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OPTIMIZATION OF CUTTING PARAMETERS BASED ON TOOL-CHIP INTERFACE TEMPERATURE IN TURNING PROCESS USING TAGUCHI’S METHOD

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ABSTRACT
Determination of optimal machining parameters is continuous engineering task which goals are to reduce the production costs and to achieve the desired product quality. This paper discusses the use of Taguchi’s method for optimizing the cutting parameters in turning for minimizing the tool-chip interface temperature. The cutting temperature is a key factor which directly affects cutting tool wear, workpiece surface integrity and machining precision. In this research work the tool-chip interface temperature is measured experimentally during turning of Č1730 (EN C60) steel with cemented carbide inserts using a tool-work thermocouple technique. The study shows that the Taguchi method is suitable for optimizing the cutting parameters with the minimum number of experiments. From the analysis using Taguchi’s method, results indicate that among the all-significant parameters, cutting speed is the most significant parameter. Results obtained from Taguchi method closely match with ANOVA.

Keywords: Taguchi method, turning, tool-chip interface temperature

1. INTRODUCTION
The cutting temperature is a key factor which directly affects cutting tool wear, workpiece surface integrity and machining precision according to the relative motion between the tool and workpiece. The amount of heat generated varies with the type of material being machined, cutting parameters, contact length between tool and chip, cutting forces and friction between tool and workpiece material. The temperatures which are of major interests are: average shear zone temperature, average (and maximum) temperature at the chip-tool interface, temperature at the work-tool interface (tool flanks), average cutting temperature. Temperature on the chip-tool interface is important parameters in the analysis and control of machining process. Total tool wear rate and crater wear on the rake face are strongly influenced by the temperature at chip-tool interface. Much research has been undertaken into measuring the temperatures generated during cutting operations.To measure the tool temperature at the tool chip interface many experimental methods have been developed. The main techniques used to evaluate the cutting temperature during machining are tool-work thermocouple, embedded thermocouple and thermal radiation method [1].
Design and develop control system to control the temperature lead to decrease tool wear and better surface finish. Production research activities in a real production environment supported by statistical experimental procedures enable continuous improvement of control processes and further cost

reductions. The Taguchi method of experimental design is one of the widely accepted techniques for off line quality assurance of products and processes. This method is a traditional approach for robust experimental design that seeks to obtain a best combination set of factors /levels with the lowest cost societal solution to achieve customer requirements.
In this research work the tool-chip interface temperature is measured experimentally during turning of Č1730 (DIN C60) steel with cemented carbide inserts using a tool-work thermocouple technique. The cutting parameters evaluated are cutting speed, feed and depth of cut. Taguchi method and ANOVA analysis are used to analyze the effect of cutting parameters on temperature on the chip-tool interface.

2. TAGUCHI METHOD AND EXPERIMENTAL DETAILS

2.1. Taguchi method

The Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization and this is a powerful tool for the design of high quality systems. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. This is an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs [2]. Signal to noise ratio and orthogonal array are two major tools used in robust design.
The S/N ratio characteristics can be divided into three categories when the characteristic is continuous: nominal is the best, smaller the better and larger is better characteristics. For the minimal cutting temperature, the solution is „smaller is better“, and S/N ratio is determined according to the following equation:

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \tag{1}$$

where n is the number of replication and y_i is the measured value of output variable. The minimal θ_{sr} is achieved using the cutting parameters where S/N ratio is maximal. The influence of each control factor can be more clearly presented with response graphs. Optimal cutting conditions of control factors can be very easily determined from S/N response graphs, too.
Parameters design is the key step in Taguchi method to achieve reliable results without increasing the experimental costs. An $L_9(3^4)$ orthogonal array and ANOVA analysis are used to analyze the effect of cutting parameters on tool-chip interface temperature.

2.2. Experimental details

The experimental work was carried out at the Department for Production Engineering, the Faculty of Technical Sciences in Novi Sad. The turning experiments were carried out on the late machine "Potisje-Morando PA-22", by orthogonal arrays with three levels (coded by:1,2 and 3), Table 1.

Table 1. Machining parameters and their levels

Symbol	Parameters	Levels		
		1	2	3
A	Cutting speed v, m/min	85	113	150
B	Feed s, mm/rev	0,16	0,249	0,392
C	Depth of cut a_p, mm	1,5	2,1	3

Test samples were steel bars Č1730 (EN C60) with 180 mm in diameter and 600 mm in length and turning tool with the holder mark PROMAX-A and cemented carbide insert ("Sintal" type P25) under dry cutting conditions. The chip-tool interface temperature measurements were performed with tool-workpiece thermocouple technique by mercury bath.
The thermocouple methods are based on the thermocouple principle that states that two contacting materials produce an electromotive force (emf) due to difference in temperatures of cold and hot junctions. The most widely used method for measuring the average chip-tool interface temperature is the tool-work thermocouple. This method uses the tool and workpiece as the elements of a

thermocouple. In tool-work thermocouple the chip-tool interface forms the hot junction, while the tool end forms the cold junction. Whenever one of the junctions is heated, the difference in temperature at the hot and cold junctions produce a proportional thermal voltage which is detected and measured by a milli-voltmeter. The tool and workpiece need to be electrically insulated from the machine tool. The experimental setup was designed as shown in Figure 1.a.

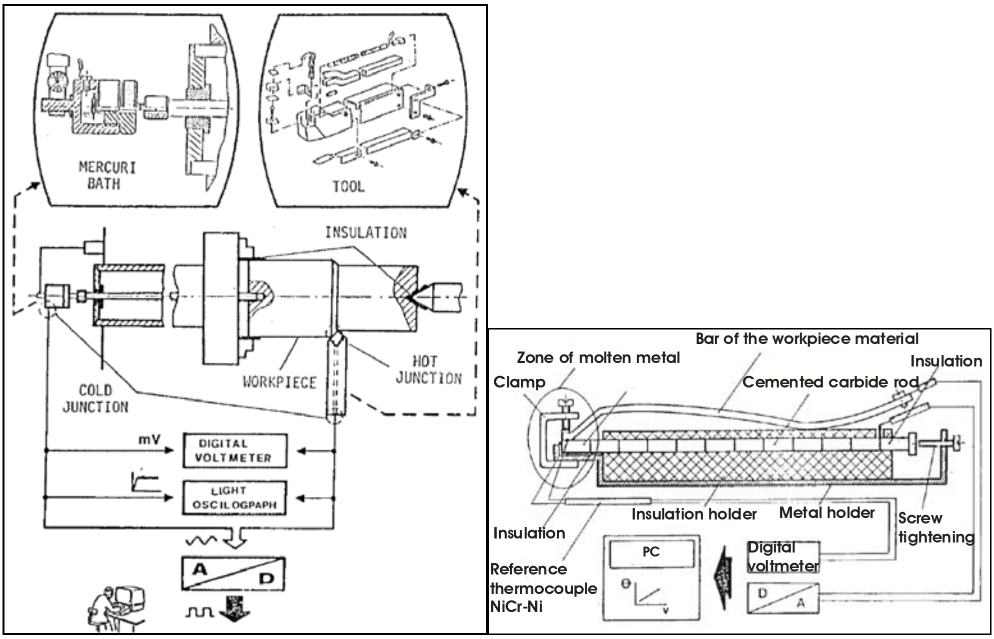

Figure 1. Experimental setup for a)measuring average chip-tool interface temperature, b) calibrating the tool-work thermocouple [3]

The difficulty of this method is concerned with the necessity for an accurate calibration of the tool and workpiece materials as a thermocouple pair. The average cutting temperature is evaluated from the mV after thorough calibration for establishing the exact relation between mV and the cutting temperature. The purpose in calibrating the tool-work thermocouple is to develop a thermoelectric relationship between the cutting tool material and the workpiece material. For the present investigation, the calibration of the tool-work thermocouple was carried out by immersion the tool-work thermocouple junction in the dissolution of metals (tin, plumb, aluminium). Design of the tool-work thermocouple junction is shown in Figure 1.b [3]. Standard thermocouple directly monitored the junction temperature (NiCr-Ni). In the present case almost linear relationship is obtained between the temperature and emf.

3. RESULTS AND DISCUSSIONS

Experimental results, together with their transformations into signal-to-noise ratios are given in Table 2. In this study all the analysis based on the Taguchi method is done by Qualitek-4 software to determine the main effects of the cutting parameters, to perform the analysis of variance (ANOVA) and establish the optimum conditions.

From Table 2 it can be determined which control factor have strong influence on chip-tool interface temperature in turning. Optimal cutting conditions of these control factors can be very easily determined from the S/N response graphs in Figure 2. The best chip-tool interface temperature is at the higher S/N values in the response graphs. Optimal cutting conditions are shown in Table 3.

The experimental results were analyzed with Analysis of Variance (ANOVA), which is used for identifying the factors significantly affecting the performance measures, Table 4.

From the analysis using Taguchi's method, results indicate that among the all-significant parameters, cutting speed is the most significant parameter. Results obtained from Taguchi method closely match with ANOVA.

Table 2. Orthogonal array $L_9(3^4)$ with average cutting temperature results and calculated S/N ratio

№	Factors				Parameters			θ_{sr}, °C	S/N
	A	B	C	D	*v*, m/min	*s*, mm/rev	a_p, mm		
	v	s	a_p	*Experimental error*					
1	1	1	1	0	85	0,16	1,5	795	-58,008
2	1	2	2	0	85	0,249	2,1	844	-58,527
3	1	3	3	0	85	0,392	3	791	-57,969
4	2	1	2	0	113	0,16	2,1	852	-58,609
5	2	2	3	0	113	0,249	3	896	-59,047
6	2	3	1	0	113	0,392	1,5	917	-59,248
7	3	1	3	0	150	0,16	3	819	-58,266
8	3	2	1	0	150	0,249	1,5	925	-59,233
9	3	3	2	0	150	0,392	2,1	933	-59,398

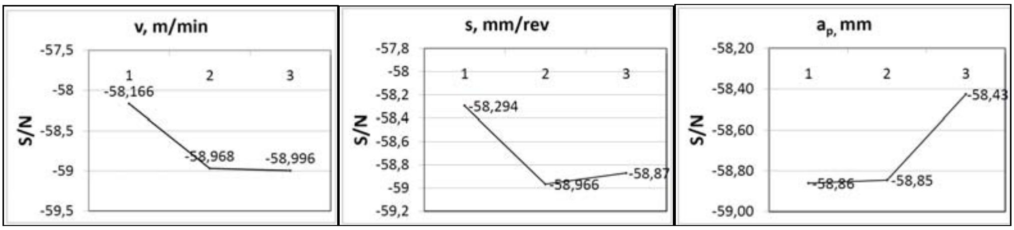

Figure 2. S/N response graphs for all control parameters

Table 3. Optimal settings of control parameters

Control parameters	Level	Setting
Cutting speed *v*, m/min	1	85
Feed *s*, mm/rev	1	0,16
Depth of cut a_p, mm	3	3

Table 4. ANOVA table

Factor	DOf	Sum of Sqrs (S)	Variance (V)	F-Ratio (F)	Pure Sum (S')	Percent P (%)
v	2	1,329	0,664	24,55	1,275	50,178
s	2	0,789	0,394	14,58	0,735	28,933
a_p	2	0,369	0,184	6,80	0,314	12,365
Error	2	0,53	0,026			8,524

4. CONLUSION

This paper has discussed the influence cutting parameters on chip-tool interface temperature in turning. The study shows that the Taguchi method is suitable for optimizing the cutting parameters with the minimum number of experiments. The significant factors in turning Č1730 (EN C60) on chip-tool interface temperature were cutting speed and feed, with contribution 50.178% and 28.933%, respectively.

5. REFERENCES

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