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Influence of binder content on the wear behaviour of carbide milling tools in high-precision machining of injection moulds made of AlMgSi1

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Abstract

Injection moulding is the most commonly used process for the high-volume production of plastic components. To meet the increasing demands on surface quality and dimensional accuracy of these components, the preparation of the corresponding injection moulds made of AlMgSi1 requires technological research on innovative cutting materials in the development process. In industrial environment, uncoated and diamond coated tungsten carbide-cobalt (WC-Co) cutting tools are conventionally used for machining AlMgSi1-alloys. However, milling of AlMgSi1-alloys is characterised by increased temperature development during the cutting process, whereby a significant tool wear occurs. This results in an early elution of the binder phase and a fast chipping of the coating, which leads to a destabilisation of the cutting material structure and reduces the economic efficiency for the manufacturing process of components made of AlMgSi1. Using binderless WC-Co tools as cutting material for machining AlMgSi1-alloys represent a promising approach to overcome the present state of the art challenges. The binderless WC-Co material shows a great potential to avoid an early tool failure as the structural cohesion is archieved by the chemical bonding of the individual grains rather than by the binder phase. For this purpose, this study investigated the influence of different binder contents C_{Co} on the wear development concerning abrasion and surface attrition. Silicon carbide abrasives were used in blasting tests at various blasting angles α_S. Furthermore, cemented carbide materials with different binder contents of C_{Co} = 13 %, C_{Co} = 3 % and C_{Co} = 0.9 % were applied. Initial results show that wear resistance significantly improves with decreasing binder content C_{Co} and the potential of binderless WC as a cutting material for the production of AlMgSi1-alloys could be proven.

Keywords: abrasive tool wear, binderless tungsten carbide, AlMgSi1 cutting

1. Introduction

To enhance surface quality and precision in high-volume plastic component production via injection moulding, ongoing research on cutting materials is crucial, especially for injection moulds made of AlMgSi. Conventional tungsten carbide-cobald (WC-Co) cutting tools, whether uncoated or diamond-coated, encounter high challenges such as elevated temperatures ϑ and substantial wear when milling AlMgSi1 alloys. A promising approach to significantly decrease the tool wear is the use of binderless carbide tools with a binder content of C_{Co} < 1 %. The cobalt phase in the material structure represents a weak point that is susceptible to an early elution and followed by fast chipping, according to Uhlmann and Polte [1,2]. Binderless WC milling tools with increased hardness and no binder phase show a high potential to prevent an early tool failure. Previous studies [3,4] showed that a binder content range of 0.25 % < C_{Co} < 6.00 %, with decreasing binder content C_{Co}, leads to an improvement in wear resistance. However, understanding specific and isolated wear mechanisms in relation to binder content C_{Co} remains incomplete. For this purpose, the ongoing study analyses abrasive wear and surface attrition in WC-Co cemented carbide tools with binder contents between 0.9 % < C_{Co} < 13.0 %.

2. Material specification

For the investigations of abrasive wear and surface attrition on prospective rake and flank surfaces, three specimen with different WC-Co configurations A1, BL130 and BL100 from the company Sumitomo Electric Industries, Itami, Japan, were analysed. The cemented carbide specimen A1 and BL130 feature an average grain size of d_g = 0.7 µm and BL100 with d_g = 0.4 µm. The specific material characteristics are shown in Table 1. Although BL100 has a binder content of C_{Co} = 0.9 %, it is described as a binderless carbide material.

Table 1 Characteristics of the different tungsten carbide-cobalt materials

Abbreviation	Composition	Hardness HV30
A1	WC-13Co	1,423
BL130	WC-3Co	2,117
BL100	WC-0.9Co	2,473

The abrasive used to analyse the wear behaviour is silicon carbide (SiC) type F220 with an average grain size of d_g = 50 µm, supplied by Hausen GmbH, Telfs, Austria. The SiC-particles used for blasting tests represent the carbides that occur as a result of tribological effects during machining of AlMgSi1 alloys.

3. Experimental method

In this study, the wear mechanisms concerning abrasion and surface attrition were characterised by analysing the mass losses m_l and by optical examination of the machined surfaces. The experimental setup and the parameters used were chosen in accordance with the blasting tests carried out by Polte [2] as well as the standard testing method ASTM G76-18 [5]. For abrasion, a blasting incident angle of α_S = 30 ° was choosen, since the degradation mechanism occurs through shearing processes with micro-cutting and ploughing of the matrix, resulting in spalling of the carbide phase [2-4]. The surface attrition experiments were carried out at a blasting incident angle of α_S = 90 °, as the particle indentation induces stresses σ, causing micro-cracks and pitting [2,6]. This demonstrates the material's ability to resist fatigue from overlapping tangential stress τ and normal stress σ in the machining process, particularly in interrupted cutting [2,6]. Each specimen was studied by particle irradiation for different blasting times of t_B = 30 s, t_B = 60 s, t_B = 90 s and t_B = 120 s. The tests were repeated twice and the results were averaged. For partical blasting tests the air blast machine FSA-1 of the company SABLUX TECHNIK AG, Bachenbülach, Switzerland with a blasting pressure of p_b = 0.5 N/mm² was used. The nozzle, directing particles onto the surface, consists of a diameter D_d = 0.8 mm and is positioned at a distance of D_D = 10.0 mm. The respective mass losses m_l are determined as a function of the blasting time t_B with a precision scale PLS 1200 from KERN & SOHN GMBH, Balingen, Germany. To evaluate the wear mechanisms in relation to the binder content C_{Co}, the LEO 1455 VP SEM scanning electron microscope from LEICA ELECTRONIC OPTICS, Wetzlar, Germany, with a magnification of M_A = 5,000x and acceleration voltage of $V_{||}$ = 15 kV was used.

4. Experimental investigations and results

Figure 1 illustrates the wear behaviour concerning abrasion and surface attrition for the three carbide types used. The isolated abrasive wear at an impact angle of α_S = 30° reveals a direct correlation between binder content C_{Co} and wear in terms of mass loss m_l. The wear rates m_l for all specimens show an almost linear progression, indicative of stable plastic deformations. In general, WC-13Co shows a total mass loss of m_l = 1.18 %, WC-3Co a mass loss of m_l = 0.8 % and BL100 a mass loss of m_l = 0.17 % after a blasting time of t_B = 120 s. Based on the results, it could be demonstrated that an improvement in abrasive wear of 86 % was achieved for binderless WC and 32 % for WC-3Co compared to specimen type A1.

Measurement device:
Blasting machine FSA-1 of SABLUX TECHNIK AG
Weight scale:
Precision scale PLS 1200 of KERN & SOHN GMBH
Process parameter:

Blasting pressure	P	= 0.5	N/mm²
Nozzle diameter	d_d	= 0.8	mm
Nozzle distance	d_D	= 10	mm
Blasting angle	α_S		°
Abrasive SiC-grain size	d_k	= 220	µm

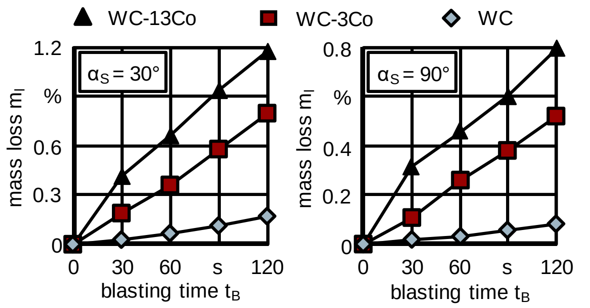

Figure 1. Wear of different binder contents C_{Co} and impact angles α_S

At an impact angle of α_S = 90 ° to investigate the surface attrition, WC-13Co shows the highest mass loss of m_l = 0.77 % after t_B = 120 s. In comparison, WC-3Co is characterised by a mass loss of m_l = 0.52 % and WC demonstrates the lowest mass loss of m_l = 0.08 %, indicating reductions of 32 % as well as 90 %, respectively. In general, all investigated specimen show the lowest mass loss m_l at an impact angle of α_S = 90°, suggesting a greater resistance to surface attrition than abrasion wear.

Figure 2 presents additionally SEM images of the surfaces related to the machined specimen concerning abrasive wear behaviour and surface attrition. The specimens of type WC-13Co (A1) show a recognisable wear behaviour, which is characterised by pronounced cutting and ploughing grooves (2a). In contrast, the specimens of type WC-3Co (Figure 2b) showcases a reduced wear but lip formations were detected, which could be attributed to plastic deformations. Based on the investigations of the binderless WC (Figure 2c), a minimum topographical wear could be determined, which corresponds to the results of the quantitative analyses in Figure 1. As a result, the binderless WC shows no typical characteristics of a brittle material.

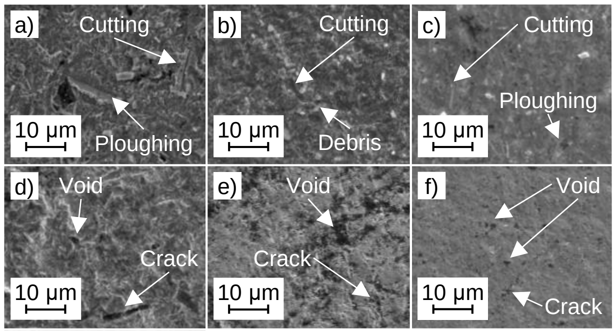

Figure 2. Surfaces of all investigated specimen after t_B = 120 s. a) A1, α_S = 30°; b) BL130, α_S = 30°; c) BL100, α_S = 30°; d) A1, α_S = 90°; e) BL130, α_S = 90°; f) BL100, α_S = 90°

Examinations into surface attrition for WC-13Co unveil the presence of voids and an expansion of pits attributed to crack propagation, accompanied by ploughing traces (Figure 2d). In the case of WC-3Co (Figure 2e), substantial lip formations and debris are observed, while process-dependent hole expansions are noted to a lesser degree than in specimens with a binder content of C_{Co} = 13 % (WC-13Co). Significantly, binderless WC (Figure 2f) shows a low topographic wear, featuring well-defined fractures and pronounced surface craters compared to the other investigated specimens. The binderless WC demonstrates the lowest abrasive wear and surface attrition, while the specimens with a binder content of C_{Co} = 13 % exhibits the highest wear behaviour in terms of abrasion and surface attrition.

5. Conclusion and further investigations

This study established that binder content C_{Co} in cemented carbide affects abrasive wear and surface attrition. The results support the theories of various research studies [3-5]. With decreasing binder content C_{CO}, the material separation remains plastic during abrasion and surface attrition. Specimens made of binderless WC show the most potential for milling AlMgSi1 alloys, demonstrating superior resistance to tensile stresses σ and shear stresses τ compared to the investigated specimen in an binder content area of 0.9 % < C_{Co} < 13.0 %. Further research works will explore the wear behaviour of innovative binderless WC configurations with binder contents between 0.25 % < C_{CO} < 1.00 % to fully understand the impact of the cobalt binder C_{Co} in material structure. Examining the performance of cutting tools made of binderless WC under different machining conditions will enhance their applicability, particularly in scenarios involving the manufacturing of injection moulds made of AlMgSi1 alloys. This work was funded by the GERMAN RESEARCH FOUNDATION DFG.

References

[1] Uhlmann, E; Polte, M; Oberschmidt, D; Polte, J; Löwenstein, A: Werkzeugkonzept zum Mikrofräsen mit superharten Schneidstoffen. Diamond Business (2014) 03/2014, S. 24 – 29.

[2] Polte, J: Kubisch-kristallines Bornitrid ohne Bindephase als Schneidstoff in der UP-Zerspanung. Berichte aus dem PTZ Berlin. Hrsg.: Uhlmann, E. Stuttgart: Fraunhofer IRB, 2016.

[3] Gee, M.G.; Phatak, C; Darling, R: Determination of wear mechanisms by stepwise erosion and stereological analysis. Wear (2005) 258(1–4). S. 412 – 425.

[4] Beste, U; Hammerström, L.; Engqvist, H.; Rimlinger, S.; Jacobson, S.: Particle erosion of cemented carbides with Low Co content. Wear (2001) 250(1–12). S. 809 – 817.

[5] ASTM G76-18, (2018) Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets, West Conshohocken, USA: ASTM International.

[6] Czichos, H.; Habig, K.-H.: Tribologie-Handbuch. Wiesbaden: Vieweg + Teubner, 2010. S. 133 – 140.