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Cemented carbide tools in high speed gear hobbing applications

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ABSTRACT

Gears in the modulus range between $m_n = 1$ mm and $m_n = 4$ mm are widely used in automotive gear boxes. To enable maximum productivity in gear hobbing cutting tools made of cemented tungsten carbide are used. Despite its ability the full potential of the substrate material is not applied in industry because of unknown process limits and wear mechanisms. To examine the mechanisms and to close down the lack of knowledge three different cases of gearings were thoroughly examined. The wear phenomena and tool life behaviour were inspected within the fly-tooth analogy test at different frame conditions, reaching cutting speeds up to 1000 m/min. To determine causal relations the process was also analysed by the means of interpenetration- and FEM-simulations.

1. Problem description and motivation

Gearboxes and gears are a good example of a component combining multiple manufacturing technologies within highly automated machining systems. Within the green processing for external spur and helical gears hobbing is the dominating manufacturing process. Due to the large degree of automation and linking the hobbing process needs to meet certain requirements. Usually there is ambivalence between productivity and time depending costs on one side and process stability and wear behaviour on the other side. Hobs made of cemented carbide substrate are able to perform at advanced cutting parameters compared to other cutting substrates such has powder metallurgical high speed steel (PM-HSS), leading to short cycle times and free machine capacity [1–4]. Even though this superior material has a huge potential in mass production there is severe reluctance in industry to apply the substrate material. Only about 20% of the applied hobs are made of cemented carbide. Major reasons for the lack of appliance are the high investment costs for tools and the incapability of older hobbing machines to realize high cutting speeds. Using modern hobbing machines and applying suitable cutting parameters cemented carbide hobs offer savings for large batch productions.

2. Frame of investigation

The last scientific research regarding hobbing with cemented carbide substrates was performed more than 10 years ago [1,2].

Today, the industrial state of the art are tools made of K30 [5] carbide substrate with AlCrN-based wear resistance coating. Depending on the manufacturer these substrates possess hardnesses around 1675 HV_{30} and transverse rapture strengths nearby 3600 N/mm^2.

2.1. Content of experimental study

The wear mechanisms and tool life-productivity behaviour was analysed examining three different cases of gearing [6]. These three gears are representatives for gears in manual ($m_n = 2.7$ mm) and automatic ($m_n = 1.23$ mm) car transmissions and commercial vehicle gear boxes ($m_n = 3.45$ mm), Table 1.

Besides the different modulus the gears also have different outer diameters and tooth profiles. The gears of modulus $m_n = 1.23$ mm and $m_n = 2.7$ mm were cut by tools with protuberance.

Regarding the test design the cutting tests were mainly performed in similar ways for the different gears. Starting from a progressive setup of feed and cutting speed only feed or cutting speed was varied keeping all frame conditions constant.

Generally, the tests were performed without lubrication in climb hobbing mode. To identify the effects of the feed direction and lubrication single tests were conducted nevertheless.

Table 1
Geometry information of examined gears and corresponding tools.

Tool	Modulus	[mm]	1.23	2.70	3.45
	Profile angle	[°]	20	22.5	24
	Tip diameter	[mm]	60	100	80
	Number of starts/lead direction		3/R	2/L	1/L
	Number of flutes		19	22	17
	Substrate material		Cemented carbide K30		
	Coating		Al,Cr based		
Workpiece	Helix angle/helix direction	[°]	20.6/R	24.5/L	20/L
	Number of teeth		37	41	22
	Gear width	[mm]	23.7	29	17
	Material		AISI 5115/16MnCr5		
	Tensile strength	[N/mm^2]	590		
	VB_{max}	[μm]	120		

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2.2. Fly cutting analogy test

In gear hobbing the final geometry of the gap is a result of the basic profile of the hob and the utilized process kinematics. Applying the principle multiple cutting engagements are necessary to generate the shape of an involute gear gap. In hobbing these positions are called generating positions (GP), see Fig. 1.

To save time and material, the well-established fly cutting analogy test was utilized for the examination [7–9]. The general functional principle of the test is illustrated in Fig. 1.

A single tooth, which was parted from a real hob by wire EDM, is moving tangentially (f_t) regarding the workpiece at multiple axial positions (f_a). That way it occupies all the relative positions of the teeth of a real shifted hob and the resulting load and gear quality stay the same.

Main advantages are the faster developing wear due to the fact that all the GP's are performed by one tooth and that multiple test tools can be generated from one hob.

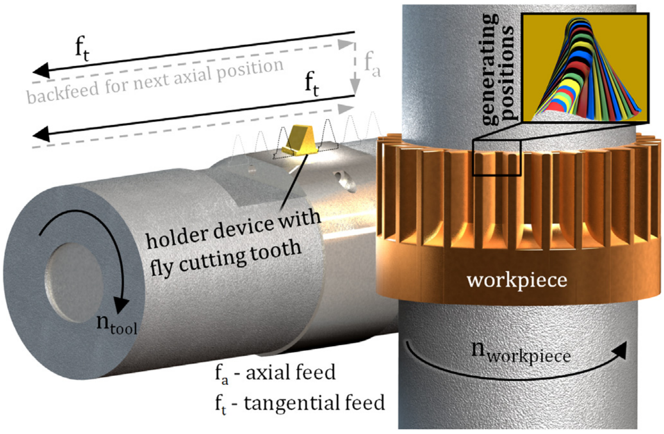

Fig. 1. Fly cutting analogy test – kinematics and arrangement.

3. Experimental test results

3.1. Wear phenomena of carbide hobs

Generally, three different wear phenomena in different specifications occurred. In hobbing flank and crater wear are common wear phenomena occurring on any substrate material. Compared to PM-HSS cemented tungsten carbide is a hard and brittle substrate material. Hence different wear phenomena occurred in the experiments. Due to the temperature gradients between the cut and the non-cut section hairline cracks arise. They are the initial point for fractures of the cutting edge, compare Fig. 2d. As illustrated in Fig. 2 for every gear type a change of the wear phenomena by increasing cutting parameters was detected.

For near-standard parameters mostly abrasive wear at the cutting edge was tool life critical. In contrast crater wear and fractures occurred mostly at increased cutting speeds and feed rates.

3.2. Wear and tool life behaviour depending on cutting speed

The main advantage of cemented carbide hobs is the ability to perform at increased cutting speeds. Industrial standard (std.) are cutting speeds between 300 and 400 m/min for a modulus range up to m_n = 4 mm. To find the process limits cutting speeds well above that area were examined within the project.

Fig. 3 shows that the run of the tool life depending on the cutting speed is comparable between the three gears. Increasing cutting speed the tool life is steadily decreasing. The substrate can bear cutting speeds of $v_c > 1000$ m/min without total rupture.

Generally the performance of a hob is influenced by the geometry of the gear [10]. Due to different gear geometry, the modulus has no linear effect on the performance. For example the m_n = 1.23 mm gear is more wear critical compared to m_n = 2.7 mm.

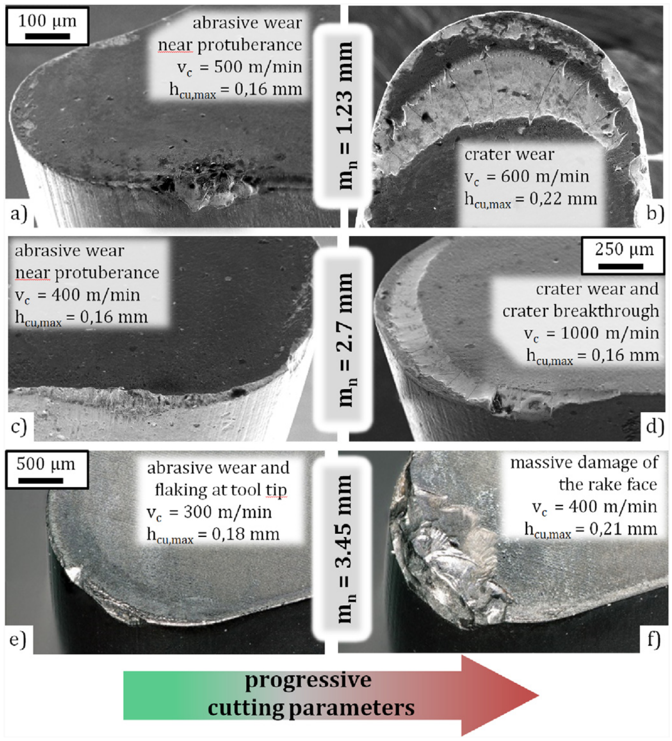

Fig. 2. Change of wear phenomena by increasing the cutting parameters.

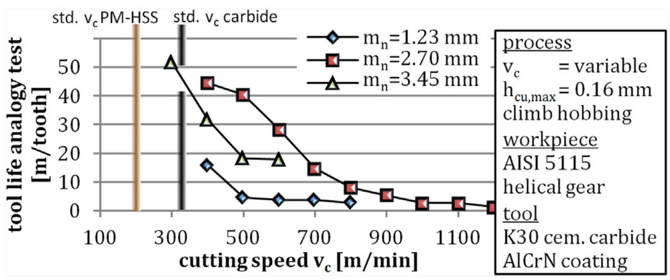

Fig. 3. Influence of the cutting speed on tool life.

With increasing cutting speeds the thermal process load increases and the tool wears out faster. In the examined cases with a constant Hoffmeister chip thickness [9,11] of $h_{cu,max}$ = 0.16 mm the cutting speed had no influence on the wear mechanism itself cutting the m_n = 1.23 mm pinion gear. Here only abrasive flank wear led to end of life, Fig. 2a. In contrast the cutting speed had a vast influence on the critical wear phenomena for m_n = 2.7 mm and m_n = 3.45 mm gears. At low cutting speeds ($v_{c,2.7\ mm} \leq 500$ m/min; $v_{c,3.45\ mm} \leq 300$ m/min) the dominating wear is abrasive brittling of the cutting edge as well. Increasing the cutting speed, rake face effects occur. Regarding the modulus m_n = 2.7 mm gear the tool teeth showed crater wear and crater breakthrough due to hairline cracks. For m_n = 3.45 mm fractures at the tool tip and even total rake face fractures occurred by increasing the cutting speed above 500 m/min.

Generally, an increased cutting speed leads to reduced tool life. It is important to see that an extreme cutting speed does not necessarily lead to total tool fracture. Opposing the decreased tool life a larger cutting speed reduces the machining time and enables free machine capacities.

Hence, Fig. 4 shows that decreased tool life does not necessarily mean larger total costs. Only the most important basic conditions are mentioned in the figure whereas the calculated costs base on a more detailed set of data and assumptions that have been adapted to established industrial calculation tools. Following decreasing tool life due to increased cutting speeds the absolute tool costs increase as well. On the other side the machine costs decrease vice versa. A cost optimal cutting speed for m_n 2.7 mm was found at 520 m/min.

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