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CHIP FORMING AND FORMS IN MILLING AND DRILLING ZINC ALLOYS

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Abstract: *Manufacturing ability of a material and cutting capacity of a cutting tool, as well, are evaluated by means of several criteria, among which chip forming and forms criterion. This becomes important when for protection of human operator and technological system the detached chips must not be continuous (flowing chips) and must have small dimensions. Many important technological aspects – chip evacuation, cutting temperature, cutting efforts, cutting tool durability, surface roughness and secondary plastic phenomena – are solved depending on the chips' forming and forms. This paper presents a study on chip forming and forms in milling and drilling zinc alloy ZnAl4Cu1T, one of the most used zinc alloys.*

Key words: *cutting, chip, milling, drilling, zinc alloy, research.*

1. INTRODUCTION

The fact that chip formation and forms are important in manufacturing ability evaluation is proved by the attention of many researchers [5, 8, and 9] especially when it influences the quality of the cutting process.

Chip evacuation, together with cooling and lubricating the cutting tool, are done by the coolant liquid brought in the active cutting zone. In order to evacuate the chips from this zone they must have dimensions corresponding to the evacuation channels.

Fragmentation and crushing the chips are imposed by the necessity to continuously evacuate them with the coolant liquid, in order to avoid their blockage in the evacuation channels of the cutting tool. In case of fragile materials, as cast iron is, this problem is self solved, because these materials give breaking chips – small chips, not linked – which can be easily evacuated without blockages.

In case of tenacious materials, like steel, there are slip chips, linked, in some cases continuous (flow chips) which, in order to be evacuated and for protection reasons as well, must be fragmented and crushed. In these cases the cutting tool edge must have chip breakers, edged being fragmented along the chip width. Slip chips, depending on the plastic deformation capacity and the ratio between normal and tangential stresses are divided into fragmented slip chips (having relatively small length), jointed slip chips (bonded fragmented slip chips) and flow chips (continuous, having big lengths).

An analysis of chip forming and a classification of chip forms considering the mechanical properties of the workpiece material and the influences of the cutting regime parameters are presented in technical literature influenced by the former USSR specialists – Davidenko-Friedman diagram – [1,3,4, and 6].

American technical literature [2, 7], without specifying theoretical support, presents a classification of chip forms only for aluminium alloys cutting, in five groups:

A – very short, crushed chips, excellent finish;

B – curved, helical, short chips, very good finish;

C – continuous, not helical, long chips, good finish;

D – continuous, helical, long chips, satisfactory finish;

E – non uniform, long, jagged chips, unsatisfactory cutting.

This classification does not consider the properties of the workpiece material, but indicates the quality of cutting operation. It must be underlined the quality diminishes when the length of the chip increases.

In technical literature there are other ways to classify the chip forms, with little applicability, for example the international standard ISO 3685 (Table 1).

Quantitative description (measurement) of chip forming and forms can be done by determination of chip crush coefficients, which give the measure of the plastic deformation energy needed to transform the cutting layer into chips.

Table 1

Chip forms classification in ISO 3685

Cutting		Favourable	Unfavourable	
Straight	1 Ribbon Chips	1.2 Short		1.1 Long/1.3 Snarled
Mainly up curling	2 Tubular Chips	2.2 Short	2.1 Long	2.3 Snarled
	3 Spiral Chips		3.1 Flat/3.2 Conical	
Mainly Side curling	4 Washer type Chips	4.2 Short	4.1 Long	4.3 Snarled
Up and Side Curling	5 Conical Helical Chips	5.2 Short	5.1 Long	5.3 Snarled
	6 Arc Chips	6.2 Loose/6.1 Conn		
	7-8 Natural Broken Chips	7 Elemental		8 Needle

Cutting theory uses three plastic deformation coefficients to characterize plastic deformations of the real chip, corresponding to its nominal dimensions:

- shortening coefficient, $k_l = l / l_1 = (1.5 \ldots 4.5)$;
- widening coefficient, $k_b = b_1 / b = (1 \ldots 1.5)$;
- thickening coefficient, $k_a = a_1 / a = (1.5 \ldots 4.5)$,

where *l, b, a* represent the length, wideness and thickness of the theoretical chip (cutting layer) and l_1, b_1, a_1 represent the length, wideness and thickness of the real chip (detached chip). Just for information, the usual values of the three coefficients are given in the brackets. It must be underlined that along length and thickness of the chip deformations are more important than along the wideness of the chip.

2. EXPERIMENTAL RESEARCH SET

2.1. Milling case

The experiments to evaluate chip forming and forms at milling zinc alloys were performed together with experiments to determine cutting efforts and surface roughness. During each experiment samples of resulted chips were preserved.

The experimental stand is presented in Fig. 1.

The milling experiments were performed in the following conditions:

- workpiece material was plates of zinc alloy ZnAl4Cu1T;
- four end milling cutters were chosen (symbolized *A, B, C* and *E*), 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 machine tool was a milling machine TOS Type FN32 Cehoslovakia;
- no cooling during end milling cutting process;
- cutting regimes were chosen considering the possibilities of the machine tool. For each milling cutter diameter were chosen three values for the cutting speed, three values for the feed and two values for the axial cutting depth, as following:
    - d_A = 16 mm: v_c = 40.2/50.3/62.8 m/min; f_z = 0.04/0.063/0.1 mm/tooth, a_p = 2/4 mm;
    - d_B = 20 mm: v_c = 50.3/63/78.6 m/min; f_z = 0.04/ 0.063/0.1 mm/tooth, a_p = 2/4 mm;
    - d_C = 22 mm: v_c = 55.3/69.2/86.4 m/min; f_z = 0.04/ 0.063/0.1 mm/tooth, a_p=2/4 mm;

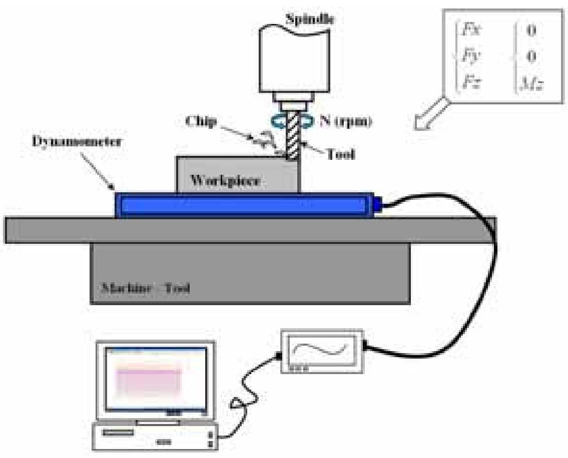

Fig. 1. Structure of the experimental stand.

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    - d_E = 25 mm: v_c = 49.5/62.8/78.5 m/min; f_z = 0.04/ 0.063/0.1 mm/tooth, a_p = 2/4 mm.

A smaller cutting depth (*ap* = 1 mm) does not influence significantly the chip form. This was proved experimentally. As well, in such case it would be difficult to evaluate the chips type (slip chips or breaking chips).

2.2. Drilling case

The experiments to evaluate chip forming and forms at drilling zinc alloys were performed together with experiments to determine cutting efforts. During each experiment samples of resulted chips were preserved.

The experimental stand is presented in Fig. 1.

The drilling experiments were performed in the following conditions:

- workpiece material was plates of zinc alloy ZnAl4Cu1T, clamped on the table of KISTLER dynamometer used for cutting efforts measurement;
- HSS Rp4 drills, with normal construction (N type), having standard geometry with point angle of 118° and helical channels angle of 30°. The drills had helical channels obtained by milling. Three drills were used, having the following diameters: d_{bA} = 6 mm, d_{Bb} = 8.5 mm and d_{bC} = 12 mm;
- the used machine tool was a milling machine TOS Type FN32;
- no cooling during drilling process;
- cutting regimes were chosen considering the possibilities of the machine tool. For each drill diameter were chosen three values for the spindle rpm and three values for the feed:
    - n_c = 1000/1250/2000 rpm;
    - f = 0.04/0.063/0.1 mm/rev.

3. RESULTS AND CONCLUSIONS

3.1. Milling case

The samples of resulted chips were collected to appreciate the chip forms, especially qualitatively and less quantitatively, in the known conditions. For this purpose there were organized some exhibition boards with the samples of chips preserved from each experiment.

From the very beginning, at an overall appreciation it must be underlined the material ZnAl4Cu1T is tenacious, with a great plastic deformation capacity, because in all cases the chips were of slip chip type, of all three divisions (fragmented, jointed, continuous). On all chips can be seen the flow lines, which do not occur in case of breaking chips. This conclusion leads to the fact that zinc alloys have a good or very good cutting ability.

Analyzing the forms and dimensions of the chips shows the chip forms change from fragmented chips to jointed and even flow chips with the increase of the cutting regime parameters. Breaking chips did not occur at all.

In all cases, on the detached chip visible slip lines occurred, which means along these directions tangential stresses had values above the flowing stress. Cutting speed increase leads to more visible slip lines. As well, cutting depth, feed and milling cutter diameter increase lead to more visible slip lines.

At the increase of the milling cutter diameter some aspects occur:

- the length of the jointed chips increase, the chips type change from fragmented chips to jointed, even flow chips; the phenomenon is more visible with the increase of the cutting depth;
- with the increase of the cutting regime parameters, like feed and cutting speed, crowded chips occur. Because of the increase of cutting speed the cutting temperature increase, and if the chips volume is enough the chips are crowded, even bonded. In this respect, it would be useful to use cutters with bigger evacuation channels between the teeth of the cutting tool instead the standardized cutting tools;
- with the increase of the diameter from 16 mm to 25 mm it was observed the detached chip segment has a trend to become from curved to straight.

As in other tenacious materials cutting cases, it was observed the chip surface in contact with the rake face of the cutting tool is shiny, having a small roughness. This means there is great friction between the chip and rake face of the cutting tool, with great mechanical power consumed. It was also observed the length of the jointed or flow chips increase with the increase of both feed and cutting depth.

For a specific value of feed and cutting depth the length of the jointed chips increase with the increase of the cutting speed. This means the increase of cutting speed leads to the increase of the plastic deformation capacity of the zinc alloy, which is explained by the increase of the cutting temperature.

A quantitative approach was used upon the aspects related to chip forming and forms, after the qualitative approach presented before. This quantitative approach means the determination of the chip crush coefficients, which depend on the mechanical power used for plastic deformation along chip's dimensions.

In this research the widening and thickening coefficients were determined. For this purpose, the real wideness and thickness of the real chip were measured, and compared to the nominal cutting depth and feed per tooth.

The crush coefficients ranges are presented in Table 2.

Correct measurement of the real chip thickness was altered by the existence of the slip lines on the chip, even if their height is relatively small.

It was determined that along the wideness of the chip the widening coefficient was relatively small, showing small deformations, but along the thickness of the chip the thickening coefficient is relatively big.

Generally, the shortening coefficient is equal to the thickening coefficient.

The methodology to determine the chip forms and forming presented in this paper is used to evaluate the cutting ability of any workpiece material, not only zinc alloys, and also to evaluate cutting capacity of any cutting tool.

Just for example, Fig. 2 presents one exhibition board in case of milling with milling cutter *E*.

Table 2

Crush coefficients of the measured chips

Widening coefficient, k_b	1.1 … 1.75
Thickening coefficient, k_a	1.4 … 4.5

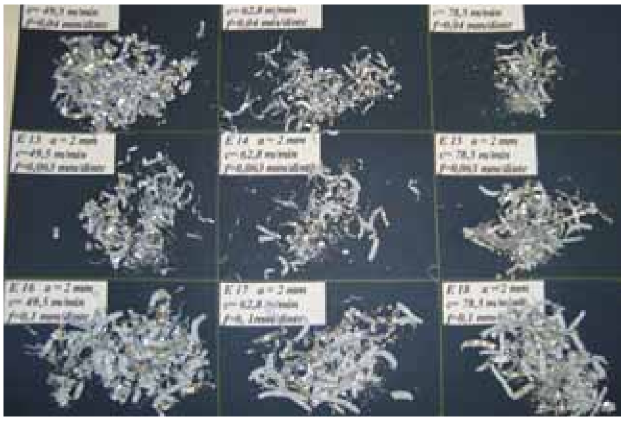

Fig. 2. Chip forms in milling.

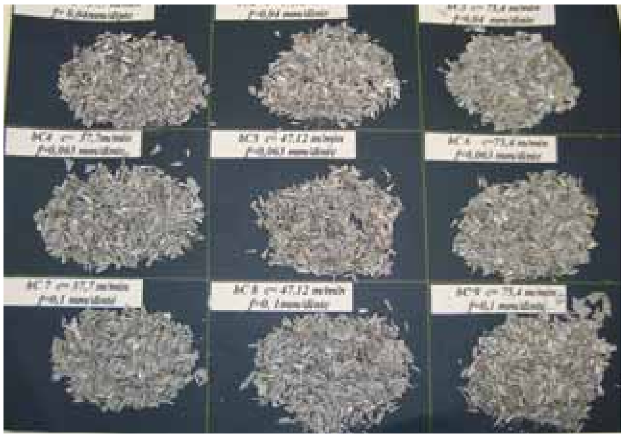

Fig. 3. Chip forms in drilling.

Considering all the observations and conclusions presented in this research, the influence of the cutting regime parameters upon the chip forming and forms and the classification of the chips versus the mechanical properties of the workpiece material it can be stated the zinc alloy ZnAl4Cu1T has a very good milling ability.

3.2. Drilling case

With the presented cutting regime parameters drilling operations were performed and chip samples were collected for each of the 27 experiments, being made exhibition boards with the preserved chip samples as in the case of milling.

In order to make qualitative appreciations on chip forming and forms, especially to appreciate qualitatively the influence of cutting regime parameters upon the chip forming and forms the exhibition boards were organized using the order imposed by the cutting regime parameters.

Each exhibition board corresponds to the drilling operation with a specific drill diameter. For example, Fig. 3 presents the exhibition board in case of drill *C*.

In all cases, considering the length of chips, the existence of slip lines, the chip form and so on, it can be stated the studied material is tenacious, occurring slip chips of all types: fragmented slip chips (having relatively small length), jointed slip chips (bonded fragmented slip chips) and flow chips (continuous, having big lengths). Breaking chips did not occur at all.

Chip length is proportional to the drill diameter, being greater with the increase of the diameter.

Even if they are more difficult to be seen because of the chip rolling, the slip lines exist, confirming the material is tenacious and the detached chips are slip chips.

In some cases flow chips occurred, having big length and being helical.

The cutting speed has a small influence upon the chip length, but the feed has an significant influence, its increase leading to the increase of the chip length.

The fact that in all cases the chips are of slip type shows the cutting process is performed in good conditions, being uniform, with relatively small vibrations. This statement is confirmed also by the American standards and ISO 3685. Corresponding to the American standards the chips belong to A and B groups (see 1-st paragraph). This shows the studied zinc alloy ZnAl4Cu1T has a good cutting ability.

In case of high cutting speeds the diminish of the chip length was observed (see Fig. 3, along horizontal line). At a specific feed, the chip length diminishes with the increase of the cutting speed.

As in case of milling, zinc alloys have a good cutting ability if considering that in drilling burr did not occur.

During the drilling operations deposit cutting edge and sticking chips on the evacuation channels did not occur. It is probable the cutting temperature did not rise so much the workpiece material should become plastic.

Finally, it can be stated the studied zinc alloy has a very good drilling ability, because the detached chips are relatively small, fragmented or jointed, which makes that their evacuation along the evacuation channels of the drill is done easily. There is not the risk of chips jam, the drilled hole roughness is not affected, the deposit cutting edge does not occur, the chips do not stick on the helical evacuation channels of the drill.

4. FURTHER RESEARCH

The study of chip forming and forms did not evolve spectacularly. It is based on the observation of the real chips obtained in the cutting operations and their comparison with the theoretical chips.

Theoretical chips have dimensions determined by the cutting regime parameters as feed, cutting depth and length of the cutting trajectory.

Real chips have dimensions determined by the real forming process, respectively the chip's plastic deformation and breaking.

Most of the research on chips forming and forms is based on observation, meaning it is qualitative.

The only quantitative parameters are the chip's plastic deformation coefficients, as shown in the first paragraph.

In real cases, the problem to change chip forming and forms in order to avoid some due difficulties is solved by several tries.

It should be useful for the engineers concerned in (metal) cutting technology to have an instrument to predict the chip form.

This predictive instrument could be obtained at least in the following research ways:

- determination of mathematical models (functions) similar to Taylor models or other modern ones, to predict chip form depending on the cutting process parameters. Like in case of Taylor functions determination, these models should be obtained using observation of the cutting process, which means a lot of time involved;
- determination of simulation models (mathematical or IT), which predict the chip forming and forms based on the study of plastic deformation process. If such a method would be found the time needed for the research should be restricted to only issue the algorithm and verify several real cases, but the problem should be finally solved.

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