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CARBIDE MILLING CUTTER BLADES DURABILITY DURING MACHINING OF AL-SI CASTING ALLOY

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Abstract: The paper presents results of wear measurements of carbide shank milling cutters during machining of AlSi10Mg casting alloy. The comparison was made between blades wear of milling cutters without protective coating, with TiB_2 coating, and with TiAlCN coating. All cutters had identical geometry dedicated to milling of materials of ISO N group. To assess blades wear degree, measurement of two direct indicators, i.e. VB_C and VB_{Bmax}, and one indirect indicator, i.e. machined surfaces roughness, were used. Received results allowed to determine usefulness of using selected protective coatings in machining of aluminium alloys, especially Al-Si casting alloys.

Keywords: machining of aluminium alloys, tool coating, tool wear

1. INTRODUCTION

Tool blade wear is one of the main factors determining development of innovative materials and tool coatings. The major causes of wear are thermal, mechanical, and molecular reactions between blade, machined material, and chip. Thus, the wear may have mechanical (abrasive, endurance, plastic deformation), adhesive, chemical (diffusive, oxidative), or thermal form (Kupczyk, 2004; Suh, 1980).

Aluminium alloys (with exception of certain types) characterise with a good machinability. Wide variety of those alloys induced their separation into groups of similar machinability. One of the division criteria is silicone content in the alloy (Feld, 1984; Pieśko and Zagórski, 2011). Extended division takes into consideration also intended use and type of heat treatment (Oczoś, 2009; Oczoś and Kawalec, 2012):

- group I – pure aluminium and low-alloy materials for plastic working,
- group II – work-hardened (of so-called natural hardness) or precipitation-hardened materials for plastic working and casting alloys of Si concentration < 12%,
- group III – casting alloys of Si concentration > 12%.

It may be said, then, that aluminium alloys machinability depends primarily on alloy chemical composition and structure, which is related to the conducted heat treatment. Aluminium alloys of group I of low hardness, high plasticity, and adhesion to the tool material are prone to “smudging” and creating built-up edge. For machining of them, sharp tools with polished surfaces of chip spaces or with protective coating are applied. The main purpose of utilising tool coating during machining of materials from this group is to decrease adhesion and facilitate forming and discarding chips, not to increase blade durability (Jemielniak, 1998; Oczoś, 2009; Oczoś and Kawalec, 2012). Adhesive and diffusive phenomena are the main factors of causing tool wear during machining of those alloys. As the result of diffusion, which consists of components of the cut material penetrating the blade material or of dissolving of blade material components within its surface layer, the tool loses its initial machining properties (Calatoru et al., 2008; Hovsepian et al., 2006).

Aluminium alloys of group II characterise with better machinability. 10-12% silicone content in the aluminium alloys is a significant limit pointing of their machinability. Above this Si content, that is for alloys of group III, an increased tool blade wear occurs during machining as a result of strong abrasive reaction of initial silicone precipitation. It is primarily abrasive wear of the flank face. It increases with the growth of concentration of alloy components and pollutions. Thus, the alloys are mostly cut by blade with coated self-bonded carbides or polycrystalline diamond (PCD) (Feld, 1984; Oczoś, 2009; Oczoś and Kawalec, 2012).

Used tool coatings fulfil several functions, the most crucial of which are (Hovsepian et al., 2006; Lahres, 1997; Martini and Morri, 2011):

- increasing tool surface layer hardness,
- increasing resistance to the abrasive wear,
- improving tribological properties (adhesion reduction),
- increasing thermal resistance.

Protective coatings may be divided into single-layer and multi-layer. The single-layer coatings include (Kupczyk, 2004):

- basic coatings - consisting of one element or one compound,
- complex coatings:
  - multicomponent - consisting of two or more materials,
  - metastable,
  - multiphase.

Multi-layer coatings may be divided into (Kupczyk, 2004):

- made of basic material layers,
- made of complex material layers,
- made of combination of basic and complex materials,
- gradient coatings.

Protective coating is applied in order to improve mechanical, tribological, and thermophysical properties of tool material. A wear process of a coated tool differs from the wear process of a tool without coating. Coated blades wear is primarily mechanical as a result of cracking, crumbling, and detaching of coating micro fragments. The coatings characterise with high hardness, which is why percentage of the abrasive wear is small, as opposed to the tools without protective coating. In the case of aluminium alloys, it is particularly visible for materials of group III (Grzesik, 1998; Kuczmaszewski and Pieśko, 2014; Loadze, 1978). For machining of aluminium and its alloys, uncoated tools made of micro grain or ultra-micro grain self-bonded carbides are used very frequently, as well as tools made of polycrystalline diamond (PCD). PCD tools, due to their high hardness and resistance to adhesive wear, are mostly used for cutting of hypereutectic casting Al-Si alloys. An alternative for machining of those alloys is using coated carbide tools. Particularly effective are diamond coatings and DLC (diamond-like carbon) coatings over carbide basis, which characterise with high hardness and smooth, monocrystalline structure preventing creation of built-up edges and facilitating chips removal (Arumugam et al., 2006; Hovsepian et al., 2006; Oczoś and Kawalec, 2012; Oerlikon Balzers Coating, 2008).

In the case of machining of aluminium alloys without silicon, using protective coating seems unfounded, even unfavourable, due to sufficient carbide tools durability. The coating increases cutting edge rounding radius that may lead to creation of a “fin” and an escalating cutting force (Adamski, 2009; Andrae, 2000). On the other hand, using coating decreases coefficient of friction by limiting adherence of aluminium to the blade surface. Smooth cutter tooth face facilitates chips forming process and its removal from the cutting area, which increases blade durability and improves machined surface quality (Arumugam et al., 2006; Fukui et al., 2004; Sreejith, 2008).

2. METHODOLOGY

The purpose of the conducted research was to determine whether during machining of casting Al-Si alloys using tool coating and its type has influence on the wear process and the durability of carbide cutters. Cutting tests were performed using AVIA VMC 800HS vertical machining centre. Table 1 compares technological parameters recommended by the producer and parameters used in tests. In order to intensify the wear process, utilised parameters were significantly higher than the ones recommended by the producer.

Table 1
Recommended cutting parameters and parameters used in tests

v_c [m/min]	f_z [mm]	a_p [mm]	a_e [mm]	n [rpm]	v_f [mm/min]
Recommended parameters					
300	0.125	9.6	5.4	7,960	1,990
Used parameters in tests					
754	0.15	4	9	20,000	6,000

Source: (Fraisa, 2011).

The cut material was EN AC-AlSi10Mg casting aluminium alloy, so-called silumin, the chemical composition and basic properties of which presents table 2.

Table 2
Chemical composition and selected properties of the EN AC-AlSi10Mg alloy

Chemical composition [%]	**Si**	**Cu**	**Mg**	**Mn**	**Cr**	**Fe**	**Ti**	**Zn**	**Ni**	**Pb**
	10	≤ 0.05	0.33	≤ 0.45	≤ 0.1	≤ 0.55	≤ 0.15	≤ 0.1	≤ 0.05	≤ 0.05
Mechanical properties	**Density, ρ**		**Tensile strength, R_m**		**Yield strength, $R_{p0,2}$**		**Brinell hardness**			
	2.78 g/cm3		220 MPa		180 MPa		175 HB			

Source: (PN-EN 1706:2011 and PN-EN 1780-2:2004).

The research evaluated durability of three types of double-blade milling cutters of Fraisa brand with identical geometry:

- Milling cutter 1 – carbide cutter without coating – 5275.501nn,
- Milling cutter 2 – carbide cutter with TiB2 coating – C5275.501,
- Milling cutter 3 – carbide cutter with TiAlCN coating – U5275.501.

Fig. 1 presents basic dimensions of the tools. The cutters have “sharp geometry” (rake angle $\gamma_o = 15^o$), dedicated to cutting plastics, aluminium, copper, and their alloys (Fraisa, 2011).

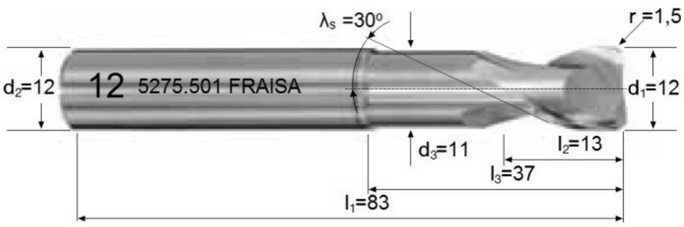

Fig. 1. View and dimensions of tools used during the tests

Source: (Fraisa, 2011).

All tools had been made of self-bonded carbide of ultra-micro grain of ca. 0.4 µm grain size. Cutter 1 had no coating, cutter 2 had TiB2 coating dedicated to Al and Cu alloys cutting under the commercial name CELERO, preventing adhesion. Cutter 3 had a universal TiAlCN coating of commercial name UNICUT-4X. Table 3 presents important properties of carbides used in production of these tools and properties of coatings covering cutters 2 and 3 (Fraisa, 2011; Kuczmaszewski and Pieśko, 2013; Twardowski and Wieczorkowski, 2000; Wieczorkowski and Pollak, 2000).

Table 3
Comparison of properties of basis material and tool coating

Tool marker	Cutter 1 5275.501nn	Cutter 2 C5275	Cutter 3 U5275
Carbide marker	HM MG10	HM MG10	HM MG10
Carbide type	Ultra-micro grain	Ultra-micro grain	Ultra-micro grain
Grain size [µm]	0.4	0.4	0.4
Co content [%]	10	10	10
Carbide hardness [HV]	1,600	1,600	1,600
Coating name	-	CELERO	UNICUT-4X
Coating material	-	TiB_2	TiAlCN
Coating hardness [HV]	-	4,000	3,200
Coating thickness [µm]	-	1-2	2
Max. temperature of applying coating [°C]	-	700	650
Intended use and properties	Cutting of Al, Cu, and plastics	Cutting of Al, Cu and plastics – coating of very good antiadhesion properties	Universal coating of high hardness intended for cutting of steel, superalloys, and Al and Cu alloys

Source: (Fraisa, 2011; Kuczmaszewski and Pieśko, 2013; Twardowski and Wieczorkowski, 2000; Wieczorkowski and Pollak, 2000).

In order to evaluate tool blades wear degree the measurements were taken of corner wear band width (VB_C), and the largest wear band width (VB_{Bmax}), using digital optical microscope Keyence VHX 5000. They are indicators describing flank face wear, which is typical for machining of Al alloys. Wear degree assessment utilised also measurement of indirect indicator of cut surfaces roughness by measuring Ra parameter of roughness profile using profilometer Hommel Tester T1000. The measurements were taken after machining of two layers of sample material of 260 x 180 x 80 mm dimensions, which equalled 10,400 mm of cutting length and ca. 1.73 min of cutting time. The tests were to be conducted until tool wear would prevent further cutting, or until achieving cutting time equal ca. 30 min.

3. RESULTS

During the conducted tests it has been determined, in accordance with the literary data, that tool blades wear during cutting of EN AC-AlSi10Mg alloys occurrs0 mostly on the flank face, thus, the examined cutters wear degree assessment was conducted using two indicators describing tool wear on this surface, i.e. corner wear band width indicator (VB_C), and the largest wear band width indicator (VB_{Bmax}).

Fig. 2 presents flank face of the milling cutters after finishing the tests. For cutters 1 and 3 (Figs 2a, c), all the planned tests were conducted, which complied cutting length equalled 270,400 mm, and, consequently, cutting time amounted to ca. 30.5 min. First cutter wear was mostly mechanical abrasive, while on cutter 3, besides abrasive wear, after cutting for ca. 18 min, edge chipping was noted, which resulted in surges of VB_C and VB_{Bmax} indicators (Figs 3 and 4). For cutter 2, wear had different form, i.e. of mechanical endurance. Wear preventing further machining happened as soon as after cutting time equalled ca. 5.2 min. Numerous chips and notches appeared on the tool blade, particularly in the corner area, which resulted in significant, dynamic increase of VB_C indicator (Fig. 3).

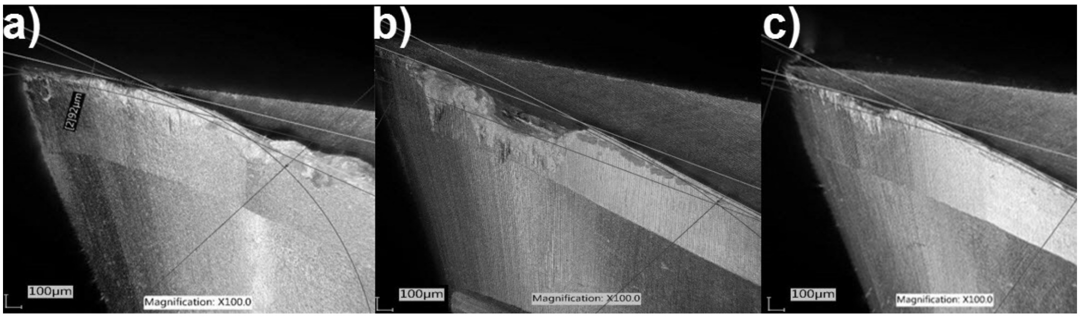

Fig. 2. Cutters blades after finishing the tests : a) milling cutter 1 - 5275.501nn, b) milling cutter 2 – C5275, c) milling cutter 3 – U5275

Figures 3 and 4 present changes in VB_C and VB_{Bmax} indicators in function of cutting time.

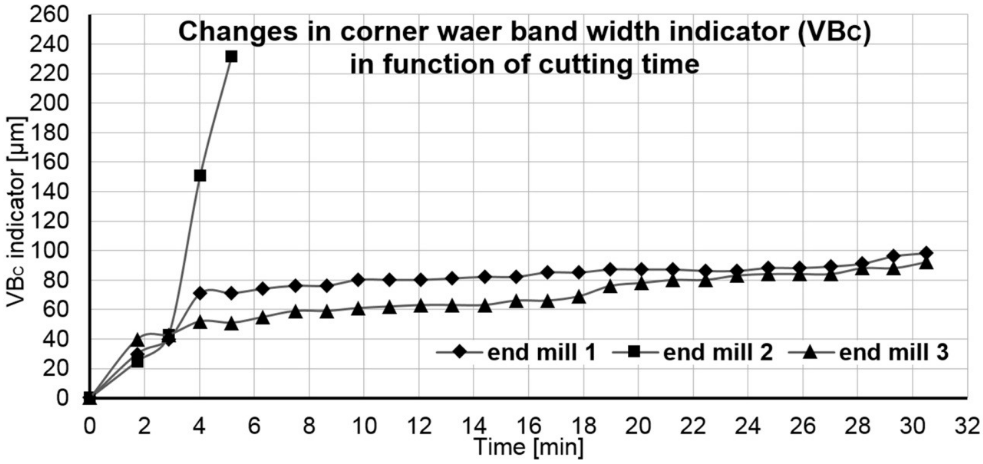

Fig. 3. Changes in corner wear band width indicator (VB_C) in function of cutting time

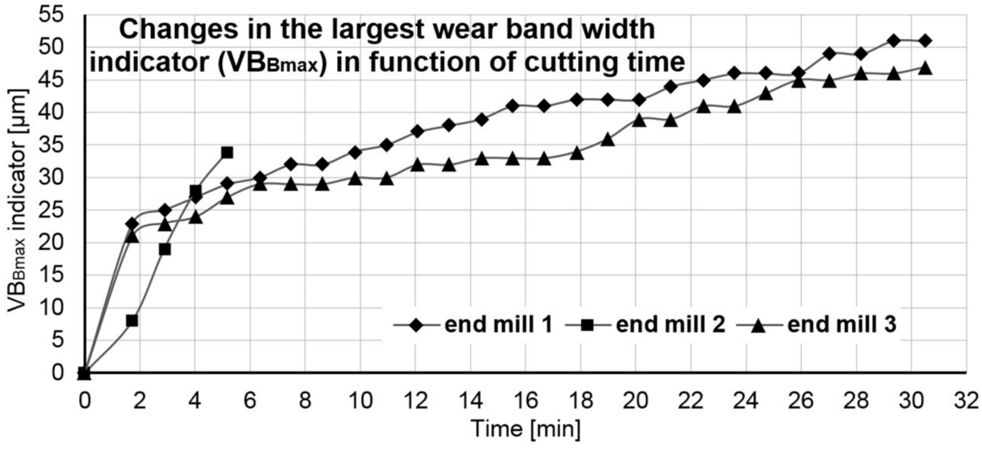

Fig. 4. Changes in the largest wear band width indicator (VB_{Bmax}) in function of cutting time

In the case of cutters 1 and 3, there is clear period of initial wear, which goes on until cutting time equal ca. 2÷4 min. Then there is period of even, normal wear, matching mechanical abrasive wear. Wear process of cutters 1 and 3 has slightly different character, since for cutter 3, at cutting time amount to ca. 18 min, small chipping of the cutting edge was noted that resulted in surges of VB_C and VB_{Bmax} indicators. After that time period, further wear of tool 3 had constant, even intensity. Moreover, values of VB_{Bmax} indicator of cutter 3 are lower than of cutter 1 in the whole time period (Fig. 3). Fig. 5 presents changes in Ra parameter in function of cutting time.

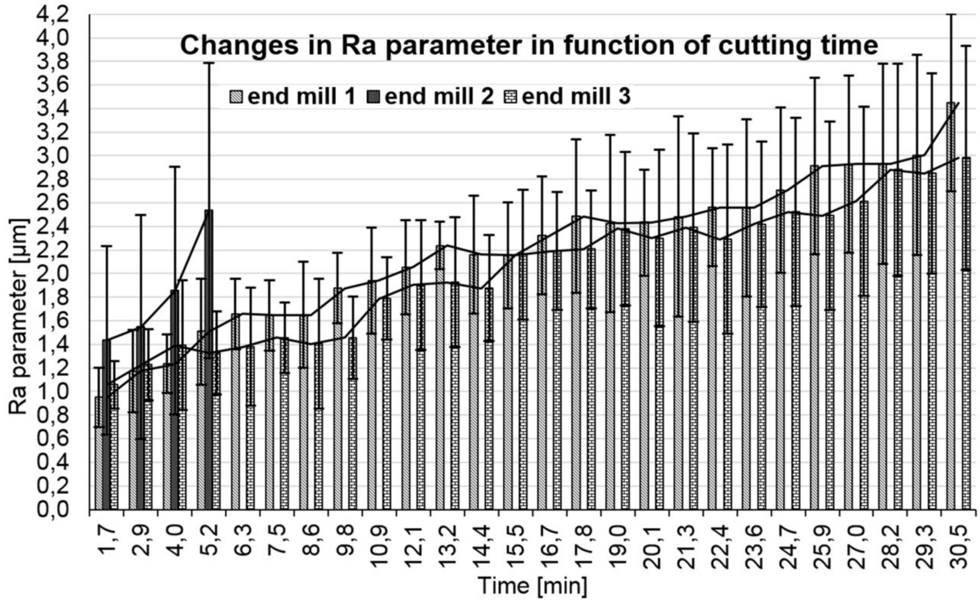

Fig. 5. Changes in Ra parameter in function of cutting time

VB_C indicator (Fig. 3) during the initial wear period is smaller for the cutter 1 without protective coating than for the cutter 3 with the universal coating. In the period of even wear, it's the opposite: VB_C indicator of cutter 1 is higher than of cutter 3. It is also reflected in value of indirect indicator, i.e. Ra parameter of roughness profile, and it is connected to the slower wear of tool 3 with the protective coating. Simultaneously, in initial wear period of cutter 3, due to the width of the applied coating, it has larger cutting edge rounding radius, which translates into worse quality of the cut surface in comparison to cutter 1. After initial wear period, tool 1 undergoes heavier wear, particularly in the corner area (Fig. 3) in comparison to tool 3, which translates into higher surface roughness (Fig. 5).

In the case of cutter 2, there is also an initial wear period, matching cutting time equal ca. 2 min. After that time, significant intensification of the wear process occurs, which is connected to the blade mechanical endurance wear (chips and notches). It translates into considerable decrease of cut surface quality (Fig. 5).

4. CONCLUSION

On the basis of conducted tests, the following conclusions may be drawn:

- Cut EN AC-AlSil0Mg alloy of significant plasticity (malleability) contains hard interjections of Al-Si phases, which at cutting parameters heightened in relation to the recommended ones, cause significant intensity of the wear process.
- Cutter 1 without protective coating has mostly mechanical abrasive wear, cutter 2 – mechanical endurance wear, while cutter 3 has mechanical mixed wear (abrasive and endurance), which confirms literary information.
- On the figures presenting changes of VB_C and VB_{Bmax} indicators in function of cutting time, all milling cutters have a clearly visible initial wear (lapping) period, which at the utilised parameters equals cutting time of ca. 2÷4 min.
- Cutter 1 without protective coating within initial wear period has the lowest value of corner wear band width indicator VB_C, which probably translates to the better quality of the cut surface and is connected to the cutting edge rounding radius.
- Due to their durability, the most favourable for cutting Al-Si alloys among the examined tools are the tools with the universal coating TiAlCN.
- However, it should be emphasised that mechanical endurance wear of cutter 2 has nearly catastrophic character and received results of the tool durability measurements, have in high random nature.

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