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STUDY ON CHIPS' MORPHOLOGY AT CONVENTIONAL AND ENVIRONMENTAL-FRIENDLY TURNING OF 42CrMo4 ALLOYED STEEL

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Abstract: *This paper is a part of a large research concerning the orthogonal turning of 42CrMo4 alloyed steel, a widely used material, under conventional and environment-friendly cutting conditions. The approach consists of series of tests and an experimental study with respect to cutting parameters and conditions such as: depth of cut, cutting speed, feed rate and flow rate of cooling-lubrication environment. Two ecological cooling-lubricating techniques have been used: dry cutting and minimal lubrication. Just for comparison reasons, the conventional flood cooling has also been considered. The goal of the study concerns the analysis of chips shape, an important criterion for evaluation of the cutting processes. The results show a limited influence of the cooling and lubrication conditions on changes in chip's morphology and shape, when the feed rate ranges in low and medium domain. More convenient and easier to remove chips are getting by increasing the depth of cut and feed rate.*

Key words: *turning; dry cutting; lubrication; cooling; surface roughness; machine load; chip formation*

1. INTRODUCTION

Considering the limited implementation of dry cutting (DC), several cutting practical alternatives have been implemented: minimum quantity lubrication (MQL), cryogenic machining (CM), high pressure jet assisted machining (HPJAM) [1, 2, 5, 6, 7, 34]. By simply eliminating cutting fluids usage and applying one of these methods, there would be a huge progress for sustainable technologies [3, 4, 8, 12]. MQL can be considered an intermediate way between flood lubrication (FL) and DC. Referred also as near-dry machining (NDM), micro-lubrication or pseudo-dry cutting, it is highlighted by both ecological and financial benefits, being recognized as a practical route to the green manufacturing [9, 10, 34]. Thus, all problems associated with cutting fluids could be eliminated and many advantages gained such as: avoidance of high costs for cutting fluids purchasing, reducing of costs for chips treating, avoidance of storage, supply, treatment and transport of cutting fluids, avoidance of disposal for cutting fluids in form of waste [1, 5, 11, 16, 34].

Several investigations have been done related the implementation of green cutting methods in the practice. In the case of turning AISI-1040, Islam et al. have analyzed in [16] the influence of environment-friendly cutting methods on cutting zone temperature, chip morphology and surface's accuracy in AISI 1040 turning. The implementation of MQL with vegetable oil in AISI 9310 turning has been studied by Khan et al [17].

As it is well known, the cutting starts with an intensive plastic deformation of work piece material for forming chips. The theoretical research and practical experience show that the complete elimination of coolants and lubricants from cutting processes of several materials requires an appropriate choosing of cutting parameters [13, 14, 15, 18, 29, 30, 33, 34]. Obviously, DC not only leads to increasing of the temperature causing higher tool wear and tools durability decreasing, but also to difficulties in chips formation and inappropriate evacuation of chips. An important evaluations criterion of the machining process is the chips shape, being influenced by:

• Type of interaction at the chip-tool interface;

• Requirement of specific energy in machining operation;
• Behavior of the blank material under certain cutting conditions.

Chip formation is an important factor, if the chips have to be easily removed from cutting area, especially when processing difficult-to-machine materials. The knowledge on the chip shape can increase the manufacturing efficiency with respect on tool life and part's accuracy.

The mechanism of chip formation is quite similar for most machining processes, and it needs to be researched for finding the optimal cutting parameters and conditions. CNC machine tools allow manufacturing parts at faster rates and it has become important to provide algorithms for determining the optimal cutting parameters [31, 32, 34, 35]. The chip formation has also consequences on cutting productivity and operators' safety. Due to their shapes, the chips produced in processing of metals or alloys can be classified into some categories: discontinuous chips come off as small particles, continuous chips like a long ribbon, and continuous chips with a built up edge.

In terms of chip removal possibilities, machined surface quality, continuous machine operation, and machine operator's safety, the chips can be divided into two classes: acceptable (tubular, conical, ribbon-shaped short, helical short, etc.) and unacceptable (ribbon-shaped long, tubular, conical, helical long, etc.) [18, 20, 22].

Material strength and hardness are factors influencing the chips shape, deformations and stresses in the cutting zone [18, 19]. Beside the properties of the work piece material, the cutting circumstances are decisive in establishing the conditions for chips morphology as demonstrated in [17]. Some developments in chip control research and theirs applications are presented in [18]. Other materials, like hardened steels Ti-6Al-4V, alloy Y5553, have been studied in terms of chip formation mechanism [20-25].

Chips produced from machining advanced materials such as reinforced composites or ceramics are quite different in physical nature than those resulted in metal machining. A new classification system has been developed by Shih et al. in [26] for defining 7 chips' types obtained in machining nonmetallic elastomers under different cutting conditions. Dabade et al. in [27] and by Zenia et al. in [28] presented some studies related to chip formation and defects of the processed surface when cutting Al/SiCP composites with metallic matrix.

The motivation of present work is given by the need to investigate the implementation opportunity of environment-friendly cutting methods. The investigations should cover several materials or materials' categories. The results could be (and are) different in any case. This work is focused on 42CrMo4, alloyed steel with wide range of applications.

2. MATERIALS AND METHODS

The study presented in this work is a part of a large research concerning the orthogonal turning of 42CrMo4 [34] and aims to analyze the chips' morphology on turning using two strategies for metal working fluid application (FCL and MQL) and on DC conditions. The next goal refers at the influence of the machining conditions on chip formation for getting the most favorable chip form. The series of experiments were performed on the CNC-lathe LYNX 220 of 15 kW power (Figure 1) by external turning of alloyed high grade steel 42CrMo4 [34].

Fig. 1. Experimental setup for turning of 42CrMo4.

This material is considered being difficult to machine due to its mechanical properties (high strength, ductility and work hardening tendency) given in Table 1, beside the chemical composition.

Table 1

Properties of 42CrMo4 alloyed steel.

Material: 42CrMo4						
Chemical composition						
C	*Si*	*Mn*	*Cr*	*Mo*	*S*	*Other*
0.42	0.25	0.75	1.1	0.22	<0.035	(Pb)
Mechanical properties						
0,2% proof stress $R_{p0,2}$ [N/mm²]		Tensile strength R_m [N/mm²]		Fracture elongation A_5 [%]		HB
min. 650		900-1100		min. 12		255

The work piece to be processed had the following dimensions: diameter d= Ø 75 mm, length L= 300 mm. As cutting tool has been used a multilayer coated carbide insert CNMG 120408-MP P20 (Figure 2), fixed on tool holder PCLNL 2525 M12 [34]. The first layer of insert coating consists of Al_2O_3 that provides a very good heat resistance and minimizes the crater wear progress. The second layer of TiCN delivers the wear resistance, while the carbide substrate (P20) ensures stable cutting and avoid the cracks propagation.

Cutting edge length LE=12 mm, IC=12.7 mm
Insert thickness (S) = **4.763 mm**
Nose radius: 0.8 mm
Shape: 80° Rhombic
Chip breacker: MP
Substrate: HC
Coating: CVD Ti(CN)+Al_2O_3+TiN

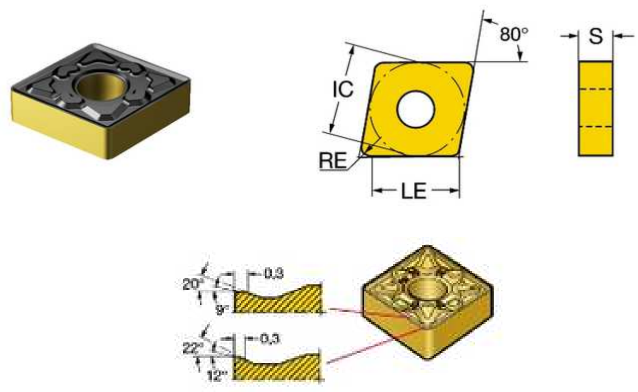


Fig. 2. Insert shape and geometrical parameters.

The recommended cutting parameters for this insert falls within the following ranges: $v_c = 190\text{-}310$ *m/min*, $f = 0.15\text{-}0.5$ *mm/rev*, $a_p = 0.3 - 4$ *mm*.

For reproducing the orthogonal turning the following angles have been considered: $\kappa_r = 95°$ and $\lambda_s = 0°$. The rake angle of tool takes typically values from $+15°$ to $-6°$ and strongly influences the deformation of work piece material, forces, chip thickness, temperature in the cutting area. The insert used in this research had a negative rake angle of $-6°$.

For a short chip-tool contact length, the chips need to be broken into small segments of regular dimension and form.

In turning of 42CrMo4, the insert used had a *MP* breaker with a butterfly shape allowing a broad range of cutting conditions, being recommended for medium cutting. The steep gradient of breaker butterfly protrusion increases chip breakability.

The cooling-lubrication effect in was also considered. The turning trials have been performed under following conditions: DC, MQL and FL.

Lubrimat L60 Steidle with vegetable oil *Lubrimax* has been used as dispersing device for pseudo-dry turning. Emulsion *SAROL 474 EP* has been used for conventional flood lubrication. A cutting fluid flow rate obviously corresponds to the DC turning sequences.

The cutting fluid rates, cutting parameters considered by trials and their variation levels are given in Table 2.

Table 2

Cutting parameters.

Parameter	Level		
	1	**2**	**3**
P1: Depth of cut, a_p *[mm]*	0.3	1	2
P2: Feed rate, *f [mm/rev]*	0.15	0.2	0.3
P3: Cuting speed, v_c *[m/min]*	200	250	300
P4: Cutting fluid flow rate, q_l *[l/h]*	0	0.024	90

Table 3

Matrix L20 –Combination of cutting conditions for turning trials.

Trial no.	Levels of				***P1:*** a_p *[mm]*	***P2:*** *f [mm/rev]*	***P3:*** *v [m/min]*	***P4:*** q_l *[l/h]*
	P1	***P2***	***P3***	***P4***				
1	1	1	2	3	0.3	0.15	250	90
2	1	2	2	2	0.3	0.2	250	0.024
3	1	3	3	3	0.3	0.3	300	90
4	2	1	2	3	1	0.15	250	90
5	2	2	3	1	1	0.2	300	0
6	3	1	3	2	2	0.15	300	0.024
7	3	2	1	3	2	0.2	200	90
8	3	3	2	1	2	0.3	250	0
9	1	1	2	1	0.3	0.15	250	0
10	1	2	1	2	0.3	0.2	200	0.024
11	1	2	3	3	0.3	0,2	300	90
12	2	3	1	1	1	0.3	200	0
13	2	1	3	2	1	0.15	300	0.024
14	3	1	1	3	2	0.15	200	90
15	3	2	3	2	2	0.2	300	0.024
16	3	1	2	1	2	0.15	250	0
17	3	2	1	1	2	0.2	200	0
18	3	3	3	3	2	0.3	300	90
19	2	3	1	2	1	0.3	200	0.024
20	2	3	3	3	1	0.3	300	90

3. RESULTS AND DISCUSSIONS

To analyze chip segmentation and shape, steel chips were collected after each trial. Different chip types of various shape size and color were produced.

Table 4, Table 5, Table 6 show the form of the chips after turning the alloyed steel 42CrMo4 in the range of employed cutting parameters under the cooling and lubricating conditions: DC, MQL and conventional FL.

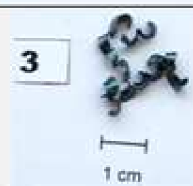
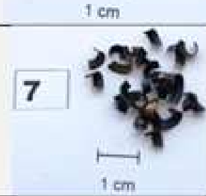
Discontinuous chips are acceptable because they do not damage part surface or lathe subassemblies. Furthermore, they can be easily removed from working area, handled and disposed.Production of favorable discontinuous chips is possible by the following principles: proper selection of cutting conditions (cutting speed, feed rate, material and cutting tool geometry), use of chip breakers, work material properties, and selection of machining environment that influence friction conditions at the chip-tool-part interfaces.

Due to the need for machining systems automation, the most convenient chips shapes are loose arcs and short helical pieces. Because of tangling around the tool and part and removing difficulties from the cutting zone, the helical tubular chips or washer long type are generally not acceptable.

Continuous chips, looking a long tape with smooth shining surfaces, indicate high speeds, low feed rates and ductile work materials.

Table 4

Influence of the cutting conditions on the chips form (a_p=2 mm).

Cutting parameters and cooling-lubrication conditions				Chips form	
a_p [mm]	f[mm/rev]	v_c [m/min]	q_l [l/h]		
2	0.3	300	90		
		250	0		
	0.2	300	0.024		
		200	90		
			0		
	0.15	300	0.024		
		200	90		
		250	0		

The next chips type, continuous with a built up edge, still looks like a long ribbon. The difference is given by their surface that is no longer smooth and shining.

Under conditions such as low cutting speeds, negative rake angles, the high grade steel 42CrMo4 tends to develop the built-up edge. This represents a hardened layer of blank material attached to the tool. After reaching the critical size, the built-up edge passes off with chips and disappears at high cutting speeds. Chip breaks and cutting forces decrease, but the machined surface becomes rough.

Based on the Figure 3, at constant cutting speed, it can be defined the map area of favorable chip formation as a function of feed rate and cut depth, for the particular work piece material 42CrMo4 and for the considered cutting tool material and geometry (Figure 2).

Table 5

Influence of the cutting conditions on the chips form *(a_p=1 mm)*.

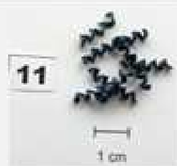
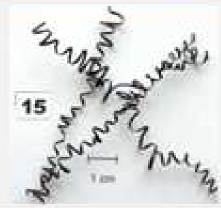
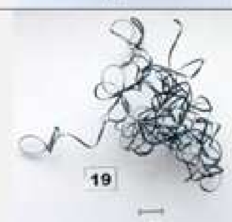
Cutting parameters and cooling-lubricating conditions				Chips form	
a_p *[mm]*	*f [mm/rev]*	v_c *[m/min]*	q_l *[l/h]*		
1	0.3	300	90		
		200	0.024		
			0		
	0.2	300			
	0.3	300	0.024		
		250	90		

Table 6

Influence of the cutting conditions on the chips form ***(a$_p$=0.3 mm).***

Cutting parameters and cooling-lubricating conditions				Chips form	
a_p [mm]	f [mm/rev]	v_c [m/min]	q_l [l/h]		
0.3	0.3	300	90		
	0.2				
		250	0.024		
		200			
	0.15	250	0		
			90		

Elimination of the metal working fluids causes higher cutting temperatures and an intensive friction between the chips and tool rake face that causes compression and curling of the chip. After dry turning, the back surface of the chip is rough and mat. Its color is dark blue pointing a high cutting temperature.

Circumstances for chips building and their removal along the tool rake face are changed in the case of MQL application. Adhesion at chip-tool contact is prevented by the penetration of the cutting fluid mist on the chips. As a result of lower chip compression and better chip flow conditions, the chip surfaces are smoother and lighter.

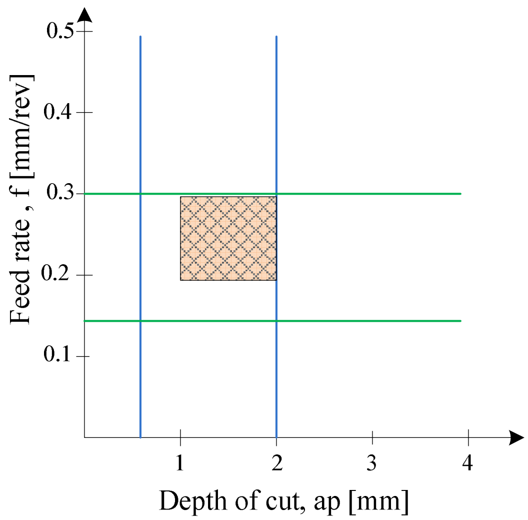


Fig. 3. Area of favorable chip formation for constant cutting speed.

Cutting velocity changes chip form as well. Working at low cutting speeds leads at decreasing of the process productivity and worsening of the surface roughness. If the cutting speed has to be kept high for the before mentioned reason, changing the cut depth and feed rate is the solution for chip control.

4. CONCLUSIONS

The chip form and chip formation mechanism is influenced by cutting conditions. The cooling and lubrication conditions have a low influence on changes in chip's morphology and shape, when the feed rate ranges in low and medium domain. A more convenient and easier to remove chips are getting by increasing the depth of cut and feed rate. To get a chip shape that allows an easier removal from the cutting area, it is recommended to increase the feed rate and depth. Since the cutting speed needs to be high in order to achieve the desired surface roughness and process productivity, the control of chips formation can be done by choosing appropriate values of cut depth and feed rate.

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STUDIU PRIVIND MORFOLOGIA AŞCHIEI LA STRUNJIREA CONVENȚIONALĂ ȘI ECOLOGICĂ A OȚELULUI ALIAT 42CrMo4

Rezumat: Această lucrare face parte dintr-o cercetare amplă privind strunirea ortogonală a oțelului aliat 42CrMo4, material utilizat pe scară largă, în condiții de așchiere convenționale și ecologice. Abordarea constă într-o serie de teste și un studiu experimental privind parametrii și condițiile prelucrare cum ar fi: adâncimea așchiere, viteza de așchiere, viteza de avans și debitul mediului de răcire-lubrifiere. Au fost utilizate două tehnici ecologice de răcire și lubrifiere: așchierea uscată și lubrifierea minimală. Pentru comparație a fost luată în considerare și răcirea convențională. Scopul studiului este analiza formei așchiilor, un criteriu important pentru evaluarea proceselor de așchiere. Rezultatele arată o influență limitată a condițiilor de răcire și lubrifiere asupra morfologiei și formei așchiilor, pentru valori mici și medii ale vitezei de avans. O formă mai convenabilă și mai ușor de îndepărtat a așchiilor se obține prin creșterea adâncimii de așchiere și a avansului.

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