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THE INFLUENCE OF TECHNOLOGICAL PARAMETERS AND GEOMETRIC FEATURES OF A CUTTING EDGE ON CUTTING FORCES DURING AZ91HP ALLOY MILLING

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S u m m a r y

This article presents the state of knowledge on cutting forces during the milling of light alloys. Research results presented in the paper concern cutting forces and their amplitudes depending on the technological parameters (v_c, f_z, a_p) with the use of two carbide milling cutters having a different cutting edge geometry ($\gamma = 5^o$ and $\gamma = 30^o$). Research and analysis of cutting forces appear to be a significant factor determining chip deformation, temperature and cutting area strain, among others. Lower values of cutting force components are observed in the case of $\gamma = 30^o$ tool processing. For the purpose of this research casting magnesium alloy AZ91HP was selected.

Keywords: high-speed dry milling, magnesium alloys, machinability, cutting forces

Wpływ parametrów technologicznych i cech geometrycznych krawędzi skrawającej na siły skrawania w procesie frezowania stopu AZ91HP

S t r e s z c z e n i e

W pracy wykonano analizę ogólnego stanu wiedzy dotyczącą sił skrawania podczas frezowania stopów lekkich. Przedstawiono wyniki pomiarów sił skrawania w zależności od zmiany określonych parametrów technologicznych (v_c, f_z, a_p) przy zastosowaniu dwóch frezów węglikowych o zmiennej geometrii ostrza ($\gamma = 5^o$ i $\gamma = 30^o$). Ustalono, że wartości sił skrawania są czynnikiem determinującym m.in. odkształcanie się wióra, temperaturę oraz odkształcenia materiału warstwy wierzchniej w strefie skrawania. Mniejsze wartości składowych sił skrawania stwierdzono dla obróbki narzędziem o kącie $\gamma = 30^o$. Proces obróbki prowadzono dla stopu magnezu AZ91HP.

Słowa kluczowe: frezowanie na sucho, stopy magnezu, skrawalność, siły skrawania

1. Introduction

When product weight is of crucial importance, the application of magnesium alloys is getting wider due to their low absolute weight and considerable strength. Furthermore, magnesium alloys they can be distinguished

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by their casting qualities, the ability to deaden vibrations and be recycled. They are also noted for satisfactory screening of electromagnetic radiation [1]. The availability of magnesium, which can be found in nature in the form of chemical compounds occurring in dolomite, magnesite, carnallite or sea water, does not stay unnoticed.

Magnesium alloys find applications in the following fields: aviation, astronautics, electrotechnology, automotive industry or machine construction. Objects like a car door frame, lever brackets, dashboard elements, laptops and camera casings (e.g. Toshiba notebooks or OLYMPUS OM-D main body), plane and helicopter planking are all manufactured with magnesium alloys [2]. A considerable majority of them is produced through casting (sand molds, metal molds, pressure casts). When plastic processing is taken into consideration, magnesium alloys are formed mainly with the use of forging, rolling and extrusion methods. An unquestionable advantage of magnesium alloys is also their fine machinability which can be proven by a high quality surface after processing and little appropriate cutting forces having a positive influence on a high wear of cutting tools. For instance, when milling magnesium alloy AZ91HP using a tool with a PCD cutting edge, cutting forces have lower values and grow linearly with an increasing feed rate [3, 4].

2. Current state of knowledge

Research on magnesium alloys has proven [3] that they are suitable for both HSC (high speed cutting) and HPC (high performance cutting). Processing tools (mainly consisting of PCD (polycrystalline diamond) or fine-grained cemented carbide) should have a relatively big clearance angle, positive rake angle and sharp cutting edges.

During High Speed Machining (HSM) the increase in cutting speed (with constant process efficiency) results in a reduction of cutting forces. This seems to be of high significance due to the possibility of processing of thin-walled elements and shortening the time of this process with the retention of high quality surface and shape accuracy. There is a commonly accepted division into "conventional" machining and HSM. HSM can therefore be defined as a range of speeds in which cutting force derivative takes a negative value in relation to cutting speed [5]:

- $\partial F/\partial v_c < 0$, HSM,
- $\partial F/\partial v_c > 0$, conventional machining.

Despite multiple advantages, material removal processing of magnesium alloys involves a number of threats. Magnesium dust emerging during the processing has a negative influence on both machine tool operators' health and machine tools themselves (it can damage their bearings and guideways). What seems equally dangerous is a tendency of magnesium to self-ignite when a sudden temperature increase occurs (480ºC is the ignition temperature of magnesium) [3]. Another problem is build-up appearing on a flank face or a cutter tooth face which results from the intensification of adhesion.

What should be paid attention to is the increase of a cutting process efficiency using HSM without the stability of the milling process being impaired. In such a case it is a stability curve (for the selection of the most beneficial cutting parameters embracing stable areas of processing with regard to the absence of self-oscilation) and recurrence plots that can be applied most successfully. With their help, so called, stable cutting areas can be determined [5, 6].

The influence of various tool coats (TiB_2 and TiAlCN among others) on cutting forces with the application of carbide end mills is also of crucial importance. The lowest values of cutting force components Fx, Fy during Al 6082 alloy milling were obtained for TiB_2 coated tools. What could be observed during v_c change is a specific "switch point" in HSC machining (for v_{cgr} = 450-600 m/min) [7]. Also, when turning alloy AZ91HP, the following tools were compared: a carbide TiN and PCD coated tools, uncoated carbide tools and PCD tools. Machining with PCD coated tools or the ones having a PCD cutting edge allows to obtain lower cutting forces, makes a tool less prone to overheating (lower coefficient of friction) and therefore lower temperatures in the cutting area [8].

Additionally, cutting force amplitudes, constituting a significant indicator of the cutting force dynamics, are the highest in the case of compound tools (this fact should be taken into consideration when selecting tools for specific purposes) [9]. During milling magnesium alloys AZ31 and AZ91HP, in most cases, PCD cutting edge tool induced higher values of cutting force components compared to carbide tools (presumably because of a zero helix angle $\lambda s = 0°$) taking into account both "conventional" and "high speed" (HSM) machining [10]. When machining with "classical geometry" tools, cutting forces and their amplitudes were influenced by changes in feed rate per tooth f_z rather than a change in cutting forces v_c [11, 12].

Moreover, cutting forces may cause strain of the processed machine components and their increase prompts a reduction in so-called deformation of chip thickness. This results in a change of a shear angle and, consequently, the shear plane temperature rises. Additionally, cutting force increases when an undeformed chip thickness is decreased [13].

Taking into account the stability of the process and the quality of a surface finish, the analysis of the influence of some of the geometric tool qualities on a cutting force value seems to be of high importance. It has been acknowledged that it is machining with tools having radically different rake angle values that supplies vital information.

3. Methodology, aims and scope of the research

Figure 1 shows a research plan whose aim is to present changes concerning the values of cutting force components and their amplitudes depending on a change of the established parameters. Changing parameters are as follows: cutting speed v_c = 400-1200 m/min, feed rate per tooth f_z = 0.05-0.3 mm/tooth, depth of cut a_p = 0.5-3 mm and a tool rake angle γ (5º, 30º). A constant milling width a_e = 14 mm and a type of workpiece material (AZ91HP alloy) are constant.

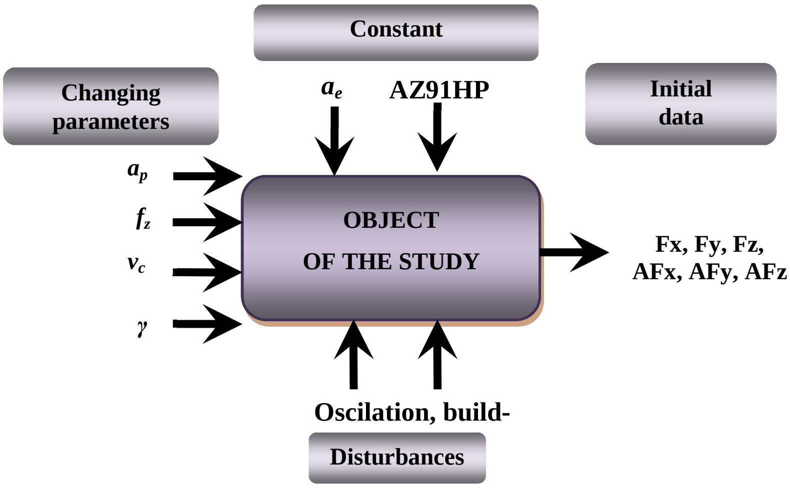

Fig. 1. Research plan for the analysis of cutting forces and their amplitudes depending on a change of parameters

The research was conducted in a machining center AVIA VMC 800HS. The tools applied in the study are two carbide triple cutting edge end mills with a variable cutting edge geometry used for light alloy machining. Table 1 presents geometry of the tools mentioned.

Table 1. Geometry of the tools used during the research

No.	Diameter D_c, mm	Cutting edge number z_n	Helix angle λ_s	Clearance angle α	Rake angle γ
1.	16	3	35º	8º	5º
2.	16	3	35º	8º	30º

Cutting forces were measured using a Kistler 9257B piezoelectric dynamometer and a 5017B amplifier. This enabled obtaining adequate signal sequences in the established time series for the measured parameters. Every time interval included tens of thousands of measuring points due to which maximum values of cutting force components and their amplitudes were specified. The graphs presented reflect standard deviation per 100 points for cutting forces and 10 points for their amplitudes.

The essence of this research is the analysis of technological aspects of a proper selection of cut depth, feed per tooth, cutting speed and cutting edge geometry in relation to occurring cutting forces and their amplitudes during the milling of a casting magnesium alloy AZ91HP. For the purpose of achieving the best possible process stability, establishing proper relations between the abovementioned parameters is vital.

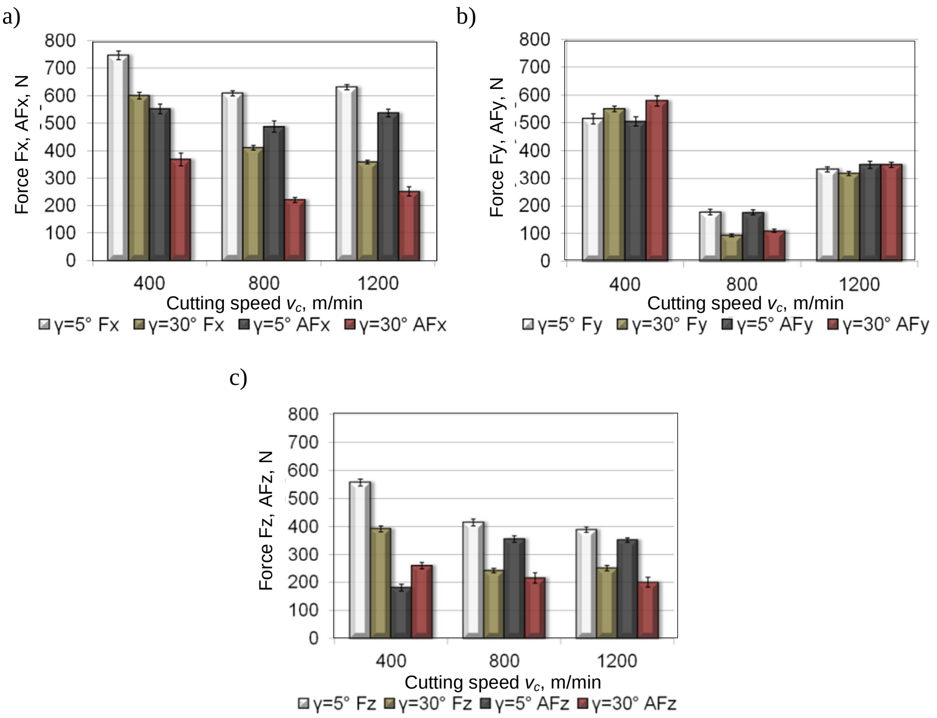

Fig. 2. The effect of change in cutting speed v_c on the value of cutting force components and their amplitudes during milling of AZ91HP magnesium alloy using tools of various rake angels: a) F_x, AF_x, b) F_y, AF_y, c) F_z, AF_z

4. Test results and their analysis

Correlations between cutting forces components and their amplitudes as a function of technological parameters of processing based on the obtained test results. Figure 2 presents the effect of change in cutting speed v_c on cutting forces components and their amplitudes values.

The diagrams presented in Figure 2 prove that regardless of the tool used, an increase in v_c resulted in decreasing Fx and Fz and their amplitudes. No regular tendency was observed for Fy as its initially high value decreased at v_c = 800m/min, which was followed by an increase at 1200 m/min. The highest value observed was reached by Fx for γ = 5º angle (747 N) at the speed of 400 m/min, then a decrease and a slow inconsiderable increase were observed. This tendency can be well observed in regard to both Fy components which present a clear decrease at 800 m/min. The contrary situation was noted for AFz component amplitude which increased at 400-800 m/min. The highest diversity of results was noted for AFx.

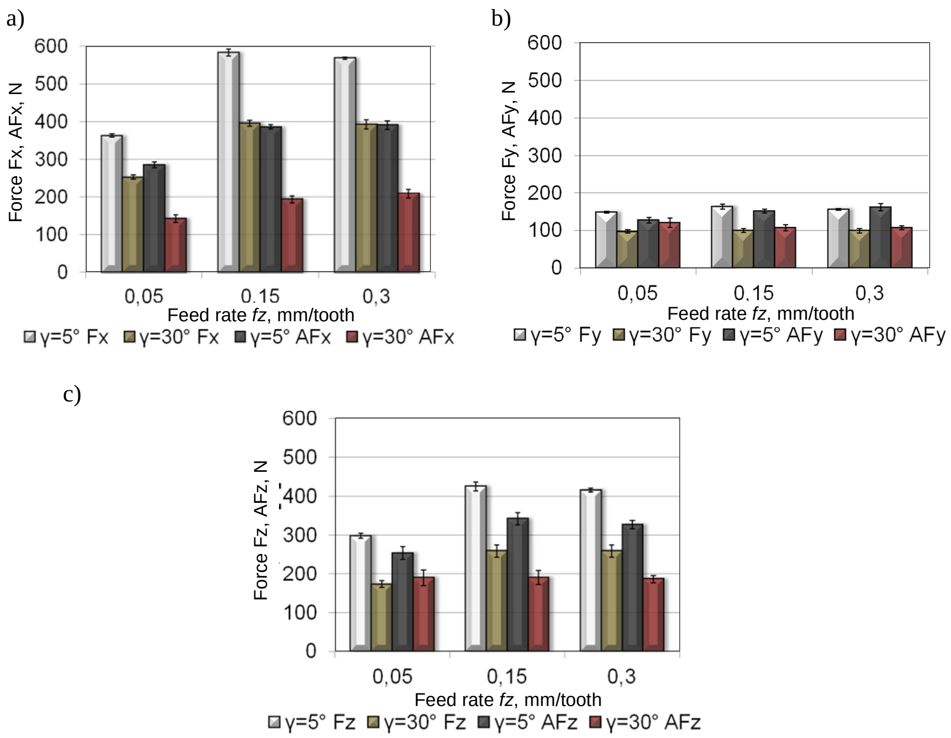

Fig. 3. The effect of change in feed rate per tooth f_z on the value of cutting force components and their amplitudes during milling of AZ91HP magnesium alloy using tools of various rake angles: a) F_x, AF_x, b) F_y, AF_y, c) F_z, AF_z

Figure 3 presents the effect of change in feed rate per tooth f_z on cutting forces and their amplitudes.

Analysis of data presented in Figure 3 allowed to noted that the initial increase in cutting forces components and their amplitudes arises around f_z = 0.15 mm/tooth followed by a relative stabilization (with standard deviation having been considered). The feed rate per tooth change does not influence considerably cutting forces components or their amplitudes (feed rate per tooth influence was lowest for Fy). The greatest changes concerned the Fx component (γ = 5º), however only within 0.05-0.15 mm/tooth. For both γ = 5º angle as well as γ = 30º angle similar relations can be observed, despite the fact that force values are higher for γ = 5º.

Figure 4 presents the influence of depth of cut change a_p (at f_z = 0.05 mm/tooth) on cutting forces components and their amplitudes.

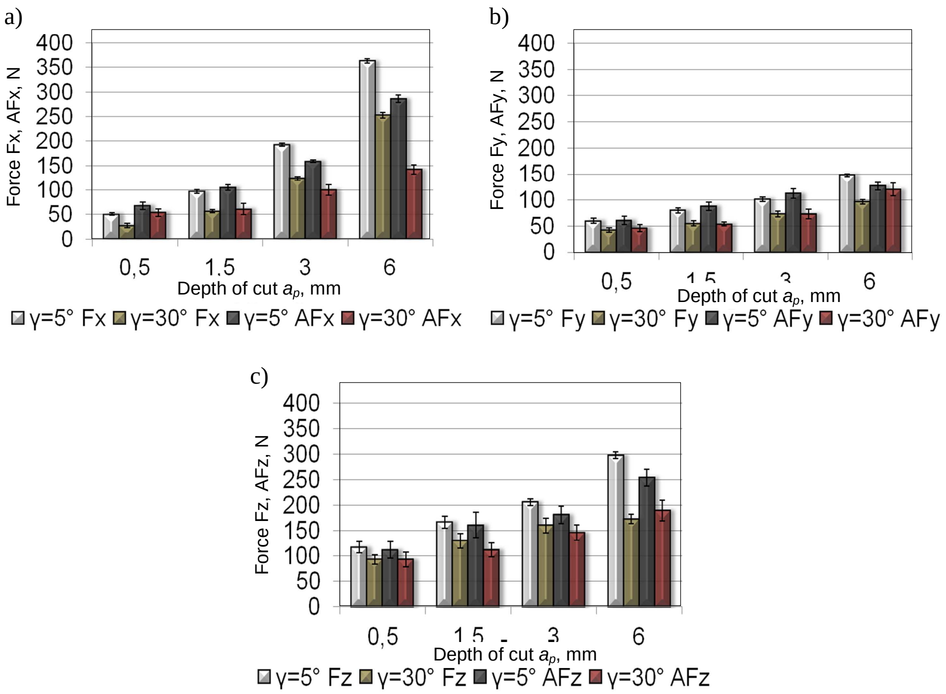

Fig. 4. The influence of change in depth of cut a_p (at f_z = 0.05 mm/tooth) on cutting forces components and their amplitudes during milling of AZ91HP magnesium alloy using tools of various rake angles: a) F_x, AF_x, b) F_y, AF_y, c) F_z, AF_z; f_z = 0.05 mm/tooth, v_c = 800 m/min

The analysis of change in depth of cut a_p (at f_z = 0.05 mm/tooth) showed an increase in cutting forces and their amplitudes with increasing a_p. An increasing a_p influenced Fy and its amplitude to the lowest degree. For depth of cut equal to

a_p = 0.5 mm the highest value was observed for *Fz*, whereas for a_p = 6 mm it was *Fx* and its amplitude which obtained the highest values. Figure 4 demonstrates that the highest force values were obtained using a $\gamma = 5^o$ tool.

Figure 5 presents the influence of depth of cut change a_p (at f_z = 0.15 mm/tooth) on cutting forces components and their amplitudes.

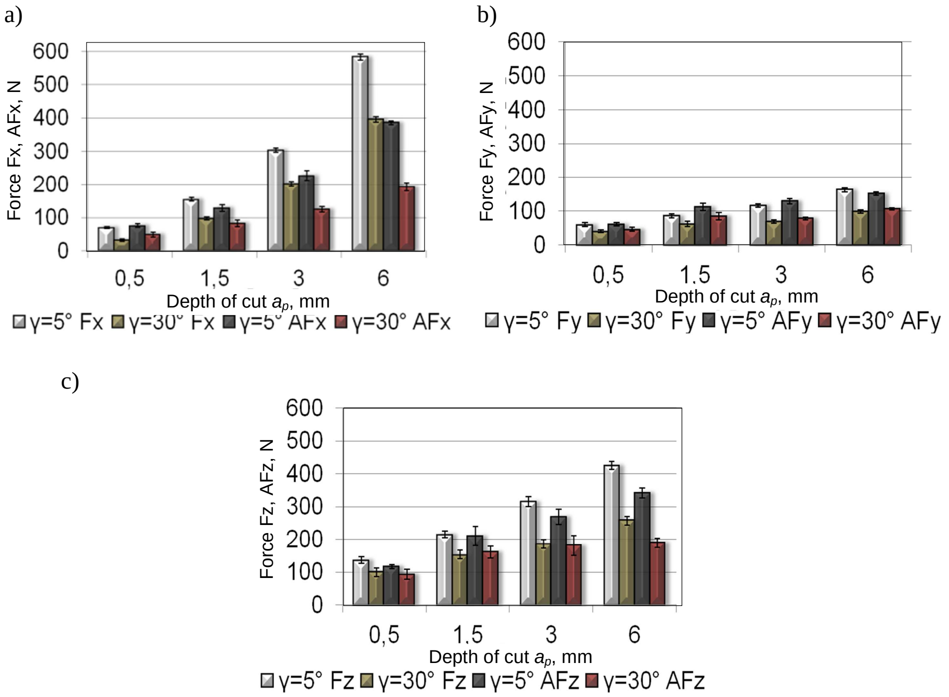

Fig. 5. The influence of change in depth of cut a_p (at f_z = 0.15 mm/tooth) on cutting forces components and their amplitudes during milling of AZ91HP magnesium alloy: a) F_x , AF_x, b) F_y, AF_y, c) F_z, AF_z, f_z = 0.15 mm/tooth, v_c = 800m/min

With feed rate per tooth equal to f_z = 0.15 mm/tooth (Fig. 5) it was observed that an increase in depth of cut a_p is followed by an increase in cutting forces and their amplitudes. The highest value was noted for *Fx* ($\gamma = 5^o$), which at depth of cut equal to a_p = 0.6 mm reached 583 N. Lower forces and their amplitudes values for a $\gamma = 30^o$ tool indicate a better stabilization of the process. An increase in feed rate pert tooth resulted in higher cutting forces increase compared to the ones presented in Figure 4 (feed rate per tooth equal to f_z = 0.05 mm/tooth).

5. Summary and Conclusions

When designing a technological process exceptional attention is paid to careful selection of parameters which would allow achieving highest and most stable results. Stabilization is a crucial indicator of a process. Technological parameters values as well as the machine tools rigidity are among the fundamental factors influencing stabilization of a process.

The conducted tests measured cutting forces components and their amplitudes during machining of AZ91HP magnesium alloy depending on technological parameters values (v_c, f_z, a_p) as well as the rake angle γ. The obtained results allowed to formulate the following conclusions:

- Lower cutting forces and their amplitudes values were observed for a $\gamma = 30^{\circ}$ tool indicating a better stabilization of the process. This also seems to be a fundamental issue regarding safety, as lower values in the cutting area generate lower temperatures, which is crucial with respect to magnesium chip ignition during machining.
- An increase in depth of cut causes a linear increase in cutting force components and their amplitudes.
- In the case of change in cutting speed v_c, cutting forces components reached highest values for cutting speed equalling v_c = 400 m/min, and the highest value was obtained in the case of Fx for $\gamma = 5^{\circ}$ (747N).
- An increase in feed rate per tooth to 0,15 mm/tooth with various depth of cut values caused an increase in cutting forces components when compared with f_z = 0.05 mm/tooth.
- The change in feed rate pr tooth (within f_z = 0.05-0.15 mm/tooth) resulted in an increase of cutting forces components as well as their stabilization (for f_z = 0.15-0.3 mm/tooth)

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