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Investigation and Assessment of Resource Consumption of Process Chains

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Abstract

Many different technologies and processes have been established in production within the last decades. These technologies have to be integrated into sophisticated process chains to achieve today's requirements of high performance products. For most of these products the costs can be determined or at least estimated accurately. However, resource intensive and thus cost intensive processes and their potential within the process chains are often neither identified nor quantified. For identifying, measuring and subsequently assessing the need of resources, like energy or material and their monetary as well as environmental impact, four different process chains of high industrial relevance have been chosen and investigated with regards to their resource consumption. These process chains are used for manufacturing turbine blades made of Inconel and titanium aluminide as well as for comparisons of a conventional and an innovative process chain to manufacture an insert for an injection mold. By measuring and assessing their resource consumption the most resource intensive and thus influential processes have been identified and their potential for resource reduction has been evaluated. Due to the change of single processes to reduce resource consumption and thus the conditions for subsequent processes, the requirements might change and lead to adaptions within the entire process chain. For the assessment of the process chains and the changes within the processes themselves, a scenario based assessment has been modelled. This results in an economic and ecologic evaluation of these process chains and enables a comparison of these to choose the most meaningful process chain.

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Keywords: Process chains; turbine blade manufacturing; injection mold manufacturing; scenario based resource assessment, use phase, maintenance

1. Introduction

Resource efficiency and sustainable production have become of increasing importance in industry due to economical but also environmental issues. In production, processes are responsible for most of the emissions and thus the environmental impact. Depending on the choice of technologies and their integration into the whole production, the resource efficiency and thus the sustainability differ heavily. On the one hand for most of these processes the costs can be determined or at least estimated accurately. However, on the other hand resource intensive processes and their potential within the process chains are often neither identified nor quantified. Thus investigations and assessments of process chains are becoming increasingly interesting for the industrial planning and thinking. It is not only necessary to high volume produce, it is also important to be flexible. This is due to the fact that continuously changing customer requirements are challenges for a profitable and resource-saving production.

Thus the goal within this research was to measure and assess the resource consumption to identify the most resource intensive and thus influential processes of different process chains. These have been identified, evaluated and, based on a developed method, assessed.

2. Description of different process chains

In this paper four different process chains and their process steps have been investigated. The objective is the comparison between a conventional and an innovative process chain using additive manufacturing technologies. Therefore two

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demonstrator parts have been chosen and manufactured using both process chains - the conventional one as well as the innovative process chain. Both innovative process chains include additive manufacturing technologies whose resource consumption have not been investigated in detail [1], [2], [3].

2.1. Low Pressure Turbine Blades

Comparisons refer to process steps within the defined balance sheet. This begins right after the ‘Design’ and ends with the ‘Post-machining’, see Fig. 1. This balance sheet is chosen for both process chains.

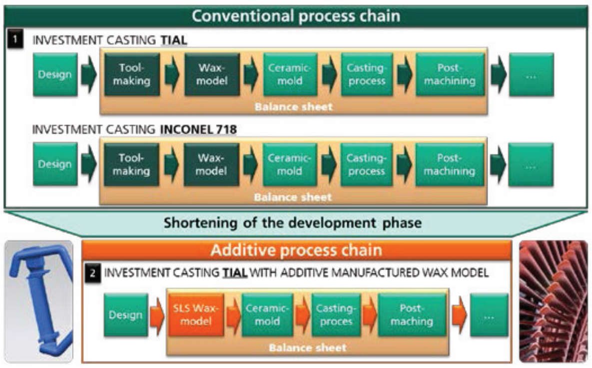

Fig. 1. Definition of the process chains on example of low pressure turbine blades

First to be examined is the conventional process chain. When the ‘Design’ is finished the ‘Tool-making’ follows. ‘Tool-making’ is one of the cost drivers because a special tool with a lot of sliding mechanisms is needed. The ‘Wax model’ is also the positive model of the real turbine blade. Due to this reason the tool’s surface quality is important, too. A defective ‘Wax model’ leads to an incorrect blade and causes more rejects in the process chain. Following the successful production of the ‘Wax model’ the ‘Ceramic mold’ can be produced. This involves that the ‘Wax model’ is dipped into slurry (ceramic components: aluminum-, yttrium or zirconium oxide) and sprinkled by sand several times. This adds ceramic layers and a subsequently drying provides a stabile shape. Finally the wax has to be burned out by an autoclave to finalize the casting form. The next process step is the actual ‘Casting process’. Therefore the melted alloy, TiAl or Inconel 718 (two highly important alloys for the production of turbine blades in aerospace manufacturing), are poured into the ceramic mold. After casting, the cast is cooled down slowly to ambient temperature. This avoids uncontrolled cracks form because the cast’s slightly shrinking. The consideration of two different materials is necessary to visualize the impact on the sustainability their impact when enlarging the scope by the use phase, maintenance as well as the end of life (see chapter 4).

The last process step of the conventional process chain is the ‘Post-machining’. This step includes carefully removal of the ceramic mold and sprues as well as sandblasting for cleaning. A subsequently polishing leads to the finished part.

So far this conventional process chain is not very flexible e.g. for every new development it is necessary to produce a new expensive tool for the wax model. That was the reason to develop an innovative process chain with an additive manufactured wax-similar model. In this way it will be possible to minimize the number of process steps from five to four. Therefore a 3D-Printing process has been used [4]. The process principle is local bonding of starch plastic powder (PMMA = Polymethylmethacrylat) by binder using an ink jet. The powder is deposited layer by layer, so that the part grows up in a powder-bed. For later final surface quality for the turbine blades a subsequently infiltration with wax is necessary. It is important, that the surface quality can only be as good as the printing quality.

2.2. Injection Molds

When considering the conventional and innovative process chain for the manufacturing of a part of an injection mold the defined balance sheet is the same as before for low pressure turbine blade production. It begins after ‘Design’ and ends after ‘Post-machining’, see Fig. 2.

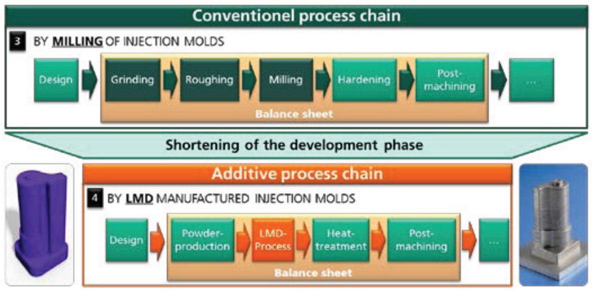

Fig. 2. Definition of the process chains on example of injection molds

The conventional process for the production of parts for injection molds is an ablating process. After the ‘Design’ sliced base material is grinded in the process step ‘Grinding’. This leads to a defined part with plan parallel surfaces. The part can be rigidly fixed in the machine system and prepared for following ‘Roughing’. Due to roughing a lot of material can be removed for a near-net-shape base body. But in this process step the tool for roughing is subjected to extreme forces and worn out quickly. This leads to high tool costs. It is also worth mentioning that the huge ablation of material is not resource efficient. Material, which is not needed, should be avoided and the roughing process should be restricted to a minimum. In the following ablative ‘Milling’ process the part is chipped to the almost final geometry. Only a small material allowance (0.3-1.0 mm) is not removed. The subsequently process step ‘Hardening’ ensures the correct microstructure and hardness. Due to segregations of the alloy during the heat treatment at the surface it is necessary to perform a last process step. The ‘Post-machining’ provides a perfect surface finish and leads to the finished part.

As in previous investigation from the casting process, the conventional process chain is not very flexible. Just three ablative process steps are needed and there is a lot of chip material lowering resource efficiency. A solution is the integration of an additive manufacturing (LMD = Laser Metal Deposition) technology for creating an additive-integrated