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Procedia CIRP 45 (2016) 155 – 158

www.elsevier.com/locate/procedia

3rd CIRP Conference on Surface Integrity (CIRP CSI)

Residual stress evaluation of a high performance machined pre-formed Ti6Al4V part

D.M. Dimitrov[a]* , R.F. Laubscher[b], A.Sterzing[c], P.J.T. Conradie[a], G.A. Oosthuizen[a], P. Blau[c], G. Schmidt[c], C. Hochmuth[c], G. Styger[b] and R. Zachäus[c]

[a]*Stellenbosch University, Joubert St, Stellenbosch 7600, South Africa*
[b]*University of Johannesburg, Auckland Park, Johannesburg 2006, South Africa*
[c]*Fraunhofer IWU, Reichenhainer Str. 88, 09126 Chemnitz, Germany*

* Corresponding author. Tel.: +27 (0)21 808 4234; fax: +27 (0)21 808 4245. *E-mail address:* dimitrov@sun.ac.za

Abstract

Near net-shape technologies are increasingly used to enhance resource efficiency in high performance machining for various applications, including aerospace. In this paper the effect of a pre-formed based manufacturing route on the residual stress state of an aerospace part in Ti6Al4V is presented. The manufacturing strategies, including the pre-form and machining stages, are outlined in detail. Two similar pre-formed billets were manufactured. High performance machining was then conducted at two different laboratories to manufacture a similar part utilizing different machining strategies. The effect of the manufacturing route and strategies utilized on the residual stress state of selected regions of the part were then evaluated by XRD (surface) and neutron diffraction (body) techniques. The results show that productivity improvements can be realized by utilizing a pre-form without incurring noteworthy residual stresses as a result of the forming process. The surface residual stress state, however, is substantial and found to be largely a function of the cutting strategy applied.

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Keywords: Residual stress; Milling; Titanium alloy; Pre-form

1. Introduction

Globally, the aerospace industry is continuously under pressure to reduce costs due to increased fuel prices, demand for air travel and global outsourcing. Particularly, reduced costs are critical for suppliers and manufacturers to remain competitive [1]. Within the larger manufacturing context of the metal cutting industry, the main challenges are the development and application of innovative strategies for reducing machining costs and cycle time. This is not only related to higher productivity, increased profitability and improved energy and resource efficiency, but also to better performance and lower emissions. This must be achieved while maintaining or enhancing part quality and performance [2].

Ti6Al4V is the most commonly used titanium alloy in the aerospace industry. This is attributed to the alloy's high strength-to-weight ratio, low density, high temperature and chemical resistance and compatibility with carbon fibre composites. These properties, however, are also responsible for the challenges associated with milling processes, and therefore contribute to longer machining times and higher costs [3].

During the last decade there has been a worldwide manufacturing trend to move beyond optimization achieved exclusively through increased cutting parameters. The research focus therefore shifted to enhancing the resource efficiency of the entire process chain. To achieve this, production processes have not only been increasingly governed by high performance operations, but also by the implementation of near-net-shape technologies and hybrid processes [2].

The objective of this paper is to investigate the use of pre-form technologies to reduce the machining time and material waste for high performance machining (HPM) of titanium alloys. A key part of this investigation is the evaluation of

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doi:10.1016/j.procir.2016.02.049

residual stresses induced by the pre-form process and high performance machining strategies to assess the suitability of such a process combination.

2. Process chain optimization

2.1. Pre-forming process characteristics

Characterisation of the forming procedure includes evaluation of the influence of the forming process on the machining operation and consequently on the part quality. This interaction is illustrated in Fig. 1.

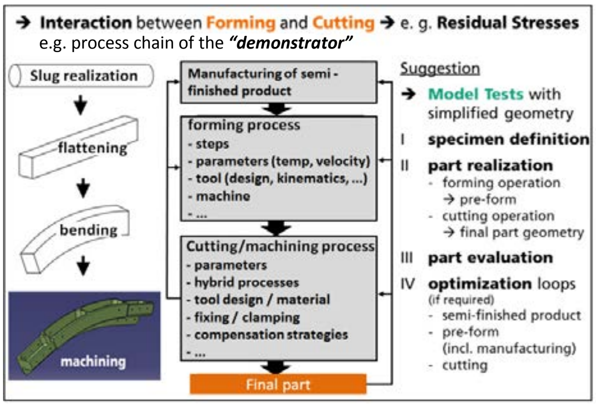
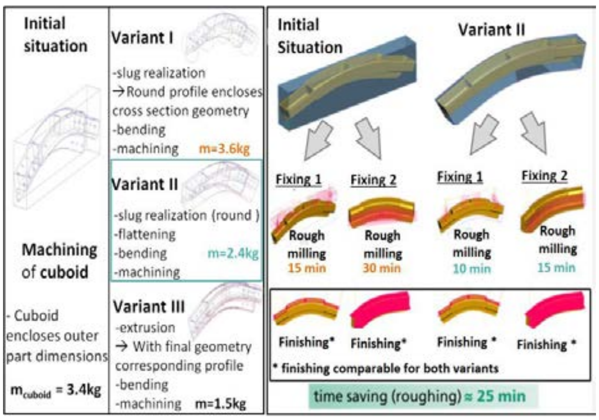


Fig. 1. Interaction between forming and machining.

Variations on the forming process should be investigated to realize the most suitable process in terms of time and cost. This includes an economic evaluation of the pre- and post-manufacturing steps associated with the process variations.

2.2. Process combination

An aerospace titanium based component was selected as demonstrator for the evaluation of a process combination that involves forming and subsequent machining (Fig. 2). With the use of the same pre-forming process, two cuboid billets were formed into the curved geometry representing the final



(a) (b)

Fig. 2. Saving potential for process combination: (a) material and (b) machining time.

shape of the part shown in Fig. 2. As part of the process combination, each of the billets was machined with different machining strategies in the respective laboratories classified as Process I and Process II.

3. Experimental setup and design

3.1. Pre-forming

With regard to the material characteristics of Ti6Al4V, a heated forming process was applied. A temperature of ϑ = 960°C was used. This is as high as possible to improve ductility, without exceeding the point above which embrittlement occurs ($\vartheta \approx$ 980°C). The tool temperature was set at 20°C and the punch velocity at 20 mm/s.

3.2. High performance machining

Process I

Process I includes face milling and swarf milling. The cutting parameters strongly depend on the tool used and the geometric characteristics of the machined features as summarized in Table 1.

Table 1. Main cutting parameters and strategies for Process I.

Operation	Strategy	v_c [m/min]	a_p [mm]	a_e [mm]	f_z [mm/z]
Roughing	Swarf milling	88-94	3-12	0.3-13	0.03-0.1
	Surface milling	75-88	0.8-1	3-20	0.08-0.1
Finishing	Swarf milling	57-101	2.8-7	0.1-3.5	0.04-0.17
	Surface milling	75-126	0.5	7-12	0.1-0.17

The strategy therefore not only refers to the toolpath, but the specific combination of the toolpath with corresponding cutting parameters. A toolpath on the flange is shown in Fig.3

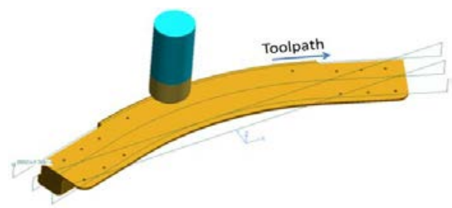


Fig. 3. Tool path during process step (surface milling)

Process II

The high performance cutting strategy implemented for Process II included a constant engagement angle (CEA) milling strategy. With the geometric features considered, the optimal engagement angle is calculated. From this, the tool paths are created so that the engagement angle is controlled according to the features surrounding the immediate toolpath. This is of particular importance for titanium to reduce cutting forces and increase tool life [4]. Finishing strategies included swarf milling and surface milling. A summary of the main cutting parameters and corresponding strategies for Process II are summarized in Table 2. The strategies were selected based on the results of extensive in-house experiments revealing the best tool life and surface finish for titanium.