EXPERIMENTAL MEASUREMENT OF CUTTING EFFORTS AT MILLING ZINC ALLOYS

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În lucrare se prezintă standul de măsurare a eforturilor de aşchiere, rezultatele cercetărilor experimentale şi interpretarea rezultatelor la frezarea aliajelor de zinc. În final sunt stabilite funcţiile de regresie politropice cu care se pot calcula aceste forţe şi momente de aşchiere în funcţie de parametrii regimului de aşchiere.

The paper presents the experimental stand for cutting efforts measurement, results of the experimental research and their interpretation for the milling zinc alloys. Finally, the exponential regression functions to determine these cutting forces and torques depending on the cutting regime parameters.

Keywords: experimental research, milling, cutting force, torque, zinc alloys.

1. Introduction

Zinc alloys are easy melting materials, used to manufacture a great number of products in different industrial domains (machine building, households, toys, pneumatic and hydraulic drives, etc.).

Being poorly known from the point of view of cutting ability, this paper intends to determine the cutting efforts for the milling zinc alloys. This aspect is an evaluation criterion of the cutting ability concept [7].

There are three zinc alloys standardized in Romania (STAS 6925/2-88). The most used of these alloys is ZnAl4Cu1T. As a separate group of zinc alloys there are those known as "zamak" (having as specific feature the proportion of 4% aluminium).

The studied alloy ZnAl4Cu1T has the chemical structure and physical properties similar to the alloy Zamak 5.

This alloy has the following physical properties (influencing cutting ability): hardness 90…100 HB, mass density 6,7 kg/dm3, ultimate tensile stress

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27 daN/mm2, Young modulus 96 GPa, melting temperature 389…390°C. In comparison, the same properties of the steel OLC45 are the following: hardness 300 HB, mass density 7,83 kg/dm3, ultimate tensile stress 80 daN/mm2, Young's modulus 210 GPa, melting temperature 1400°C.

2. Experimental set-up

It consists of two parts: the mechanical part, including the machine tool, cutting tools – milling cutters, workpieces made of zinc alloy and the data acquisition part, including the KISTLER measuring table, an electronic amplifier and the PC having a data acquisition system.

The recommended cutting tools are milling cutters with inclined teeth, depending on the cutting depth. Cutting speed may be up to 100 m/min for smaller cutting depths (under 1.5 mm) or up to 30 m/min for larger cutting depths (1.5 to 4 mm). Cutting depth varies in a large range: up to 3.5…4 mm for roughing operations and 0.6 to 1 mm for finishing operations. The feed depends on the requested surface quality and the stiffness of the technological system, varying between 0.1 – 0.4 mm/tooth.

During the experiments, the frontal milling operations were symmetrical (complete).The structure of the experimental set-up is shown in figure 1.

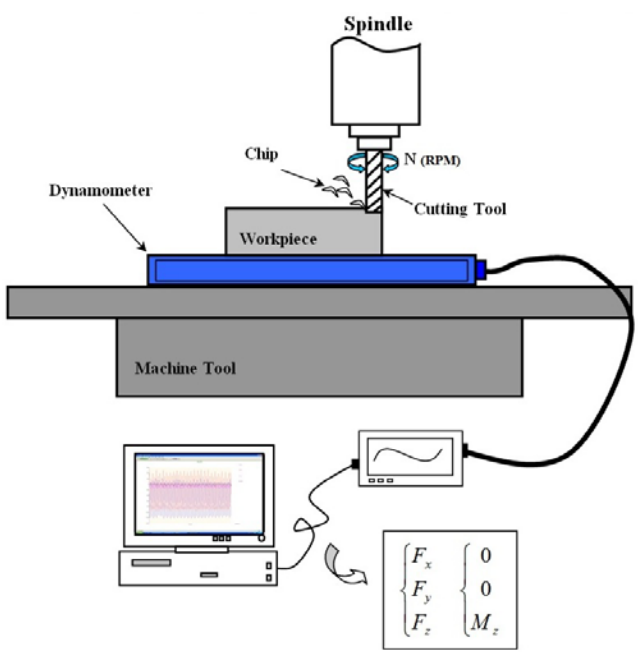

Fig. 1. The experimental set-up.

In order to evaluate the cutting ability, four face milling cutters were chosen, having the diameters of 16 mm, 20 mm, 22 mm and 25 mm. The milling cutters are made of HSS *Rp3* and *Rp4*, having two inclined teeth. The used HSS face milling cutters were selected using the recommendations of the zinc alloy products manufacturers.

The used machine tool was a milling machine TOS type FN32 made in Cehoslovakia.

KISTLER dynamometer has the possibility to measure simultaneously 6 components of the cutting efforts.

In the beginning the independent variables of the studied milling process are determined, variables which are the parameters of the cutting conditions. As well, the variation range of the variables and the structure of the experimental program should be determined.

Independent variables of the considered face milling cutting process are the following:

- cutting speed c [m/min],
- feed per tooth f_z [mm/tooth],
- cutting depth a_p [mm],
- milling cutter diameter d [mm].

Considering that for each variable three values along its variation range are considered, a complete factorial program of $3x3^3$=81 experiments results.

It could be difficult to work with this complex program structure. It is easier to split this program into 3 subprograms which consider only 3 variables, the fourth one being constant. In this case, the subprogram has 3^3=27 experiments.

Thus, considering that the constant independent variable has four values, the total program has $4x3^3$=108 experiments.

In the studied case, out of the four independent variables mentioned above, the milling cutter diameter is considered as constant independent variable.

The milling cutters have the following geometric parameters: rake angle γ=15°, clearance angle α=14°, teeth inclined angle ω=18°, main profile angle κ=90° and secondary profile angle κ=4°.

Corresponding to the diameter values, the milling cutters were symbolized as follows: milling cutter *A* having d_A=16 mm, milling cutter *B* having d_B=20 mm, milling cutter *C* having d_C=22 mm, milling cutter *E* having d_E=25 mm.

This means for each milling cutter there was a factorial program of 3^3=27 experiments. Multiplied by four (milling cutters), the total experimental program had 108 experiments.

With the recommendations for the cutting regime parameters and considering the possibilities of the used machine tool, the variation levels of independent variables were determined for each milling cutter (see table 1).

Table 1

Variation levels of the independent variables

Milling cutter A d_A**=16 mm,** z**=2 teeth**	**Code\Level**	**Symbol**		
		-1	**0**	**+1**
cutting speed c [m/min]	X_1	40.24	50.3	62.8
feed per tooth f_z [mm/tooth]	X_2	0.040	0.063	0.100
cutting depth a_p [mm]	X_3	1	2	4
Milling cutter B d_B**=20 mm,** z**=2 teeth**	**Code\Level**	**Symbol**		
		-1	**0**	**+1**
cutting speed c [m/min]	X_1	50.3	63	78.6
feed per tooth f_z [mm/tooth]	X_2	0.040	0.063	0.100
cutting depth a_p [mm]	X_3	1	2	4
Milling cutter C d_C**=22 mm,** z**=2 teeth**	**Code\Level**	**Symbol**		
		-1	**0**	**+1**
cutting speed c [m/min]	X_1	55.3	69.2	86.4
feed per tooth f_z [mm/tooth]	X_2	0.040	0.063	0.100
cutting depth a_p [mm]	X_3	1	2	4
Milling cutter E d_E**=25 mm,** z**=2 teeth**	**Code\Level**	**Symbol**		
		-1	**0**	**+1**
cutting speed c [m/min]	X_1	49.5	62.8	78.5
feed per tooth f_z [mm/tooth]	X_2	0.040	0.063	0.100
cutting depth a_p [mm]	X_3	1	2	4

3. Results of the experimental research

For each test the KISTLER dynamometer gives signals of force and torque generated during the cutting process.

Corresponding to the reference system of the KISTLER dynamometer (see figure 1) the cutting force F_X is measured along X axis and torque M_Z is measured around Z axis.

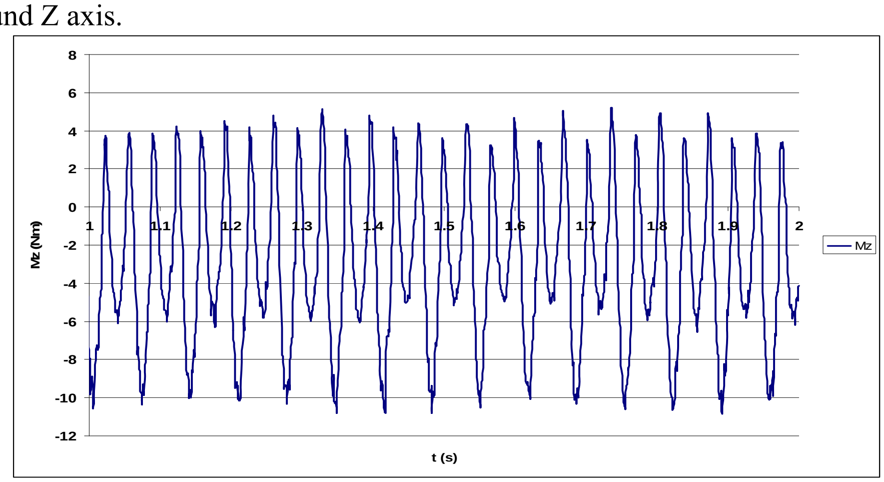

Fig. 2. Example of torque variation diagram

For each test two diagrams were recorded: one for the cutting force F_X and one for the torque M_Z, thus meaning a total of 2x108 diagrams. Just for example one of these diagrams is presented in Figure 2: diagram of torque variation in case of milling with the milling cutter B, with the following cutting regime: cutting speed 37.68 m/min, feed 0.04 mm/tooth and cutting depth 1 mm.

For each face milling cutter, 27 diagrams were determined to show the variation of the cutting force component F_X and cutting torque M_Z.

After data acquisition, using the software Dynoware KISTLER (belonging to the measurement system) each signal is analyzed, being obtained the diagrams of the influence of the cutting conditions parameters upon the cutting efforts.

The plots showing the influence of the cutting conditions parameters upon both cutting efforts were obtained: 108 graphics for the cutting force and 108 diagrams for cutting torque.

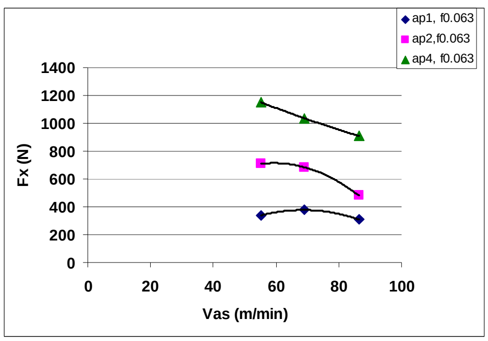

Fig. 3

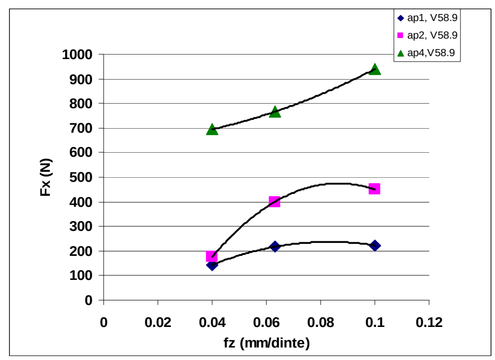

Fig. 4

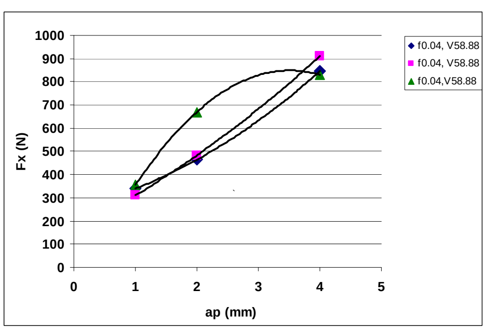

Fig. 5

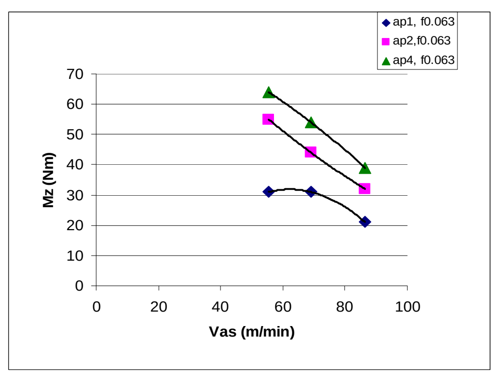

Fig. 6

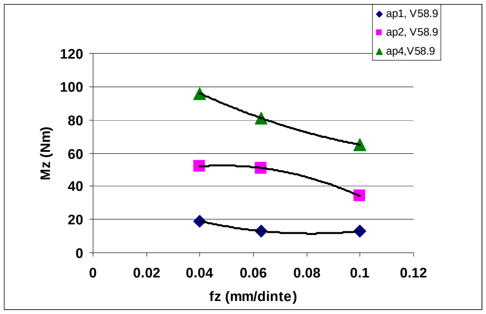

Fig. 7

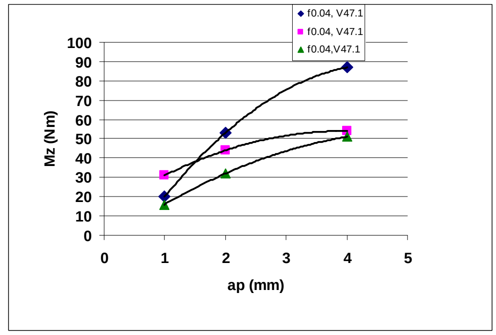

Fig. 8

Three graphics for the cutting force (figures 3, 4 and 5) and three graphics for the cutting torque (figures 6, 7 and 8) are presented. The cutting conditions are explained in the figures.

4. Interpretation of results

Based on these graphics and the considered values of cutting force and torque, the exponential functions to describe the influence of the cutting conditions upon cutting force and torque are determined.

The processing of experimental results processing, using the data acquired by KISTLER dynamometer and Microsoft Excel software, aim at determining the regression functions which are the mathematical models of cutting force and torque in case of zinc alloys milling.

The regression functions are exponential. The problem is to determine the coefficients and exponents of the complex exponential functions as following:

$$F_X = C_F \cdot a_p^{x_F} \cdot f_z^{y_F} \cdot c^{z_F} ; M_Z = C_M \cdot a_p^{x_M} \cdot f_z^{y_M} \cdot c^{z_M} \quad (1)$$

The determined exponential functions for each milling cutter are presented in the following.

Milling cutter A

$$F_X = 1609.96 \cdot a_p^{1.05013} \cdot f_z^{0.264168} \cdot c^{-0.29981} \quad (2)$$

$$M_Z = 62.387 \cdot a_p^{1.113144} \cdot f_z^{-0.45227} \cdot c - 0.68111 \quad (3)$$

Milling cutter B

$$F_X = 481.5616 \cdot a_p^{1.130939} \cdot f_z^{0.432019} \cdot c^{0.037405} \quad (4)$$

$$M_Z = 41.45725 \cdot a_p^{1.181513} \cdot f_z^{-0.15456} \cdot c^{-0.42149} \quad (5)$$

Milling cutter C

$$F_X = 2986.027 \cdot a_p^{0.694652} \cdot f_z^{0.109078} \cdot c^{-0.41342} \quad (6)$$

Milling cutter E

$$F_X = 322.4151 \cdot a_p^{1.24913} \cdot f_z^{0.06912} \cdot c^{-0.1026} \quad (7)$$

5. Conclusions

Analyzing the results, one can observe that the cutting efforts F_X force and M_Z torque are small compared to the case of cutting steel. They are similar to the case of cutting aluminum alloys.

For the variation range of the chosen cutting regime parameters the cutting efforts have the following limits:

- milling cutter *A*, d_A=16 mm: $F_X \in [182; 1267]$ N; $M_Z \in [9.4; 98]$ Nm;
- milling cutter *B*, d_B=20 mm: $F_X \in [126; 985]$ N; $M_Z \in [10.7; 74]$ Nm;
- milling cutter *C*, d_C=22 mm: $F_X \in [221; 1330]$ N; $M_Z \in [20; 97]$ Nm;
- milling cutter *E*, d_E=25 mm: $F_X \in [233; 1493]$ N; $M_Z \in [12; 127]$ Nm.

The greatest values occur at cutting with smallest cutting speed and highest cutting depth.

Influence of cutting speed on the cutting efforts

Study of the obtained diagrams reveals that both force F_X and torque M_Z have decreasing trend with the increase of the cutting speed (see figures 3 and 6).

In cases of milling cutters C and E situations when graphics of force and torque have a maximum point occurred: on a cutting speed range the force and torque increase, on another they decrease. This is similar to the cutting of steel.

The same conclusions result from the analysis of exponential regression functions. In all cases the exponents of the cutting speed are negative, showing the decreasing trend of the cutting efforts with the increase of the cutting speed.

Influence of the feed on the cutting efforts

Within the variation range of the cutting regime parameters the zinc alloy ZnAl4Cu1T has a different behavior related to the cutting force and torque: the cutting force FX slightly increases with the increase of the feed and the cutting torque decreases with the increase of the feed (see Figures 4 and 7).

The same conclusions result from the analysis of the exponents in the regression functions: the exponent y_F is positive and the exponent y_M is negative, showing the cutting force is increasing and the cutting torque is decreasing with the increase of the feed.

Influence of the cutting depth on the cutting efforts

Corresponding to the graphics in Figures 5 and 8, the cutting efforts increase with the cutting depth. The same conclusion results observing that the exponent x_F and x_M are positive, which shows the increase of the cutting efforts with the cutting depth.

R E F E R E N C E S

[1]. *M. Dumitraş*, Cercetări privind prelucrabilitatea prin aşchiere a alaijelor de zirconium (Research on the machinability by cutting zirconium alloys), Teză de dcotorat POLITEHNICA University of Bucharest, 2005.

[2]. *C. Minciu, E. Străjescu, M. Zamfirache,* The cutting capacity of the turning tools at the titan alloys machining, DAAAM Symposium – Maribor, 1994.

[3]. *D. Oprea*, Contribuții privind studiul prelucrabilității prin aşchiere la gaurirea aliajelor de aluminiu (Contributions to the machinability study for cutting holes in aluminum alloys) Teză de dcotorat, POLITEHNICA University of Bucharest, 2007.

[4]. *Iulian Popescu*, Aşchierea aliajelor de aluminiu (Cutting aluminun alloys), Ed. Tehnică, Bucureşti, 1974.

[5]. *M. Zamfirache*, Contribuții privind studiul prelucrabilității la strunjirea unor aliaje de titan-greu prelucrabile (Contributions to the study of machinability in turning titanium alloy-hard cutting), Teză de doctorat, Universitatea POLITEHNICA Bucureşti, 1995.

[6]. *** Internet information related to zinc alloy cutting from Dynacast Europe - Germany; ZINCALOY Inc. – Canada; INCALOY Inc. – Ontario, Canada; EASTERN ALLOYS Inc. – USA; HAUSE MACHINES. Inc. – Montpelier, France; WIKIPEDIA.

[7]. *A.Vlase, V. Bendic,* Theoretic-experimental research on Optimizing the Tools Working Life and the Cutting Speed Boring the W1-4306 Stainless Stell, Scientific Bulletin of Politehnica University of Bucharest, Tome LV, no. 1-2, pages: 183-189, Bucharest, 1993.