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INFLUENCE OF CUTTING ENVIRONMENT ON TOOL LIFE

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Abstract

The issues of cutting environment and a suitable choice of cutting conditions by drilling are the main subjects of the article. Attention is paid to the application of the drilling process into the carbon steel. Analysed were the phenomena that adversely affect the tool life. The article demonstrated solutions how to remove these adverse effects. The multicriteria optimisation of input factors (cutting fluid concentration, cutting speed) for a defined target function (tool life) was applied. The measured values were subjected to mathematical–statistical analysis (ANOVA). Based on the implemented experiment and study of this issue, we determined the combinations of input factors, which achieved minimal values of target functions. Based on the implemented experiment and study of this issue, we also determined the combinations of input factors, which achieved minimal values of target functions. Based on this allegation, the most appropriate combination of the following input factors was proved: concentration 6.3 % and cutting speed 100 m/min.

Key words

cutting fluids, cutting speed, drilling, tool life, ANOVA

INTRODUCTION

Requirements for the machining process are increasing. New solutions to improving the quality of the workpiece and longer tool life are sought. The parameters affecting this process include cutting conditions and cutting environment. Based on experimental studies, it is possible to claim, that the cutting fluids research is extensive and diverse in terms of the methods of the experiment; for example processing of statistical data and use of various technologies in the application of cutting fluids. Research of cutting fluids is currently engaged on environmental friendliness, biodegradability, environmental impact, reduction of cutting fluids through the trends such as dry or MQL machining, durability of tools and other important parameters influencing the machining process. However, not only the environment but also the appropriate cutting conditions are important in terms of tool life. The issue of drills wear is very often encountered in practice.

Therefore, we conducted an experiment evaluating the effect of concentrations of cutting fluid and cutting speed on tool life.

Each tool wear is characterised by (1):

- changing the typical dimension,
- weight loss.

A wear criterion is not to be associated with a tool life criterion (2). A tool life criterion represents the point at which a cutting tool fails to function as it should in a given application, whereas a wear criterion represents the point at which one decides to replace a cutting tool in view of the risk of its failing to function. Thus the wear criterion contains a certain limit regarding how long it will be possible to use it. The choice of wear criterion depends very much upon the requirements one places on the cutting tool in the application at hand, i.e. always select a wear criterion involving certain particular probability that a part produced by the cutting tool at that point will be of acceptable quality.

The degree of tolerable flank wear is VB_k (3). The flank wear VB_k should not generally exceed the level of 0.20 – 0.30 mm. This level depends on the workpiece material, cutting conditions, technology of machining etc. Examples of VB_k for drills are in Table 1.

Table 1 Level of flank wear for drill tools (3, 4)

Tools	**Technology**	**VB_K [mm]**	**Workpiece material**
HSS drill	drilling	1÷1.5; 0,9÷1.2	steel, cast iron
Carbide drill	drilling	0.3	steel

DESIGNED EXPERIMENT – DOE

The experiment was aimed at the evaluation of the impact of the cutting fluid concentration and cutting speed on the tool life when drilling the C45carbon steel. Experimental research consisted of measuring two factors, which influence drilling: cutting fluids' concentration and cutting speed.

This paper deals with two dimensional models. Experiments for these factors are implemented in 2^2 combinations. Process factors, resp. substances, which enter the drilling process, acting on the tool and thus directly influencing the tool life. The evaluated criteria which depend on the process factors are:

- width area of flank wear VB,
- time of tool work until chosen flank wear criterion respectively T (tool life).

Table 2 comprises values of the minimal and maximal levels and their assigned coded identification of process factors.

Table 2 Coding levels of process factors

Factor No.	Factor	Dimension	Marking		Factor levels	
					Min	Max
			Original	Coded	-1	1
1	Cutting fluid concentration	%	c	x_1	6,3	8,3
2	Cutting speed	$m.min^{-1}$	v_c	x_2	100	140

Table 3 Matrix with current and coded conditions

No. of experiment	Current experimental conditions		Coded experimental conditions	
	[%]	[$m.min^{-1}$]	x_1	x_2
1	6.3	100	-1	-1
2	6.3	140	-1	1
3	8.3	100	1	-1
4	8.3	140	1	1

When investigating the influence of process factors on the tool life, two procedural factors with two levels of their sizes are selected. Experimental design matrix then contains four rows and two columns (Table 3). The number of lines of the matrix corresponds to the number of the measurements.

Procedures and conditions

The experiment was performed in the Centre of Excellence of 5–Axis Machining at the Faculty of Materials Science and Technology in Trnava.
Machine tool: CNC machining centre of DMU 85 monoBLOCK.
Tool: carbide drill D= 12mm, which was made in the Centre of Excellence of 5–Axis Machining by WZS 60Reinecker grinding machine. Drill was designed for machining steel, without internal cooling. Drill was not polishing and was made without coated layer. Drill parameters are in Table 4.

Table 4 Drill parameters SK - PF 10

Clamping length	Length of blank	Cutting edge length	D	Core diameter	εr	α	γ	λs	Core taper angle
[mm]	[mm]	[mm]	[mm]	[mm]	[°]	[°]	[°]	[°]	[°]
57.5	82.5	25	12	3.6	130	11	10	35	1.677

Workpiece material: square rod of 100x100x25mm C45 carbon steel. Holes with length of 10 mm and diameter of D=12 mm were drilled.
Cutting environment (selected for this experiment): Syntilo 9913 - water-miscible machining liquid, synthetic pH neutral coolant designed especially for demanding machining of aluminium and other alloys (manufacturer recommends a minimum rate amounts to 6 % concentration for all operations, which ensures reliable protection of metal surfaces against corrosion).

Cutting conditions:
v_{c1} = 100 m/min, v_{c2} = 140m/min, v_f = 530 mm/min, f_z = 0.1 mm, VB_k = 0.3 mm.
Measurement of observed characteristics:

- width area of flank wear VB,
- time of tool work until chosen flank wear criterion respectively T (tool life).

Measurement device:
Digital Microscope Dino-Lite Pro.

The actual experiment consisted of drilling holes by SK – PF 10 carbide drills into C45 carbon steel and of monitoring critical flank wear VB_k = 0.3 mm. At first, 6 holes to a depth of 10 mm were drilled and flank wear VB was measured by a handheld digital microscope of Dino-Lite with increase of 55 times. The experiment was repeated 4 times using the new drill. After two experiments, in which cutting fluids concentration 6.3 % was used and cutting speed 100 m/min and 140 m/min, the cutting fluids concentration changed from 6.3 % to 8.3 % as recommended by Castrol company, which provided the cutting emulsion of Syntilo 9913.

Other two experiments in low concentration were also made at the cutting speeds of 100 m/min and 140 m/min. For example, the results of the first tool wear (Fig. 2 and Table 5) under the following conditions: c = 6.3 %, v_c = 100 m/min, workpiece – C45, drill D = 12 mm SK – PF 10, v_f = 530 mm/min, f_z = 0.1 mm, external cooling, cutting time = 1.132 s, VB_k = 0.3 mm.

We repeated the measurement of flank wear three times.

Table 5 Results of measurement 1

Amount of holes [-] / cutting time [s]	**VB – 1. cutting edge [mm]**	**VB - 2. cutting edge [mm]**
6 / 6.793	0.147	0.100
12 / 13.584	0.130	0.200 BUE
19 / 21.508	0.160	0.139 BUE
24 / 27.168	0.179	0.178 BUE
30 / 33.96	0.124	0.201
36 / 40.752	0.147	0.472 BUE
54 / 61.128	0.104	0.218
72 / 81.504	0.181	**0.335**

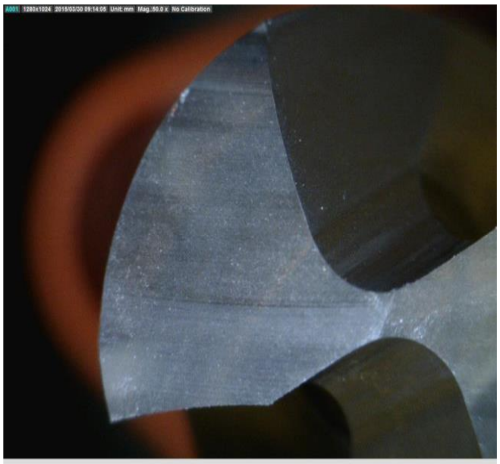

Fig. 1 *New cutting edge of first drill*

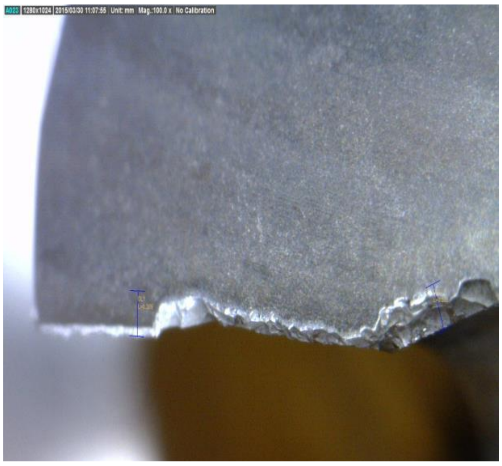

Fig. 2 *Cutting edge 2., VB_k = 0335 mm*

Based on the measured results, it is clear that the tool life is extremely short. We attributed it to the fact that drills were "raw". Drills were not polishing and were made without coated layer. Other results required for analysis of variance (ANOVA) are shown in Table 6.

ANOVA - Analysis of Variance

Analysis of Variance = ANOVA is a technique that allows to consider the various sources of variability in the data. When measurements are repeated there are always some deviations. These random deviations may cause that the significance of the differences between groups of repeated measurement will be more difficult to establish.

The basic idea of analysis of variance in this case is whether and how it may be statistically identified dividing into groups in the set of results of parallel determinations.

The total variance of the summary data is the combination of variance between groups and within groups. ANOVA allows separating the different sources of variance and mutually comparing partial variances in order to determine whether the differences between them were statistically significant. Respectively, providing the answer to the question of whether different groups are representing selections from the basic set (5).

The principle of the analysis of variance lies in decomposition of the total variance (Sum of Squares Total = SST), which is expressed in sums of squares, to the intergroup, that is explained by the group (Sum of Squares Between = SSB) and to intragroup, thus error (Sum of Squares Error = SSE) (6).

Analysis of the experiment is based on the obtained values, where the result is illustrated by the analysis of desirability. Specifically, it uses the value of comprehensive suitability indices from Table 5. The sequence of individual steps in the calculation is as follows (7):

1. There will be a calculation of the total variability (SST) of set of comprehensive suitability indices according to the following formula:

$$SST = \sum_{i=1}^{n}\left(d_{Gi} - \bar{d}_G\right)^2, \qquad [1]$$

where d_{Gi} is an index of the suitability of i factor,

d_G – comprehensive average value of all factors indices of suitability,

n – an overall number of experiments.

2. Consequently, it continues by the calculation of the individual variances after classes (SSB), where the comprehensive suitability indices are used as a baseline:

$$SSB = n\sum_{i=1}^{n}\left(\bar{d}_{Gin} - \bar{d}_G\right)^2, \qquad [2]$$

where n is number of studies which were carried out,

d_{Gin} – medium value in appropriate class.

3. It is possible to evaluate percentage impact of the individual factors (Pi) on the base of the previous formulas and calculations:

$$P_i = \frac{SSE}{SST}.100\% \;. \qquad [3]$$

4. The test criteria (F-test) - which is determined for a given input factors individually - is used for comparison with corresponding table value of F – distribution (Fα) and the result may decide about the outcome of the test. This criterion for the cutting environment and the feed is calculated according to:

$$F_i = \frac{\frac{SSB_i}{m-1}}{\frac{SSB}{m.n-m}} \quad , \qquad [4]$$

where SSB_i is a intragroup variability of i factor,
m – number of factor´s level.

Table 6 Inputs for ANOVA

Tool	**Fluid concentration c [%]**	**Cutting speed v_c [m/min]**	**Tool life T [s]**
1.	6.3	100	**81.504**
2.	6.3	140	**61.128**
3.	8.3	100	**54.336**
4.	8.3	140	**40.752**

Table 7 Outputs of ANOVA

Variability source	**SSB [-]**	**F -criterion**	**Pi [%]**
Concentration	565.107984	147	65.33
Cutting speed	288.3204	75	33.33
Error (SSE)	11.532816	-	1.33
Total (SSC)	864.9612	-	100

Obtained values indicate that the cutting environment has the significant impact on the tool life. The percentage value of this factor is 65.33 %. Using suitably chosen cutting environment makes therefore possible to prolong tool life. On the contrary, the percentage value of the impact of the cutting speed factor is evaluated at the level of 33.33 %. It suggests that changes of the cutting speed settings for a given process do not so significantly affect the tool life.

Error value represents the fact that the process is also influenced by other phenomena which are not dealt with in this experiment, resp. are not under investigation. This value was only 1.33 %.

The preceding analysis makes it clear that, if measuring the impact of input factors on the process, the most appropriate combination is that of c=6.3 % and v_c= 100 m/min.

If evaluating the test results by the test criteria, it can be argued that a significant influence on the observed target function is just that of the cutting fluid concentration. This argument reflects the fact that the calculated F comparative criterion for the cutting fluid concentration takes the value 147, which is greater than the tabulated value (10, 13). F comparative criterion for the cutting speed takes the value of 75, which is also greater than the tabulated value (10, 13).

Therefore, it is possible to speak of the statistical significance of the mentioned input factors.

SUMMARY

Most components in engineering production are machined by drill tools and it clearly demonstrates the importance of drilling in modern times. It is exactly for this reason that most manufacturers put emphasis on the quality of the drill and the tools are constantly being improved and upgraded.

This phenomenon leads to the formation of built-up edge and thus to damaging the tool, which results is in a lack of precision machining. To eliminate this adverse impact, the drills with a modified geometry, ensuring smooth formation of short chips are used. The equally important role is paled by the use of suitable cutting environment that removes chips from the cutting zone.

Based on the acquired expertise of the current state of the issue, the plan of the experiment was elaborated. The aim was to identify and subsequently analyse the changes of input factors (cutting fluid concentration and cutting speed) on the tool life.

In analysing and evaluating the measured values, we used mathematical-statistical methods (ANOVA) through which the optimal combination of input factors was obtained. These combinations give us the maximum values of tool life. Based on the realized experiment of multicriterial optimization of input factors in terms of tool life and subsequent use of the above mentioned evaluation methods, we came to the conclusion that the input factors affect the observed target function in different ways. It was found that the greatest impact on the characteristics was that of the cutting fluid concentration and, on the other hand, change of the cutting speed is not affected so significantly. Using appropriately selected cutting fluid concentration, it is possible to reduce the tool wear, which also leads to the actual increase in the quality of the machined holes. Based on this allegation, the most appropriate combination of the following input factors was proved: concentration 6.3 % and cutting speed 100 m/min.

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