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CHIP FORMATION AND CUTTING FORCE IN THE MACHINING OF HARDENED RUL1V STEEL

Alexandru STANIMIR[1], Ileana-Cristina PASCU[1], Ştefan BUZATU[1], Ionuț GEONEA[2]
[1]University of Craiova, Faculty of Mechanics, Department of Materials and Technologies,
[2]Department of Applied Mechanics
e-mail: alexstanimir@yahoo.com, i_pascu@yahoo.com

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Abstract: In this study, in order to establish a connection between the chip formation mechanism and the cutting forces variations due to the influence of cutting speed, rake angle and flank wear in orthogonal cutting of hardened Rul1V steel were experimentally investigated. For different values of the considered influence factors, both the chip roots microstructures and cutting forces components Fc and Fp have been analysed. The results show that the negative rake angle values γ<-30° and the flank wear VB>0,2mm increase significantly the cutting forces and concomitantly rise the contribution of plastic deformations to the chip formation. The experiments prove a possible useful solution to decrease cutting forces, especially the thrust force Fp with 30-40% and to extend the ceramic insert life by the tilt of the worn turning tool in order to increase the flank angle.

1. INTRODUCTION

The structure production optimization by the use of hard cutting, especially by turning, in the machining of some parts from hard steel, allows the decrease or elimination of thermal treatments and of some operation of mechanical process, trough combination of the forming techniques with the cutting methods, and the substitution of grinding. These changes offers a series of advantages which can be expressed in terms of reduction of cycles and spaces of production, reduction of the investments for machine tools and installations, reduction of spends with the maintenance and the power consumption, and of increase of manufacture flexibility, of forms complexity, of machined parts performance and so on.

Despite these evident advantages, industrial realization of hard machining has remained slight in comparison with the potential spectrum of applications, and these situation can be attributed partially to the uncertainty about the attainable accuracies to size and shape and partially to the suspicions concerning functional surfaces behaviour in use [3, 4]. To eliminate those uncertainty, until the 90 years, Konig and co. [5, 6] recommend a complex approach of study the cutting process of hard materials, from the chip formation, until the machined surfaces integrity and their comportment in exploitation. This way of approach of researches in the area in maintained and in present, they being obviously completed with new techniques, starting with analyze of variance and until neuronal networks [9,10].

The study of the metal cutting forces, and finding new modalities of their diminution, in the machining of steel parts, that are hardened usually between 45-70 HRC, present an especial interest, more else then when is followed the obtain of dimensional and shape precision, or of surface integrity characterized by minimum structural transformations and internal stresses in the superficial layer.

The researches presented in this paper follow to emphasise a series of connections between the cutting forces and the chips formation in machining of hardened steel, then when the manufacture process is influenced by diverse factors. The analyse of the mechanism of chips formation and of particular aspects of this mechanism follows to offer a series of justifications concerning the necessity to limit some parameters, which belong to the work regime and of cutting tool geometry, if is wanted the limitation of cutting forces values and especially of the F_p component, responsible in bigger way of the dimensional and geometrical imperfections which can appear in the machining of hard steel parts.

2. BRIEF LITERATURE REVIEW

A brief review of the technical literature reveals that the cutting forces increase with the depth of cut and the feed rate. In the machining of hardened steels, the cutting force and especially the thrust force Fp, increase with the flank wear VB, and when the rake angle γ takes big negative values. Usually, in finish turning the maximum flank wear VB is 0,2 mm and a frequently used value of rake angle is -6º [6, 4, 9, 15].

In the machining of ductile materials, the chip formation is accompanied with very severe plastic deformation at the shear zone. When a work material has not enough ductility, the deformation is limited by a crack initiation at the surface where no hydrostatic pressure exists, and the chip thus produced was named saw-toothed chip, from the shape of its cross-section [1, 2, 7, 11]. From this point of view, in the machining of hardened steels the cutting forces must not have excessive big values.

3. ORTHOGONAL CUTTING EXPERIMENTS

In order to study of the cutting process in the machining of hardened steel the orthogonal cutting tests was made by turning with longitudinal feed.

From the factors which influence the cutting forces and the chip formation process is take into account: the rake angle γ (-6…-50º), the flank wear VB (0; 0,1; 0,2; 0,3 and 0,4 mm) and the cutting speed Vc (40; 80 and 120 m/min). On experimentations have been used mixed ceramic inserts CC650 TNGN 16 04 08 T 010 20 (notated CM), and polycrystalline cubic boron nitride inserts BZ 435 TPGN 22 04 16 (notated PCBN). The workpiece, with the shape of a pipe from RUL 1V steel, with the hardness of 60-62 HRC, has been dimensioned for a undeformed chip width b_1=0,5mm, and the undeformed chip thickness a_1 has been adjusted to different values (0,028; 0,1 and 0,2 mm) by the proper choose of longitudinal feed. The experiments have been performed on a SNA 500 lathe machine, on which have been take measures for the stiffness increase, equipped with a system of force measurement (fig. 1). A special tool holder device has been used for the turning tool positioning in the sight of modifying the rake angle value [12], and another special quick-stop device has been used for obtain the chip root [13].

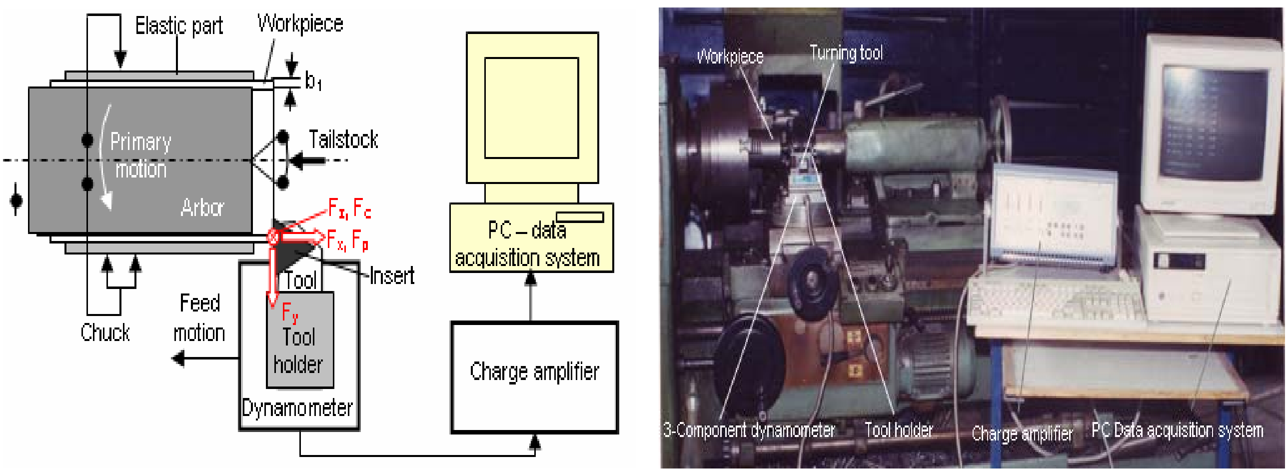
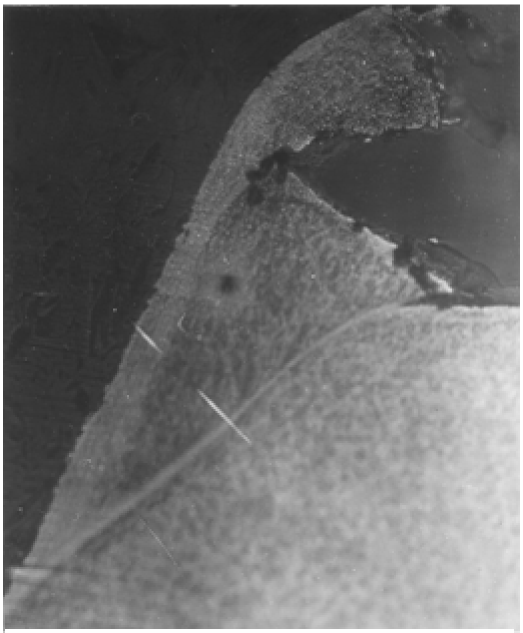


Fig. 1. Orthogonal cutting test set-up

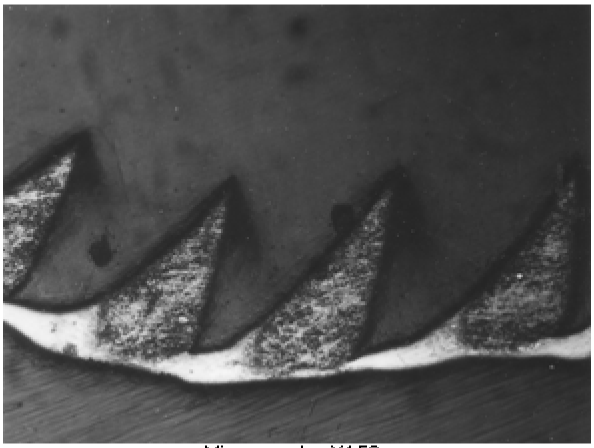
4. RESULTS AND DISCUSSIONS CONCERNING THE CHIPS FORMATION

In order to analyse the chip formation mechanism a quick stop cutting process device was used. The chip root in the figure 2 represents a chip segment which has just been produced (γ=-28°, Vc=125m/min, a_1=0,1mm). Owing to the negative rake angle, high compressive stresses are created both on the cutting edge and in the material. As a result, the material is parted and chips are formed. Due to the brittleness of the hardened steel, the high compressive stress initially leads not to a material flow but to formation of a crack. This crack releases the stored energy and thus acts as a sliding surface for the material segment, allowing the segment to be forced out between the parting surfaces. In the same times, heating and plastic deformation of the steel occur at the leading edge of the cutting tool. The process is cyclic, once the chip segment has slid away, renewed cutting pressure results in formation of a fresh crack and chip segment. The same chip formation mechanism, that has already been discussed by several authors [1, 2, 4, 5, 6,11], was observed for the rake angle value -6°. The chip microstructure (fig. 3) shows individual chip segments (grey zones) linked by small proportion of material plastically deformed and heated to a high temperature (white zones). A smaller undeformed chip thickness value (fig. 4) leads to smaller saw teeth, causing cross-sections similar to those of continuous chips, but the two zones of deformed and undeformed material show the same mechanism of chip formation.



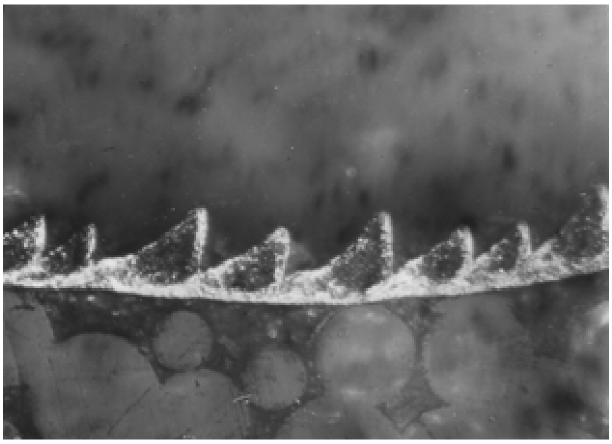
Micrography X250;
Cutting test parameters: CM insert; a_1=0,1mm; Vc=120m/min; γ=-28°; no coolant

Fig. 2. Chip root, γ=-28º



Micrography X150;
Cutting test parameters: CM insert; a_1=0,1mm; Vc=120m/min; γ=-6°; no coolant

Fig. 3. Chip microstructure, a_1=0,1mm



Micrography X500;
Cutting test parameters: CM insert; a_1=0,028mm; Vc=120m/min; γ=-6°; no coolant

Fig. 4. Chip microstructure, a_1=0,028mm

The chip root in the figure 5 corresponds to a rake angle value -50° insert. In this case, a significant white layer arises, the plastic deformation becomes dominant in the chip formation mechanism, and that can explain the increase of cutting forces. Similar results was observed on the chip root obtained with a worn tool VB=0,2mm (fig. 6).

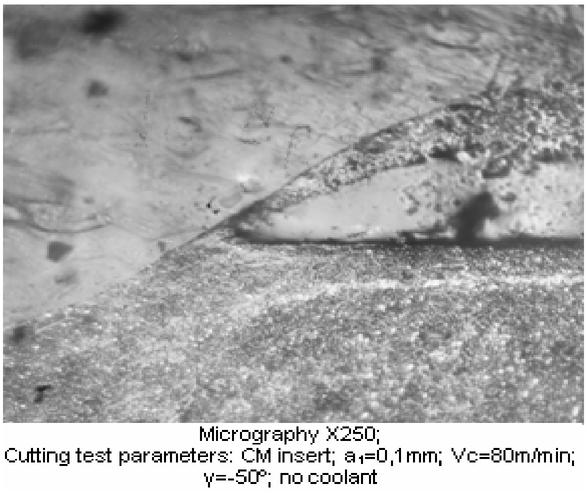


Fig. 5. Chip root, γ=-50º, VB=0mm

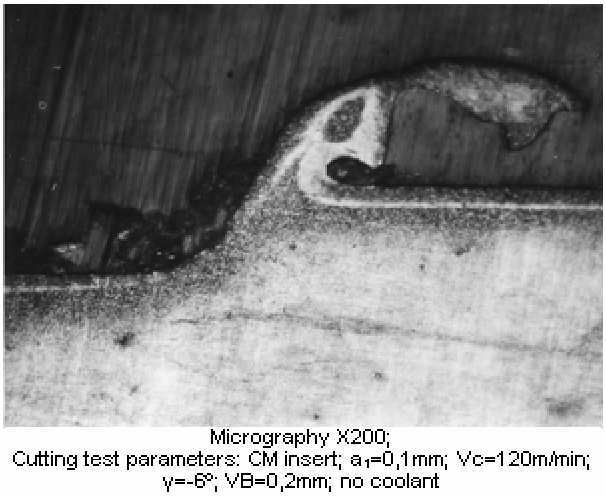


Fig. 6. Chip root, γ=-6º, VB=0,2mm

5. RESULTS AND DISCUSSIONS CONCERNING CUTTING FORCES

In order to emphasize the effect of cutting speed and negative rake angle on Fc and Fp forces, four diagrams are presented in the figure 7. The tests show a minor influence of the cutting speed between 80 and 120 m/min, and a quick increase of thrust force, especially for the rake angle values between -30 and -50 º.

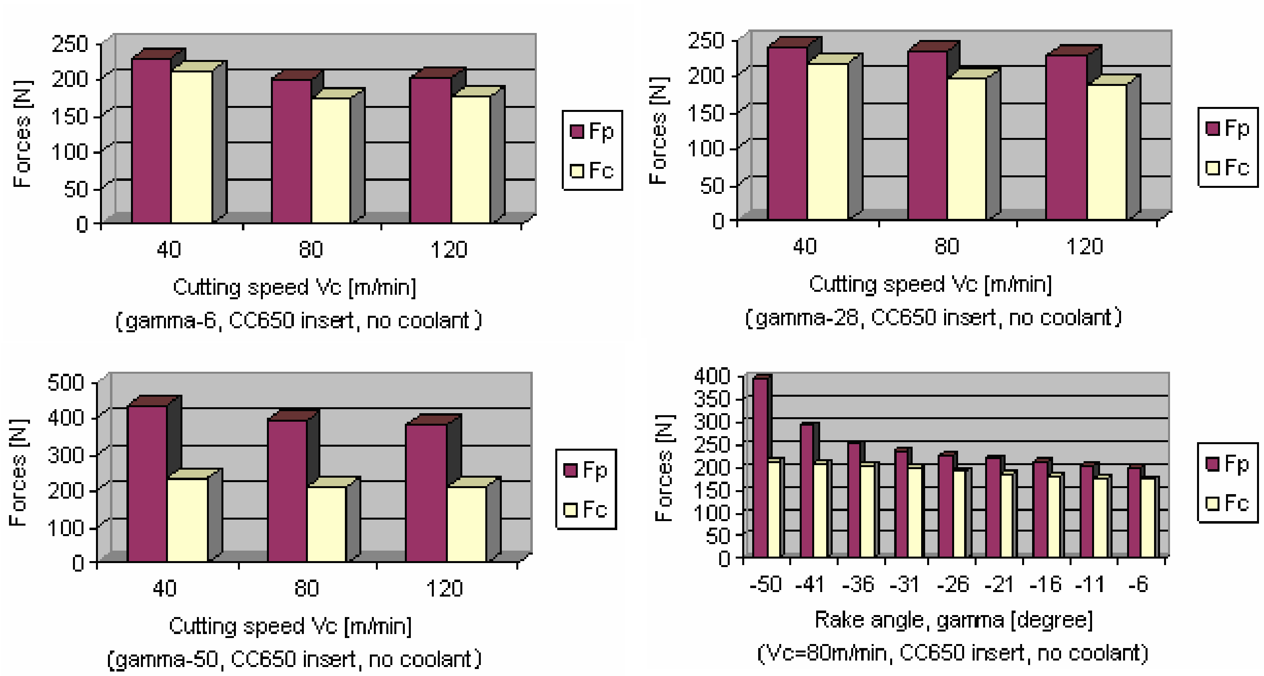


Fig. 7. The rake angle influence on cutting force Fc and thrust force Fp

The figure 8 illustrates the effect of flank wear (VB=0...0,4 mm, artificially made) on Fc and Fp forces for two different edge geometry (chamfer for CM inserts and sharp for PCBN inserts, in both cases γ=-6°) and material inserts. The tests show a considerable increase of the thrust force with the flank wear, especially for CM insert. The influence of flank wear on cutting force Fc is minor. However, by comparison with PCBN insert, due to the larger value of the friction coefficient at the worn flank [7, 14], the increase of cutting force Fc with the flank wear is more important when a CM insert is used.

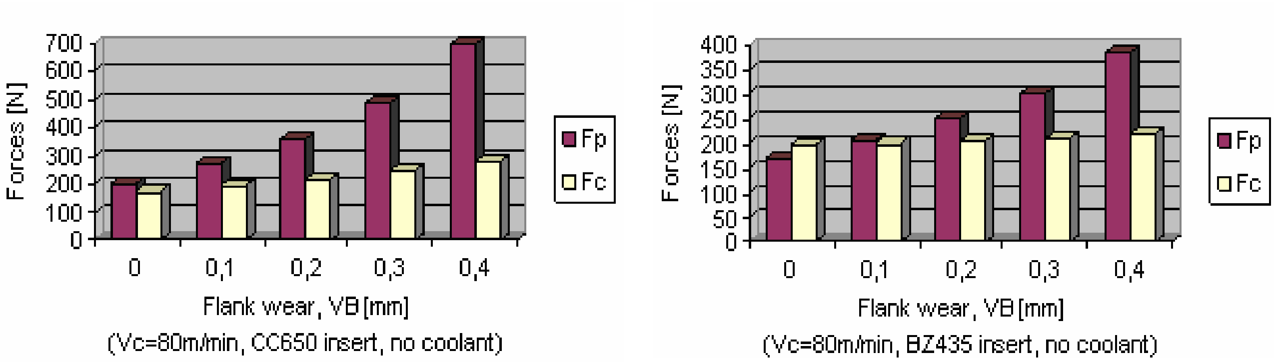


Fig. 8. The flank wear influence on cutting force Fc and thrust force Fp

The diagram from figure 9 presents a comparison of cutting and thrust force values in the cutting with worn (VB=0,3 mm) and unworn CM inserts. The increased thrust force due to the flank wear can be diminished by heeling the insert so as to increase the relief angle by 6º (bottom of figure). Though this makes the rake angle more negative, the test indicates a decrease in the thrust force, about 40% for γ=-6º and 30% for γ=-28º, obtained by tilting the insert by 6º.

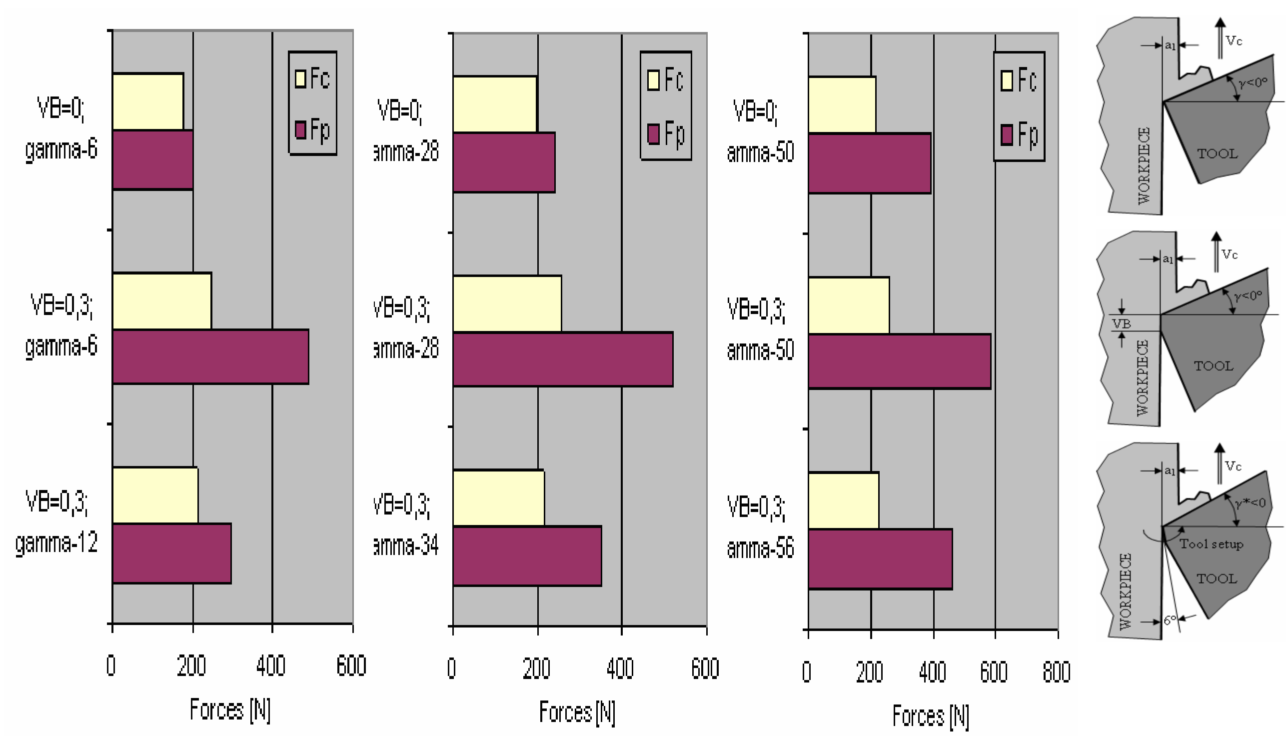


Fig. 9. The effect of the increase 6º of relief angle on cutting force Fc and thrust force Fp in the cutting with worn CM inserts

6. CONCLUSIONS

The formation of sow-toothed chip, due to the poor ductility of workpiece material, lowers the forces in spite of the high strength of hardened steel. However, the chip formation mechanism takes peculiar aspects when the rake angle becomes to negative (γ=-50°) or the flank wear increase (VB=0,2..0,4mm). In such cases, a white layer arises in the machined surface, the plastic deformations become important and the cutting forces increase.

The increase of forces, especially thrust force, justify the low values of flank wear and negative rake angle used in the finish turning.

Due to the smaller friction coefficient between the flank face of tool and the work material, and partially to the edge geometry, the increase of the cutting force Fc with the flank wear is lower in the cutting using PCBN inserts by comparison with ceramic inserts.

A possible useful solution to decrease cutting forces and to extend the ceramic insert life (with single use edges) is the tilt of the worn turning tool in order to increase the flank angle.

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