International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 24 (2015) pp 44920-44926
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Finite Element Modeling Of Cutting Process At External Longitudinal Turning

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Abstract- The paper describes cutting process finite element modeling on the example of AISI 316L steel workpiece external longitudinal turning by a carbide cutting tool. The simulation was performed in the speed range 100-550 m/min. The influence of technological regimes on the chip formation nature, magnitude of the cutting force tangential and radial components, and on the thermal condition of the cutting insert's contact zone with the workpiece was revealed. The nature of the cutting force change in times of the tool's entry and exit from the cutting zone was defined. The temperature fields' distribution and the maximum temperature change dynamics on the surface of the workpiece and the tool since the start of the cutting was revealed. The cutting speed value for specific processing conditions in which the temperature in the cutting zone reaches the maximum value was determined. Simulation results confirm existing data on the ambiguous influence of cutting speed on the temperature in the cutting zone. The cutting edge wear components qualitative relationship determined by the thermal condition in the cutting zone was shown.

Keywords: finite element modeling, cutting process, feed, speed, temperature, cutting force

INTRODUCTION

The surface layer optimal condition of the product is formed as by machining under the influence of many elastic-plastic processes factors in the cutting zone, metal flow, thermal fields and stress-strain state of the workpiece and the tool. Maintaining the optimal cutting temperature during processing allows us to consistently maintain the set quality parameters of the surface layer: micro-hardness, residual stresses magnitude and the hardened layer's depth [1]. The complex of these indicators within the established values has a positive effect on the product's reliability. In addition to the qualitative characteristics, the thermal process in the cutting zone affects the accuracy of the system "Machine−Device−Tool−Workpiece" and the workpiece's shape accuracy. The cutting tool persistence is determined by the amount of the cutting edge wear, which, in turn, depends on three types of wear: adhesion, diffusion, abrasive [2, 3]. Depending on the cutting conditions there can run concurrently three types of wear or any of them can dominate others. In describing the turning processes, as a rule, abrasive wear is neglected. When processing at a certain cutting speed and temperature in the cutting zone about 600 ° C occurs adhesive wear of the tool [4], which runs with constant speed, while the wear's relative velocity is almost constant. With cutting speed increasing the adhesion wear is reduced. When the temperature in the cutting zone is about 800 ° C there begins the weakening of the insert's hard carbide and adhesive wear becomes diffusive (Fig. 1). The dependence of resistance on temperature in the cutting zone (Fig. 2) has an extremum and low wear and tear area; moreover, there may be more than one extremum.

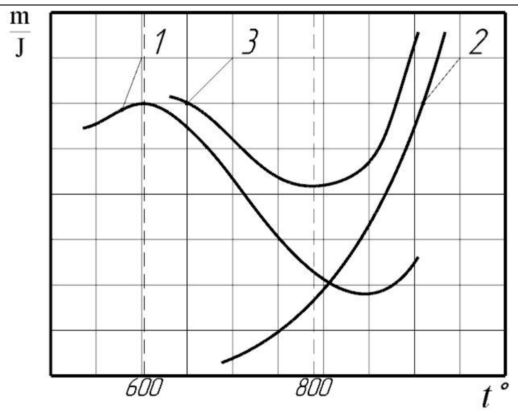


Fig. 1 - Temperature dependence scheme of the carbide tools wear components intensity: 1 - adhesive wear; 2 - diffusion wear; 3 - total wear

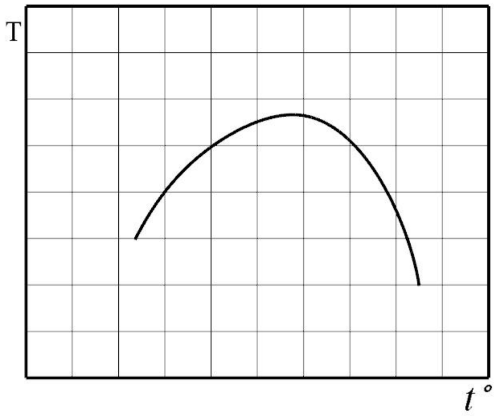


Fig. 2. Temperature dependence of the tool resistance

Dependencies in Fig. 1 and Fig. 2 have a common qualitative nature and may vary greatly depending on the steel grade of the insert, the presence or absence of cooling lubricants and machining conditions. For achieve optimal temperature and power status in the cutting zone is necessary the modeling of the cutting process and the indicators set definition describing the chip formation process. Based on these data it will be possible to define the relevant technological regimes and required components provision of the desired wear and tear balance, and therefore the increase in the cutting tool durability. Machining process's experimental studies are a time-consuming task for engineers. The temperature measured values in the cutting area and power parameters may give inaccurate empirical temperature and power dependences or be not consistent with analytical models due to several factors [5]: workpiece surface layer physical and mechanical properties unevenness, due to the method of workpiece production or processing in the preceding operation; constantly changing during cutting by tool's cutting edge geometry; the random nature of the processes associated with the tool wear.

Chip formation numerical simulation when machining offers the following advantages compared to analytical and experimental research methods [6, 7, 8]:

– Obtaining full three-dimensional picture of elastic-plastic, power and heat transfer processes;

- Complex relationships identification between the processing modes and the product's surface layer condition [9].

The main part

Finite element modeling of the external longitudinal turning. As a finite element tool was used a special application for cutting process modeling. The cylindrical workpiece diameter is – 250 mm, material – steel AISI 410. Table 1 shows the simulation main parameters, including basic geometric and constructive parameters, physical and mechanical properties of the workpiece material and the cutting insert.

Table 1. Estimation parameters

Cutting Parameters	**Values**
Workpiece Material	AISI 316l
Cutting Material	WC (Tungsten Carbide)
Insert Type	CNMA 432
Cutting Tool Tip Radius (mm)	0.8
Rake Angle	−5

Clearance Angle	−5
Cutting Speed (m/min.)	100-200-300-400-550
Depth of Cut (mm)	2
Feed Rate (mm/rev.)	0.05-0.3
Temparature (°C)	20
Heat Transfer Coefficient (W/mK)	62
Friction Coefficient	0.5
Grid construction method	Absolute
Element's minimum size	25% of the feed
The ratio between the highest and lowest side of the element	7

The type of workpiece material is plastic; the type of tool material is a hard one. For the destruction process' numerical description in the finite element package are used semi-empirical and empirical models: Johnson-Cook, Zerilli-Armstrong and Oxley. Below are the modeling highlights:

- A three-dimensional workpiece model is the circle arc with a diameter of 250 mm and an angle of 40°; (Fig. 3);
- Building a grid on the workpiece with a minimum element size equal to 25% of the feed (Fig. 4).

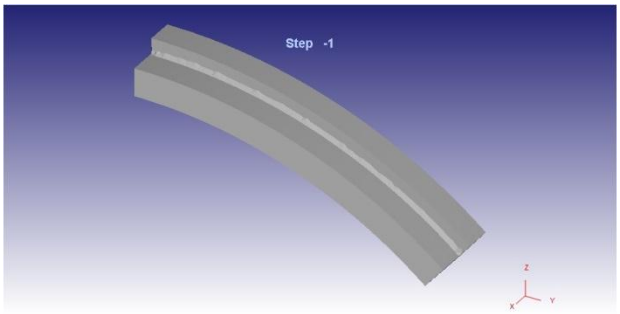
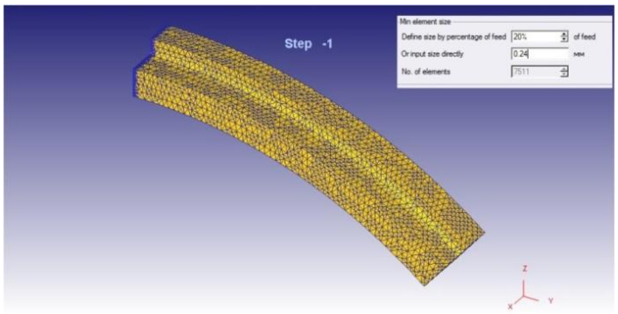


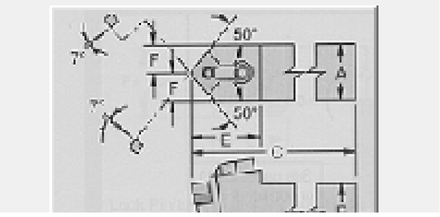
Fig. 3. - Three-dimensional model of the workpiece



Min element size
Define size by percentage of feed 20% of feed
Or input size directly 0.24 MM
No. of elements 7511

Fig. 4 - The change of the cutting force Fy component at the feeding s=0.7 mm/rev

The cutting insert is carbide, diamond shaped, its structural and geometrical parameters are shown in Fig. 5.



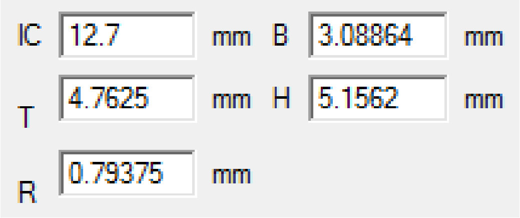

IC 12.7 mm B 3.08864 mm
T 4.7625 mm H 5.1562 mm
R 0.79375 mm

Fig. 5. - Structural and geometrical parameters of the cutting insert and a tool holder

The calculation was carried out for the cutting depth of 4 mm and a cutting speed of 120 m/min at feed rates recommended for roughing - 0.7 mm/rev and 1.2 mm/rev. As a result of the modeling was received a picture of chip formation during cutting. Fig. 6-9 show the variation of the cutting forces Fy and Fz components in the processing at the feed of 0.7 mm/rev and 1.2 mm/rev respectively.

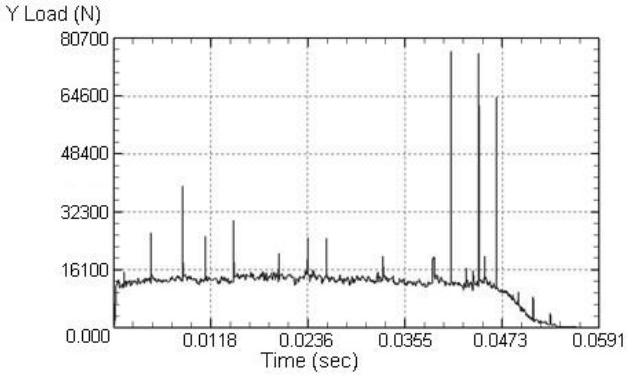


Fig. 6. - The change of the cutting force Fy component at the feeding s=0.7 mm/rev

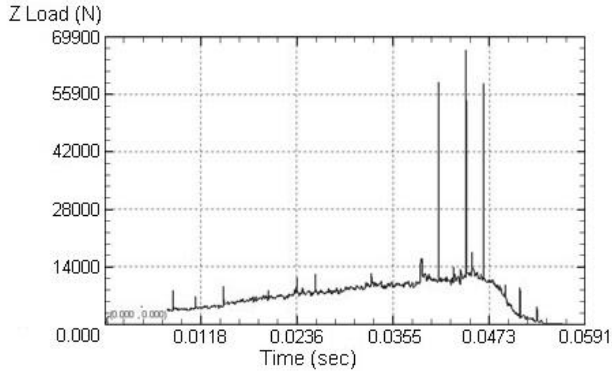


Fig. 7. - The change of the cutting force Fz component at the feeding s=0.7 mm/rev

In the graphs can be traced three states of the cutting process due to the chip formation and gathering: the cutting edge introduction into the material operated (non-stationary cutting mode); steady-state cutting process; tool’s release moment from the cutting zone (non-stationary cutting mode).

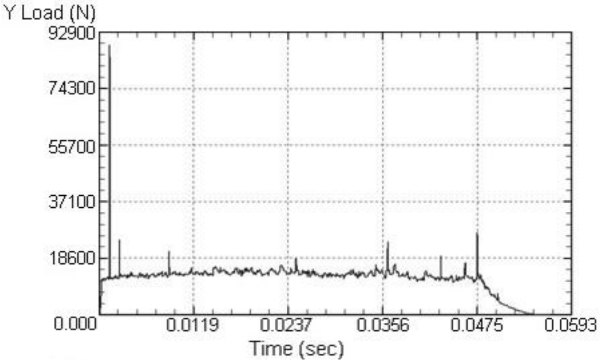


Fig. 8. - The change of the cutting force Fy component at the feeding s=1.2 mm/rev

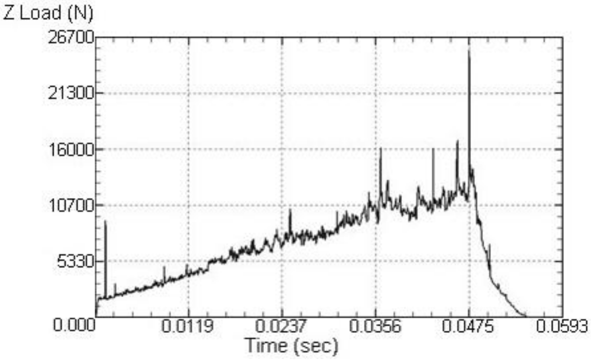


Fig. 9. - The change of the cutting force Fz component at the feeding s=1.2 mm/rev

Fig. 10 shows the tool insertion beginning, and Fig. 11 – the graph of the cutting force change caused by the cutting edge introduction into the workpiece.

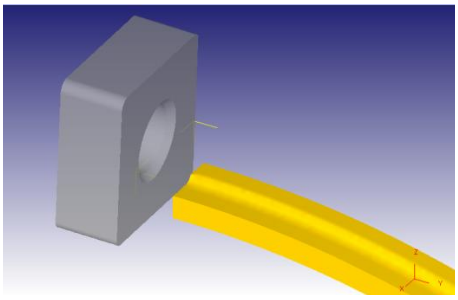


Fig. 10. - The input of the tool into the cutting area

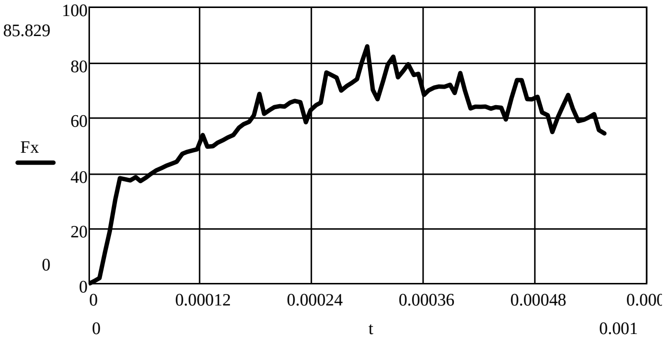


Fig. 11. – The graph of cutting force change during the tool introduction into the workpiece

Figures 13 and 12 respectively show the tool's output from the cutting area and a cutting force change graph.

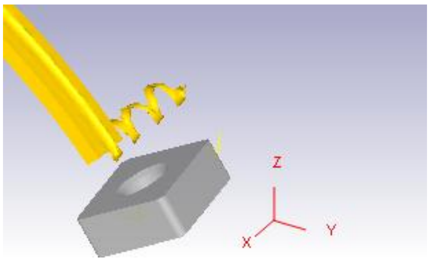


Fig. 12. - The output of the tool from the cutting area

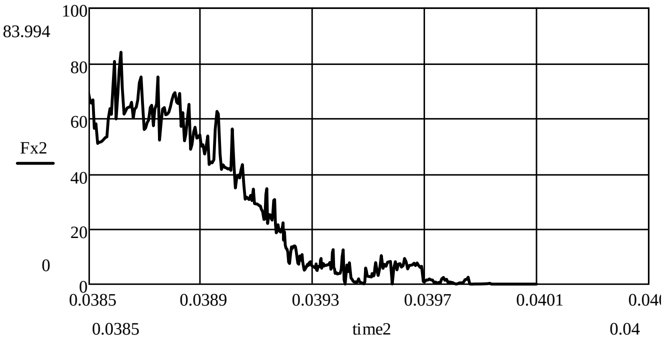


Fig. 13. - The graph of cutting forces change at the exit from the cutting area

Thermal process in the cutting zone. In Fig.14 and Fig. 15 there are graphs showing changes of the maximum temperature in the surface layer of the workpiece and on the cutting edge when feeding 0.7 mm/rev.

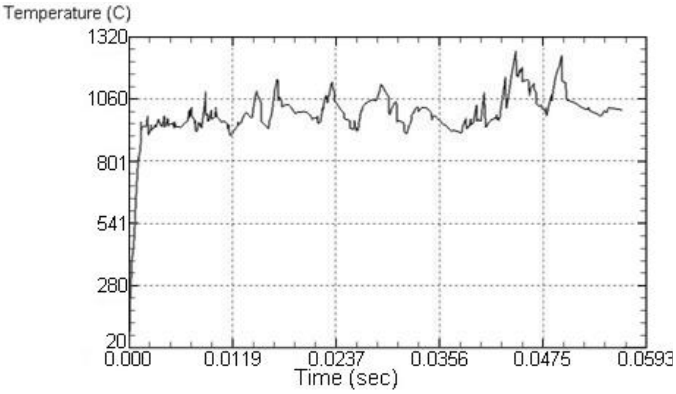


Fig. 14. - Maximum temperature change of the workpiece surface at the feeding s = 0.7mm/rev

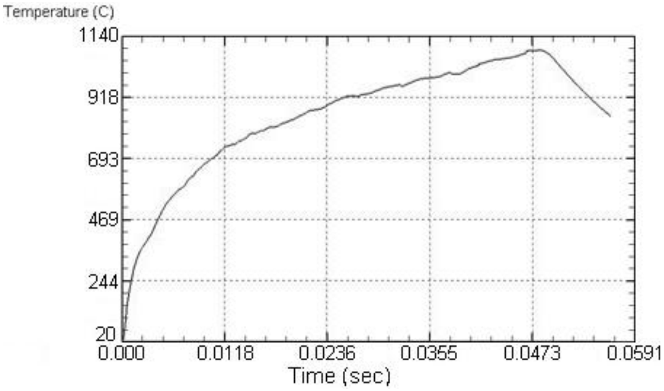


Fig. 15. – Maximum temperature change of the tool at the feeding s = 0.7mm/rev

I. A number of finite element problems solved for the velocity range 100-550 m/min allowed to determine and reveal the influence of cutting speed on the workpiece surface and cutting edge maximum temperature. Obtained by finite element model results confirm existing data [10] on the existence of an optimal value in the high speeds range. They show a decrease in temperature due to the increased intensity of the workpiece convective heat transfer with the environment and an increase in heat removal into chips [2].

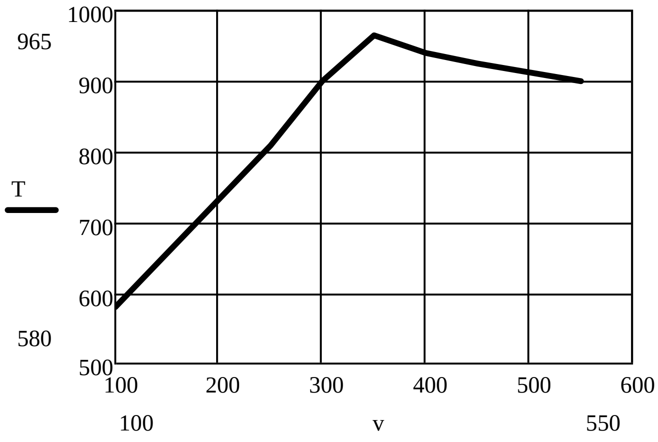


Fig. 16. - The change of the workpiece surface maximum temperature at the feed s=0.05 mm/rev

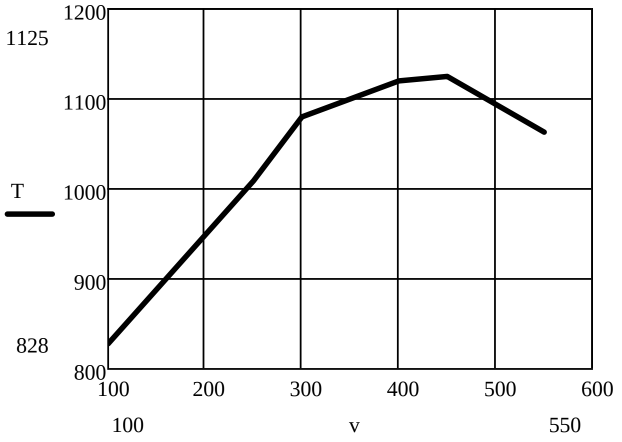


Fig. 17. - The change of the tool maximum temperature at the feed s=0.3 mm/rev

In Fig. 18 there are diagrams showing the thermal field distribution in the cutting zone: on the workpiece surface and the chip temperature growth at increasing cutting speed.

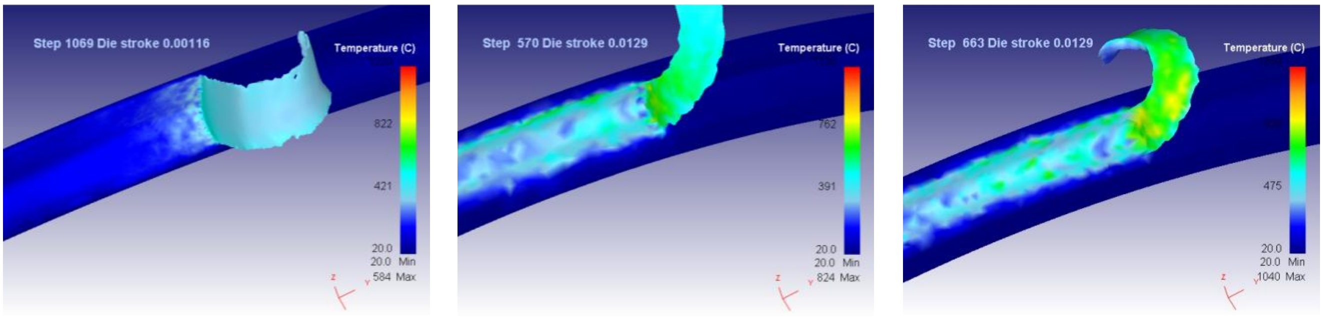


Fig. 18. - The temperature distribution on the workpiece surface at the feeding 0.3 mm/rev with a cutting speed: 100 m/min, 300 m/min and 550 m/min

Conclusion

- The cutting process finite element modeling using a special software package was carried out. The character of changes in the cutting force at the time of tool's entry and exit from the cutting area was defined;

- The influence of technological conditions on the chip formation nature at the outer longitudinal turning, the behavior of the cutting forces and thermal condition of the workpiece and the cutting tool was investigated.

- The curves of the maximum temperature change on the workpiece and tool's surface were obtained;

- Cutting speed range modeling at 100-550 m / min confirmed data on the ambiguous influence of cutting speed on the temperature in the cutting zone. There was received a critical point of the cutting speed value which gives the optimum temperature.

The results obtained provide a further opportunity to determine the optimum technological conditions that ensure a favorable temperature and force condition of the tool's workpiece in the cutting zone. The study was performed under a grant №14-41-08044 «Mathematical modeling and optimization of machining processes as a means of technological parameters control on the basis of indistinct logic."

References

1. A.G. Suslov, The surface layer quality assurance 2000. M.: Engineering, P. 320.
2. A.N. Reznikov, 1981. Thermal physics processes of materials machining. P. 340.

3. Kitawaga T., Kubo A., 1997. Temperature and wear of Cutting Tools in Hıgh Speed Machining of Inconel 718 and Ti-Al-6V-2Sn, pp: 142–148, 202.

4. Encyclopedia of mechanical engineering XXL. Reference date: 06.12.2015 http://mash-xxl.info/

5. V.A. Arshinov, G.A. Alekseev, 1967. Cutting metals and a cutting tool, p. 340.

6. Gök K., Gök A., Bilgin M.B., 2014. Finite Element Modeling as Three Dimensional Cutting Speed Effect in Turning Proces. Journal of Engineering and Fundamentals, 1(1), 11–22.

7. Bareggi A., Donnell O. and Torrance A., 2007. Modelling of thermal effects in Machining by Finite Element Methods. Processing of the 24 th International Manufacturing Conference, pp: 263–272.

8. Patrascu G., Carutasu G., 2007. Using Virtual Manufacturing Simulation in 3D Cutting Forces Prediction, Fascicle of Management and Technological Engineering, Volume VI (XVI), pp: 1423–1426.

9. T.A. Duyun, A.V. Grinek, D.V. Zakharov, 2013. The modeling and optimization of technological processes of products manufacturing using the method of dynamic programming. Bulletin of Shukhov BSTU, 3: 61-65.

10. V.F. Bobrov. Fundamentals of the metal cutting theory, 1975. M.: Engineering, p. 344.