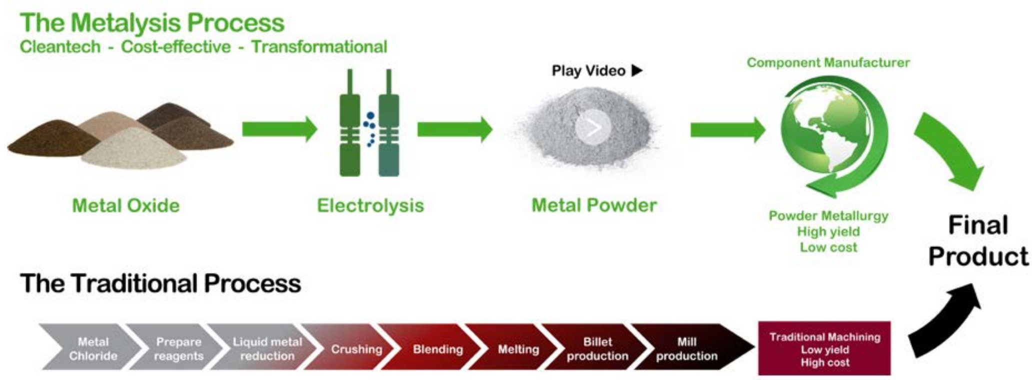

Fig.3. Metalysis Process vs. Kroll Process [9]

When compared with the conventional Kroll process for titanium metal extraction (Table 1), Metalysis process offers many significant advantages. Hereby, the conventional extraction process is known as Kroll process, which extracts titanium in a non-powder but spongy form from the minerals [7]. Because of the complicated, energy and time-consuming procedures, Kroll is an expensive pyro-metallurgical process to extract titanium [1].

Table 1. Comparison of industrial titanium production processes with Metalysis process [6]

Process	Feedstock	Reductant	By-products	Duration	Product
Kroll	$TiCl_4$	Magnesium	$MgCl_2$	Batches, up to 7 days	Sponge
Metalysis (FFC)	TiO_2	Applied current (electrons)	CO, CO_2	Semi-continuous, 8-24 hours	Pellets/powder

Literature gap

The current body of knowledge is mostly focused on the investigation of Metalysis and similar metal extraction methods from the technical perspective. This makes the analysis of novel ways of metal extraction methods on the choice of production method and supply chain implications of such choices, unexplored. We aim to fill the gap in the literature with regard to the possibilities of a much cheaper raw material for novel and superior supply chains. Our research question is as follows;

What are the supply chain effects of an unconventional raw material supply?

Method

The methodology chosen for this study is modeling of actual cases for the competitiveness comparison of the production methods and building up on top of with supply chain interpretations. We utilized case data, expert opinion in addition to well referenced articles and books. The cost modeling lead us to the selection of more competitive scenarios and the shifting points were calculated based on the lower costs. Our cases are two parts used on the commercial airplanes, first a low pressure turbine blade (LPB) and second, a jet engine loading bracket (ELB). Both parts are manufactured with Ti6Al4V which is among the most common titanium alloys.

For each case we calculated the production cost utilizing additive and conventional manufacturing methods while using raw material from Kroll or Metalysis process. As a result of that analysis we ended up with eight models and respective cost values for each.

Results

As mentioned, Metalysis process can reduce the cost of extracting high-purity titanium powder by 75% compared to the Kroll process. Since in this study the cost of Kroll Ti6Al4V-ingot and -bar is 32€/kg, then the Metalysis Ti6Al4V-powder price is calculated to be 8€/kg. Moreover, because the low pressure turbine blade (LPB) is a casted part and jet engine loading bracket (ELB) is CNC machined while analyzing the conventional manufacturing (CM) methods costs are presented in two separate tables. Table 2 presents the cost competitiveness of manufacturing methods with different sources of raw material for LPB when the production batch is assumed to be 1000 parts. Moreover, the assumption in case of Metalysis powder use for the casting is that no cost saving is gained from the use of raw material in powder form.

Table 2. Per part manufacturing cost comparison of low pressure turbine blade (LPB) under different circumstances

	Kroll	Metalysis
AM	73.01€	53.35€
CM (casting)	36.65€	31.03€

A cost reduction of about 37% per LPB parts is achieved for the additive manufacturing while the source of raw material becomes Metalysis powder. However, the cost of casting LPB is only reduced by 18%. All in all, on the per part basis for the production batch of 1000 parts, casting is cheaper than AM. The per part production cost of AM and CM crosses at 318 while Kroll raw material is in use. This number increases to 432 when Metalysis powder is in use. This is a promising improvement in the competitiveness of AM over CM (casting in this case).

Table 3 presents the cost competitiveness of manufacturing methods with different sources of raw material for ELB. The assumption in the case of Metalysis utilization for machining process is that 10% additional cost is added to the raw material cost for the powder solidification before the process.

Table 3. Per part manufacturing cost comparison of jet engine loading bracket (ELB) under different circumstances

	Kroll	Metalysis
AM	180.49€	108.81€
CM (machining)	115.49€	49.45€

A cost reduction of about 66% per ELB parts is achieved for the additive manufacturing while the source of raw material becomes Metalysis powder. However, the cost of machining an ELB is reduced by 134%. All in all, on the per part basis for the production batch of 1000 parts, machining is cheaper than AM. The per part production cost of AM and CM crosses at 6 while Kroll raw material is in use. This number merely increases to 7 when Metalysis powder is in use. This is a marginal improvement in the competitiveness of AM over CM (machining in this case).

As we illustrated above, AM gains additional competitiveness while the raw material of choice (the more cost effective source) is also in powder form and this has impacts on the supply chain. The first most obvious effect is the reduced complexity of raw material supply chain and therefore higher reliability. Metalysis as a single step method of extraction can contribute to the supply chain robustness and lower the supply interruptions due to market demand fluctuations.

Decentralization of production is another potential supply chain improvement that increases flexibility and reduces excess costs related to inventory keeping and transportations [3]. If the value of the low lead time can justify the additional production cost (for instance in a maintenance setting), then AM can deliver the intended benefits in a decentralized setting.

Another known benefit of AM is risk reduction in uncertain market settings [4]. In these cases (especially the LPB), improvements in AM switch over (to CM) volume enables a longer period of AM utilization and allows market failure risk reduction (for example in a new product introduction setting). This can be extremely valuable as it allows the manufacturer to postpone the tool production and accelerates the supply chain.

And if we take all the above mentioned factors into account, utilization of AM with a Metalysis like raw material provision method will potentially lead to simplification throughout supply chain. From shortening of the raw material production chain to the faster parts manufacturing (without long tool production lead times) and in-situ delivery. Therefore, the planning and control will be reduced and partly eliminated (no need for inventory and less sub-contractors and parts transshipments).

Conclusions

In this research we utilized real world cases to illustrate the impact of a phenomenon (Lower cost, more reliable, Metalysis raw material extraction method) on the cost competitiveness of additive manufacturing and how that can change supply chains. Results showed that in both cases a much cheaper source of raw material powder will improve AM cost competitiveness over conventional methods; however the impact is of different magnitude for different cases and production methods. Finally we summarized the implication of such AM feasibility improvements on the supply chains.

This study was performed using the available selective laser melting (SLM) metal machines which are meant for research. However since the economics of scale for additive manufacturing to some extend can result in more cost effective parts while the production chamber becomes larger, we think future research should address this issue. Moreover, we encourage the researchers to expand the results of this paper with replicating the case results on an electron beam melting (EBM) machine and update the supply chain implications based on the those results.

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