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Influence of the tool geometry on the machining of cobalt chromium femoral heads

Bernhard Karpuschewski[a], Joachim Döring[a]*

[a] *Otto-von-Guericke-University Magdeburg, Institute of Manufacturing Technology and Quality Management, Universitätsplatz 2, 39106 Magdeburg, Germany*

* Corresponding author. Tel.: +49 391 67 12372; fax: +49 391 67 12370. *E-mail address:* Joachim.doering@ovgu.de

Abstract

In the industrial processing of cobalt-chromium (CoCr) cast alloys, tungsten carbide and CBN cutting materials are mainly used. Ceramic cutting materials have a high hardness and only suffer a decrease in hardness of 50 % at 1200 °C compared to room temperature. This effect occurs with carbide at 800 °C. In addition, the pressure resistance is temperature dependent and decreases with increasing temperature. At room temperature, the compressive strength of alumina ceramic (Al_2O_3) is about 3000 N/mm² and at 1500 °C only 100 N/mm². The edge preparation has also an important influence on the chip formation, the chip transport, the tool wear, the surface integrity of the material and on the roughness of the workpiece surface. To investigate a new process, the influences of different cutting edge preparations and different cutting materials have been tested.

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Keywords: Ceramic; Cutting edge; Hard machining¸ Turning; Surface integrity

1. Introduction

The need for medical implants due to demographic change and increasing life expectancy is steadily rising. The aim of these research activities is to identify new manufacturing strategies in order to contribute to a faster and more productive manufacturing process and thus reduce the costs of optimal medical care for people. The main materials for medical supplies in the orthopedic and dental sector are ceramics, polymers and metals like titanium, stainless steel and cobalt-chromium alloys [1]. They have been established due to their good compatibility with the human body. These materials are difficult to process and therefore require special production technologies. This paper discusses the use of cutting ceramics with different cutting edge preparations as a replacement for conventional machining with tungsten carbide in order to explore the potential for a more economical production by turning of femoral heads of cobalt-chromium (CoCr).

2. Ceramics as cutting material

Ceramic cutting tool materials have been established in machining for decades as they have no binding phase in their microstructure. Unlike tungsten carbide, the hardness of the ceramics is less decreasing with increasing temperature. Due to this fact, cutting ceramics have a very good wear resistance, even at high cutting speeds [2] compared to other cutting materials. However, the non-existing binder phase leads to inferior properties in the area of toughness, flexural strength and crack resistance [3, 4]. The result of this brittleness is that cutting ceramics break under mechanical strain without plastic deformation. When ceramic cutting tools are successfully applied, they can far exceed the removal rate by several times obtained with conventional tool materials [5]. A trend for cutting ceramics is towards new ones, which are strengthened by means of directional fibers. With this special adaptation a higher wear resistance can be achieved and the productivity of the process is improved [6].

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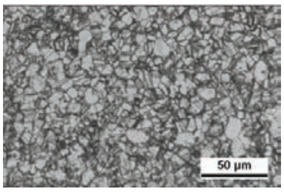
3. Workpiece material

The main components of cobalt chromium (CoCr) are cobalt (60 %) and chromium (30 %). Pure cobalt is known for its high strength, but it only has moderate ductility. At higher temperatures, pure cobalt has a low corrosion resistance. To avoid these negative qualities of cobalt, certain elements are added to achieve improved mechanical and biocompatible properties. For example, a solid solution strengthening effect and thus a high creep resistance and fatigue strength is obtained by chromium, nickel and tungsten [7]. Moreover cobalt base alloys have relatively high density (8.9 g/cm³) and a high Young's modulus (210-253 GPa) [8]. By adding chromium, the strength and corrosion resistance of the workpiece are improved. Also tungsten and molybdenum increase the strength of the structure due to their atomic size [9].

Important components of cobalt-based alloys are carbides. The matrix and the inclination of the grain boundary compared to diffusion creep and grain boundary sliding are affected by their thermal and temporal stability, their kind, amount, size and distribution. This has an impact on the abrasive wear, and thus the life time of the workpiece [7].

Table 1 Elemental composition and micrograph of the structure investigations

element	concentration in % (m/m) to DIN ISO 5832-4	EDX-analysis in % (m/m)
Cr	26.5 - 30	27.8
Mo	4.5 – 7.0	6.6
Ni	max. 1.0	-
Fe	max. 1.0	0.9
C	max. 0.35	-
Mn	max. 1.0	0.4
Si	max. 1.0	0.8
Co	bal.	63.5



The cobalt-chromium-molybdenum (CoCrMo) alloy is characterized by very good mechanical properties such as hardness, strength and wear resistance, but also by its high corrosion resistance and rigidity. In addition, the cobalt-based alloy has a very high strength and is stable, even at high temperatures [10]. Many of the characteristics of this alloy will be apparent from the crystallographic structure of cobalt and the ability of a strong bond with chromium and molybdenum, and so this material develops very hard carbides. The structure of cobalt-based alloys consists of several phase constituents in a face-centered cubic matrix. The microstructure is homogeneous and fine-grained. CoCrMo has in comparison to other cobalt-based alloys a high carbon content of up to 0.35 %. This improves the abrasion resistance of this material, since hard mixed crystals of the elements chromium and molybdenum are caused by the carbon content in the solidification of the dendrites. The strength of the alloy is improved by diffusion annealing [8, 11].

4. Cutting investigations of different ceramic cutting materials

It is known from the literature that chamfers are useful in rough machining and hard turning for the cutting materials CBN and ceramic. For this reason, all cutting inserts have the same design of the cutting edge with a chamfer width of 0.1 mm and a chamfer angle of 25° (T01025). The tightening torque of the inserts is 3.6 Nm.

The cutting edge radiuses of the tools are determined before the cutting tests, because they have an influence on the machining process, especially on the cutting forces. The type C has a larger radius than the other cutting materials without coating due to their coating. Another key feature of the tool edge is the chipping. An overview of the different tool materials and the results of the measurements are shown in Table 2.

In the experiments, all cutting inserts are examined under the same conditions at different cutting speeds on an INDEX GU600 CNC lathe. All experiments are performed with a feed f = 0.2 mm/rev and depth of cut a_p = 1 mm.

Table 2 Cutting materials

	A	B	C
material	$95Al_2O_3$ ZrO_2	$70Al_2O_3$ TiC	$55Al_2O_3$
coating	-	-	TiN
radius [µm]	6.03	6.89	8.45
roughness Rt [µm]	2.129	1.440	1.570

For the wear tests, the inserts are used up to a width of flank wear land of VB_{end} = 0.25 mm for each cutting material type. The workpiece is machined in a longitudinal circular rotation process. To measure the cutting force components (tangential, feed and radial force), a 3-component tool holder dynamometer from Kistler (type 9121) is used. The geometric cutting parameters are shown in Table 3.

Table 3 Geometric cutting parameters

parameter		value
rake angle	γ	-6°
clearance angle	α	6°
included angle	ε	80°
cutting edge angle	κ	95°
corner radius	r_ε	0.8 mm

The investigation shows that tool life decreases gradually with increasing cutting speed. From the kinematics of the longitudinal cutting arises a geometric shape of the cutting path a helix. The arc length of the helix in this case is equal to the size of the cutting path. Figure 1 shows the detected cutting paths graphically.