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Procedia CIRP 46 (2016) 412 – 415

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7th HPC 2016 – CIRP Conference on High Performance Cutting

A Cost Modelling Approach for Milling Titanium Alloys

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Abstract

The demand for titanium is continuously growing with the increased use of its alloys in new generation aircrafts. It is classified as a difficult-to-machine metal and therefore large costs are associated with the removal of material during machining operations. Working towards more resource efficient process chains, the aim is to reduce cycle time and cost, while maintaining or enhancing the machined product's performance. Despite extensive research on cost modelling over the years and the availability of commercial and free software solutions, their implementation on a wider scale is still missing. Addressing these needs in this paper, a practical approach for cost modelling is presented and its applicability in production environment demonstrated.

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz

Keywords: Cost modelling; Milling; Titanium Alloys

Nomenclature

C_{aux}	additional costs associated with regrinding process
C_e	cost of new end mill cutting tool
$(C_e)_t$	total end mill tool cost
C_{man}	manufacturing cost per unit [R]
C_{pm}	cost per pre-manufacturing process [R]
C_{pp}	auxiliary cost associated with pre-man. process [R]
C_{rg}	cost of regrinding an end mill
C_t	tool cost [R]
C_{tot}	total manufacturing cost per unit [R]
HSM	high speed machining
HPM	high performance machining
M_r	machining rate [R/hr]
MRR	material removal rate [cm³/min]
n_f	number of features
n_{op}	number of machining operations
n_{pm}	number of pre-manufacturing processes
n_{rg}	number of cutting tool regrinding cycles
n_s	number of setups
n_{sf}	number of strategies per feature
n_t	number of cutting tools
$n_{u/pm}$	number of units per pre-manufacturing process
Q_{prod}	production rate [units/hour]
R	South African rand (ZAR)
T_{ad}	approach and depart movements [min]
T_c	cutting time [min]
$T_{c/m}$	cutting time or material removed (depends how tool life is defined) [min or cm³]
T_{np}	non-productive time (setup, appr., dep., trav.) [min]
T_{set}	setup time per machining orientation [min]
T_{st}	strategy traverse movement times [min]
T_{tc}	tool change times [min]
T_{tot}	total time to machine a part [min]
TL	tool life [min or cm³]
$(TL_e)_t$	total tool life of end mill cutting tool [min or cm³]
$(TL_e)_n$	tool life of new end mill [min or cm³]
$(TL_e)_{rg}$	tool life of regrinded end mill [min or cm³]

1. Introduction and background

Competing in a global market, manufacturers are continuously under pressure to enhance performance by reducing costs and time and improving quality. South Africa is positioned as the second largest producer of titanium mineral concentrates, but has no market position further along the value chain [1]. It is argued that the key factor for South

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz
doi:10.1016/j.procir.2016.04.014

African manufacturers to penetrate the global market is knowledge development in the area of HPM of titanium alloys. The differentiating competence lies in the ability to design and implement more resource efficient manufacturing process chains. Improvements are aimed at reducing costs through decreased material usage and shorter machining times. Focusing on the aerospace industry as main driver of the development, machining of Ti alloys is a core competency for producing finished products. Challenges associated with aerospace parts are material restrictions and complex weigh-saving geometries that require high volume removal and lengthy manufacturing processes. Hence, manufacturing techniques and production methods remain key cost factors.

Cost modelling has been the subject of much research over numerous years, but still it is not readily applied in manufacturing industries. According to Mocho et al. [2] this can be attributed to two main reasons. Firstly, manufacturers do not consider the effort necessary to obtain accurate results worth the effort compared to the possible savings that can be achieved. Secondly, input processes accompanying the cost modelling methods are considered to be too tedious and complex. These findings were confirmed with industry collaboration. Addressing these shortcomings, a practical approach for cost modelling is presented in this paper. This is not only applicable to titanium alloys, but with the availability of suitable tool life databases can include other metals such as high strength aluminium, steels and nickel based alloys.

Cost-modelling techniques can be classified based on qualitative or quantitative approaches. Models based on qualitative methods make use of heuristic rules and expert judgement for determining the cost and can further be classified into intuitive and analogous techniques. Quantitative methods are based on a detailed analysis of the product design, associated features and corresponding manufacturing processes, further classified as parametric and analytical techniques. Costs are therefore determined utilizing analytical functions of variables presenting different product parameters. Quantitative methods are known to be more accurate and eliminate the need for an expert estimator. Providing only a high level overview here, more research on the various cost modelling techniques can be found in [3].

2. Approach to cost modelling

The machining process is characterised by different cost factors that vary depending on the type of setup or process. The main costs, however, can be categorized into three groups namely: machining cost, cutting tool cost and non-productive costs. The aim is to reduce each of the respective cost elements so that the overall costs can be minimised (Fig. 1).

The machining costs include the rate of the operator, maintenance, depreciation and overheads. The cutting tool costs depend on the tool life and amount of tools used. The non-productive costs include costs of processes during which no cutting takes place such as setup, tool changes, approach and retreat movements and rapid traverse motions. Material costs are not included here as it remains constant regardless of the approach, machine or process used.

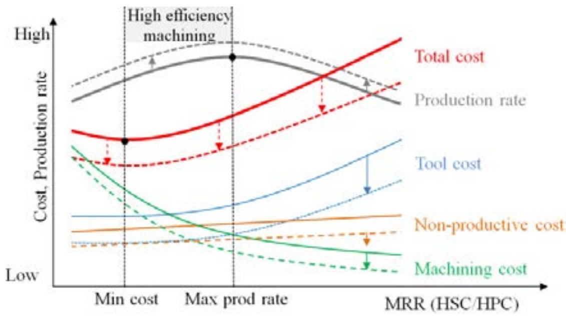

Fig. 1. Schematic illustration of interaction between main cost components and effect of cost modelling – not to scale (adapted from [4])

The purpose of this cost modelling framework (Fig. 2) is to present a systematic approach for assisting manufacturing companies to improve their machining processes. Implementation of a rule-based breakdown approach enables the minimum costs and maximum production rate to be determined. Furthermore, isolation of the cost drivers together with their effects and interactions allow improvements towards better machining performance and profitability.

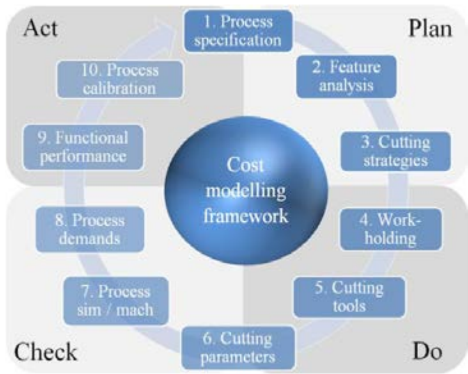

Fig. 2. Cost modelling framework for milling processes

Process specification is characterized by customer requirements that, together with available resources, give rise to potential manufacturing process chains. Often integrated process chains are implemented to achieve similar outcomes using different manufacturing process steps such as hybrid additive, subtractive and forming technologies. The choice of process is dependent on economic analyses to assess time and costs associated with each process chain (eq. 1).

$$C_{tot} = \sum_{i=1}^{n_{pm}} \left[\frac{1}{n_{u/pm}} (C_{pm} + C_{pp}) \right]_i + C_{man} \ [R] \qquad (1)$$

Feature analysis pertains to the evaluation of geometric and topological features together with their interactions. Included in this process step is the modelling of part complexity and evaluation of machine precision and capability requirements. Along with geometrically defined inputs and potential strategies, removal volume and sequencing operations are