Article citation info:
KUCZMASZEWSKI J, PIEŚKO P. Wear of milling cutters resulting from high silicon aluminium alloy cast AlSi21CuNi machining. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2014; 16 (1): 37–41.

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WEAR OF MILLING CUTTERS RESULTING FROM HIGH SILICON ALUMINIUM ALLOY CAST AlSi21CuNi MACHINING

ZUŻYCIE OSTRZY FREZÓW PODCZAS OBRÓBKI WYSOKOKRZEMOWEGO, ODLEWNICZEGO STOPU ALUMINIUM AlSi21CuNi*

This paper presents results of tests on the wear of milling cutters resulting from high silicon silumins machining. As a representative for this group of materials EN AC-AlSi21CuNi alloy was chosen. Aluminium alloys containing less than 12 % of Si are classified as difficult-to-cut due to increased abrasive wear of the cutters caused by the influence of silicon precipitates. This affects the cutting process by damaging the quality and accuracy of the manufactured elements. Therefore, it is so significant to determine the durability of the teeth and stop the cutting process when it is being excessively worn.

Keywords: *silumins, wear of tools, tools durability, cutting forces, surface roughness.*

W artykule przedstawiono wyniki badań zużycia ostrzy narzędzi frezarskich podczas obróbki wysokokrzemowych siluminów. Jako przedstawiciela tego rodzaju materiałów wybrano stop EN AC-AlSi21CuNi. Stopy aluminium o zawartości Si > 12% określane są jako trudnoskrawalne, ze względu na zwiększone zużycie ścierne ostrzy, wywołane oddziaływaniem wydzieleń krzemu.Ma to niekorzystny wpływ na proces skrawania, pogarsza jakość i dokładność wykonywanych elementów. Istotne jest więc aby określić trwałość ostrza narzędzi i w momencie jego nadmiernego zużycia przerwać proces skrawania.

Słowa kluczowe: *siluminy, zużycie narzędzi, trwałość narzędzi, siły skrawania, chropowatość.*

1. Introduction

Aluminium alloys can be characterized as free machining, however, it is difficult to compare with machinabilty of other metals. This is induced by the properties of aluminium alloys, such as high linear expansion coefficients and relatively low linear elasticity coefficients [6, 11].

There are many grades of aluminium alloys and due to that fact, to facilitate the choice of machining conditions, they were grouped into categories according to three major criteria: silicon content, method of the performed heat treatment (heat treating and cold working) and their purpose (for plastic working and for casting) [6, 11, 12]. Aluminium alloys are grouped as follows:

- group 1 — alloys with Si ≤ 2 %,
- group 2 — alloys with 2% < Si ≤ 12 %,
- group 3 — alloys with Si > 12 %.

Alloys from the 2nd group are free machining, ergo they are not problematic for the process. The machinability of the alloys from groups 1 and 3, however, can be characterized as more difficult to work with. In group 1 this feature is caused by high plasticity and tendency to form built-up edges or even "clogging" the flutes of rotary tools. Yet, when machining the alloys from group 3 exceeded tool use occurs due to highly abrasive in their nature silicon precipitates [2, 9, 11]. Nonetheless, these alloys posses many beneficial operating properties, such as high strength, resistance to corrosion and abrasive wear, as well as low thermal expansion and excellent castability. All that contributes to their having application in manufacturing of spare parts for combustion engines, compressors, pumps and components of braking systems [5, 7, 9, 11].

To determine the value of wear, the so-called wear indices are used. With geometric quantities they define the wear of flank face and rake face (Fig. 1). The following are the wear indexes of the flank face wear [3, 13]:

VB_B – average flank face wear bandwidth;
VB_{Bmax} – maximum flank face wear bandwidth;
VB_C – nose wear bandwidth;
VB_A – wear bandwidth in A zone;
VB_N – notch wear width;

Rake face wear indices are the following [3, 13]:

KT – crater depth (maximum crater depth on the rake face);
KB – crater width (the distance between primary cutting edge and the most distant crater edge on the rake face);
KE – retreat of tool nose (radius wear) depicted on the tool reference plane as P_r on the intersection point with the tool back plane P_p;
KM – crater center distance defined as the distance between primary cutting edge and its maximum depth, perpendicular to the cutting edge;
KF – the distance between the crater and the primary cutting edge;
K – crater index $K = KT/KM$.

Apart from the aforementioned indices the so-called indirect indices are used, which can be divided into physical and technological. Physical indices are the following [3]:

- vibrations, including acoustic emission (amplitude, frequency),
- components of cutting forces, torque and power,
- cutting temperature,
- chip colour,
- chip form and shape.
- Technological indices are the following [3]:
- dimensional and shape accuracy,
- quality of the surface layer, including mostly surface roughness etc.

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

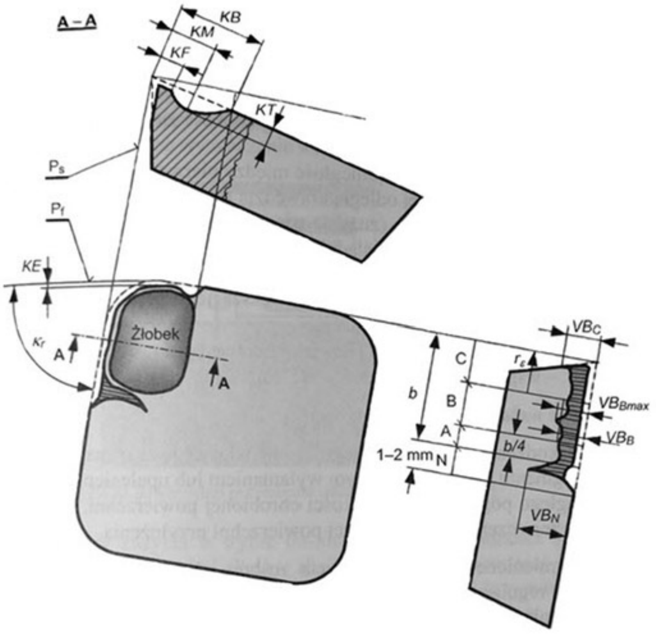

Fig. 1. Wear indices [1]

This paper presents the results of the test concerning wear on cutters of the chosen milling tools resulting from high silicon casting aluminium alloys machining. The criteria for the tool wear identification, except for geometric wear indices, indirect indices were applied, that is cutting forces and machine surface roughness measurements. Excessive usage of tools that occurs when machining these type of alloys increases cutting forces, which affects the machine tool operating conditions [1, 4, 8, 9]. Surface quality deterioration [1], which is also present, affects the utilization qualities of the manufactured elements – surface defects result in lower endurance as the majority of cracks are generated in the surface layer.

To machine hypereutectoid Al-Si alloys machine tools with carbonado teeth or made of carbonado coating sintered carbides are recommended. Such tools are durable and using them, beside decreasing cutting forces, improves the quality of the surface manufactured [1, 2, 8, 10, 16, 18]. However, they are very expensive, which increases manufacturing costs, therefore for the purpose of this paper tests were made with HSS, uncoated carbide machine tools and milling cutters with replaceable inserts, for which the biggest obstacle in high silicon alloys Al-Si machining is their durability.

2. Description and results of the research

As an representative of high silicon silumins EN AC-AlSi21CuNi alloy was used for the purpose of this research. Its chemical composition as well as physical and mechanical properties are presented in Table 1. This alloy is employed mostly for casting of highly loaded pistons in combustion engines and it proves good durability in elevated temperature, low friction factor, high resistance to corrosion and abrasion plus good castability.

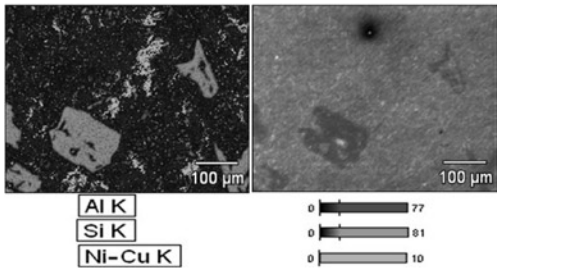

Fig. 2. Depiction of AlSi21CuNi surface from SEM microscope and a map of chemical elements distribution for this alloy

Figure 2 depicts alloy's surface seen through an SEM microscope and a map of chemical elements distribution developed with use of an EDS probe. On the map colour green represents silicon precipitates, light blue shows Ni-Cu phase and red stands for aluminium. Silicon precipitates, which demonstrate high hardness and abrasibility properties causing excessive use of cutters, are clearly visible here.

Three milling cutters, each 20 mm in diameter and made from a different type of material, were used (Fig. 3):

- monolithic HSS milling cutter NFPa Φ20 Z=4,
- folding milling cutter R390-020B20-11L with R390-11 T308E-ML tips,
- monolithic carbide milling cutter without coating E5423200.

Fig. 3. Tools that were used for machining: a) NFPa, b) R390-020B20-11L, c) E5423200

For each tool different cutting parameters were applied (Table 2), chosen according to the specialist literature or producer's guidelines [14, 15, 17].

Cutting tests consisted of milling a groove (with full diameter of a tool), 20 mm wide and 6 mm deep. Altogether there was 3.6 mm of groove to mill for each tool.

Machining parameters for the milling cutters NFPa φ20, R390-020B20-11L and E5423200 were tagged in Table 2 as P1, P2, P3 accordingly. They differ for each tool in cutting speed, which was assigned depending on the material of a tool.

2.1. Wear of teeth

Most of all, when cutting aluminium alloys, teeth wear occurs in the flank face [3]. Consequently the following two indices were applied to evaluate the wear:

Table 1. Chemical content and properties of the alloy AlSi21CuNi [5, 13]

Designation and chemical content	PN-EN1780-2	Feature	Si	Cu	Ni	Mg	Mn	Cr	Fe	Ti	Zn
	EN AC-AlSi21CuNi	AK20	20-22	1.4-1.5	1.4-1.6	0.4-0.6	0.4-0.6	≤0.7	≤0.7	≤0.2	≤0.2
Physical and chemical properties	Density	Hardness		Abrasability in reference to Al-Cu		Durability R_m		Young's modulus		Poisson ratio	
	2700 kg/m^3	85-110 HB		0.65		150-190 MPa		82000 MPa		0.26	

Table 2. A set of parameters for each tool [14, 15, 17]

The tool	Slot and end mill	Folding slot and end mill	Carbide slot and end mill without coating
Parameter number	P1	P2	P3
Tool designation	NFPa φ20	R390-020B20-11L	E5423200
Working part material	HSS	R390-11 T308E-ML	H10F
Number of teeth	4	2	3
Cutting speed v_c	75 m/min	300 m/min	500 m/min
Rotational speed n	1194 rev/min	4777 rev/min	7962 rev/min
Rate of feed f_z	0,1 mm/tooth	0,1 mm/tooth	0,1 mm/tooth
Rate of travel v_f	478 mm/min	955 mm/min	2389 mm/min
Depth of cut a_p	6 mm	6 mm	6 mm
Width of cut a_e	20 mm	20 mm	20 mm

- maximum wear bandwidth VB_B,
- nose wear bandwidth VB_C.

When performing each test, the course of wear process of each tool was being analyzed, both as a function of the machining time (Fig. 4) and milling path (Fig. 5).

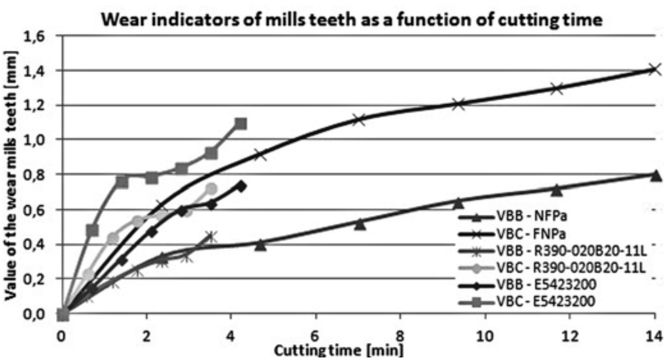

Fig. 4. Wear of the cutter as a function of cutting time (machining parameters for mills: NFPa – P1; R390-020B20-11L – P2; E5423200 – P3 according to Table 2)

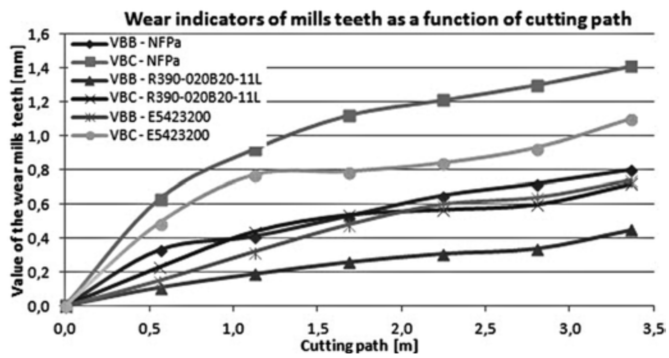

Fig. 5. Wear of the cutter as a function of cutting path (machining parameters for mills: NFPa – P1; R390-020B20-11L – P2; E5423200 – P3 according to Table 2)

The most substantial wear was detected in NFPa mill and a smaller in size but also considerable in carbide tool E5423200. The reason for that is high cutting speed and lack of coating. For R390-020B20-11L mill cutting speed was lower than for the carbide mill and the wear was the smallest. Less sizable wear is also a result of applying indexable tool insert with coating, which reduces abrasion. It is particularly significant in case of hypereutectic silumins machining. When milling them silicon precipitates which appear increase this kind of wear. This research confirms high "abrasibility" of this alloy making it difficult machining.

2.2. Surface quality

There are many factors which influence the roughness of the surface, such as material, quality of workmanship, tool contour and angles, milled material properties, technological parameters applied and other. Among technological parameters the one of the highest influence for the surface quality is rate of feed per tooth f_z. Cutting speed v_c has lower impact on it. When carrying out the research, roughness of the milled groove bottom (Fig. 6a) and its lateral surface (Fig. 6b) were measured. Surface quality, as predicted, deteriorates along with the increased wear of tools. The worst surface quality was observed for NFPa mill made of HSS. Similar surface condition measured on the bottom was detected when the folding and carbide milling cutters were used. These tests proved the lowest roughness of the lateral surface of the groove when carbide mill was applied.

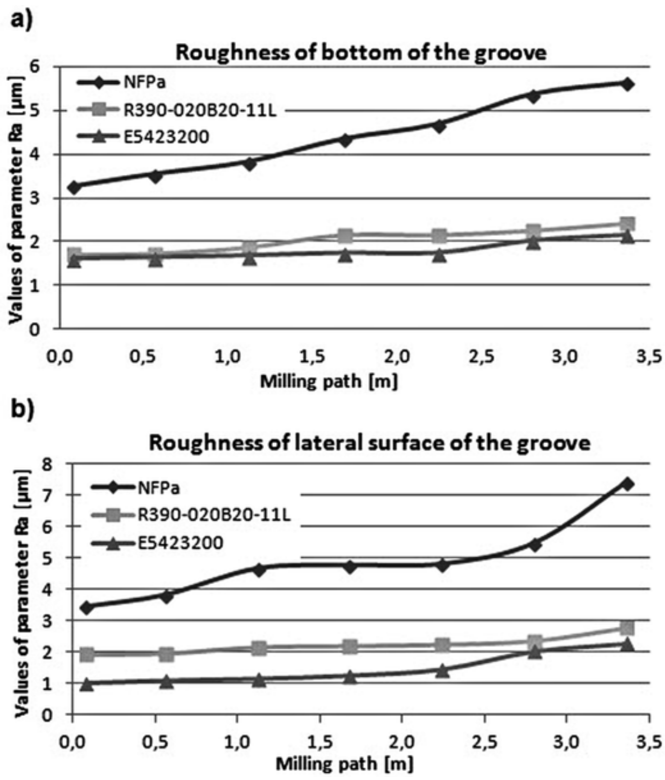

Fig. 6. Surface roughness of: a) bottom of the groove, b) lateral surface of the groove (machining parameters for mills: NFPa – P1; R390-020B20-11L – P2; E5423200 – P3 according to Table 2)

It is worth emphasizing that in spite of substantial wear of the milling cutters, defined with VB_B i VB_C indices, surface roughness as a function of cutting path for mills R390-020B20-11L andE5423200, changes only slightly. These alterations are calculated around 1µm. Yet, the R_a parameter change for NFPa mill circulates around 3µm.

2.3. Cutting forces

Values and amplitudes of cutting forces influence the accuracy and quality of the elements manufactured. High cutting forces cause increased wear of the tools and tool-in-use machines systems. The highest values of cutting forces was observed for the folding tool (mill R390-020B20-11L) and the lowest for the mill E5423200 (Fig. 7).

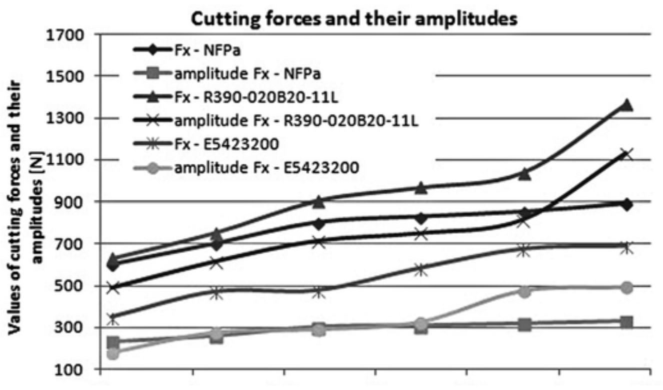

Fig. 7. Maximum values and amplitudes of cutting forces components for different tools (machining parameters for mills: NFPa – P1; R390-020-B20-11L – P2; E5423200 – P3 according to Table 2)

Decreased cutting forces for the carbide tool result from lower cutting resistance which can be contributed to “sharp” tool geometry and high cutting speed (after exceeding certain value v_c, increase in cutting speed causes the cutting forces to decrease). These forces in case of the folding tool are similar to the forces for HSS mill. The forces amplitudes, however, which are the process stability indicators, are the highest for this tool and they exceed to a high degree the values for the two other mills (for the forces components: Fx i Fy ca. 40%). The key factor here is the geometry of the teeth, especially less teeth than in case of the two other tools (Table 2), lower tool rake and helix angles λ_s=5°. Such parameters affect the operating stability of a tool, which results in the increase of cutting forces amplitudes [12].

3. Summary and conclusions

The conducted study and experimental research triggered the following conclusions:

- HSS tools should not be used when machining high silicon silumins.
- The highest increase in cutting forces occurred when machining with folding tool, which is unprofitable due to mill durability, machining tools and quality of the machined surfaces.
- The study shows that among the tools analyzed the most satisfactory results were observed for the carbide mill.
- Ra parameter value is comparable for the carbide mill and the folding mill, thus the choice of the most appropriate tool should be based on economic analysis for each technological situation.
- Cutting forces amplitudes, being a meaningful indicator of the cutting process dynamics, are the highest for the folding mill, which ought to be considered when choosing tools for particular purposes.
- Regardless of significant wear of the tools during the machining, the change of the Ra parameter is relatively small, comparing the beginning and the end of the process. It is of high importance regarding the machining quality.

The experimental study indicate that the tools durability is significant when machining high silicon silumins. This concerns especially automated machining on numerically controlled machine tools. Frequent exchange of tools due to their wear can result in problems both with technological machines control and quality of the elements machined.

Financial support of Structural Funds in the Operational Program – Innovative Economy (IE OP) financed from the European Regional Development Fund, IE OP No. 01.01.02-00-015/08-00 is gratefully acknowledged.

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