Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 21 (2018) 259–265

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

15th Global Conference on Sustainable Manufacturing

Automatic Regeneration of Cemented Carbide Tools for a Resource Efficient Tool Production

Berend Denkena, Marc-André Dittrich, Yanwei Liu*, Mirko Theuer

Institute of Production Engineering and Machine Tools, An der Universität 2, 30823 Garbsen, Germany

Abstract

Cemented carbide tools have become widely established in machining of metallic materials in recent decades. However, due to rising prices of cemented carbide and an imminent scarcity of resources, there is a growing need for an efficient recycling of worn cemented carbide tools. This article presents a novel process chain for the automatic regeneration of cemented carbide tools. The process chain contains the measurement, classification and evaluation of the worn cutting tools as well as the automatic planning and simulation of the grinding process. In comparison to conventional manufacturing of cemented carbide tools the production costs are reduced by up to 50 % and the required resources are decreased significantly.

Peer-review under responsibility of the scientific committee of the 15th Global Conference on Sustainable Manufacturing (GCSM).

Keywords: grinding; regeneration process; cemented carbide tools; measurement; identification; path planning; simulation

1. Introduction

Because of the favorable combination of high hardness with a relatively high toughness and good temperature wear resistance, cemented carbide is excellently suited for machining [1]. Cemented carbide tools resist high loads in the process and enable high cutting speeds. For this reason, cemented carbide tools are used to process difficult-to-cut materials such as titanium [2].

* Corresponding author. Tel.: +49 (0)511 762-19793; fax: +49 (0)511 762 5115.
E-mail address: liu@ifw.uni-hannover.de

2351-9789
Peer-review under responsibility of the scientific committee of the 15th Global Conference on Sustainable Manufacturing (GCSM).
10.1016/j.promfg.2018.02.119

The production of cemented carbide milling tools is currently carried out in two process steps. In the first step, a cemented carbide blank is sintered to the required diameter (usually as cylindrical blanks) in an energy intensive process. The blanks are either produced entirely from the scarce raw materials, such as tungsten and cobalt, or from an admixture of chemically elaborately recycled cemented carbide. In the second step, the cylindrical blanks are machined by grinding processes in order to create the form elements and functional surfaces of the cutting tool. Despite the large variety of tool shapes, shank tools can be produced in most cases by means of the manufacturing of flutes, end faces and flank faces [3] (Figure 1).

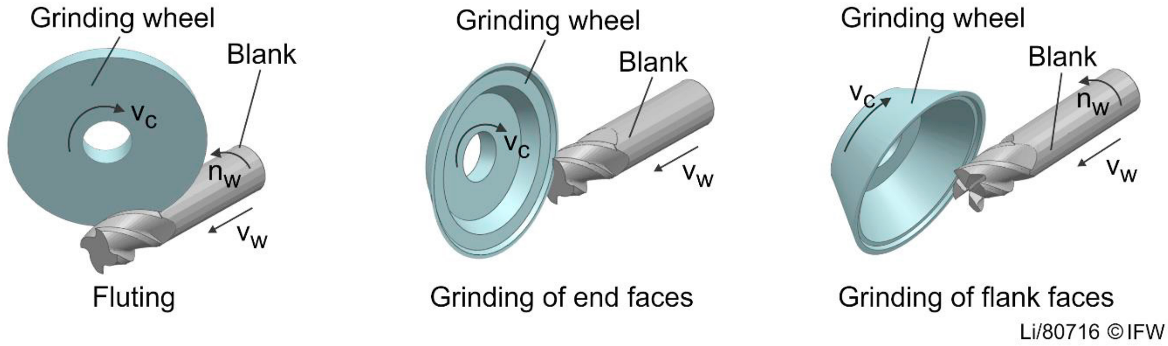

Fig. 1. Manufacturing of shank tools (n_w: rotational speed of workpiece; v_c: cutting speed; v_w: axial feed of the workpiece).

Investigations by [4] show that more than 50% of the total energy required for the production of cemented carbide milling tools is required for the production of cemented carbide blanks. The required energy for producing a blank having a diameter of 10 mm and a length of 73 mm is calculated to 9.01 MJ. In terms of the economical dimension, the costs for material purchase can account for up to 80% of the tool's price [5]. In addition, a large proportion of available raw materials are concentrated in very few countries such as China, Russia and Bolivia [6]. This situation gives the mining countries great market power, which results in a strong economic dependency on the cemented carbide producers. Thus, the recycling of cemented carbide tools is becoming increasingly attractive, despite high costs. In industrial application, worn tools are reused by reground, in which the functional surfaces of the tools are regenerated by grinding. The number of permissible regrinding processes is limited by the type and the level of the damage. If no regrinding is possible or if the tool is severely damaged by large breakouts, the tools are disposed of as scrap. However, conventional recycling techniques suffer from the problem that large quantities of chemicals and energy are used in the purification process, resulting in waste being generated with the consequence that great environmental loads are imposed [5].

Facing the situation, the authors have developed a process chain for a more energy efficient and less toxic recycling process of worn cemented carbide tools. In this method, the worn cemented carbide tools are directly used as blanks for grinding of new tools [6]. Thus, the process chain of recycling is shortened drastically. However, the shape of the worn tool results in complex engagement conditions as well as varying loads on the grinding wheel in the regenerative grinding process. For dealing with these matters, the process load is analyzed using an NC simulation. Based on the simulated results, a process strategy for the regenerative grinding process is developed and experimentally investigated.

2. Process chain for the regenerative grinding process

The planning and optimization of the regenerative tool grinding process is carried out by using a measuring and analysis system, a CAD-CAM system and a simulation module. In a first step, the worn tool is scanned by a 3D measuring system and prepared as a CAD file for use in a grinding simulation. Depending on the application scenario, the measured blank shape can be stored in a blank database or passed directly to the analysis system. A database for managing workpieces is linked to the CAD-CAM system. In the regeneration of a certain worn tool, a search algorithm in the analysis system is used to identify an optimal workpiece from the workpiece database with regard to the geometrical similarity and minimum volume difference. For the production of a desired tool, the analysis system searches from the blank database for the optimal blank shape. On the basis of the target tool shape and corresponding machine information (machine, clamping chuck, grinding wheels), a grinding process for machining the target tool from a cylindrical blank is automatically generated in the CAD-CAM system. The pairing of the blank and the tool to be produced, as well as the NC program from the CAD-CAM system are transferred to the simulation system CutS, which is a simulation software to model process kinematics, simulate the material removal and calculate different process parameters like process forces or workpiece deviation [7]. In CutS, the optimal positioning of the blank identified by a best-fit method. On this basis, processes for grinding a specific blank with a minimal material removal are planned. Subsequently, a grinding simulation is used to check the process for collisions and to characterize the process in terms of technological parameters. Furthermore, the grinding process for machining from a cylindrical blank from the CAD-CAM system is extended with a path planning for the regenerative grinding process and optimized based on the simulation results by adapting the feed rate. In the last step, the NC program is transferred to the grinding machine for running the regenerative grinding process.

3. Measurement and identification of the worn tools

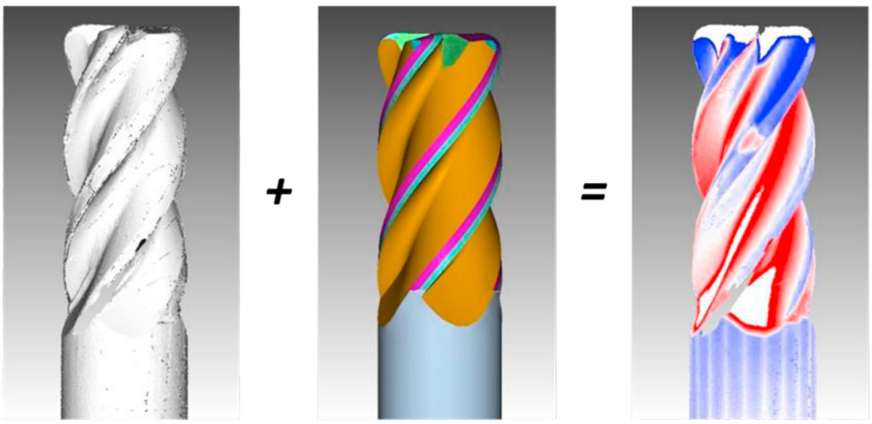

Fig. 2. Comparison of a scanned tool with wear and the CAD data of the tool [8]

The worn tool is measured by a 3D measuring system, which consists of a 3D scanner with a local resolution of approximately 0.2 - 0.3 mm and a 3D micro scanner with a local resolution of 4.5 µm [8]. The measurement accuracy and resolution of the 3D scanner meet the requirements for the determination of the tool parameters. It can also be used for the detection and localization of typical defects. The 3D micro scanner is used to detect the defects and wear of cutting tools. The measurement data from the micro scanner can be used for the detailed investigation and quantification of the defect images. With the measuring system, the complete data sets of a worn tool are created as point clouds. On the basis of measuring data the defects and wear can be detected and evaluated in the further steps.

In the analysis system, a procedure for the determination and selection of geometrically suitable workpiece candidates for the regenerative process is carried out based on a distance analysis (Fig. 2). Deviations between the target and actual shape are determined and visualized over the entire tool surface in a calculation-intensive process. The main criteria of the search for the optimal combination of blank and target workpiece for the regenerative grinding process are the geometrical similarity and the minimum volume removal difference.

4. Path planning for the regeneration process

In order to analyze and optimize the regenerative grinding process an NC simulation is performed in CutS. For the simulation, a Walter Helitronic Basic grinding machine is modeled. A worn tool is used as the blank. The grinding path is initially designed based on the grinding of the target workpiece from a cylindrical blank. The regenerative process is evaluated with a contact zone analysis (Fig. 3). By means of a contact zone analysis, the contact conditions are described by the specific material removal rate Q'_w of the workpiece. An increasing specific material removal rate correlates usually with an increasing local load of the grinding wheel, which leads to higher local wear of the grinding wheel.

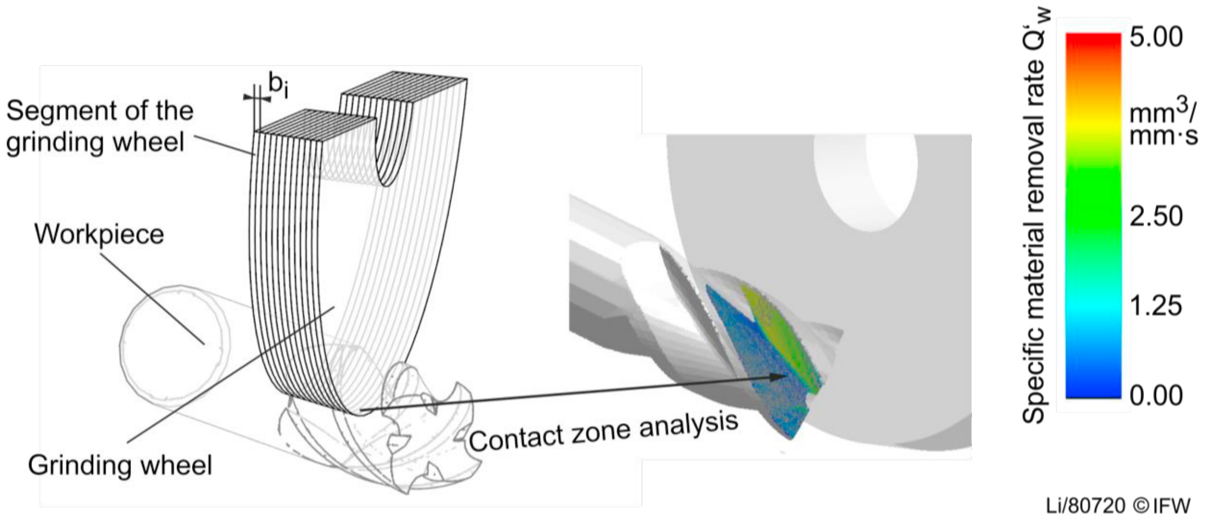

Fig. 3. Contact zone analysis in CutS

The simulation shows that the load varies widely across the width of the grinding wheel. The maximum values of the specific material removal rate occur in the contact area of the grinding wheel edge and the cutting edges of the tool, as well as in the transition region between the cutting edges and the shank of the tool. This distribution of loads results in a heavy and irregular wear of the grinding wheel. To solve this problem, new strategies for the process design are developed, in which a neck is placed between the cutting part and the shank part, and the worn cutting edges of the worn tool are removed in a first step (Fig. 4), which is followed by the grinding steps for conventional production.

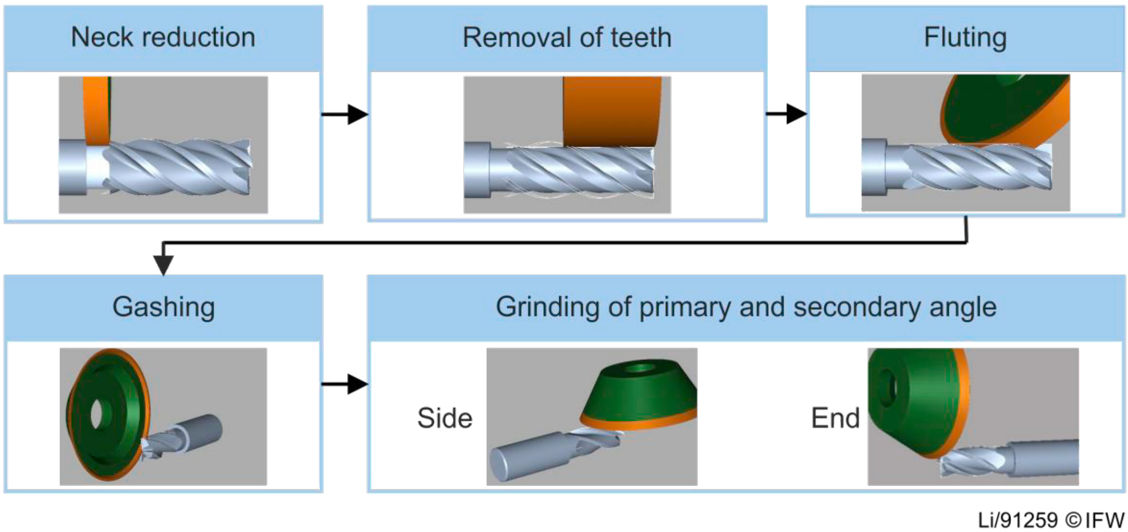

Fig. 4. New process steps for regenerative grinding of worn tools

5. Feed rate optimization

Although the teeth of the worn tool are removed before the machining of the flutes, the contact condition in fluting are still complicated due to the helical shape of the worn tool. Therefore, an optimization method is used for the control of the local tool load in the fluting process. By optimizing the feed rate a uniform removal and, thus, a uniform loading of the grinding wheel within the process limits is realized

During the grinding simulation, the positions of the axes, the feed rates and the specific material removal rates of the workpiece related to each grinding wheel segment are calculated and recorded at each time step. For each time step, the maximum specific material removal rate $Q'_{w,\,max}$ is compared with the predetermined process limit. If the upper limit of the maximum specific material removal rate is exceeded, the feed rate is reduced. Thus, an overloading of the tool can be prevented. On the other hand, the feed rate is increased when the maximum specific material removal rate $Q'_{w,\,max}$ is lower than the threshold. On the basis of the calculated feed rates as well as the corresponding axis positions, a new NC program is generated and then checked in a further simulation.

Fig. 5 shows the optimized result for grinding of one flute. Fig. 5 (a) depicts the behavior of the maximum specific material removal rate $Q'_{w,\,max}$. The upper limit of the maximum specific material removal rate is set as $Q'_{w,\,max} = 9$ mm^3/mm·s. Fig. 5 (b) shows the feed rate before and after the optimization. The feed rate is kept constant in the original NC program ($v_f = 180$ mm/min). After the optimization, the feed is initially increased in order to shorten the machining time. With the consideration of the maximum permissible specific material removal rate, the feed rate is reduced in the followed phase of the grinding process.

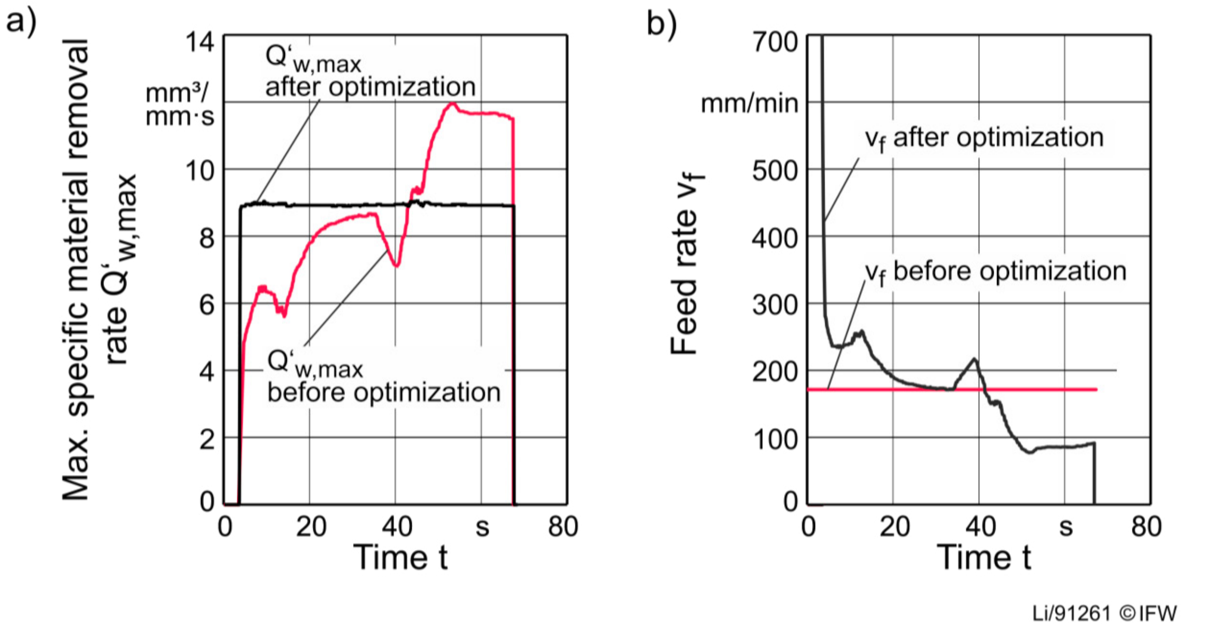

Fig. 5. Optimized flute grinding process: (a) maximum specific material removal rate before and after optimization; (b) feed rate before and after optimization

6. Implementation and validation

The developed process chain is tested in regenerative grinding of a milling tool with a diameter of 25 mm and a helix angle of $\delta = 40°$. In the workpiece database of the CAD-CAM-System Walter Tool Studio, target tools from a product catalogue with a diameter from 2 mm up to 20 mm are stored. The helix angle of the target tools varies among 30°, 35°, 40° and 45° at every diameter group. Using the analysis system, a milling tool with a diameter of 20 mm and a helix angle of $\delta = 35°$ is defined as the target tool from the workpiece database. Next, an NC program for producing the target tool from a cylindrical blank is generated in Walter Tool Studio. Subsequently, the CAD data of the worn tool, and the NC program are imported into CutS. The planning and simulation of the regenerative production process is carried out tool in CutS. The new NC program, which is generated by CutS, is imported into the control system of the grinding machine and the target tool is produced from the worn tool.

The profitability of the regenerative grinding process is shown in Fig. 6. The calculation is based on production of milling tools from cemented carbide with a market price of 90 €/kg and a machine-hour rate of 40 €/h. It is shown that the total costs are mainly influenced by the material costs (Fig. 6 (a)). Since the worn tool price is 19 €/kg on the market, material costs can be saved in a high degree by the regeneration from worn tools. To investigate the efficiency of the regeneration of the above used 25 mm diameter worn tool, the costs of producing tools with diameters from 3 mm to 20 mm from a new cemented carbide blank and from a 25 mm diameter worn tool are compared in Fig. 6 (b). In the regeneration of the worn tool with a diameter of 25 mm, the total costs are dominatingly decided by the material cost (price of the worn tool). The influence of the process costs on the total costs is very small. Because of the input of the measuring system, the machine-hour rate was estimated to 50 €/h. Due to the addition processes for the neck reduction and the removal of teeth, the process time in the regenerative grinding is longer than the process time in conventional production. Thus, the process costs of the regenerative process are higher than the costs in production from cylindrical blanks. For the production of milling tools with diameters from 13 mm to 20 mm, the extended part of process costs can be covered by the saving of the material costs. If the target tool diameter is smaller than 13 mm, the regenerative process will be more expensive than the conventional production. The highest saving potential is shown by the above tested process, in which a milling tool with a diameter of 20 mm is produced from a worn tool with a diameter of 25 mm. The highest savings are 52% compared to the new production of a 20 mm tool. It can be seen from the tendency of the curves, that the smaller the diameter difference between the worn tool and the target tool is, the higher the cost saving is. Conversely, for the production of a target tool with a certain diameter, a worn tool with the smallest diameter difference should be searched in the blank database.

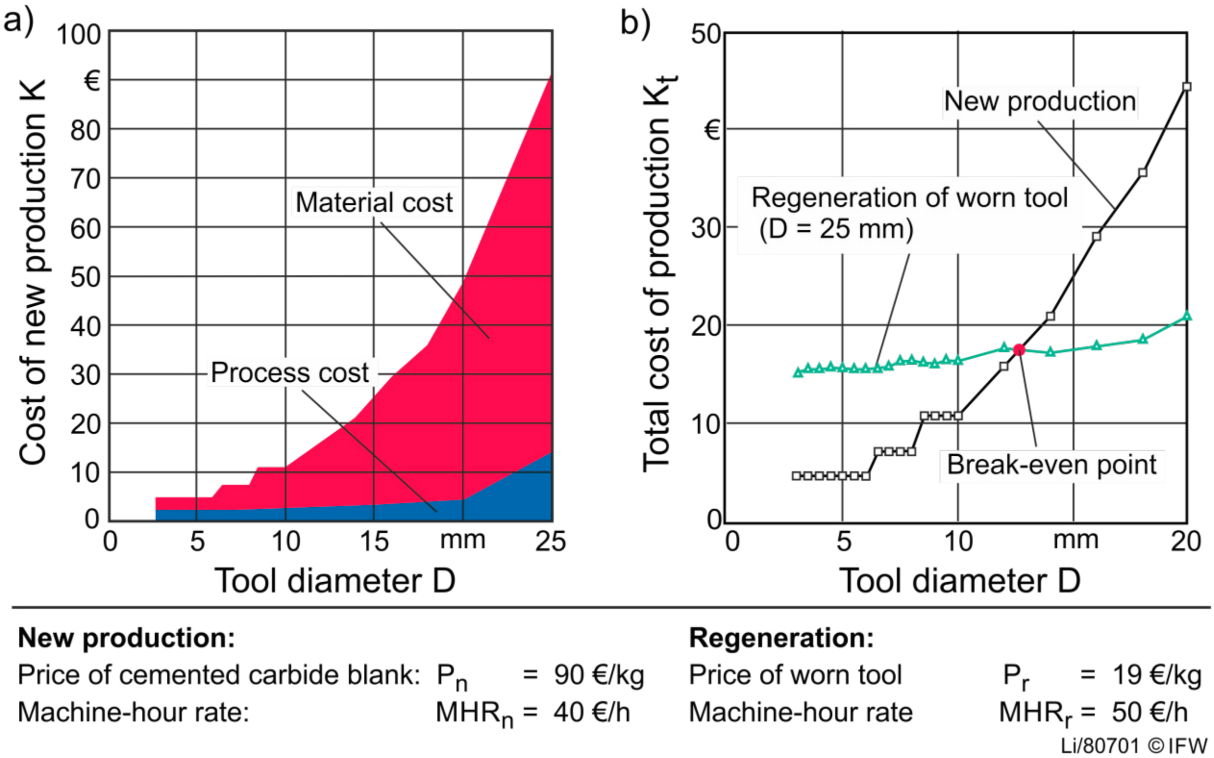

Fig. 6. Efficiency of the regenerative grinding process: (a) calculation of the cost for the production of tools with different diameter from new cemented carbide blanks; (b) comparison of total cost between the production of tools from new blanks and from a worn tool with a diameter of 25 mm (1 € = 1.18 $)

7. Conclusion and outlook

In this article, a new process chain for recycling of worn cemented carbide tools has been presented. By applying this regeneration process worn tools made of cemented carbide can be reused as blank for the production of new cutting tools. In the regeneration process, the shape of individual worn tools are scanned with a 3D measuring system. The optimal pairing of the worn tools and new target tools is carried out by a newly developed analysis system. Using an initial NC program for producing the target tool from a cylindrical blank, an NC simulation is performed in a material removal simulation. Based on the results from a contact zone analysis, the initial NC program is extended and the feed rate is adapted. In the new generated NC program a neck is placed between the cutting part and the shank part, and the worn cutting edges of the worn tool are removed in a first step. The comparison with conventional manufacturing processes has shown that the production costs can be reduced by up to 50% with the new regeneration process and the required resources are reduced significantly. Since the material properties of the worn tool might be influenced by the mechanical and thermal loads by using and regenerating, the behavior of the tools from the new process will be investigated and evaluated in future research.

Acknowledgements

The authors thank the Industrial Collective Research (IGF) for founding this work and the support of the Federal Ministry of Economic Affairs and Energy (BMWi) based on a resolution of the German Federal Parliament by funding the project "Automatic Regeneration of Cemented Carbide Tools for the Production of new Tools" (18062 BG / 1). Special thanks given to all project partners for their support and contributions to these results.

References

[1] B. Denkena, H.K. Tönshoff, Basics of Cutting and Abrasive Processes, Springer-Verlag, Berlin Heidelberg, 2013, pp. 167.
[2] J.I.Hughes, A.R.C. Sharman, K. Ridgway, The effect of cutting tool material and edge geometry on tool life and workpiece surface integrity, Proc. IMechE Vol. 220 Part B: J. Engineering Manufacture, 2006, pp. 93 – 107.
[3] J.Y. Chen, B.Y. Lee, C.H. Chen, Planning an analysis of grinding processes for end mills of cemented tungsten carbide, Journal of Materials Processing Technology 201, 2008, pp. 618 – 622.
[4] B. Kirsch, C. Effgen, M. Büchel, J.C. Aurich, Comparison of the embodied energy of a grinding wheel and an end mill, Procedia CIRP 15, 2014, pp. 74 – 79.
[5] B. Denkena, M.A. Dittrich, Y. Liu, Optimale Werkstückpositionierung in regenerativen Werkzeugschleifprozessen mittels Best-Fit-Verfahren, 19. Anwendungsbezogener Workshop zur Erfassung, Modellierung, Verarbeitung und Auswertung von 3D-Daten, 2016, Berlin, pp. 79 – 85.
[6] U. S. Geological Survey, Mineral Commodity Summaries 2017. U.S. Geological Survey, 2017, pp. 180 – 181.
[7] B. Denkena, V. Böß, Technological NC Simulation for Grinding and Cutting Pro-cesses Using CutS, Proceedings of the 12th CIRP Conference on Modelling of Machining Operations, Volume II, May 7-8, Donostia-San Sebastián, Spain, 2009, pp. 563 – 566.
[8] N. Heuwold, Geometrische Analyse von 3D-Scan- und Konstruktionsdaten gebrauchter Hartmetall-Schaftfräser im Kontext eines innovativen Werkzeug-Regenerationsverfahrens, 19. Anwendungsorientierter Workshop zur Erfassung, Modellierung, Verarbeitung und Auswertung von 3D-Daten, Tagungsband, Berlin-Adlershof, 2016, pp. 87 – 96.