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SOME ADVANTAGES OF HIGH SPEED MACHINING IN ASPECT OF MACHINED SURFACE QUALITY

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ABSRACT
High speed machining is a relatively new production technology that allows higher productivity, excellent surface finish and good dimensional accuracy in the manufacturing process. Therefore these technologies have considerable advantages over traditional machining technologies. Instead of conventional machining chain that consists of roughing in soft state + semi fininshing + hardening + fininshing, high-speed machining allows shorther chain consisting of roughing + semi finishing + finishing. Some results refered to the advantages of high-speed machining over conventional machining in aspect of machined surface quality are presented in the paper.

1. INTRODUCTION

High-speed machining is recognized as a relatively new production technology, which enables higher productivity, excellent surface finish and dimensional accuracy in manufacturing. There are several criteria used for defining of high-speed machining, i.e. the criteria for determination of boundary between the conventional and the high-speed machining [6]: a) Magnitude of cutting speed, b) Revolution of spindle or rotating tool (spindle speed), c) DN number (DN is the spindle diameter in mm multiplied by the spindle speed in revpmin), d) Dynamic behaviour, and e) Workpiece material. High-speed milling plays one of the most important role among all high-speed cutting methods, [1,2,3]. Thanks to the advances in machine tool performances (main spindle, feed drives, etc.), high-speed machining, particularly, high-speed milling, becomes a cost-effective manufacturing process that enables manufacturing of products with high surface quality, low alterations in machined surface and dimensional accuracy. Initially, high-speed milling was successfully used in aircraft and automotive industry for machining of complex machine elements made of aluminum and its alloys. Recently, with the advance in cutting tools materials and technologies, high-speed milling has also been used in machining of alloy steels in their hardened state (above 30 HRC up to 60-65 HRC) [4,5].

The axi-symmetrical pieces are machined by high speed turn-milling. Conventional turning is limited by the centrifugal forces of the work piece and clamping chuck and conventional milling by the centrifugal force acting upon the tool. The turn-milling, the combination of two above mentioned technologies, esspecialy in high speed cutting ranges, offers a new ways of applications in the manufacturing processes.
More recent high-speed machining studies direct their attention toward several characteristic areas: tool wearing mechanisms [2,7], surface quality and machined surface integrity [8,9], chip-formation mechanisms [1,2,3,12], and machining of materials in their hardened state (hard machining) [4,5,8,10,11]. The common intent of all these investigations is to explore all possibilities of high-speed machining application in industrial practice.
Some results refered the advantages of high-speed machining over conventional machining in aspect of machined surface quality are presented in the paper. The mentioned results are previously reported by the authors, but systematically preesented in this paper [13,14,15,16,17,18].

2. EXAMPLES

2.1. Example 1: High-Speed Turn-Milling versus Conventional Turning of Steel [13]

The aim of the experimental investigation was to compare results of high-speed turn-milling and conventional turning from the aspect of machined surface quality. The specific workpiece material removal rate was chosen as a constant parameter (indicator) of the machining processes. The same values of the feed for the same depth of cut was adopted for both, high-speed turn-milling and conventional turning. But the values of the cutting speed were different due to natural difference between the two of the processes. The cutting speed for turn-milling was 1000 mpmin.
The material of the workpiece was Č.4131, with chemical composition given in Table 1. The workpiece dimensions were: diameter 100 mm, length 600 mm. The average Brinell hardness of the workpiece material was 244 HB. Fig. 1 shows graphical interpretation of the measured surface roughness parameters. The analysis of the results advocates the following:

- The average value of the parameter *Ra* for conventional turning is *Ra*=8.61 μm, and for high-speed turn-milling *Ra*=2.19 μm. Obviously, the parameter *Ra* is much lower for high-speed turn-milling.
- The increment of *Ra* parameter values with feed increase is almost the same for both machining processes,
- The average value of *Rz* parameter for conventional turning is *Rz*=42,94 μm, and for high-speed turn-milling *Rz*=10.67 μm. Lower value appears again for high-speed turn-milling.
- The increment of *Rz* parameter values with feed increase is again almost the same for the both processes,
- The average value of *Rmax* parameter for conventional turning is *Rmax*=52.96 μm, and for high-speed turn-milling *Rmax*=14.52 μm. Again, the lower value relates to high-speed turn-milling,
- An increase in feed makes *Rmax* parameter higher for conventional turning, and almost constant for high-speed turn-milling,

TABLE 1. CHEMICAL COMPOSITION OF THE MACHINED STEEL.

Element	C	Si	Mn	P	S	Ni	Cr
%	0.39	0.30	0.73	0.018	0.016	0.06	1.38

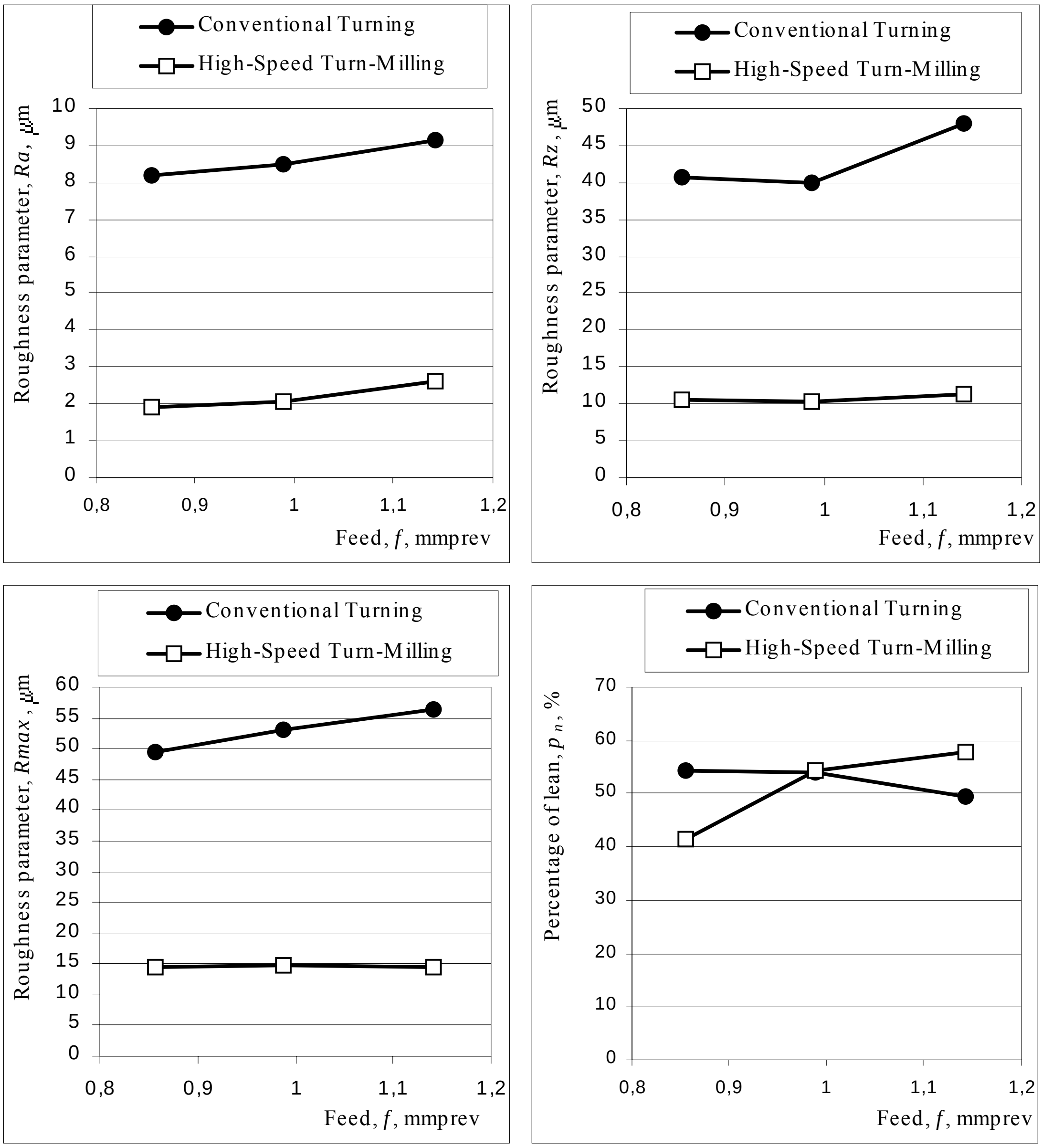


FIG.1. GRAPHICAL INTERPRETATION OF MEASURED SURFACE ROUGHNESS PARAMETERS.

2.2. Example 2: High-Speed Turn-Milling of Ductile Steel [14]

With the exception of aluminium and its alloys, one can notice that deeper investigations on high-speed machining of ductile materials, especially steels, have been omitted. In practice constructors often use harder steels just for reason to ensure the appropriate work piece machined surface quality, although sometimes-cheaper steels with lower mechanical characteristics such as strength and hardness are applicable for given working conditions of the part. The main reason for this is lower machinability of ductile steels, which makes hard to get the appropriate surface quality of machined parts (including grinding process). This example shows the results of investigation of high-speed turn-milling of steels with hardness of 105 HB in aspect of the surface quality. The chemical composition and hardness of the investigated steel are shown in Table 2, and Fig.2 shows results of investigation.

TABLE 2. CHEMICAL COMPOSITION AND HARDNESS OF INVESTIGATED STEEL.

Chemical composition, %					Hardness, HB
C	Si	Mn	S	P	
0.06	0.07	0.39	0.07	0.01	105

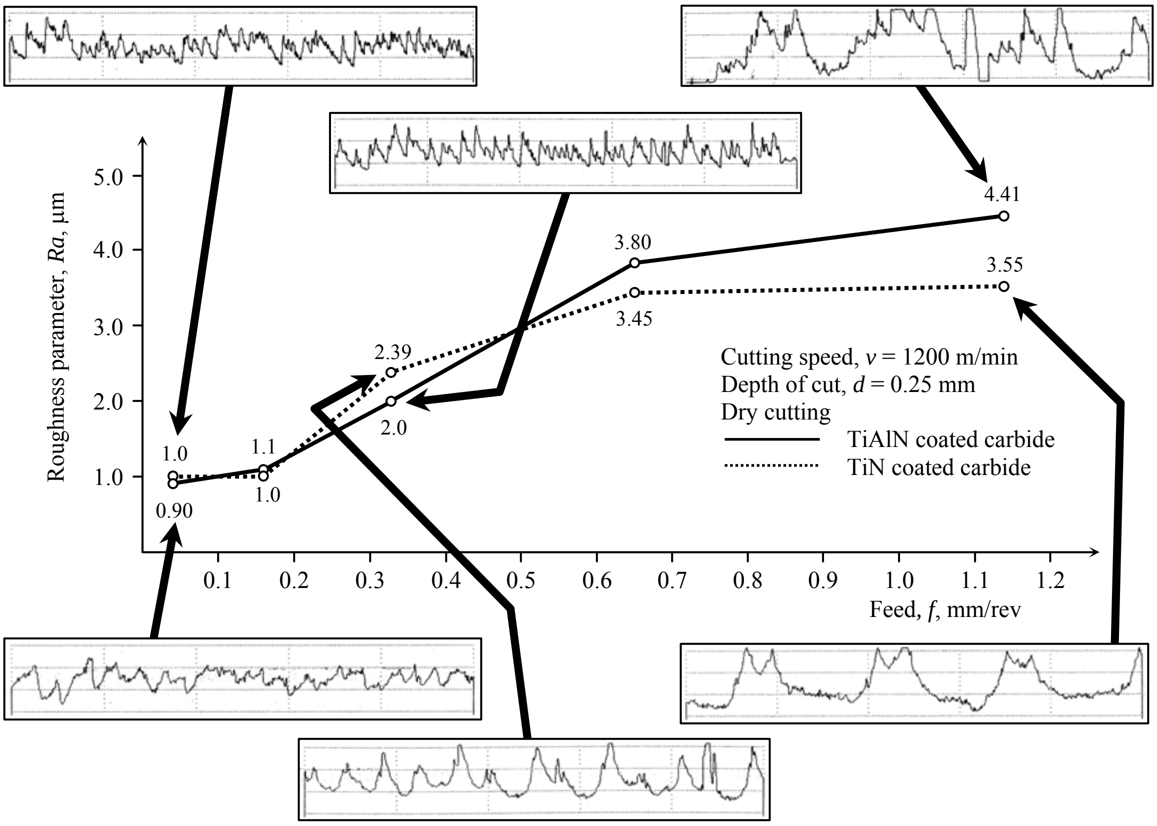


FIG. 2. RELATIONSHIP BETWEEN ROUGHNESS PARAMETER *Ra* AND FEED *f* DURING MACHINING OF STEEL 105 HB.

The cutting speed of v = 1200 m/min, which falls into the high-speed machining range, is realized by use of angular speed of the tool in the amount of 24000 rev/min and the cutter diameter D = 16 mm. Two types of cutters have been used: those with two TiN (PVD) coated carbide inserts, and solid carbide cutter coated with TiAlN (PVD) and with four cutting edges.

The diagrams on Fig. 2 present the relationship between the roughness parameter *Ra* and the feed *f* during machining of steel hardness of 105 HB. It′s obvious that if feed *f* decreases, the surface roughness *Ra* also decreases. The surface quality is better when using the TiAlN coated solid carbide tool (with four cutting edges) than the TiN coated carbide insert. The machined surface quality is ISO N7 class, but very close to the N6 class.

This example confirmed the fact that high-speed machining (i.e. high-speed turn-milling) has number advantages, not only in machining of hardened steels but in machining of ductile steels too (steel grades with hardeness 105 HB). This research also made evident the advantages of TiAlN coated tool above TiN coated carbide tool. Besides, the use of TiAlN coated tool gave better machined surface quality. These conclusions are valid only for the following machining conditions: orthogonal turn-milling with centric position of cutter and work piece, tool angular speed n_t = 24000 rev/min, angular speed of the work piece n_w = 20 rev/min, cutting speed v = 1200 m/min, depth of cut d = 0.25 mm, feed range of f = 0.04 up to f =1.142 mm/rev, and dry cutting.

2.3. Example 3: High-Speed Turning of Hardened Steel [15]

Cutting of materials in their hardened state (i.e. Hard Cutting) can seriously be regarded as an alternative for grinding [5]. Especially, in precision machining, cutting of materials in their hardened state is traditionally performed by processes using geometrically undefined cutting edges, i.e. grinding or honing. A comparison between hard cutting and grinding shows that the first offers several very important advantages. Different surfaces and shapes can be formed applying only a single tool, and the surface quality is as well comparable, i.e. applying a single tool it can be possible to achieve surface quality up to $Rz \leq 1.0$ μm, as well as dimensional and shape tolerances up to IT4 [5,11]. Therefore, hard turning turns out to have high potential to replace grinding technology.

Some results of machined surface quality investigation during hard turning by use of CBN tool are presented in this example. Work materials was high-alloy steel grade 58-60 HRC. The machining was conducted on the lathe type PA-501 Potisje ADA. The machining conditions were as follows: cutting speed v = 125 up to 270 m/min, feed f = 0.04 mm/rev, depth of cut d = 0.25 mm, dry cutting. The results of surface quality measurement are presented in the Fig. 3.

CBN tools used for hard turning and high-sped hard turning tests performed here are acceptable for finishing operation. Applying these tools it can be possible to achieve the surface quality up to $Ra \leq 0.21$ - 0.25 μm (ISO N5 class)

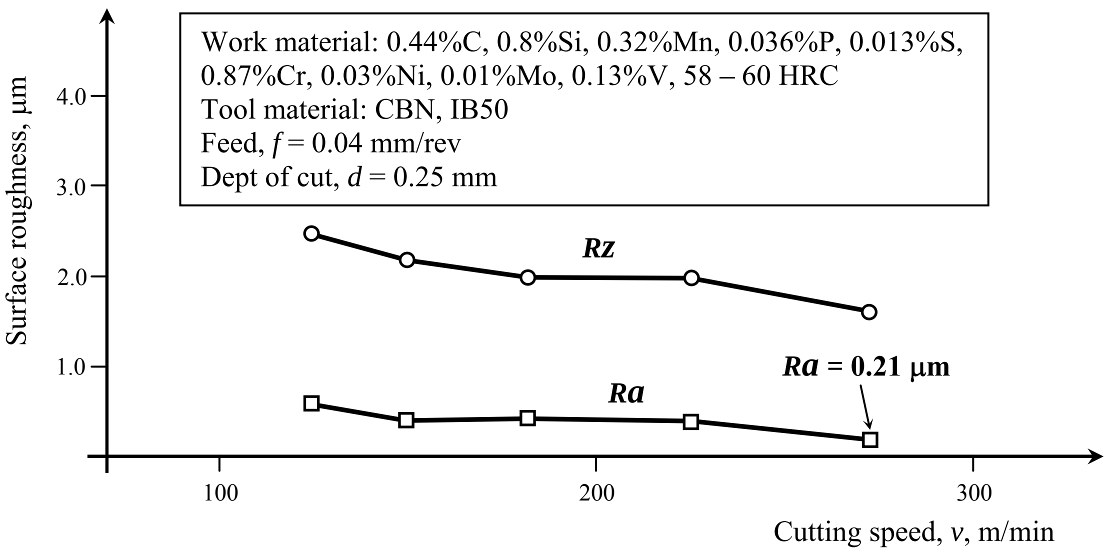


FIG. 3. RESULTS OF SURFACE ROUGHNESS MEASUREMENT DURING HARD TURNING (WORK MATERIAL: ALLOY STEEL 58 – 60 HRC)

2.4. Example 4: High-Speed Turn-Milling versus Conventional Turn-Milling of Brass [16,17,18]

This example shows some results of investigation of surface quality of brass designated as CuAl8Fe (89.4% Cu, 7.5% Al, 2.65% Fe, 0.45 % inclusions, and 118 HB) machined by high-speed orthogonal turn-milling. The range of cutting speed was 400 up to 1200 mpmin. The experiment has been performed according to $L_{16}(2^{15})$ orthogonal array of Taguchi methods. The influence of factors on surface roughness parameter *Ra* has been investigated. These factors are given in the Table 3. Fig. 4 shows standard linear graph of $L_{16}(2^{15})$ ortoghonal aray. The response table has been created according to the Taguchi method's procedure. Fig. 5 shows the graphs of the factors. Predicted roughness parameter of *Ra*=1.115 μm, has to be confirmed by verification experiment. The average result of verification experiments, *Ra*=0,95 μm (Ra_1=1.06, Ra_2=0.98, Ra_3=0.87, Ra_4=0.80, Ra_5=1.09, and Ra_6=0.92) confirms the validity of the chosen factors levels and ability to process control.

TABLE 4.THE LEVELS OF MODEL FACTORS.

Parameter (factor)	**1 Level**	**2 Level**
Cutting speed, *v*, m/min	400	1200
Feed, *f*, mm/rev	0.044	0.107
Eccentricity, *e*, mm	0	3
Radii of tool's tip, *r*, mm	0.4	0.8
Method of cutting, *o*	Up cut	Down cut

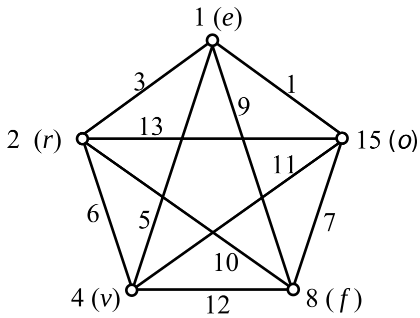


FIG. 4. STANDARD LINEAR GRAPH OF $L_{16}(2^{15})$ ORTOGHONAL ARAY.

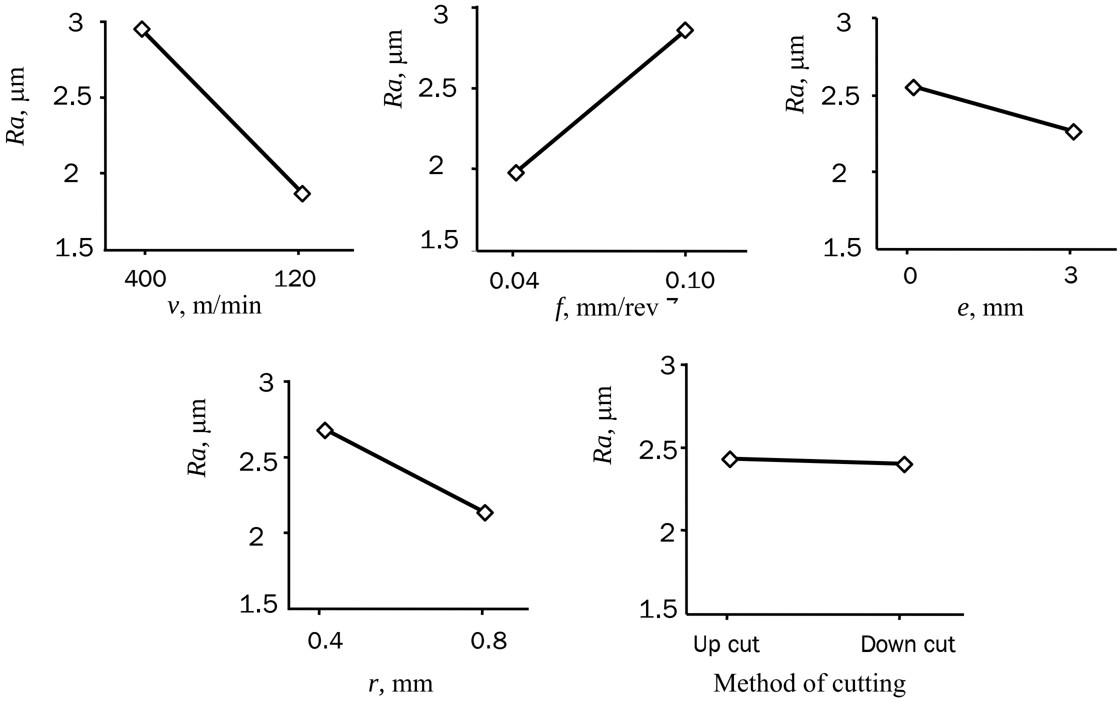


FIG. 5. RESPONSE GRAPHS OF FACTORS.

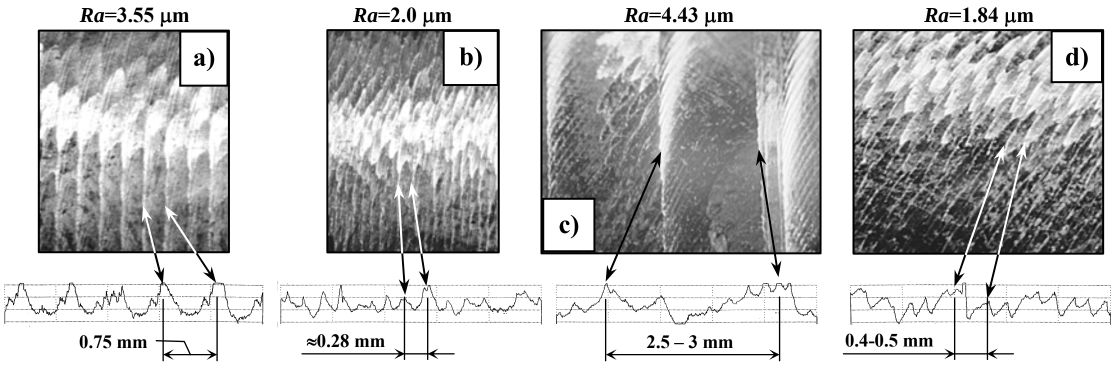
Fig. 6 and 7 systematically show the results of axially measured mean arithmetic deviation *Ra* as well as the profile photographs. Besides, there are microphotos of the machined surface in order to compare them with the machined surface profiles experimentally obtained. Note that the magnifying ratios of microphotos are different to make easier a comparison between the machined surface parts and the photographed surface profiles.

From the machined surface microphotos shown, one can see three basic types of the machined surface profiles. The first type has obvious arch grooves that remained after cut by cutter edge (the cutter of 16 mm in diameter, two cutting inserts). This type can be seen in Fig. 6b and 6d and it is a characteristic of conventional milling. The second type of the machined surface profile with regular cylindrical grooves is characteristic for conventional turning, and can be seen in Fig. 6a, 6c, and 7d. Finally, the third type of machined surface profile, which is also characteristic for conventional turning, can be seen in Fig. 7a, 7b and 7c. A specific phenomenon with alternating cylindrical grooves of different width appears here.

The experiment showed a very specific feature, that is for approximately the same measured values of *Ra* and different combinations of cutting regimes different profiles of the machined surfaces are generated. The fact that turn-milling as mahining process produces the same class of roughness but different profile shapes is very important from the aspect of tribological-exploitation characteristics of the machined surface.

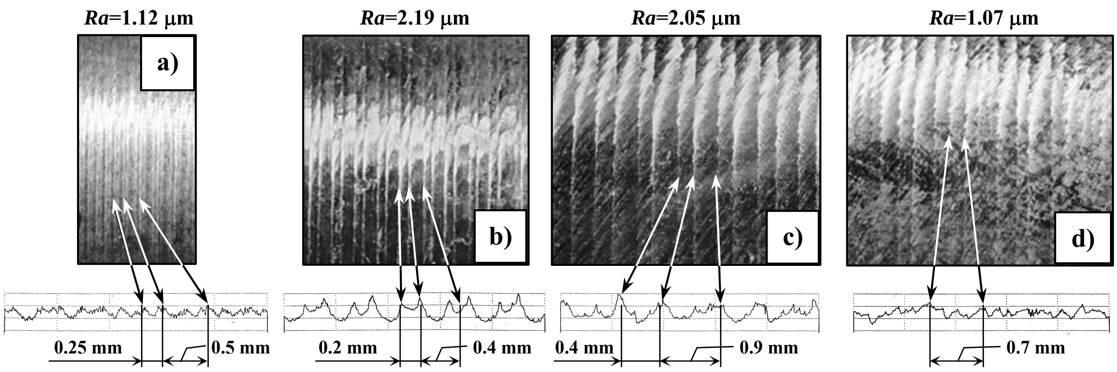
3. CONCLUSION

Some results refered the advantages of high-speed machining over conventional machining in aspect of machined surface quality are presented in the paper. The examples showed in the paper deal different methods of high-speed machining; high-speed turn-milling and high-speed turning of ductile steel, hardened steel, and brass. Results showed that high-speed machining ss a relatively new production technology allows a higher productivity, an excellent surface finish and a good dimensional accuracy in the manufacturing process.



e = 0 mm, *r* = 0.4 mm, *f* = 0.107 mm/rev | *e* = 0 mm, *r* = 0.8 mm, *f* = 0.044 mm/rev | *e* = 3 mm, *r* = 0.4 mm, *f* = 0.044 mm/rev | *e* = 3 mm, *r* = 0.8 mm, *f* = 0.107 mm/rev

FIG. 6. RESULTS OF ROUGHNESS MEASUREMENT AND PHOTOS OF MACHINED SURFACE PROFILES (CUTING SPEED, *v* = 400 m/min, DOWN-CUT, *e* - ECCENTRICITY, *r* - RADII OF TOOL'S TIP, *f* – FEED.



e = 0 mm, *r* = 0.4 mm, *f* = 0.044 mm/rev | *e* = 0 mm, *r* = 0.8 mm, *f* = 0.107 mm/rev | *e* = 3 mm, *r* = 0.4 mm, *f* = 0.107 mm/rev | *e* = 3 mm, *r* = 0.8 mm, *f* = 0.044 mm/rev

FIG. 7. THE RESULTS OF ROUGHNESS MEASUREMENT AND PHOTOS OF MACHINED SURFACE PROFILES (CUTING SPEED, *v* = 1200 m/min, DOWN-CUT, *e* - ECCENTRICITY, *r*- RADII OF TOOL'S TIP, *f* – FEED.

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