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EFFECT OF CUTTING SPEED AND FEED RATE ON TOOL GEOMETRY, TEMPERATURE AND CUTTING FORCES IN MACHINING AISI 1045 CARBON STEEL USING FEM SIMULATION

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Abstract: *Finite element simulation of the cutting process is increasingly used by researches in the field to the detriment of experimental tests because they are expensive and time consuming. Another advantage of this method is that it provides information on deformations, stresses and temperatures that occur during the machining process but also about chip shape and tool wear rate. This paper studies the influence of cutting speed and feed rate on tool geometry, temperature and cutting forces in machining AISI 1045 carbon steel. For this research were run six trials of simulation. The machining parameters (cutting speed and feed rate) were considered variable and tool geometrical parameters were kept constant. Finite element simulation was performed with the software Deform 2D Machining. Simulation results are showing that increasing the cutting speed increases the temperature values but the values of the cutting forces are decreasing. When cutting with high values of the feed rate, cutting forces and temperature are rising, causing modification of the tool geometry and thus a higher wear.*

Keywords: *finite element simulation, cutting process, feed rate, Deform 2D, cutting forces, tool geometry.*

1. INTRODUCTION

In the last years the cutting and cutting tools field have been object of study for many researchers. Various methods and models have been proposed, which are based on fundamental cutting theories. Some researchers have relied on experimental tests others have used cutting process simulation with finite element method. Due to the proven performance of finite element simulation programs most researchers have opted for this method. Thus, H. Yanda in his work [3] made seven cases simulation using finite element software Deform 3D in order to study the effect of rake angle of cutting forces, effective stresses , strains and temperatures; the results are showing that the lowest values of forces, stresses and strains were recorded for a rake angle of +15˚. Attanasio and coauthors have developed a wear model [1] which combines both the model of abrasive wear and wear by diffusion with the purpose to predict tool wear and to update the geometry tool, simulation accomplished with Deform 3D software. N. Senthil Kumar and T. Tamizharasan are showing in their paper [5] how different combinations of tool shapes and tool geometries influences the tool wear, cutting forces and heat generation at the tool-chip interface using Deform 2D software. Luigino Flice and coauthors present a wear model [4] in order to obtain a suitable geometry of the tool so that it can be implemented in finite element program to describe the evolution of wear during machining process. Patricia Muñoz Escalona, S. Melkote and Kai Liu [6] were studying using software Deform 2D and experimental tests the influence of the stress, strain and temperature on the surface roughness in machining AISI 52100 steel.

So, by using finite element simulation of the cutting process can be predict values of strains, stresses, contact pressure, temperature, cutting forces and tool wear rate.

Finite element analysis performed in this paper aims to study the influence of cutting speed and feed rate on the tool geometry, temperature and cutting forces in machining AISI 1045 steel. This analysis was considered necessary because the cutting process parameter influences the tool wear, productivity and costs, but also because it is less discussed in literature.

Nomenclature

f	feed rate, mm/rev;
v	cutting speed, m/min;
a_p	depth cut, mm;
F_x	cutting force, N;
F_y	thrust force, N;
α	clearance angle, degrees;
γ	rake angle, degrees;
r_ε	tool edge cutting radius, mm.

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2. CUTTING PROCESS SIMULATION WITH FINITE ELEMENT METHOD

To run the simulation was used Deform 2D Machining V9.0. Machining parameters, cutting speed and feed rate, were considered as variable. The values of these parameters are given in Table 1.

The tool was considered as a rigid body with rake angle and clearance angle of +5˚ and the nose radius of 0.4mm. The tool mesh was set to 1 500 elements and the material was chosen tungsten carbide coated with a TiCN layer with a thickness of 5 microns. These characteristics of the tool can be seen in Table 2.

The workpiece is considered as a plastic body with a mesh of 3 000 elements. AISI 1045 carbon steel was chosen for the workpiece material. Table 3 shows the chemical composition of the AISI 1045 carbon steel.

Figure 1 shows the general scheme of finite element simulation of an orthogonal cutting process.

There were six cases of simulation run presented in Table 5. The simulations were carried out in two stages. In the first stage has been generated effective simulation of the cutting process. In this stage the input parameters of the process were set: cutting speed, feed rate, depth of cut, tool and workpiece geometry and tool and workpiece materials. Output parameters of this stage are: workpiece strain and stress, tool-chip interface temperature, cutting forces, contact pressure and wear rate. In this study will focus on cutting forces and temperatures because these parameters are influenced by the cutting speed and feed rate. In the second stage analysis on the tool was performed. This step is necessary because it provides information about the tool geometry modifications.

Table 1

Cutting parameters

v **[m/min]**	**a_p** **[mm]**	**f** **[mm/rev]**
180	0.5	0.08
230	0.5	0.14
285	0.5	0.2

Table 2

Tool parameters

γ **[˚]**	**α** **[˚]**	**r_ε** **[mm]**	**Tool mesh**	**Tool material**	**Tool coating**
5	5	0.4	1500	WC	TiCN

Table 3

Chemical composition of AISI 1045 carbon steel

C	**Si**	**Mn**	**Cr**	**Mo**	**Ni**
0.46	0.286	0.609	0.150	0.1	0.219

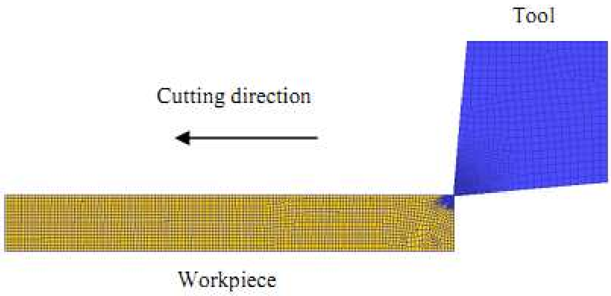


Fig. 1. General scheme of finite element simulation.

3. RESULTS AND DISCUSSION

Simulations were performed under the conditions shown in Table 5 and the results are presented in Table 6.

Analyzing the trials of Fig. 2 it can be seen the rake angle modification, clearance angle modification and nose radius modification. Due to higher feed rate and cutting speed, the rake angle of the tool increases. This result is in according with the references [1].

In Fig. 3 the temperature distribution in the tool is shown. In according with the literature [2], at temperatures of 700–800˚C occurs the oxide layers. Thus, the wear oxidation process of the tool can take place.

Effect of the feed rate on the cutting forces is due to change of the chip thickness [2]. The results obtained by finite element simulation (Figs. 4 and 5) shows that the cutting force increases as the feed rate is increased. These results are in agreement with the literature [6].

In according with the references [7], from analysis of Fig. 6, it can be observed the influence of the feed rate on temperature: increasing the feed rate, temperature increases.

Fig. 7 and Fig. 8 show the influence of the cutting speed on the forces F_x and F_y. It can be seen that in the cutting speed domain of the 180…230 m/min, the forces tend to increase. So, an increase of the cutting speed leads to lower values on the forces.

In Fig. 9 the influence of the cutting speed on the temperature is shown. It can be observed that the temperature increases as the cutting speed is increased. The result is in according with the references [8].

The maximum values of the tool displacement were obtained for the highest values of the cutting forces (trial No. 3 and trial No. 5).

Table 5

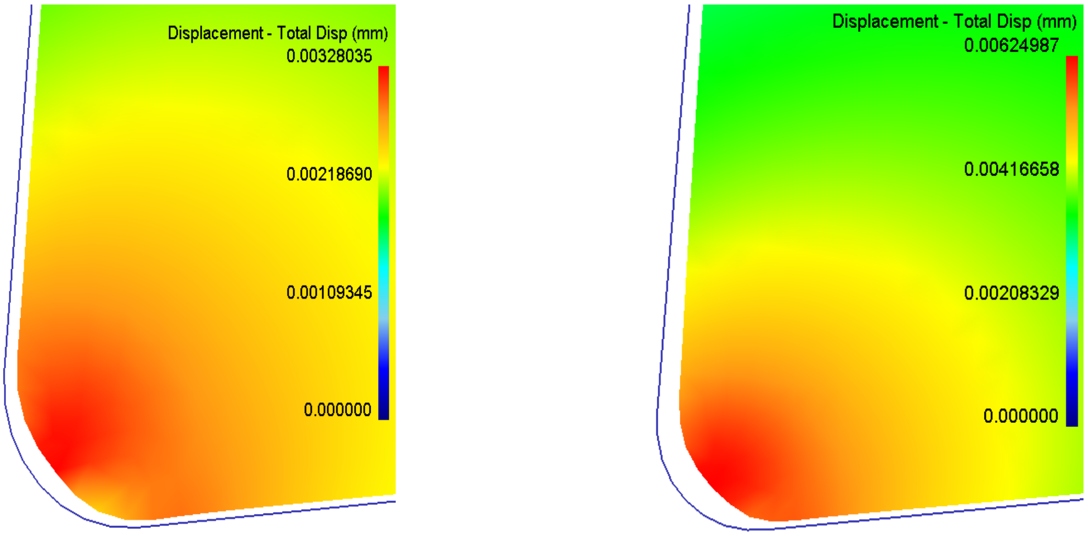
Simulation trials

Trial no.	**v** **[m/min]**	**f** **[mm/rev]**
1	285	0.08
2	285	0.14
3	285	0.2
4	180	0.2
5	230	0.2
6	280	0.2

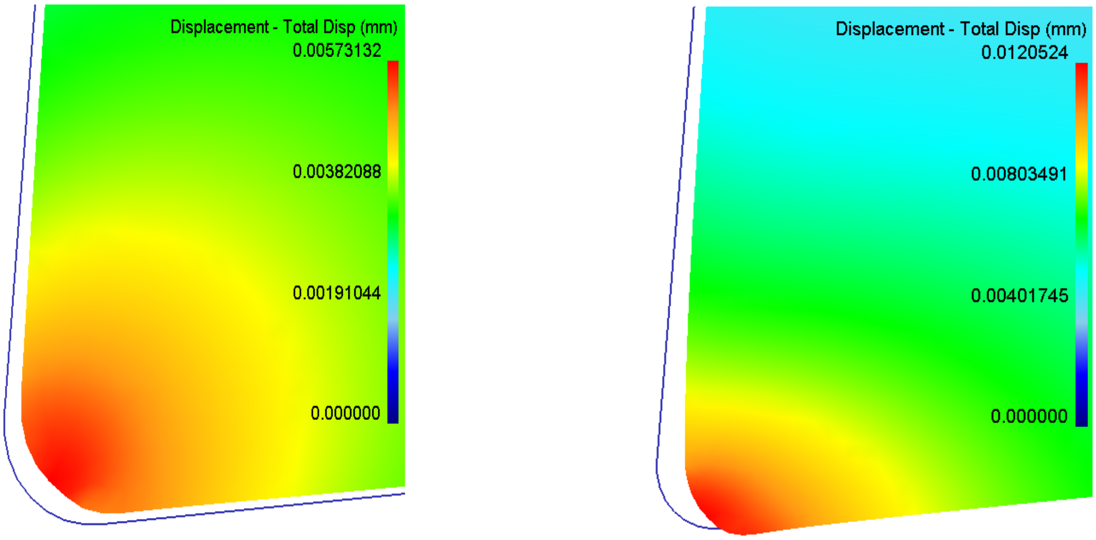
Table 6

Simulation output parameters

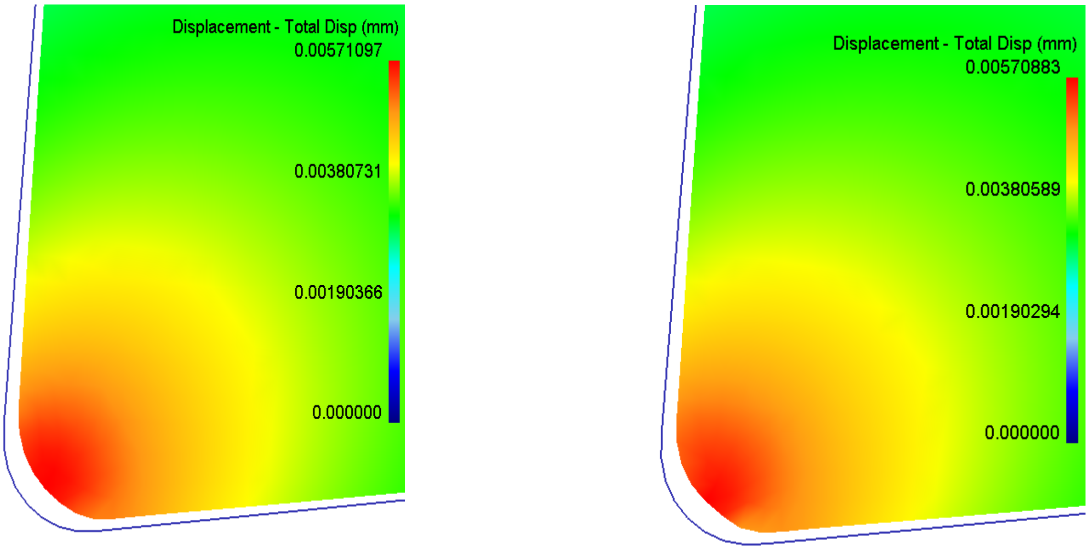
Trial no.	**Maximum displacement [mm]**	**Maximum temperature [˚C]**	**F_x** **[N]**	**F_y** **[N]**
1	0.00328035	850	731	997
2	0.00571097	855	870	1198
3	0.00624987	889	1005	1202
4	0.00573132	757	888	1127
5	0.0120524	775	991	1170
6	0.00570883	945	881	1109



(a) trial No. 1 (c) trial No. 3

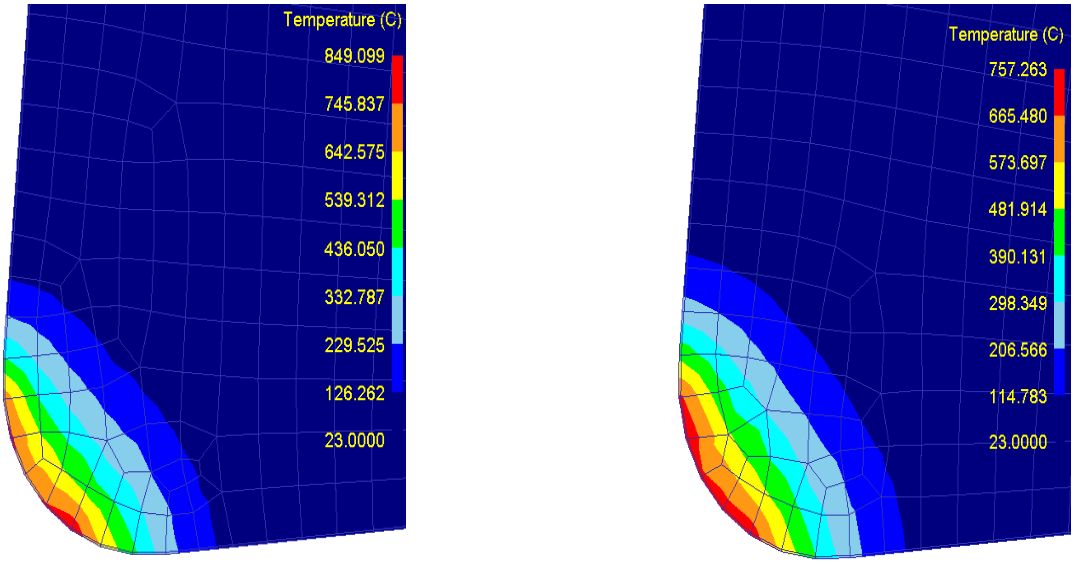


(d) trial No. 4 (e) trial No. 5



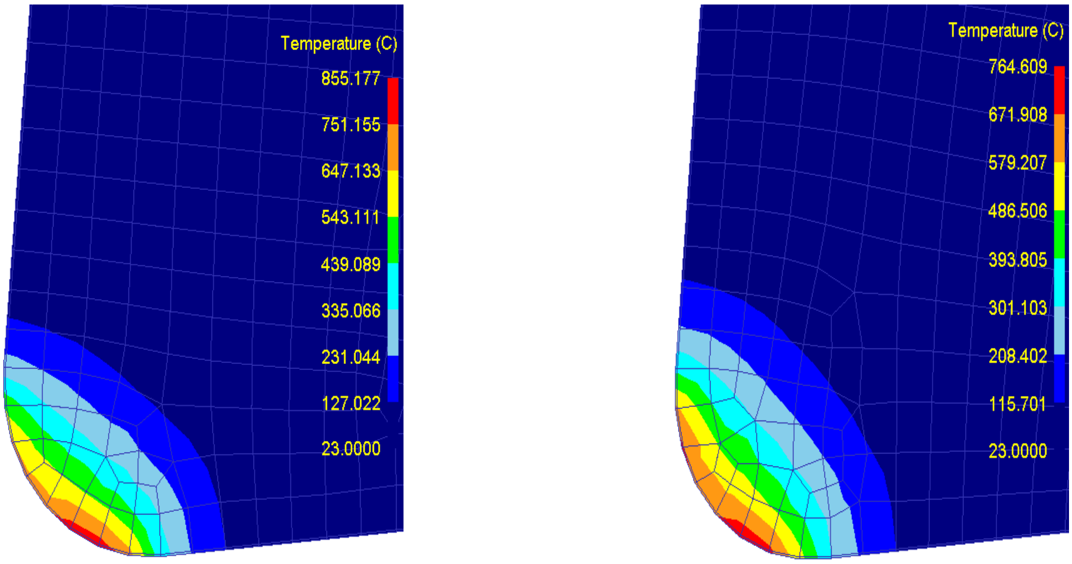
(b) trial No. 2 (f) trial No. 6

Fig. 2. Tool displacement.



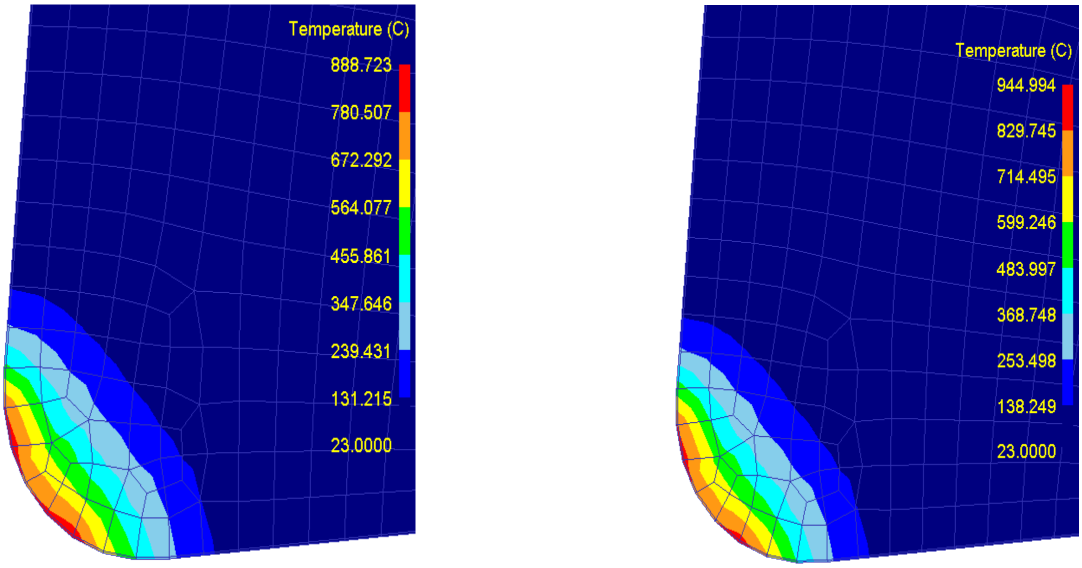
(a) trial No. 1

(d) trial No. 4



(b) trial No. 2

(e) trial No. 5



(c) trial No. 3

(f) trial No. 6

Fig. 3. Temperature field of the tool.

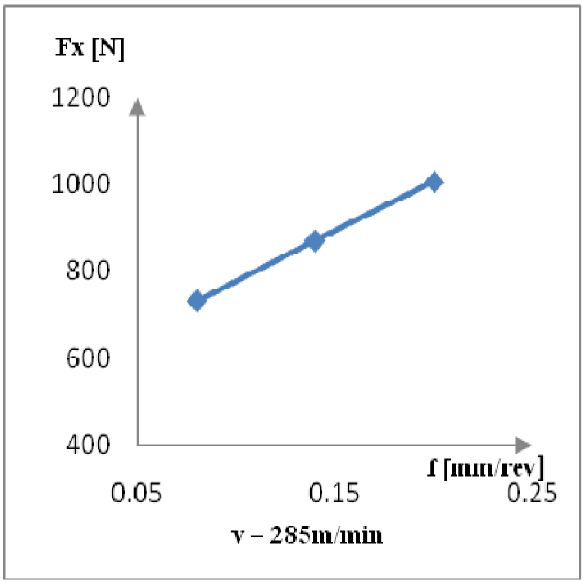


Fig. 4. Influence of the feed rate on the cutting force, F_x.

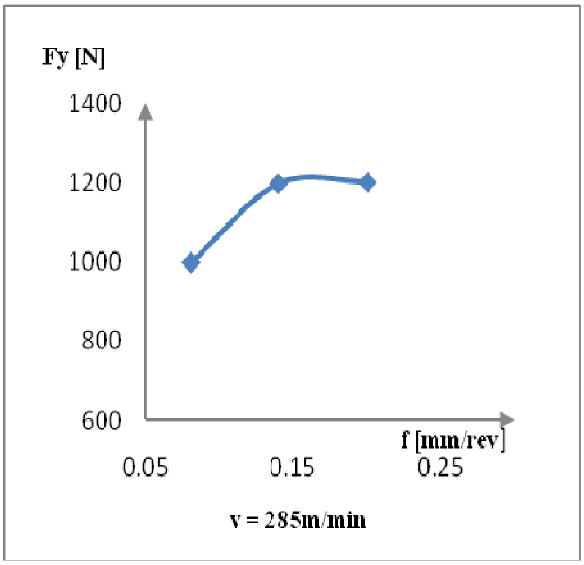


Fig. 5. Influence of the feed rate on the thrust force, F_y.

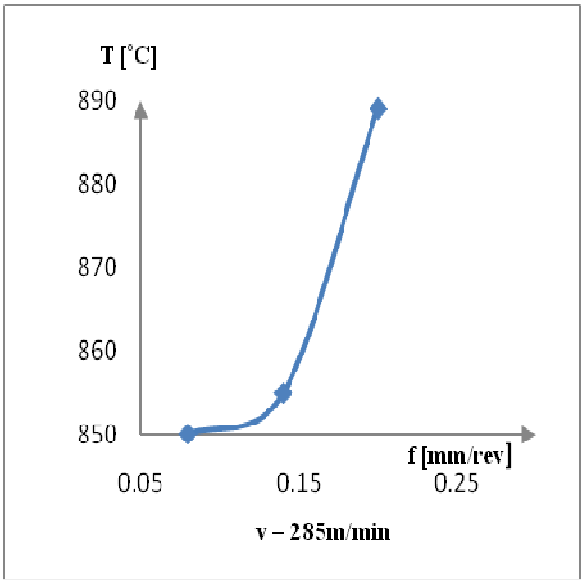


Fig. 6. Influence of the feed rate on the temperature.

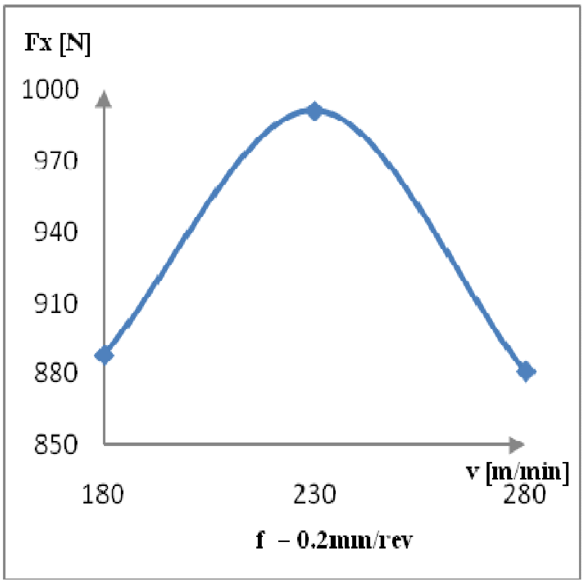


Fig. 7. Influence of the cutting speed on the cutting force, F_x.

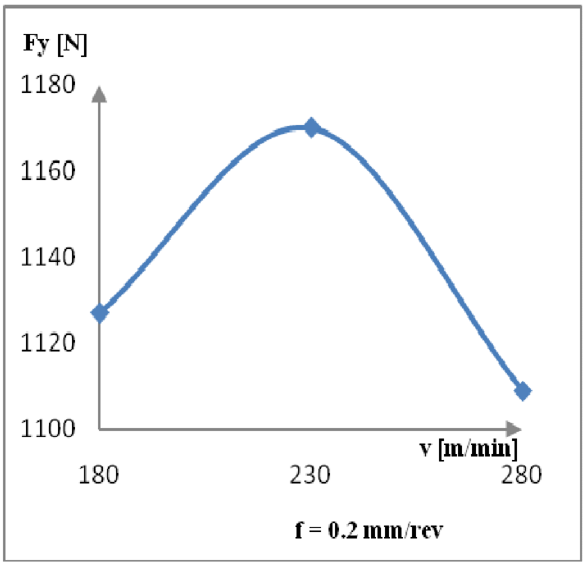


Fig. 8. Influence of the cutting speed on the cutting force, F_y.

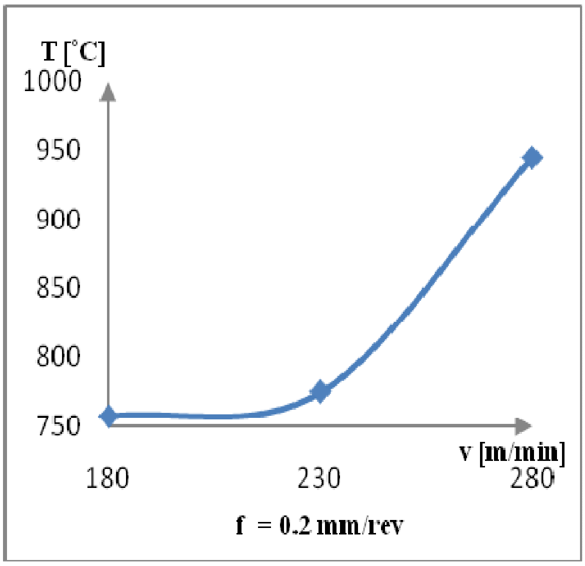


Fig. 9. Influence of the cutting speed on the temperature.

4. FURTHER RESEARCH

Further, the effect of the feed rate on the strains and stresses in the workpiece is presented. Table 7 shows the values of the strains and stresses.

Fig. 10 shows the evolution of the strains in according to the feed rate. It is a variable evolution, the lowest value of the strain recording for a feed rate of 0.14mm/rev.

As shown in Fig. 11, the evolution of the stresses is ascending. Increasing the value of the feed rate, the value of the streeses increases. Thus, the higher value of the strees recording for a feed rate of 0.2 mm. Finite element analysis shows that the chip becomes thicker with the feed rate increases (Figs. 12, 13, and14). This result is in according with previous research [2 and 6].

Table 7

Values of the strains and stresses

f [mm/rev]	Strain Effective [mm/mm]	Maximum Principal Stresses [MPa]
0.08	2.97936	589.617
0.14	1.88480	834.653
0.2	3.506360	1074.78

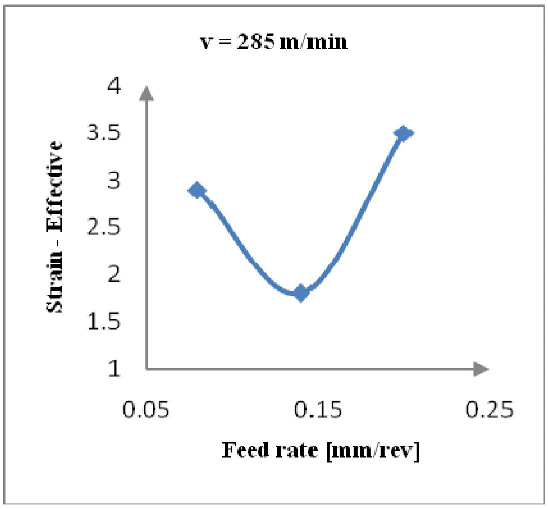


Fig. 10. Influence of the feed rate on the strain effective.

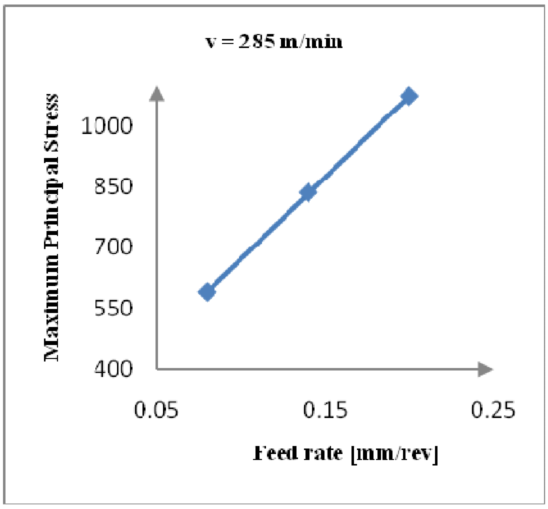


Fig. 11. Influence of the feed rate on the principal stresses.

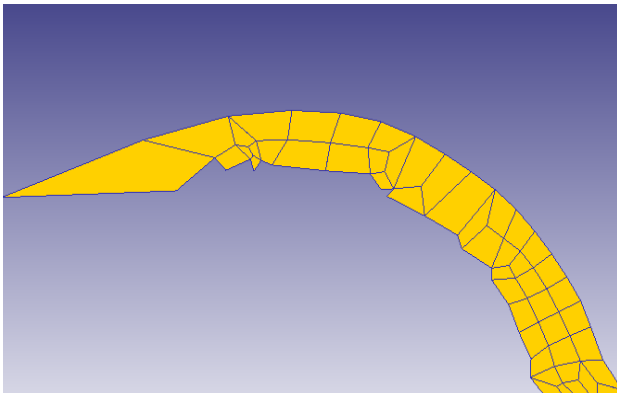


Fig. 12. Chip thickness for *f* = 0.08 mm/rev.

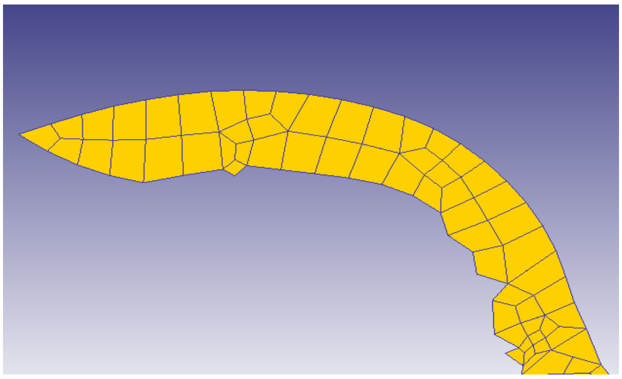


Fig. 13. Chip thickness for *f* = 0.14 mm/rot.

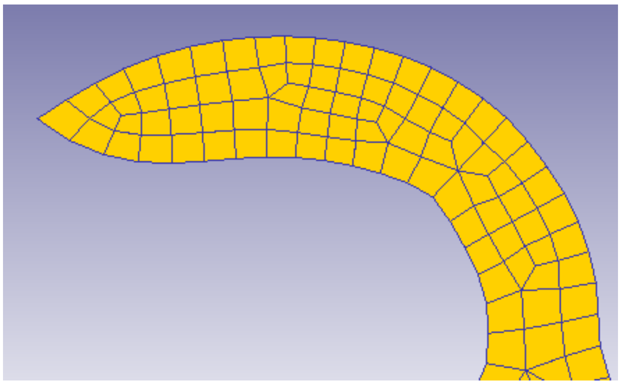


Fig. 14. Chip thickness for *f* = 0.2 mm/rot.

5. CONCLUSIONS

This paper presents the results of the finite element analysis, which refer to the effect of the cutting speed and feed rate on the tool geometry displacement, temperature and cutting forces.

Based on the simulation results, it can be concluded that:

- for large values of the feed rate and cutting speed, the tool geometry changes: the values of the rake angle, clearance angle and nose radius increase. The maximum values of the tool displacement were obtained for the highest values of cutting forces (trials No. 3 and No. 5);
- cutting force increases as the feed rate is increased. The highest value of the cutting force recorded for the feed rate value of 0.2 mm/rev;

- increasing the feed rate, the temperature increases. The highest value of the temperature (889 ˚C) is obtained for the feed rate value of 0.2 mm/rev;
- forces tend to increase in the cutting speed domain of the 180–230 m/min;
- the lowest value of the strain it was obtained for the feed rate value of 0.14 mm/rev;
- the evolution of the stresses is ascending: increasing the value of the feed rate, the value of the streeses increases;
- Deform 2D software provides a very good prediction of the tool displacement, temperature, cutting forces, strains and stresses.

The study presented in the paper is important because the cutting process parameters influencing the tool wear, productivity and costs. Of course, are necessary both finite element simulations and experimental tests wich confirming the results obtained by prediction. Thus, it can mention some future research directions that we will study:

- the evolution of tool wear by prediction;
- comparison between results obtained by FEM and experimental tests;
- cutting parameters optimization by statistical methods;
- finding ways to compensate the tool wear.

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