Available online at www.sciencedirect.com
ScienceDirect
Procedia CIRP 46 (2016) 496 – 499
www.elsevier.com/locate/procedia

7th HPC 2016 – CIRP Conference on High Performance Cutting

Dry Broaching Using Carbon Free Steel as Tool Material

Klocke, F.[a], Döbbeler, B.[a], Seimann, M.[a]*

[a]Laboratory for Machine Tools and Production Engineering (WZL), Steinbachstraße 19, 52074 Aachen, Germany

* Corresponding author. Tel.: +49-241-8028020; fax: +49-241-8022293. *E-mail address:* m.seimann@wzl.rwth-aachen.de

Abstract

One major application of broaching is the production of internal gears for the automotive industry. Today, broaching with tools made of high speed steel is state of the art. However, because of the low hot hardness the cutting parameters are limited and process lubrication is mandatory. A promising alternative is the use of the carbon free cutting material MC 90 Intermet, which possesses a higher hot hardness and increased thermal conductivity compared to HSS. These properties offer dry broaching of gears with modules higher than m_n = 1.5 mm. In this paper, the influence of different coatings and cutting parameters on the tool wear, cutting forces and tool temperatures are investigated.

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

Keywords: MC 90 Intermet, Broaching, Dry machining, 16MnCr5

1. Introduction

In industry, the design, optimization and reduction of direct manufacturing costs are continuous procedures. The aim is to increase the rate of material removal, whilst improving tool life. However, for manufacturing internal gears for automotive industries, broaching with high speed steel broaching tools, is state of the art. High speed steels are distinguished by their combination of toughness and hardness. A disadvantage of high speed steel is the hot hardness just up to 600°C, which enables only low cutting speeds compared to other machining processes and the mandatory usage of cooling lubricants.

The automotive industry is switching their machining processes systematically to dry machining. For different operations, such as turning, drilling and milling, this change has already taken place successfully. This trend should also be continued in broaching technology, but because of the primarily used cutting material high speed steel, this poses an even bigger challenge. One possibility is the use of alternative cutting materials like cemented carbide. Cemented carbide is even more expensive than high speed steel and the possibility of cutting edge chipping is higher than broaching with high speed steel because of the lower toughness. [1]

An alternative is the usage of carbon free steels as cutting material for machining internal gears with modules higher than m_n = 1.5. These tool steels have a higher thermal conductivity and higher evaluated temperature hardness compared to HSS. As a result, significant increases in the cutting parameters and hence productivity are possible. Therefore, the use of carbon free steel instead of high speed steel has already taken place in the production of hobs and as a substrate for end mills machining TiAl6V4. This paper investigates broaching of 16MnCr5 which is typical in use for internal gears comparing a carbon free tool steel with a HSS PM 30. [2]

2. Carbon free steel as tool material

The cutting material is the carbon free, iron based alloy (Fe-Co-Mo) with a cobalt content of about 25%, MC 90 Intermet. Table 1 shows the chemical composition of MC 90 Intermet by mass percent compared to a high speed steel HSS PM30. Of particular note is the complete absence of carbon as an alloying element. Hence, the hardness of MC 90 Intermet is not achieved by the formation of martensite and carbides based on carbon as in normal high speed steels.

2212-8271
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.2016.04.076

Table 1: Chemical compositon of HSS PM 30 and MC 90 Intermet

	C	Si	Mn	Cr	Mo	V	W	Co	Fe
MC 90	0	0.6	0.2	0	15	0	0	25	Rest
PM 30	1.3	0.6	0.3	4.2	5	3	6.3	8.4	Rest

Low carbon steels have similar properties regarding toughness and ductility to conventional high speed steels. The key advantage over high speed steels is the significant higher hot hardness and thermal conductivity.

The carbon free steel is produced on a powder metallurgical route. After the first step in the production chain, sintering, MC 90 has a relatively high hardness of 41 to 43 HRC compared to conventional high speed steels with a hardness of 25 to 30 HRC. After the preprocessing in the tool manufacturing route, the hardening process is carried out. The process steps of hardening the carbon free steel can be compared with the steps heating, complete austenitization and quenching of hardening conventional high speed steel, compare Figure 1.

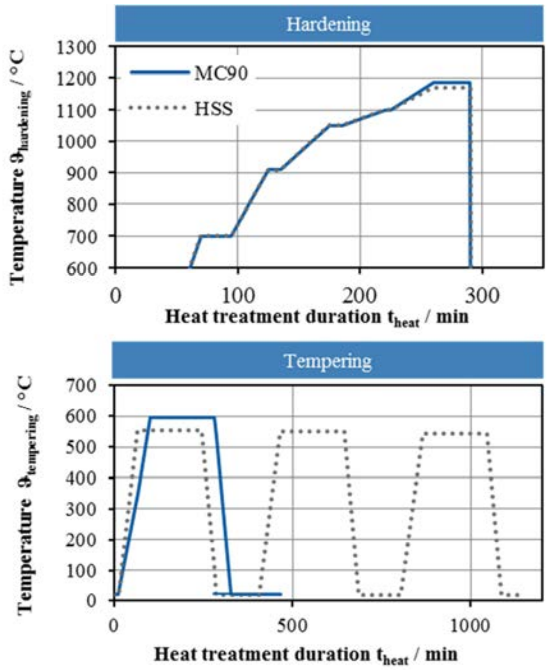

Figure 1: Hardening process of MC 90 Intermet and HSS PM 30

After quenching of the annealing temperature no undesired residual austenite is present, as in high speed steel, due to no carbon being present in the microstructure. This austenite can be eliminated through a costly and time-intensive deep-freeze treatment, or by a repeated tempering (eg. 3 x t = 2 h at $\vartheta_{tempering}$ = 560°C, see Figure 1). This is not necessary when using a non carbon steel. After the hardening process of carbon free steels a unique outsourcing in the temperature range from $\vartheta_{tempering}$ = 580°C to 630°C with a holding time of 3 h is sufficient to achieve the desired properties and required hardness of 65 to 68 HRC. This enables significantly shorter hardening process times and thus lower heat treatment costs.

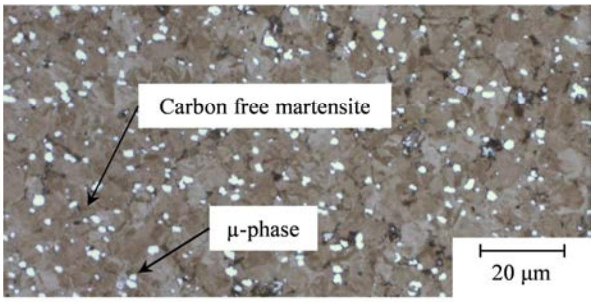

Figure 2: Microstructure MC 90 Intermet

Figure 2 shows the microstructure of MC 90 after the heat treatment. The microstructure consists of 1-3 micron sized intermetallic phases (µ-phase), which are embedded in the martensitic matrix. The matrix in turn contains very fine intermetallic precipitates in nanometer range, which are distributed homogeneously.

3. Investigation in broaching with high speed steel and carbon free steel

3.1. Workpiece material

The investigations were conducted machining the steel 16MnCr5 in soft conditions with a hardness of 146 HB 30. This typical case hardening steel represents a standard material for internal- and external gears and clutch bodies in automotive industries. Figure 3 shows a cross section in transverse direction. The steel provides a fine grain microstructure, which contains ferrite and sorbitol.

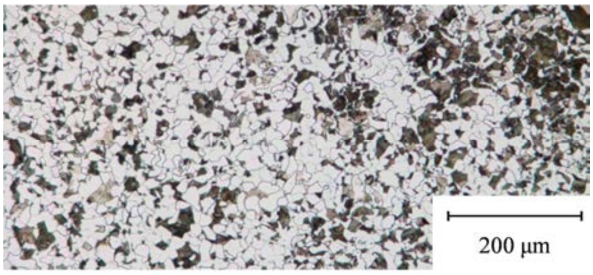

Figure 3: Transverse cross section of 16MnCr5

3.2. Experimental Tools

The carbon free steel and high speed steel tools were produced with an identical tool macro- and micro geometry, to compare and study the different cutting materials regarding their operational behavior. The studies of Lang were the basis to determine the macro geometry. However, Lang's optimal rake angle γ and clearance angle of α combination of γ = 20°- 25° and α = 3 - 5° was slightly modified to stabilize the cutting edges. [3,4] The used tools were grooving tools with a straight cutting edge. The geometrical details can be seen in Table 2.

The broaching tools were used uncoated as well as coated. The coatings were either TiN or AlCrN, which were each deposited with the PVD process.

Table 2: Geometry details of the experimental tools

Rise perthooth	f_z	mm	0.05
Width of cut	b	mm	15.075
Pitch	t	mm	10.5
Number of teeth	z	-	30
Rake angle	γ	°	15
Flank angle	α	°	2
Edge preparation	$r_β$	µm	20

3.3. Experimental test setup

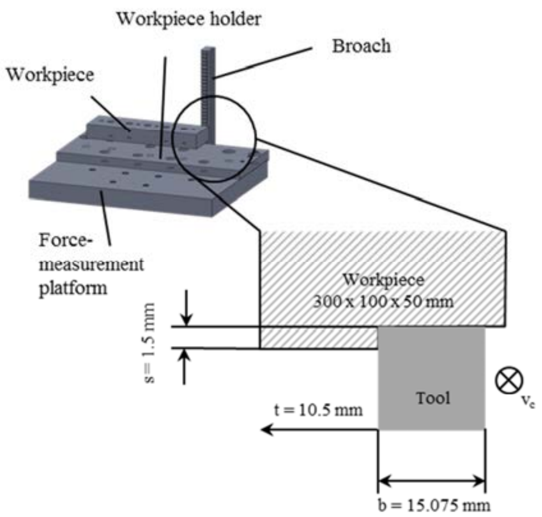

Figure 4: Experimental setup and one side bounded cut

The experiments were carried out on a Forst RASX 8x2200x600 M / CNC external broaching machine. The setup can be seen in figure 4. The workpiece material, which had an ingot form, was clamped to the baseplate. The length of the ingots was 300 mm, the width 100 mm, and the height was 50 mm, which is equal to the broaching length per stroke. Based on the experiment, the cutting materials and the cutting materials coating combinations were evaluated concerning the attainable surface quality and the tool life. Tool life tests were conducted in a one-sided bound section, as can be seen in figure 5, until the rest had a smaller width than 10.5 mm. Furthermore, the cutting temperature using specific cutting parameters was recorded. A detailed design of experiments can be seen in Table 3.

Additionally to the in Table 3 listed tools life tests, fundamental cutting test with cutting speeds up to $v_c = 150$ m/min were conducted to analyze the effect of a further increase in cutting speed from $v_c = 90$ m/min to 150 m/min on the surface roughness and the cutting temperature.

Table 3: Experimental design

Number	v_c	Cutting material	Coating
1	30	HSS	-
2	90	HSS	-
3	30	MC90	-
4	90	MC90	-
5	90	HSS	TiN
6	90	HSS	AlCrN
7	90	MC90	TiN
8	90	MC90	AlCrN

3.4. Tool life tests

Tool life tests were carried out in the one-sided bound section. The life criterion was defined as a flank wear land width of VB = 200 µm or chipping at any cutting edge. Furthermore, experiments were stopped after 1000 broaching strokes, which is equal to a cutting path length of $l_c = 50$ m. In one experiment the cutting path length was doubled to $l_c = 100$ m to evaluate the further wear development. In Figure 5 average values of the width of flank wear land VB for all experiments are depicted. To compare the tool wear the width of flank wear land VB was measured at the 5th, 10th, 15th, 20th, 25th and 30th cutting edge.

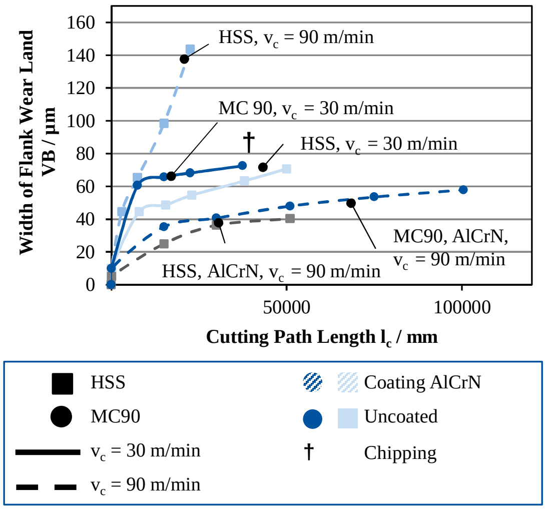

Figure 5: Tool life tests

At a cutting speed of $v_c = 30$ m/min the flank wear width of uncoated HSS as well as uncoated carbon free steel tools increased linearly, after initial wear. After 751 strokes on some cutting edges of the carbon free steel broaching tool chipping were detected, defining the end of tool life. A possible explanation is the strong adhesion tendency between the carbon free steel MC 90 and the test material 16MnCr5. An increase in cutting speed from $v_c = 30$ m/min to $v_c = 90$ m/min leads to an end of tool life of 450 strokes using the HSS tool. The experiment with carbon free steel and a cutting

speed of v_c = 90 m/min had to be stopped after just 5 strokes, due to the high adhesion tendency.
A significant improvement in tool life was achieved through the utilization of TiN or AlCrN coatings. This was so effective, that width of flank wear land was not measurable after 1000 strokes using TiN coated tools. Due to the use of the TiN or AlCrN coating adhesion could be avoided.

3.5. Surface roughness

Dry machining poses a big challenge to the surface finish, due to the lack of the lubricating effect of the broaching oil. [5] Thus the surfaces were evaluated through tactile measurements for all process parameter combinations, Figure 6. The surface roughness Rz could be improved through an increase of cutting speed from v_c = 30 m/min to v_c = 90 m/min, what can be explained by the material weakening due to the higher cutting speed. A further improvement was documented with the use of coated tools, due to the prevention of adhesion between tool and workpiece. AlCrN coated tools produced better surface finishes than the TiN tools. A further increase of the cutting speed to v_c = 150 m/min with a coated HSS or MC 90 tool did not lead to a further improvement of surface quality at all.

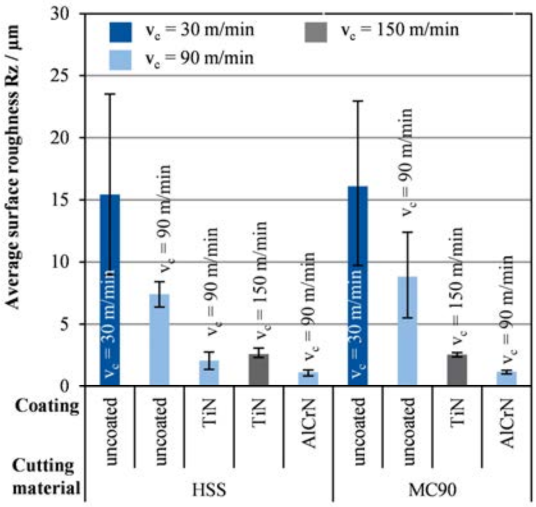

Figure 6: Average surface roughness

3.6. Cutting temperatures

An advantage of the carbon free cutting material is the higher hot hardness compared to high speed steels. To measure the maximum temperatures during cutting process a specially prepared workpiece in combination with a two-colour pyrometer was used. [6, 7] The measured temperatures are listed in Figure 7. The cutting temperature increased, when the cutting speed was changed from v_c = 30 m/min to v_c = 90 m/min. However, a further increase in cutting speed to v_c = 150 m/min did not lead to a change in maximum temperature, which was around 400°C. This is considered unproblematic for HSS materials, in regards to its hot hardness.

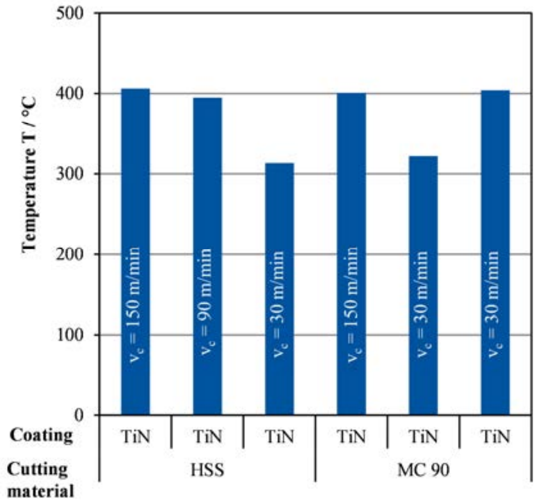

Figure 7: Cutting temperatures

4. Conclusion and outlook

The utilization of carbon free steals as a HSS-substitutes is possible. The demanded tool lives and surface properties were reached without problems. However, due to the strong adhesion tendency, a coating is necessary. Higher process temperatures have to be expected when dry machining, mainly due to the absence of cooling lubricants. However, the experiments depicted in this paper, never reached the hot hardness of HSS, which is 600°C. Thus, the advantages in hot hardness and thermal conductivity of the carbon free cutting material compared to conventional high speed steels could not be shown. However, in a next step, due to the material properties of the carbonfree steel, an increase in the rise per tooth f_z is possible, even though this leads to an increase in machining temperature.

Acknowledgements

The authors would like to thank the German Federal Ministry for Economic and Technology (BMWi) and “AiF ZIM” for funding of the research project this study is based on.

References

[1] Pöhls M.: Untersuchungen zum Räumen mit Feinstkornhartmetallen und Cermet. Aachen: Shaker 2000
[2] Meier H., Rilli R., Schulze V.: Nass- und Trockenräumen von 16MnCr5. Proceedings of Research Training Group 1483 and CCMSE, 2010
[3] Lang H.: Trocken-Räumen mit hohen Schnittgeschwindigkeiten. Werkzeug- und Prozesskenngrößen für die Weich- und Hartbearbeitung. Karlsruhe: Heinz W. Holler 2005
[4] Klocke F., König W.: Fertigungsverfahren: Drehen, Fräsen, Bohren. 8th ed. Berlin: Springer 2008
[5] Schulze, V.; Meier, H.; Strauss, T.; Gibmeier, J.: High Speed Broaching of Case Hardening Steel SAE 5120. 5th CIRP International Conference on High Performance Cutting. Procedia CIRP 1;2012; p. 431-436.
[6] Gierlings, S.: Model-Based Temperature Monitoring for Broaching Safety-Ciritical Aero Engine Components. Aachen, Apprimus Verlag 2015
[7] Klocke F., Gierlings S., Veselovac D.: Concept for Temperature Control in Broaching Nickel-Based Alloys. In: Key Engineering Materials Vols. 523-524, 2012; p. 469-474