Statistical analysis of the effect of cutting parameters on the Average temperature in hard turning of steel C 55 (DIN)

Naim Ostergllava, Simeon Simeonov, Mevludin Shabani, Bujar Pira, Afrim Loku

Abstract

The paper considers one output parameter average temperature as a function of process cutting parameters speed of cut (v), feed rate (f) , depth cut (a) and insert nose radius (r) during machining of the stainless steel C 55 - DIN. The average temperature was measured by natural thermocouple and statistically processed by computer software CADEX developed at the Faculty of Mechanical Engineering in Skopje. Mat lab software was utilized for graphically presentation and calculation of experimental results, which has been obtained at the Faculty of Mechanical Engineering Metrology laboratory in Skopje. Four factorial experimental design was utilized at the data processing.

Key words: average, temperature, cut speed, feed rate, depth of cut, nose radius

1. Introduction

The purpose in machining operation is to realize most effective separation of chips from the metal work piece. The edges of the cutting tool, influences particles of the metal to move away from the advancing cutting edge. This displacement causes the metal to fail a chip form along this line of the failed metal separated from the work material. This entire process depends on the work material; the tool material; the tool geometry; the machine tool forces, and the process conditions such as vibrations.

It is obvious that the cutting edge is a very important component, so process parameters such as the machine's power; work piece composition and hardness; the machine's feed and speed capability, and the rigidity and security of the work-holding method, should be taken into account when choosing it.

Nowadays most turning is done with coated indexable carbide inserts, so, a number of decisions are required when choosing tools for turning, such as the selection of material; tool geometry, and the tool holder design; the machine utilized for this experiment is turning single point;.

The interaction of the process parameters influence the final result; during the processing as a result of the friction of the contact surfaces of the cutting instrument and the working material, the temperature is presented, which greatly affects the quality of the product. Energy transformation influenced by other factors which occur in the cutting zone during metal removal, occupies an important place in the scientific literature.

The mechanical energy that occurs during the cutting process in order to overcome the forces applied in the cutting zone, is mostly converted into heat which is one of the main factors that characterizes the machining process condition. The heat recorded in the cutting zone greatly affect number of characteristics of the machining process such as: the intensity of consumption of the cutting tool and its durability; the quality of the treated surface; processing accuracy; economic indicators of the process (productivity, economy, etc) [1].

As temperature is of fundamental importance in metal cutting operations, many attempts have been made to predict it. Some works simply use a relationship between the work done and the volume of metal involved in the process to obtain an average temperature. Others use computers to help to give the distribution of temperature. The methods used to measure temperature in metal cutting have not been improved so much, so that it is difficult to prove the theoretical results in a precise manner [2].

In this context, this paper, through experimental measurements under controlled conditions conducted at the Faculty of Mechanical Engineering in Skopje, presents a further attempt at the overall contribution to finding optimal parameters that rely on temperature during cutting processing. The results, I believe, compared to those of other researchers, were intended to be useful as empirical material.

As a prerequisite for temperature research during cutting or machining, there is a need for deeper knowledge of the cutting process itself, then the identification of key factors in that process as they influence temperature intensity.

It is known that during the transformation of workpiece machined layer into chips, because of energy transformations in the cutting zone it is released significant quantities of heat. Created heat in the cutting process is directly dependent on the applied processing parameters *(v, f, a, r)*, workpiece material condition and cutting tool stereometry $(\varkappa, \lambda, \gamma, r_{\varepsilon}....)$ [3].

Chris Felix, at the "The Fundamentals of ChipControlhttps://www.productionmachining.com/articles/the-fundamentals-of-chip-control" states that having strategies in place for managing chips is an important part of protecting the production process, from tool life to product quality [4].

L.B.Abhang et. Al dealt with the prediction of the temperature of the interface of the chip on the scraping process. In this research, the cutting parameters of the metal were considered: cutting speed, feed rate, cutting depth and radius at the top of the cutting board. He came to a conclusion that increasing the cutting speed, feed rate and cutting depth increase the cutting temperature, while increasing the radius at the top of the cutting board reduces the cutting temperature [5].

M.Cotterell et. Al worked on measuring temperature and deformation upon forming chip sawdust in orthogonal cutting conditions. He states that the temperature and normal stress generated on the surface of the chip and tools are critical parameters for tool wear and material damage to the workpiece. The primary effect of temperature is wear on the tool. Although there are various mechanisms for carrying a tool, it is generally known that an increase in temperature causes progressive wear of the tool. In addition to the tool, the maximum temperature and temperature gradient affect the surface deformation, the metallurgical structural changes in the machined surface and the remaining stresses in the finished workpiece surface [6].

Based on information so far, we can see that is obvious is a key factor that must be taken into account as a phenomenon at machining process; measurement generally is distinguished by the methods and instruments intended for a specified purpose.

Therefore, in the machining process it is important to be precisely familiar with the magnitude of the temperature as a function of machining parameters that occurs in the cutting zone. The temperature in the cutting process can be determined in an analytical and experimental way, which are developed many methods [7].

From the experimental methods, the most widespread is the method of natural thermocouple, where the natural thermocouple consists of the cutting tool and the workpiece. Methods of natural thermocouple are simple to implement, but require knowledge of the thermoelectric characteristics of the natural thermocouple, and its determination is only by experimental way [8].

Although considerable research effort has been made on the thermal problem in metal cutting, there is hardly a consensus on the basics principles. The unique tribological contact phenomenon, which occur in metal cutting is highly localized and non-linear, and occurs at high temperatures, high pressures and high strains. This has made it extremely difficult to predict in a precise manner or even assess the performance of various models developed for modeling the machining process.

Heat generation and temperature prediction in metal cutting: A review and implications for high speed machining [9].

2. Experimental procedures

Research equipment

Results from the conducted experimental research

Machining is performed on rings, from steel material to improve C 55 (DIN). The rings are additionally heat treated to the required hardness of 52 ± 2 HRC. The dimensions of the rings are Φ 102 x Φ 82 x 20 mm, Figure 1.

During the turning processing, the rings are placed on an aid, specially made for this purpose, for research of the average temperature in the turning process, Figure 2.2.

Cutting tool holder - The cutting tool insert holder type IK.KSZNR- 064 25x25 made by company KENNAMETAL was utilized during machining process, figure 3. specially adapted for measuring the average temperature in the cutting process during turning operation, Figure 3b.

Figure 1. Rings of material C 55 (DIN), with hardness 52 ± 2 HRC.

ISSN 2229-5518

Figure 2. Special aid for research of average temperature in the cutting process upon turning

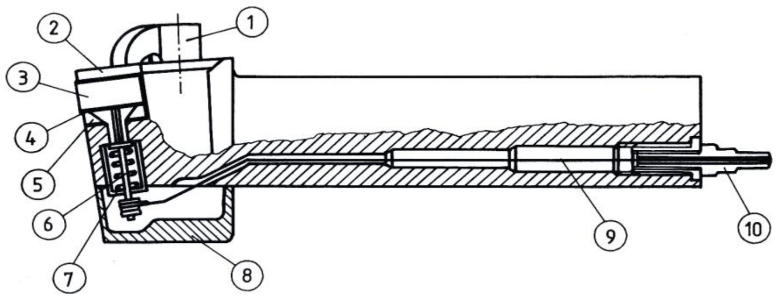


Figure 3. Cutting tool holder cross-section, 1 - thumb, 2 - chip breaker made from Al2O3, 3 - cutting tool insert made from mixed ceramics MC 2, 4 - mica, 5 - washer, 6 - mechanism, 7 – isolation bushing, 8 - protective cap, 9 - signal conductor, 10 - connector.

Cutting insert

Turning operation is performed using SNGN 120708-120712-120716 cutting inserts from mixed ceramics MC 2 (Al2O3 + TiC) from the company HERTEL, Figure 4, with the following static geometry: $\kappa=75^0$; $\kappa_1=15^0$; $\gamma = -6^0$; $\alpha = 6^0$; $\lambda = -6^0$; $r_\varepsilon = 0.8\text{-}1.2\text{-}1.6$ mm; $\gamma_f = -20^0$; $b_f = 0.2$ mm.

Figure 4. cutting inserts SNGN 120708 - 120712 - 120716 from mixed ceramics MC 2 (Al2O3 + TiC) from the company HERTEL.

Lathe - Conventional lathe Model TPV 250 from the company Prvomajska, figure 6. With the spindle power P=11.2 Kw, with the speed revolution from 16 to 2240v rot/min and feed rate ranging from 0.025 to 1.12 mm/rew was applied.

Temperature measuring device

Computerized measuring system for the average temperature measuring in the cutting process during machining.

The measurement of the average temperature in the cutting process during turning is performed by applying a computerized measurement device (fig. 5). Measurements are completed by all necessary means at the faculty of mechanical engineering in Skopje.

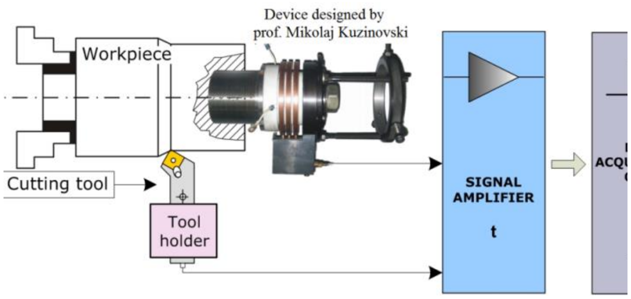


Figure 5. Working environment for exploration of the average temperature in the slicing process during turning, using a computerized measuring system

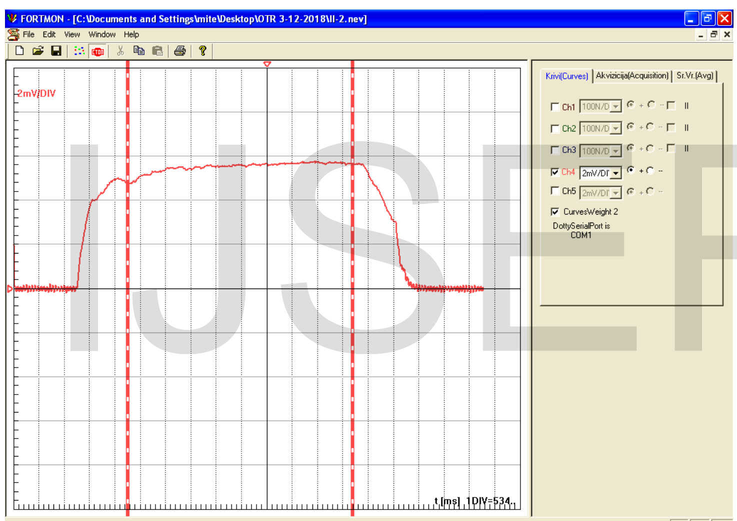
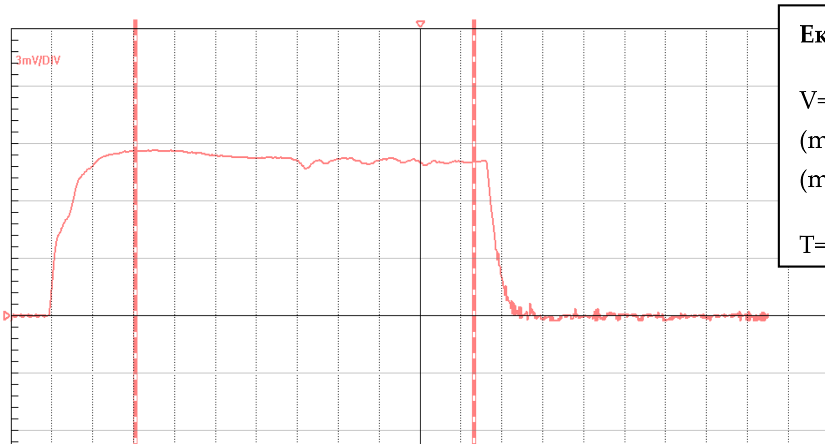


Figure 6. average temperature measured signal in the cutting process during turning.

4.1. measuring Results of the average temperature in cutting process during turning operation - graphical interpretation of the measured thermal voltage

For sake of the paper format standard we will be presenting two out of twenty measurements taken during the experimental work



Експеримент 1.1:

V=67,0 (m/min);f=0,1 (mm/vrt);a=0,4 (mm);r_ε=0,8 (mm);u=8,202 (mV);

T=813,8 (°C);

ISSN 2229-5518

Figure 7.average temperature signal in the experimental process 1.1.

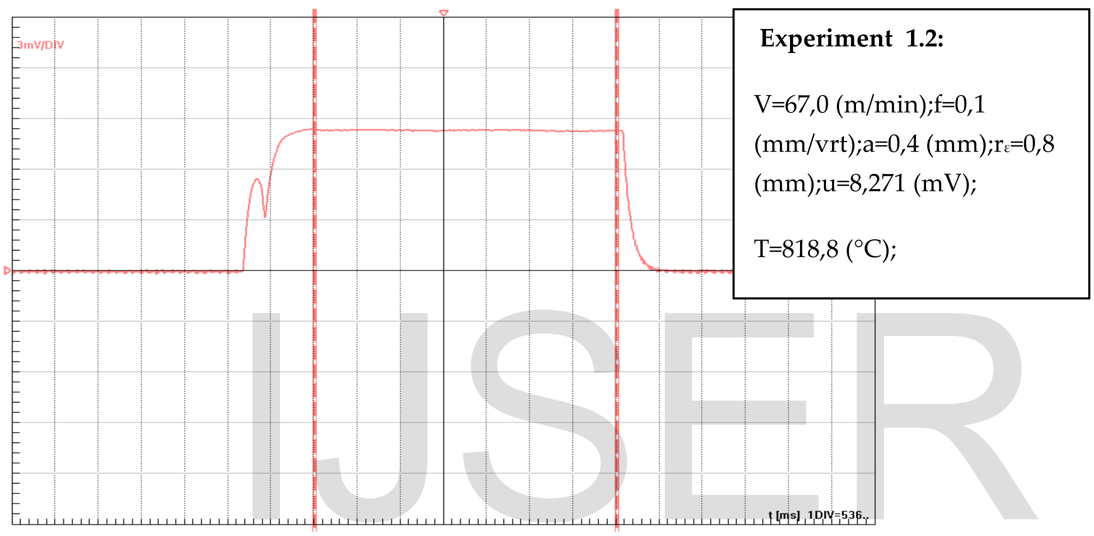
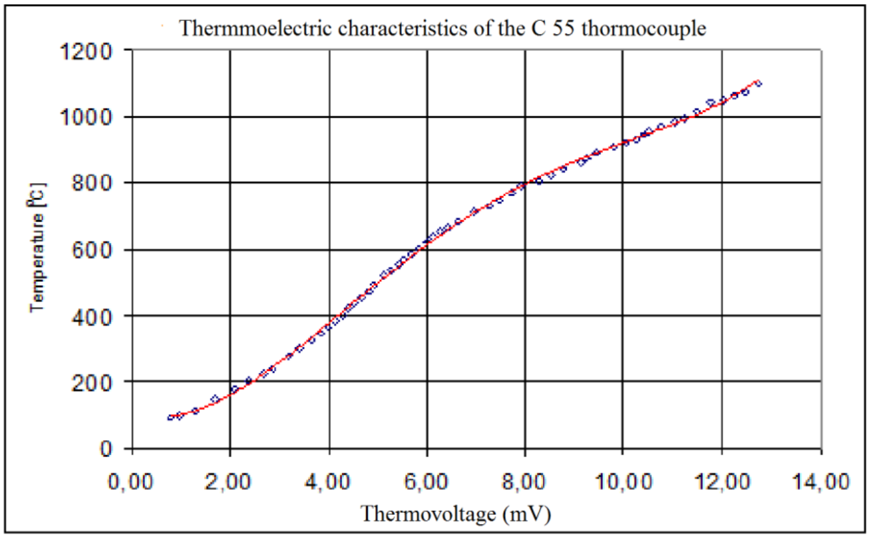


Figure 8.average temperature signal in the experimental process 1.1.

A mathematical model of 4th degrees polynomial (1) has been generated after regression analysis, utilizing results obtained based on interaction between changeable parameters thermovolatge (V) and the temperature T (°C). In our case thermocouple represents C 55. Determination of the average temperature in the cutting process during turning based on the measured thermovoltage is presented with:



$$T = 104{,}426 - 42{,}646u + 44{,}734u^2 - 4{,}937u^3 + 0{,}17u^4 \quad .....(1)$$

3. Analysis of research results

The machining is performed by changing four independently variable parameters: cutting speed (*v*), cutting feed rate (*f*), cutting depth (*a*) and the cutting insert radius (*r*), using a four-factorial experiment ($2^4 + 4$).
Table 1.

The change in independently variable sizes is shown in table 1. The designed planning and the experimental results obtained are presented in Tables 2-4.

Independent variable characteristics					
Nr.	**Process Parameters**	**Level**	**maximal**	**medium**	**minimal**
		Code	1	0	-1
1.	**v (mm/min)**	**x 1**	133.00	94.398	67.00
2.	**f (mm/rot)**	**x 2**	0.315	0.177	0.1
3.	**a (mm)**	**x 3**	0.8	0.566	0.4
4.	**r (mm)**	**x 4**	1.6	1.131	0.8

Table 2. First order four factorial experimental plan

Four factorial experimental plan of the first order					
Nr.	real plan matrix - independent variable values (process parameters)				**Temperature**
	v (m/min.)	**f** (mm/vr.)	**a** (mm)	**r_ε** (mm)	**Tcp** (°C)
1.	67.00	0.1	0.4	0.8	813.810
2.	133.00	0.1	0.4	0.8	880.690
.	…	…	…	…	…
16.	133.00	0.315	0.8	1.6	973.520
20.	94.00	0.177 (0.18)	0.566	1.13 (1.2)	887.910

Variability of the input cutting parameters was investigated, yielding a set of output average cutting temperatures T_c during measurements. To describing variability of the input parameters cutting speed (v), feed rate (f), cutting depth (a) and radius of the cutting insert (r), a power function was adopted:

$$T_c = v^x \; f^y \, a^z \, r^q \ldots (2)$$

Experimental plan and results are presented in Table 2. Processing results includes analysis of mathematical models with and without interaction; models are characterized by a high coefficient of multiple regression, from 92 to 95%. Performed analysis, after complete computer processing, showed adequacy of obtained mathematical model (3).$T = 575{,}063 \; v^{0.1297238} \; f^{0.0784023} \; a^{0.0350896} \; r_\varepsilon^{-0.0337936}$ ……(3)

Table 3.

Ordinal number of a matrix plan experiment	number of measurement			Average value
	1	**2**	**3**	
1	813,8	818,8	808,9	813,81
2	878,7	884,7	878,7	880,69
3	868,3	874,5	876,6	873,15
...	...	...	...	...
18	874,5	878,7	876,6	876,59
19	892,6	880,7	882,7	885,34
20	878,7	882,7	902,4	887,91

Based on the analysis of ceramic cutting tool temperature points on the C 55, it can be determined that the temperature of machining results is directly proportional to the cutting speed.

The higher the cutting speed, the higher the temperature measured at the cutting tool.

Based on the results from the table 1. we can visually see that the first measurement with the minimum process parameter values, namely speed (67 mm/min), feed rate (0.1 mm/rot) depth cut (0.4 mm) and radius of the tip insert cut (0.8 mm) yielded with the lowest average temperature of about 813.810 °C.

1.	67.00	0.1	0.4	0.8	813.810

On the other way the 16th measurement listed shows the an increase of the average temperature, when we have the highest process parameters interaction, namely cutting speed (133 mm/min), feed rate 0.315 mm/rot) depth cut (1.6 mm) and the tip radius of the cutting insert (1.6) yielded with 973.520 °C.

16.	133.00	0.315	0.8	1.6	973.520

So we can conclude that cutting speed is the most influential input parameter to effect the increasing temperature in cutting process during turning operation, feed rate is the second most influential parameter, cutting depth has little impact, whilst radius of the tip of cutting insert adversely proportional to the temperature; with its increase, the average temperature decreases.

The increase of the average temperature can be explained mainly as a result of the direct contact between the chip and face surface of the insert of the cutting tool. It should also be stated that increase of measured average cutting temperature is result of temperature increase on rear side of cutting wedge due to increased friction of rear main surface and auxiliary rear surface with machined surface.

4. CONCLUSIONS

Based on results obtained by the experimental research, statistical analysis using adequate statistical data processing software and mathematical model, we can easily conclude that the variability of the average temperature T_c as the output result of the interaction of the input parameters v (cutting speed), f (feed rate), a (cutting depth) and r (radius of the tip of the cutting insert) can be explained by the power function.

All input variable parameters are significant, they all have certain significance level, however, their effect differs in intensity; i.e. the cutting speed has shown the greatest effect on the average temperature increase, the highest temperature increase has been remarked at the 16th experimental in the raw measurement, weighting 973.520 °C.

Literature

[1] Çehaja, N.: Përpunimi me prerje I & II, (L i gj e r a t a të autorizuara), Prishtinë, 2013

[2] Marcio Bacci da Silva *, James Wallbank,: Cutting temperature: prediction and measurement methods - a review, Journal of Materials Processing Technology 88 (1999) 195–202

[3] Trajcevski, N., Kuzinovski, M., Cichosz, P. INVESTIGATION OF TEMPERATURE DURING MACHINING PROCESS BY HIGH SPEED TURNING, Journal of Production Engineering, Vol.12, No.1

[4] Felix, C.: "The fundamentals of chip control", https://productionmachining.com/articles/the-fundamentals-of-chip-control

[5] LB Abhang, M. Hameedullah, 'Chip-Tool Interface Temperature Prediction Model for Turning Process', International Journal of Engineering Science and Technology, 2 (4), 2010, 382-393.)

[6] E. Ares, F. Lopez, G. Pelaez, J. Yanes, M. Cotterell, P. Hernandez, 'Temperature and Strain Measurement During Chip Formation in Orthogonal Cutting Conditions', A tutorial review: Proc. 5th Manufacturing Engineering Society International Conference, 2013.)

[7] Milikić D.: *Temperature pri obradi rezanjem imogućnosti njihovog tačnog određivanja*, XIVSavetovanje proizvodnog mašinstva Jugoslavije,p.p. 292-305, Čačak, 1980

[8] Stanić, J.: *Metod inžinjeriskih merenja*, Mašinski fakultet, Beograd, 1990.

[9] Nuri Abukhshim, Paul Mativenga, Mohammed Aslam Sheikh , Article *in* (9). International Journal of Machine Tools and Manufacture 46(7-8):782-800 · June 2006 *with* 8,420 Reads
DOI: 10.1016/j.ijmachtools.2005.07.024

Co-authors:

- *Prof. Dr. Simeon Simeonov, Associate Professor at university "Goce Delcev" Stip, N.Macedonia, Email:simeon.simeonov@ugd.edu.mk*

- *Prof. Dr. Bujar Pira,Vice Rector for int. relations and quality assurance at University of Applied Sciences in Ferizaj, Kosovo,*
E-mail: bujar.pira@ushaf.net

- *Msci. Mevludin Shabani is currently pursuing PhD program in mechanical engineering at University "Goce Delcev" Stip, N. Macedonia.*
E-mail: mevludin.3264@student.ugd.edu.mk

- *Prof. Assoc. Dr. Afrim Loku, Vice-Rector for Budget Finance and Infrastructure at University of Applied Sciences in Ferizaj, Kosovo, E-mail:afrim.loku@ushaf.net*