RESEARCH ON THE PHYSICAL STRUCTURE OF THE CUTTING FORCES DURING HIGH-SPEED MACHINING OF HARDENED STEEL SAE 8620 (21NICRMO2)

Dumitru Amarandei[1], Stelian Alaci[2], Irina Beşliu[3]

[1] *„Stefan cel Mare" University - ROMANIA, mitica@fim.usv.ro*
[2] *„Stefan cel Mare" University - ROMANIA, stalaci@yahoo.com*
[3] *„Stefan cel Mare" University - ROMANIA, irina.besliu@fim.usv.ro*

Abstract: *The paper presents some experimental research regarding high-speed cutting of SAE 8620 alloy steel which has been hardened at 58-62 HRC, at SC SIDEM SRL Company that manufactures automobile components. The research focuses on the physical structure of the cutting forces, the geometrical quality of machined surfaces and the metallographic analysis resulted from machining with CBN 160C, KY 4300 and WG 300 insert. The aim of our study is to replace the grinding operation with the high-speed cutting after hardening treatment.*

Keywords: *cutting, hardened materials, turning, high-speed machining.*

1. Introduction

When using conventional cutting process two areas can be observed: one that is characterized by a stabile chip forming mechanism described by a lamellar area and another that forms a circular discontinue curved area for which buck teeth shaped chips are formed these chip thickness is described by a cyclic function with frequencies of ~100Hz for curved cycles and ~400Hz for indented chips. The share areas form and characterization depends mostly on the cutting speed and on the material hardness. For hard machining the chips obtained in the cutting processes are indented due to the high cutting forces exercise over the cutting edges.

When turning or milling hard materials the rapports between the force components are significantly changed. For these situations for cutting speed of 120-800m/min the research literature existing in this field specify the need of using special materials for the cutting tools like: ceramics and CBN and feeds around the value 0,1mm, according to the workpiece material and the desired machined surface quality.

This paper aim is to bring some specification regarding the high speed turning of hardening steel SAE 8620, heat treated at 58-62HRC. The research aim is to analyze the possibility of replacing the grinding operation with the high speed cutting after hardening treatment.

The studies focused on the performance parameters, on analyzing of the cutting force structure, the cutting power and the machined surface geometric and physic quality. For the modulation of the mentioned parameters the experimental schedule was made by the Taguchi method.

2. Theoretical remarks

The high rigidity of the machining tools used in the high speed machining of hardened steels permits the exploitation of the whole CBN tools capacity, in continue evolution , making turning a competitive alternative of the grinding operations.

Compared to the classic cutting processes included: roughing, finishing on conventional machining tools, the high speed turning operations are run on CNC lathes with four or even many axes is reduced only on one finishing turning with a ceramic insert, followed by a finishing operation with a CBN insert [3].

According to some researchers [3,4], this new technology is able to assure important cycle time reductions, high productivities, costs reductions. The increase of the cutting speed results in one piece cost reduction of 15% or even more.

3. Recommendations regarding the organization of the cutting process of hard materials

David Richards refers to the hard turning process as being the cutting process of metal parts with the hardness of above 40HRC. For materializing the hard turning three elements must be provident:

- the cutting tool (materials and geometry);
- the cutting parameters;
- the specific restrictions (admissible wear ratio, the machining tool accuracy and dynamic stability, etc)

The tool materials recommended are: ceramics, Cubic Boron Nitride (CBN), diamond, ceramics containing silicon nitride and pure aluminum oxide Al_2O_3 mixed Al_2O_3+TiC or composite Al_2O_3+TiN. The chosen of a specific material for the tool is made depending on the tool wear rate on the tool ranke face and the chip volume, figure 1.

The cutting parameters. When turning heat treated steels, with hardness of 45-65 HRC, the work piece material influents the value of the cutting speeds.

In the same time, as resulting from table 1 the cutting depth (0.5 mm/pass) and the cutting feed (0.1mm/rev) are considered according to the tool material and the work piece material.

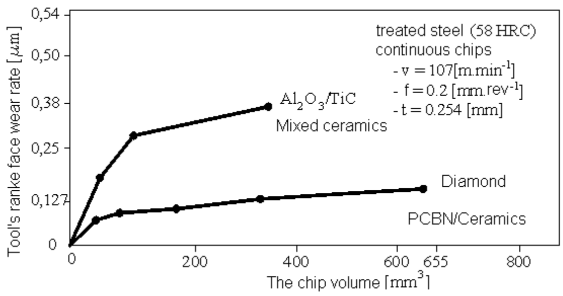


Figure.1. *Variation of the tool ranke face with the chip volume*

Table 1. The values of the cutting parameters when high speed machining hardened steels

The work piece material	Hardness	Cutting depth, cutting feed	Ceramics ($Al_2O_3+T_iC$), v [m/min $^{-1}$]
Tool steel	45 HRC	a=0,5 mm f=0,1 mm.rev^{-1}	200
Heat treated steel	55 HRC		100
Speed steel	65 HRC		60

The precautions that must be taken are related to the equipments used in machining and are referring to the following*:*

- must have required rigidity/ amortization ;
- the machining tool sleds must be adapted to the high cutting speeds ;
- the numerical control program must assure the accuracy of the movements;
- the cutting tools must resists at high and concentrated forces;

4. The Experimental Setup

The researches in the field of hard machining were essentially based on the longitudinal turning of heat treated cylindrical parts. The machining tests were carried out on a plant lathe SN 320x1500, equipped with a triaxial piezoelectric Kistler dynamometer (type 9257B) that allowed the measurement of the cutting forces and specialized equipment for the measurement of the power consumed during machining. A set of experiments were carried out on a turning center (V turn 20-TAKANG T20) from the machining department of SC Sidem SRL Suceava.

In order to determine the real rotational speed of the spindle a laser tachometer type DT–209X was used. The machining setup and the measurement equipment used for the experiments are presented in figure 2. For the real effective t the machining

The work piece material was a SAE 8620 (21NiCrMo2) alloy steel which has been hardened at 58-62 HRC, at SC SIDEM SRL. The cutting tool used had a CBN 7025 (with the following cutting geometry: γ= 6o; α= 6o; K=95o) insert (CNGA 120408S01030A-Sandvik).

The cutting force measurement setup used for the machining tests was constituted of a piezoelectric dynamometer Kistler 9257B, a force amplifier and a PC with data acquisition interface.

5. Experimental results

Before the hard turning machining test were carried out, initial roughness and the hardness of the heat treated workpieces were measured. The workpiece material hardness were in range of 50-60HRC.

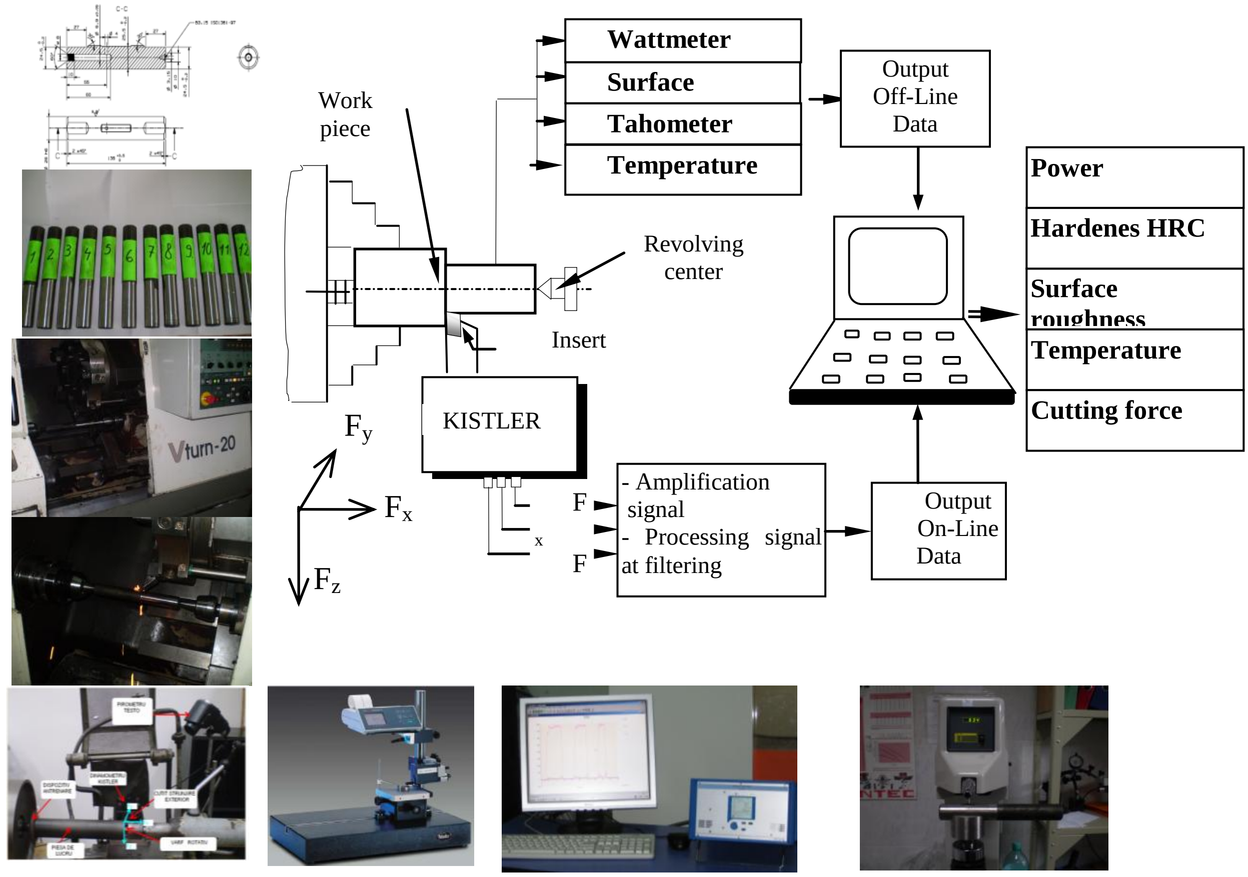


Figure 2. *Experimental setup and the data acquisition and measurement equipments chain used*

In order to evaluate the effects of machining parameters on performance characteristics (cutting force, machining power, surface roughness), and to determine the performance characteristics under the optimal machining parameters, Taguchi design of experiments technique was used.

Table 2. Experimental results obtained during hard turning of SAE 8620 steel with CBN 7025 inserts

Exp. no.	**a** [mm]	**f** [mm/rev]	**n** setted [rev/min]	**n** measured [rev/min]	**Cutting temperature,** °C	**Cutting force components**			**Ra, µm**		**HRC**
						F_x	F_y	F_z	initial	final	
1	0,1	0,1	1000	1049	934	13.46	101.55	56.81	2.387	0.349	
2	0,1	0,1	1250	1340	614	7.54	86.33	42.42	2.133	1.197	53
3	0,1	0,2	1000	1049	990	0.18	101.11	55.8	1.836	0.391	
4	0,1	0,2	1250	1340	634	6.12	84.28	22.61	1.681	1.230	51
5	0,2	0,1	1000	1049	695	33.41	142.38	66.42	2.352	0.351	
6	0,2	0,1	1250	1340	642	21.95	121.47	42.76	1.466	1.705	54.5
7	0,2	0,2	1000	1049	682	36.04	196.88	100.52	1.509	1.044	
8	0,2	0,2	1250	1340	1103	29.77	181.67	79.46	2.194	2.085	55.4
9	0,3	0,1	1000	1049	794	16.36	140.44	52.66	1.969	1.052	
10	0,3	0,1	1250	1340	890	13.65	196.76	46.25	2.772	2.101	54.5
11	0,3	0,2	1000	1049	769	70.99	185.02	92.81	3.180	1.185	
12	0,3	0,2	1250	1340	984	79.45	234.42	120.81	1.724	1.116	49.5

The plan of experiment generated through Taguchi's technique that was used to conduct experiments was based on the L8(31*22) orthogonal array. Factors and their levels used in this investigation and the values obtained for the interest parameters considered are shown in table 2.

The interaction effects of the controlled factors over the cutting force components are presented in figure 3.

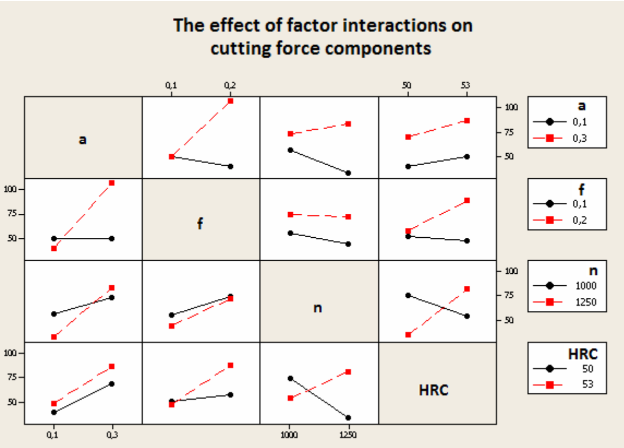


Figure 3. *The effect of factor interactions on cutting force components*

It is to be noted that tangential cutting force is very sensitive to the variation of cutting depth what affects the cutting forces in a considerable way.

Radial force was dominant in the hard turning machining tests, which makes it different from the conventional machining. High cutting forces were obtained when machining with low cutting speeds, due to low cutting temperature and built up edge formation. During hard turning machining tests we could observe that the cutting forces were higher at low cutting speeds and reduced when cutting speed increased.

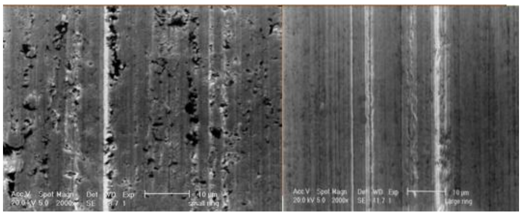
This results may be due to the fact that at high speeds, due to high cutting temperatures workpiece material thermal softening occurs reducing cutting forces required for machining.

6. CONCLUSIONS

According to the experimental results obtained when hard turning of SAE 8620 (21NiCrMo2) alloy steel hardened at 58-62 HRC with a CBN 7025 (γ= 6o; α= 6o; K=95o) insert (CNGA 120408S01030A-Sandvik) the cutting forces components increase with the majorities of cutting speeds and the chip section area. Also, after chip analyze, the following conclusions referring to the cutting process could be drawn:

The long comma chips with continuous back surface and without any recurrence signs specify that when turning hardened SAE 8620 steel continuous flow type of chip are generated.

- The high temperature measured during the machining test and the dark red colore of the chips reveal that the cutting process temperature range in the domain of 614-11000C, depending on the cutting parameters;
- The values of the Ra surface roughness parameter obtained for the in the range of machined surfaces were of 0.35-2.2 µm, comparable with the ones specific to the grinding processes.
- An improvement of the superficial layer could also be observed for the surfaces obtained by hard turning processes, by comparison with the ones generated by grinding. The micro-cracks and pores caused by high temperature gradient are covered by the deformed, figure 4.



a. b.

Figure 4 *Superficial layer morphology of the machined surfaces obtained in:*

a. grinding b. hard turning

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