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Energy Efficiency in Machining of Aircraft Components

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Abstract

High production costs and material removal rates characterize the manufacturing of aircraft components made of titanium. Due to competitive pressure, the manufacturing processes are highly optimized from an economical perspective, whereas environmental aspects are usually not considered. One example is the recycling of titanium chips. Because of process-induced contaminations they do not meet the quality required for recycling in high-grade titanium alloys. Thus the components need to be manufactured from primary material, which leads to a poor energy balance. This paper describes a methodology to increase the recycling rate and energy efficiency of the manufacturing process by investigating the influencing parameters on chip quality of the machining process with the aim to increase the chip quality to a recyclable degree under monetary aspects. The analysis shows that the recycling rate can be significantly increased through dry cutting, which also brings economic benefits.

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Keywords: Aerospace Industry; Titanium; Recycling; Energy Efficiency

1. Introduction

The manufacturing process of structural components made of titanium for the aircraft industry is characterized by high cutting rates due to its complex shape. With a length of up to 4 m and a thickness of about 2 mm, it is necessary to manufacture the components from solid hammer-forged semi-finished products. Typically, material removal rates from 95 % occur in the machining process. This results in up to 400 t of titanium chips for the production of an aircraft [1]. Usually, the chips are used for substandard products in the steel industry. A reuse of titanium chips for the production of high-grade titanium alloys is rather unusual. This is related to process-induced contaminations, with e.g. cutting fluid. The effort of cleaning and sorting to meet the high quality requirements of the aircraft industry cannot be realized economically. Thus, the high-grade titanium alloys are mainly produced from primary material (titanium sponge). The production process of titanium sponge includes generally the Kroll process, which is a very energy-intensive process. Approximately 80 % of the overall energy consumption is required for this [2-4]. Within the research project “RETURN”, methods aiming to realize a recycling of titanium chips under economic and environmental aspects are developed and evaluated. For this purpose, the suitability of the titanium chips for recycling is analyzed as well as the influence of their quality on the recycling rate. In addition, an analysis of the machine costs is carried out to investigate the effects of process changes due to the chips’ quality improvement. In order to evaluate the obtained methods, the energy consumption of a process chain for the production of a reference aircraft component was investigated (fig. 1).

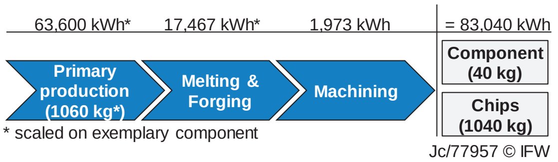

Figure 1: Energy demand for producing a titanium component

In cooperation with research partners the energy consumption of the melting, forging and machining process

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was measured. The required energy for the melting and forging had to be scaled to the reference part, since the semi-finished products usually weigh up to 10 tons. The energy consumption for the primary production was mainly determined by 1060 kg titanium sponge, which makes most of the part and is about 60 kWh/kg.

2. State of the art

The titanium alloy Ti-6Al-4V Grade 5, which is primarily used for aerospace applications, allows in addition to the main components titanium, aluminum and vanadium only small amounts of other elements. The maximum permissible limits for oxygen, nitrogen and carbon is 0.2 %, 0.05 % and 0.08 %. Other elements may be present to a maximum of 0.1 % in the alloy. During the machining process, titanium chips can be contaminated by four potential sources. One source is the coolant, which is used during processing to increase tool life. Oxygen, nitrogen, carbon and other components of the tool substrate and the coating can enter the chips as an impurity. There might be leftovers in the machine or the chip container due to previous machining and finally, the ambient air may chemically react with the chips.

Metalworking fluids are water-based emulsions and commonly used in the industry for machining titanium alloys. However, most coolants have an oil content of 6 -15 percent and thus contaminate the chips with carbon and oxygen. Additionally, supply and disposal of cutting fluid accounts for up to 17 percent of the machining costs [5]. Over the recent years, alternative strategies, like dry machining and cryogenic cooling, have attracted more notice. Hong et al. increased the tool life significantly by using liquid nitrogen (LN_2) as coolant compared to conventional cutting fluid [6]. The results are supported by other studies [7, 8]. Besides LN_2 other liquidized gases like helium and carbon dioxide are also used as cryogenic coolant. Due to new high-performance tool coatings the productivity in dry machining has risen over recent years. Though, higher temperatures in dry machining of titanium increases diffusion wear of cemented carbide tools [9]. As a consequence, higher contaminations due to coating and substrate components are expected.

Titanium chips are recycled mostly to ferro-alloys nowadays. However, Ahn et al. presented a recycling process for the production of titanium hydride, which is used as a foaming agent [10]. Levinskii et al. and Mtsariashvili et al. described the production of titanium carbide and silicide from titanium scrap [11, 12]. More recent studies are concerned with an optimized melting process in order to reduce contaminations [13, 14]. In contrast to these studies the presented approach aims to reduce impurities beforehand by optimizing the machining process.

3. Results

3.1 Machining related cost analysis

Due to high economic pressure, companies of all sizes focus on optimizing their processes under monetary aspects. This includes choosing the optimal technology for the machining process as well as selecting suitable cutting tools, process parameters and cooling strategies. Considering the high material costs, it is important to implement a stable process to secure a constantly high quality of finished components. At the same time, it is essential to achieve minimal total expenses by minimizing production time and machining costs. In the following the costs for machining an exemplary structural component of an aircraft are calculated with respect to three different cooling strategies (cutting fluid, dry, cryogenic (LN_2)). The cost analysis considers machine cost rate c_m [€/min], energy cost rate c_e [€/min], tool cost rate c_t [€/min], coolant cost rate c_c [€/min] and personnel cost rate c_p [€/min]. It is important to note that the analysis is restricted to the primary processing time t_{pp} [min] of the milling process. Moreover, the revenues from recycling the chips are not taken into account and the process parameters are assumed to be constant despite different cooling strategies. The costs per part can be calculated by Eq. 1.

$$C_{part} = t_{pp} \cdot \left(c_m + c_e + c_t + c_c + c_p \right) \quad \text{Eq. 1}$$

The analysis reveals that the use of cutting fluid gives the best result in terms of machining related costs per part (fig. 2). Dry machining exhibits high tool wear, which in turn results in higher costs (+42 percent). The use of LN_2 is characterized by high flow rate per minute, which also results in higher costs per part (+48 percent). However, the presented analysis is an isolated view of the manufacturing costs and does not reflect the influence of the cooling strategies on the recyclability of the chips. Consequently, potential differences in revenues from recycling of titanium chips are neglected so far.

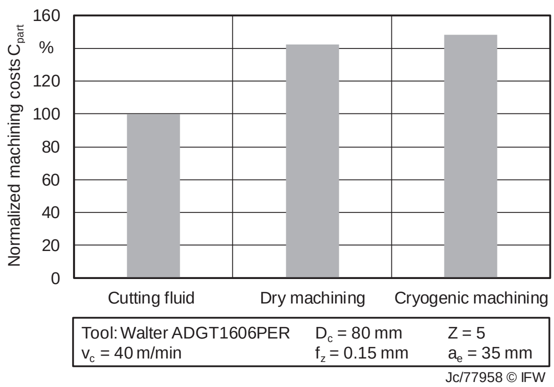

Figure 2: Machining-related costs per part for different cooling strategies

3.2 Analysis of chip quality and recycling rate

One requirement for recycling titanium chips is the macroscopic purity. Usually, the chips are mixed with other materials. One reason for this is a contamination of the machine tool due to previous processing of components from foreign materials. Another reason can be a contaminated chip container, which is generally used for all sorts of materials and is not cleaned beforehand. Consequently, other metals like iron or materials like cleaning textiles, which cannot be separated afterwards for procedural and monetary aspects,