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CHIP DEFORMATION IN HIGH SPEED FACE MILLING OF THE HARD TOOL STEEL X210CR12

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Abstract**—**High speed machining of hard materials is considered to be an efficient machining technology for die and mold industry. The paper proposes an investigation on the deformation of chips generated in high speed machining of tool steel X210Cr12. An experimental research was designed and materialized, by taking into consideration a face milling process. A power type function empirical mathematical model was established in order to highlight the influence exerted by the steel hardness, milling speed, feed rate and depth of cut on the chips apparent density. Graphical representations confirmed the increase of the apparent density when the steel hardness and milling speed increase, while the increase of the feed rate and depth of cut determine a decrease of the chips apparent density.

Keywords**—**Face milling, high speed, chips apparent density, hardness, milling speed, feed rate, depth of cut.

I. INTRODUCTION

CUTTING PROCESS is a machining process based on the material removal from the workpiece as a result of pressing the workpiece material by the tool face up the exceeding the material shearing resistance and generation of the chips.

Essentially, the cutting tool arrives in the situation of pressing the workpiece material due to existence of the main cutting motion and the feed motion, respectively, performed by cutting tool and/or workpiece.

In order to meet consumer demands concerning high precision mechanical parts at low prices and short lead times, the optimization of existing machining technologies and the investigation of new technologies became more and more frequently addressed.

The development of machine cutting technologies and the researches in tool making industry had op6ened new opportunities for investigating and applying high performance machining operations.

In the last decades, one of the main directions addressed by the researchers in order to develop new advanced cutting technologies was focused on increasing processes productivity. In cutting processes, productivity can be improved by machining with higher values of machining parameters and by reducing non-cutting times. Research studies conducted by Solomon shown that the increase of cutting speed generates the increase of cutting temperature only to a certain limit and beyond that limit the cutting temperature starts to decrease [1].

As above mentioned, the material is detached from the workpiece by means of chips. Because the chips are generated in certain cutting conditions, the study of the chips could offer significant information about the initiation and development of the cutting process.

On the other hand, the last decades confirmed an extension of using the so-called *hard materials*. Such materials are able to ensure the increase of the parts and tools service life, by their high mechanical properties and high wear resistance. Due to the fact that the material of the cutting tools must be with at least some units of Rockwel hardness harder than the workpiece material, the cheapest material able to correspond to this request was found as being the tool steel.

Other characteristic of the actual evolution of the cutting processes was the increase of the cutting speed; in this way, the concept of *high speed machining* is frequently used in the researches concerning the current trends in the cutting processes.

Thus, one can take into consideration the problem of high speed milling of the hard tool steels; one noticed the preoccupation of the researchers concerning a better knowledge of the high speed milling process and the possibility to improve the results of technological interest specific to this process.

There is the convention that the high speed machining/ cutting of hard materials corresponds to the situations when cutting speed is higher than 5.08 m/s and the material hardness is higher than 48 HRC [2].

Cui et al. appreciated that in high-speed face milling AISI H13 steel, the chip shape and chip color could offer information concerning the evolution trend of the surface roughness when the cutting speed is changing [3]. In another paper, Cui et al. noticed that the chip segmentation has a minimum to the variation of the cutting speed; they considered that there are correlations among cutting forces, chip formation, and tool wear in high-speed milling of AISI H13 steel, when cubic boron nitride tools are used [4].

Mian et al. used the wavelet transformation technique in order to decompose the acoustic emission appeared during the orthogonal micromilling process; they concluded that there are correlations between the computing energies corresponding to the deformation mechanism and chip morphology [5].

Toh developed investigations concerning the chip surface temperature in the case of up and down milling orientation in high speed rough milling of test pieces made of hardened steel; he noticed that this temperature is lower in up milling in comparison with the down milling, when various cutting conditions are used [6].

Zhang and Guo examined the chip morphology by means of optical microscopy and scanning electron microscopy; they considered that saw-tooth chips and white layers could appear only when certain combinations of the cutting parameters (high cutting speed and feed rate) are used [7].

II. Premises concerning the characteristics of chips resulted in high speed face milling of hard tools steels

The face milling supposes the rotation of the milling tool found in contact with the workpiece, while this workpiece or just the milling tool performs the feed motion. As a consequence of the pressure exerted between the active surfaces of cutting tool and the workpiece material, a strong deformation affects the workpiece material and there are moments when small quantities of workpiece material are detached forming chips -Fig. 1.

If the workpiece material is a plastic one, a relatively continuous chip could be generated; if the workpiece material is hard (and this is the case of tool steels), distinct phenomena could be expected. The chips could be segmented; however, due to the high temperature developed in the interface tool-test piece, the material behavior could be changed in comparison with the situation specific to common milling speed.

In order to characterize the chips generated by a cutting process, various parameters could be used. The most known such parameters is the coefficient of chips plastic deformation; this coefficient is defined could be

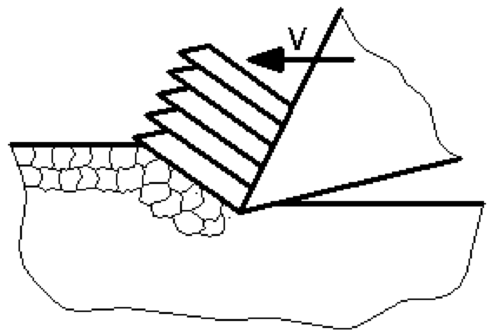

Fig. 1. Chip generation during the process of high speed milling of hard materials.

defined by taking into consideration the dimensions of the chip and the dimensions of the surface layer able to generate the chip. Another parameter is *the apparent density of chips*; this parameter can be determined as a ratio between the chips mass M_c and the chips apparent volume V_c:

$$\rho_a = \frac{M_c}{V_c} \quad (1)$$

III. Experimental results

An experimental research was designed and developed in order to establish the influence exerted by the Rockwell hardness and cutting parameters (milling speed v, feed rate f and depth of cut a_p) on the apparent density of the chips generated by high speed milling of test pieces made of hard steel [8].

The milling machine tool FU25 (made in Cugir - Romania) was used as machine tool; the maximum rotation speed for this machine tool is of 2000 revs/min; in selecting the milling equipment, one took also into consideration the necessity to ensure a high rigidity of its subassemblies. The tool was a special face mill having a diameter of 130 mm. Carbide tips (type 9603A KC1 IC12) produced by the company Franken were assembled in the rigid tool body; these tips are covered with a layer

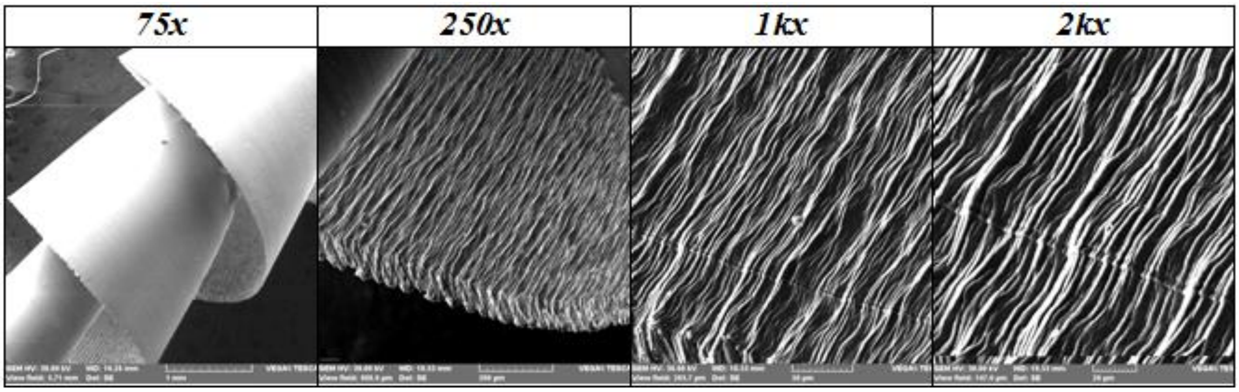

Fig. 2. Aspect of the chips obtained by face milling on test pieces of tools steel X210Cr12 (*HRC*=59 HRC, v=408.4 m/min, f=0.63 mm/rot, a_p=0.5 mm; images obtained by means of the scanning electron microscope Vega II Tescan LSH).

TABLE I
VALUES OF INDEPENDENT VARIABLES AND CHIPS APPARENT DENSITY CORRESPONDING TO THE EXPERIMENTAL RESEARCH

Exp. No.	*HRC* hardness	Cutting tool *v*, m/min	Feed rate *f*, mm/rev	Depth of cut a_p, mm	Chips apparent density ρ_a, g/cm^3
1	50	408.4	0.16	0.2	
2	50	571.8	0.25	0.5	
3	50	817	0.63	0.8	
4	55	408.4	0.25	0.8	
5	55	571.7	0.63	0.2	
6	55	817	0.16	0.5	
7	62	408.4	0.63	0.5	
8	62	571.7	0.16	0.8	
9	62	817	0.25	0.2	

of aluminum and titan nitride, in order to improve the tool life.

A fractional factorial experiment with four independent variables at three levels was designed in order to develop the experimental research.

As material for test pieces, the carbon steel type C80U SR EN ISO 4957:2002 was selected; this steel has contains about 2.0 % carbon, 12.0 % chrome, 0.3 % manganese. Various hardness of the steel were obtained

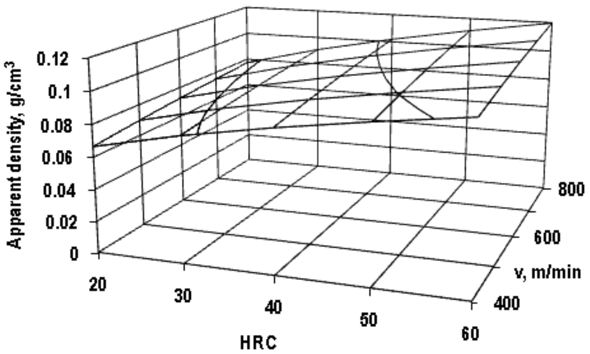

Fig. 3. Influence exerted by the test piece material hardness *HRC* and milling speed *v* on the chips apparent density ρ_a (f=0.3 mm/rev, a_p=0.5 mm).

by applying adequate heat treatment; in this way, the hardness of the test pieces were of 54-55 HRC, 58-59 HRC and 63-64 HRC.

The volume of the chips detached in specified milling conditions was determined by introducing the chips in a beaker glass; the mass of the chips was measured by means of an analytical balance type Partner Radwag AS20, which ensures an accuracy of 0.00001 g.

Some details concerning the chips shape could be observed in fig. 2; the images were obtained by means of the scanning electron microscope Vega II Tescan LSH.

The values of the independent variables and the output parameter (chips apparent density) are presented in table 1. The experimental results were processed by means of specialized software (Curve Expert) and the following power type empirical mathematical model was established:

$$\rho_a = \mathbf{0.00402} HRC^{0.397} v^{0.218} f^{-0.105} a_p^{-0.266} \quad (2)$$

On the base of the empirical relation (1), the diagrams from fig. 3, 4, 5, 6 and 7 were elaborated.

The power type function empirical mathematical model corresponding to the relation (2) and the graphical representations from fig. 3-7 show that while at increase of the hardness HRC and milling speed v, the apparent density ρ_p increases, too (since in the power type function

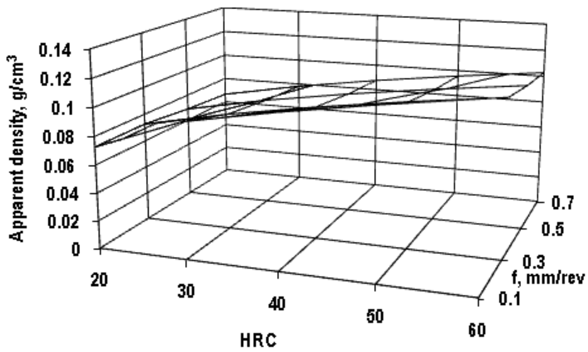

Fig. 4. Influence of the test piece material hardness *HRC* and feed rate *f* on the chips apparent density ρ_a (v=600 m/min, a_p=0.5 mm).

empirical model (1) the exponents attached to the independent variable *HRC* and *v* have positive values), the increase of the feed rate *f* and depth of cut a_p led to a decrease of the apparent density ρ_p (in the power type function (2), the exponents attached to the independent variables *f* and a_p have negative values). The decrease of the apparent density ρ_p when the depth of cut a_p increases could be generated by a strong plastic deformation of the workpiece material when the depth of cut increases.

From the four independent variables took into consideration (hardness *HRC*, milling speed *v*, feed rate *f* and depth of cut a_p), the most significant influence is exerted by the hardness *HRC*, since the value of the

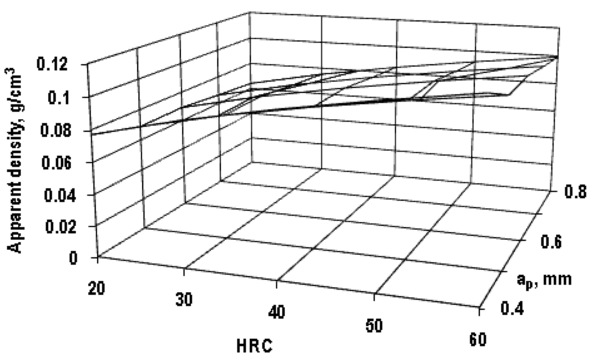

Fig. 5. Influence of the test piece material hardness HRC and depth of cut a_p on the chips apparent density ρ_a (v=600 m/min, f=0.3 mm/rev).

exponent attached to this variable in the power type function (2) has the maximum absolute value (0.397); at the same time, the minimum influence is exerted by the feed rate *f*, the exponent attached to this independent variable having the minimum absolute value (0.105).

IV. CONCLUSIONS

The initiation of the milling process determines a strong plastic deformation of the workpiece material up to the moment when a shearing effect develops and chips are generated. As a consequence of this plastic deformation of the material and influence of other milling conditions, various shapes of chips could appear. The process has specific aspects in the case of high speed milling of workpieces made of hard materials, so that the case of steel X210Cr12 is. The degree of chips plastic deformation could be characterized by many specific sizes, the apparent density being one of them. An experimental research was designed and developed in order to highlight the influence exerted by the workpiece material hardness *HRC*, milling speed *v*, feed rate *f* and depth of cut a_p on the apparent density ρ_p of the chips. On noticed that the increase of the *HRC* hardness of the workpiece material and milling speed *v* determine an increase of the chips apparent density, while the increase of feed rate *f* and depth of cut a_p generate a decrease of the chips apparent density. Some graphical representations were elaborated in order to illustrate the influence exerted by the workpiece material hardness, milling speed, feed rate and depth of cut on the chips apparent density in the case of high speed milling of the tool steel X210Cr12. In the future, there is the intention to develop a research about the possible correlations that could exist between the chips apparent density and other output variables, so that the surface roughness and cutting forces are.

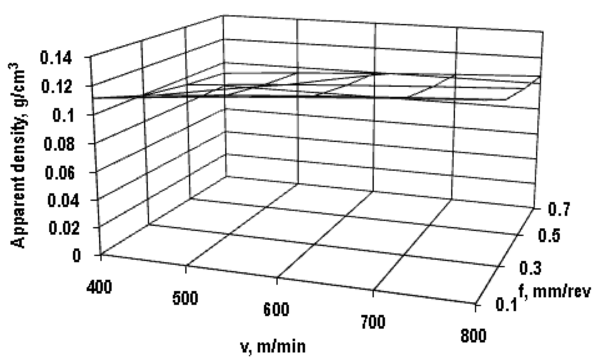

Fig. 6. Influence of the milling speed *v* and feed rate *f* on the chips apparent density ρ_a (HRC=55, a_p=0.5 mm).

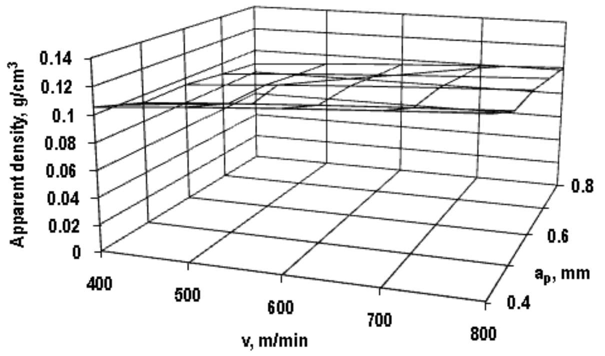

Fig. 7. Influence of the milling speed v and depth of cut a_p on the chips apparent density ρ_a (*HRC*=55, *f*=0.3 mm/rev).

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