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STAINLESS STEEL MACHINING WITH NANOCOATED DURATOMIC^{TM} CUTTING TOOLS

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Abstract: *Stainless steels are generally difficult to machine due to their high tensile strength, high ductility, high work hardening rate, low thermal conductivity, and abrasive character. This combination of properties often results in cutting forces, temperatures, and tool wear rates, as well as a susceptibility to notch wear, chip-breaking difficulties, BUE formation, and poor machined surface finish. The aim of the experiment is to study the machining parameters and machined result.*

Key words: Stainless steel, machining, turning, finite element method.

1. INTRODUCTION

Stainless steels contain a high proportion of chromium, generally 13% and more. They are generally difficult to machine due to their high tensile strength, high ductility, high work hardening rate, low thermal conductivity, and abrasive character. This combination of properties often results in cutting forces, temperatures, and tool wear rates, as well as a susceptibility to notch wear, chip-breaking difficulties, built-up-edge (BUE) formation, and poor machined surface finish [1, 2].

In our days different types of cutting inserts, with various coating thickness are used for stainless steel machining as well as for heat-resistant and hard to machined alloys. The novel turning insert with Duratomic^{TM} (from SecoTools) coating with longer tool life is used in our experiment. One of the new chip breakers for chosen turning insert is used too. The MF4 chipbreaker can handle the increased cutting forces because it’s highly secure edge configuration forms and breaks chips consistently and efficiently. This repeatability makes the MF4 very effective across a broad range of turning applications, including most stainless steel machining operations. Since cutting forces are so efficiently directed into the material being removed, instead of the insert, the MF4 geometry increases tool life by two times. When using turning inserts with a Duratomic^{TM} coating, cutting speeds and productivity can be even further increased. Experimental results are compared to finite elements models (FEM) simulation model of the cutting process. FEM are widely used for stress calculations as well as for strain and temperature distributions determinations. In consequence, temperatures in the tool, chip and work piece, as well as cutting forces, plastic deformation, chip formation and possibly of its breaking can be determined faster than using costly and time consuming experiments. It is especially important that FEM analysis can help to investigate some thermo dynamical effects occurring in the cutting zone which, as so far, cannot be measured directly. An example for such effects is the influence of cutting tool coatings on the heat transfer and friction, and resulting cutting temperature distribution in the chip and the tool. The accuracy of the solution can be improved by increasing the number of elements, although with associated increases in the computing power and time required for the simulation.

2. EXPERIMENTAL PART

2.1 Stainless steel grade selection

Stainless steel is usually classified into four categories depending on their primary content of the matrix: ferritic, martensitic, austenitic, and duplex (combined ferritic/austenitic). They may also be classified based on their heat treatment or machining characteristics (free machining versus non-free machining).

Ferritic stainless steels are alloyed primary with chromium, although molybdenum, titanium, or niobium may be added to some grades to improve corrosion resistance or as welded properties. Ferritic alloys are generally more machinable then other alloys. Their machinability generally decreases with increasing chromium content.

In addition to chromium, martensitic alloys may contain carbon, molybdenum, and nickel to increase strength. The machinability or martensitic stainless steels is influenced be hardness, carbon content, nickel content, and metallurgical structure. As with most materials, increasing hardness typically reduces tool life and machinability. Increasing the carbon content increases the proportion of abrasive chromium carbides in the matrix and reduces tool life and machinability. The metallurgical factor which has the strongest influence on machinability is the proportion of free ferrite in the matrix: generally machinability increases with free ferrite content.

Austenitic stainless steels contain nitrogen, carbon, and nickel or manganese in addition to chromium. They exhibit high strength, ductility, and toughness, and are typically more difficult to machine than ferritic or martensitic stainless steel. Specific difficulties encountered when machining austenitic stainless steel include high wear rates due to high cutting forces and temperatures, BUE formation, chip control problems, poor surface integrity (hardened machined surfaces), and a tendency to chatter. Poor tool life is related to the annealed hardness, which increases with increasing nitrogen content. Increasing the carbon content increases the work-hardening rate and also decreases machinability. Abrasive carbon/nitrogen compounds may form in the matrix and reduce tool life; these can be controlled by adding titanium or niobium. As with other stainless steels, hardness increases and machinability decreases with increasing nickel content. Imparting moderate cold work to the material typically increases machinablity by reducing the tendency for BUE formation and improving the machined surface finish and integrity [[3]].

Duplex alloys have chemistry similar to austenitic stainless steels but are generally more difficult to machine due to their high annealed strength [[4, 5, 6, 7]].

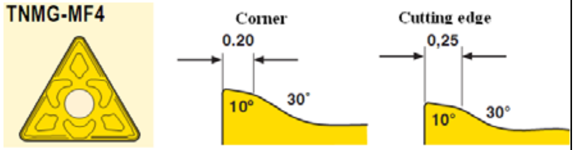
For our experiment the 420 stainless steel is chosen. Its chemical composition is following: C = 0.021%, Si = 1%, Mn = 1.5%, P = 0.04%, S = 0.03%, Cr = 13%.

2.2. Machining parameters and cutting tool selection

The aim of the experiment is to study the machining parameters and machined result, in particular the surface roughness. As it is already mentioned above, for our tree factor experiment we chosen the 420 stainless steel with high chromium content, modern Duratomic^{TM} coated turning insert TNMG 160412-MF4, TM4000 with cutting edge radius 1.2 mm. Machining technological regimes combinations (table 1) were following: feeding - 0,1 mm/Rpm and 0.35 mm/Rpm; cutting depth is 0.5mm; cutting speed 90 m/min., and 112 m/min. Machined part is divided in to 8 blocks, 5 sector each 13 mm wide. Chosen technological equipment is lathe type 16K20. The chosen chipbreker is MF4, for medium/finishing turning (table 2) with TM4000 coating (table 3), two holders with cutting angle $\varphi = 90^{o}$ and $\varphi = 60^{o}$. The main advantage of the MF4 chipbreaker is that the open and highly positive design (up to 25° rake angle) significantly reduces cutting forces. This, in turn gives: low cutting forces - higher cutting speed; increased speed capability - higher productivity; reduced crater wear – security; wide working range - less inventory. With feed rates of 0.2 - 0.35 mm and depth of cut between 1-2 mm, traditional medium - finishing inserts perform well at ordinary speeds, but fail early when the speed is increased. The MF4 can handle the increase in cutting data because it's highly secure edge configuration forms and breaks chips consistently.

Parameter comb. Nr.	1	2	3	4
Feeding, mm/Rpm	0,1	0,35	0,1	0,35
Cutting depth, mm	0,5	0,5	0,5	0,5
Cutting speed, m/min	90	90	112	112
Cutting edge angle	60°	60°	60°	60°
Parameter comb. Nr.	**5**	**6**	**7**	**8**
Feeding, mm/Rpm	0,1	0,35	0,1	0,35
Cutting depth, mm	0,5	0,5	0,5	0,5
Cutting speed, m/min	90	90	112	112
Cutting edge angle	90°	90°	90°	90°

Table 1. Machining process parameters



Chipbreaker intended for medium/finishing of stainless steels. Very open and highly positive geometry. Machining range: f (feeding) = 0.15 – 0.5 mm/rev, ap (depth of cut) = 0.5– 4 mm

Table 2. Chosen chip breaker and its description

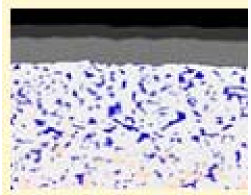
	TM4000 is intended for machining of stainless steels. The wear resistance and together with the superior edge toughness make the grade the first choice in stainless steel applications. Ti (C,N) + Al_2O_3 DURATOMIC™

Table 3. Chosen turning insert coating and its description

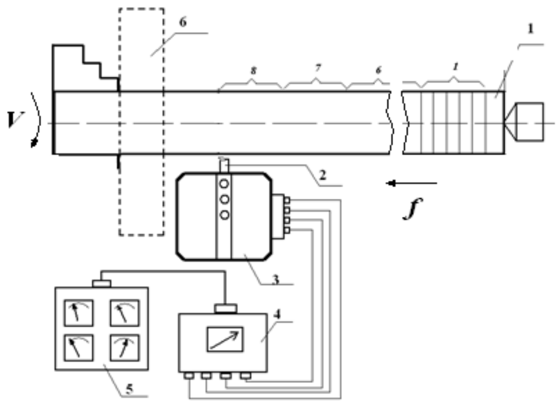


Figure 1. Experimental scheme

3. EXPERIMENTAL RESULTS

The experimental machining parameters were exanimate in combination of 8 variants with repeating five times each. Experimental scheme (figure 1) is showing: machined part of 420 stainless steel, length = 1000 mm., d = 90 mm. (1), turning insert (2), placed in the universal dynamometer UDM – 600 (3), for measuring cutting forces during machining process, four channel amplifier (4), ammeter block (5), and the stay (6), to decrease vibrations during machining process. The main idea of this experiment was to study the machining process and results of 420 stainless steel and TM4000 Duratomic^{TM} – coated turning insert with MF4 chipbreaker .The appropriate surface roughness and hardness parameters were measured: Ra - average roughness, arithmetic mean deviation of the profile; Rt - maximum height of the profile and surface hardness parameter HB (figure 2). Surface roughness parameters are shown in figures 3, 4 and tables 4, 5.

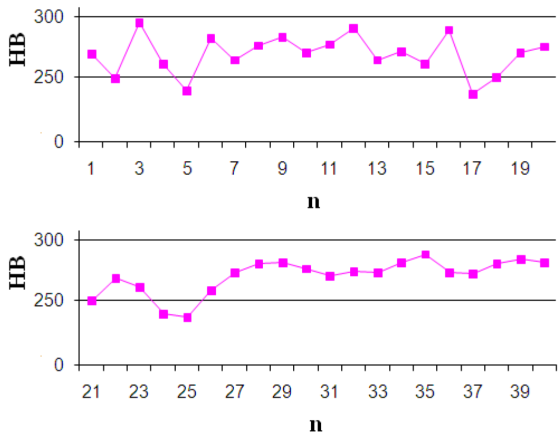


Figure 2. Machined surface hardness

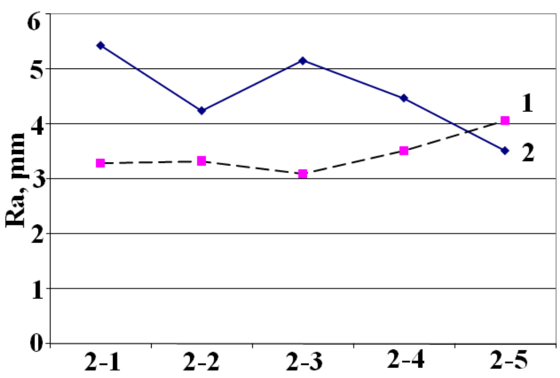


Figure 3. Ra result comparison: 1- for cutting edge angle 60 º; 2- for cutting edge angle 90 º

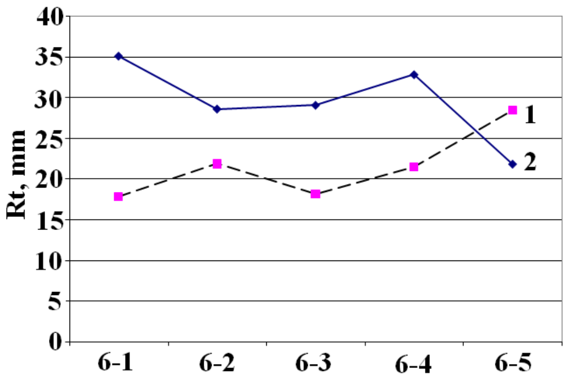


Figure 4. Rt result comparison: 1- for cutting edge angle 60 º; 2- for cutting edge angle 90 º

Machining block number	Ra, µm	Rt, µm	Hardness, HB
1	5.92	44.82	262
2	4.57	29.41	275
3	5.04	39	272
4	5.72	40.88	264
5	5.56	47.2	250
6	3.46	21.55	273
7	5.4	41.7	277
8	3.68	35.4	278

Table 4. Experimental results

Machining block number	Machining section number	Ra, µm	Rt, µm
2	2-1	5.44	35.02
	2-2	4.25	28.53
	2-3	5.16	28.99
	2-4	4.48	32.74
	2-5	3.52	21.76
6	6-1	3.29	17.83
	6-2	3.33	21.85
	6-3	3.1	18.15
	6-4	3.52	21.49
	6-5	4.06	28.44

Table 5. Best results comparison

One more important parameter, such as cutting temperature is measured with k-type, chromel - alumel thermocouple placed inside cutting insert. Computer simulations and metal cutting process modeling is widely used in our day to predict temperatures in cutting process contact zone, stress distribution zone, which is very important [8]. Obtained experimental values [9, 10] are fully corresponding to the FEM modeling results in program Third Wave AdvantEdge and is 280 °C at 1.5 mm from the cutting contact place. Chip formation process during metal cutting is well seen in Fig.2. The heat results in a rise in temperature and the contours of the temperature field and rate of temperature during this cutting process are shown in figure 5, 6, 7. On the graphical result (figure 6, 7) we can see, that sometimes on the cutting edge temperature changes from base cutting temperature (600 to 700 °C) to the maximum mark of 1100 °C – 1200 °C.

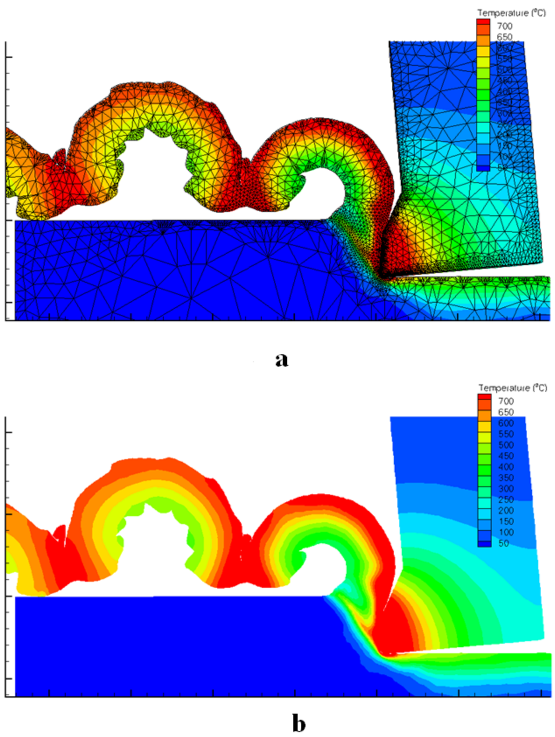


Figure 5. Simulation of cutting process, chip formation process, temperature field in the cutting tool and material distribution

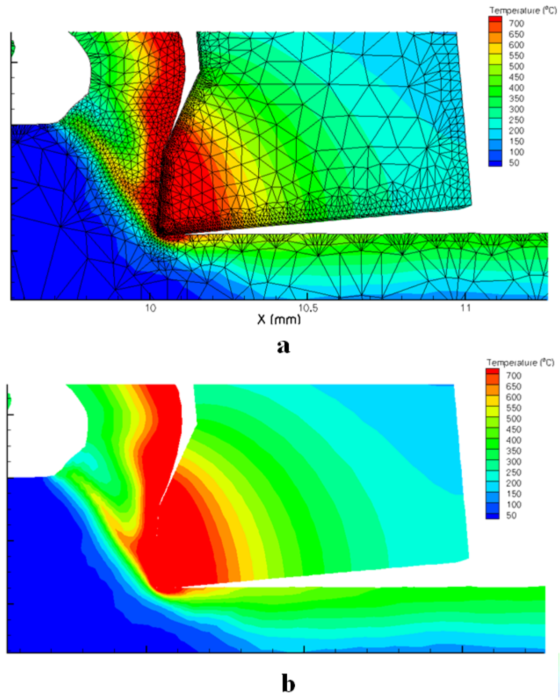


Figure 6. Simulation result of cutting process: temperature field in the cutting tool and material with meshing (a), without meshing (b)

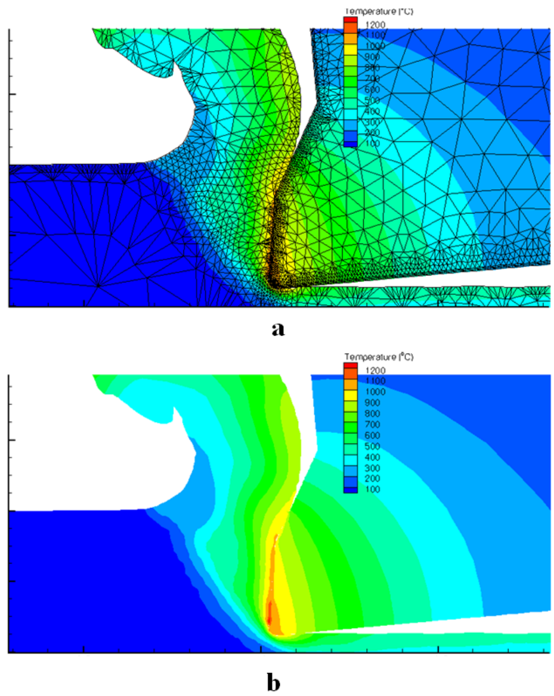


Figure 7. Simulation result of cutting process: temperature field in the cutting tool and material with meshing (a), without meshing (b)

4. CONCLUSION

The experimental results are showing how machining parameters and technological regimes combinations change machined surface results. Main conclusion is that in order to obtain better result it is necessary to change the cutting edge angle. However it is not so handy when the different profile surfaces are machined. In the same time increased cutting speed and decreased feeding are not so important factors. Furthermore, use of the new Wiper chip breaker geometry is providing better surface roughness results.

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