

An Investigation of Tool Performance in Interrupted Turning of Inconel 718

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Abstract. The paper presents the result of an investigation of cemented carbides cutting tools performance in interrupted turning of Inconel 718. The discussion is based on case study revealed from industry experience. The spacing created for operational reasons cause interruption in turning process what has crucial effect on tool life and wear. Furthermore cutting parameters and tool geometry have significant influence on creating burr at the edge of spacing which leads dimensional deviation. The research based on two stages, preliminary and modelling, was introduced. In the first an effect of cutting speed, feed, depth of cut, rake angle and tool major cutting edge angle on wear and burr size was investigated. The second step was a regression based modelling of major parameter influence on various process aspects such as values of forces, tool wear and burr size. It was found that the consequential effect on plastic deformation of edge and tool performance have depth of cut. It also has been proven that higher cutting speed, lower values of angles provides better quality of machined element. The paper gives recommendations for turning parameters selection to acceptable burr forms, tool life and process performance.

1 Introduction

Interrupted turning is process that might be challenging from the technological point of view. Additionally when the material such as Inconel 718 is being considered the process is even less effective. Cutting tool performance is being drastically reduced via severe variable loading. The inserts' wear is mainly connected with cracks and thermal fatigue. What is more Ni-based materials' tendencies for creation of build ups on tool and machined surface, low thermal conductivity, high and hardness strength in elevated temperature leads to difficulties in process optimization [1-2].

The crucial aspect on interrupted turning performance has the temperature in cutting zone. Jiang et al. [3] proved the Salomon's hypothesis for interrupted cutting. In their work the relationship between temperature and cutting speed was analysed. The temperature of tool and workpiece decreased at high cutting speeds. It is caused by increased feed rate of removed material. The main heat flux do not interfere with tool and machined surface but mainly it is consumed by removed chip. Nevertheless the temperature generated on cutting insert has great significances on tool performance. What is also important the cutting materials with high thermal conductivity allows to reduces cutting temperatures near the cutting edge [3]. Oliveira et al. [4] investigated the ceramic and PCBN cutting tool materials performance when turning under continuous and interrupted conditions of hardened steel. They found

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that increasing temperature in cutting region during continuous turning cause reduction in the tool's hardness. Such phenome do not occurs in interrupted cutting. In their work it was also stated that at lower temperatures, thermal softening is hindered and the lower hardness and thermal conductivity of Al-based ceramics with SiC whiskers is less important then in PCBN. What is most surprising experiment proved that where the tool life is longer for interrupted cutting then in continuous. Probably in turning of hardened steel the thermal influence has greater impact of tool performance then mechanical aspects of interrupted cutting.

Not only tools material have influence on cutting tool performance but also cutting tool micro and macro geometry [5]. In results presented in [6] it was stated that different cutting edge preparation is a reason of higher material deformation which leads to higher process temperature. Habrat [7] and Rybicki at al. [1] investigated a tool geometry impact on aerospace alloys machinability. It was found that chip-braking is decisive to process performance.

Cutting vibrations during milling processes is specific example of interrupted cutting. Many basic research in the field of machining mechanics is reflected in milling. During this process, key factors such as static and dynamic cutting tools displacements significantly affects the machinability indicators such as roughness and tool performance [8].

Interrupted turning is connected with the necessity of applying advanced methods of cutting parameters optimization and tool condition monitoring during the process [3, 9-11]. One of the more promising methods of diagnostics is the method of measuring dynamic response of tool and machined element [8, 11]. Ratava at al. [12] proposed a complex algorithm for detecting tool displacement based on values depth of cut, cutting speed and feed rate. Application of artificial neural networks improves the decision making process and give abilities to even better automatization [13].

The research results and analysis presented in this paper concern the assessment of an impact of technological parameters and the geometrical of tool on a technological effects of interrupted turning. This topic is strongly connected with industrial practice. In contrast to the previously mentioned papers, in this work Ni-based superalloy machinability is evaluated. Inconel 718 has tendencies to creating build-ups on tool and machined surface what is also connected with plastic deformation of components' edge.

2 Experiment

The investigation have been carried out on Inconel 718 pipe, hardness aprox. 35 HRC (Figure 1a). Tool holder were chosen with dimension according to ISO: PSSNR 2020-12 and PSRNR 2020-12. Cutting inserts were used: SNMG 120408 RP and SNMG 120408 MS by Kennametal.

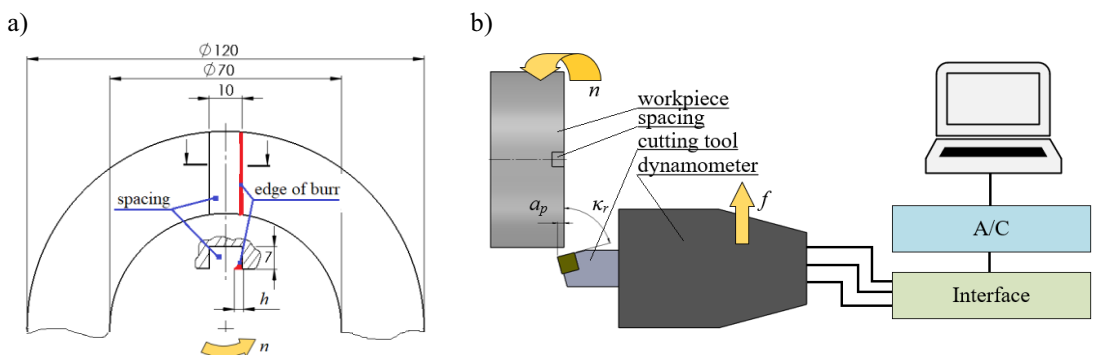


Figure 1. a) Workpiece dimensions; h – high of the burr; b) The set-up of measurement equipment.

Cutting insert material: cemented carbides with AlTiN coating (Kennametal's code – KC5510). Such selection of tool holders and inserts allows to fulfil research program shown in Table 1. The force dynamometer was connected through amplifiers and band-pass filters to a data acquisition

computer. The signals were analysed and proceed with the application of dedicated software (Figure 1b).

Research presented in this paper is based on fractional plan $2^{(k-p)}$ for five variables: feed f , depth of cut a_p , cutting speed v_c , orthogonal rake angle γ_0 and tool major cutting edge angle κ_r . The applied program based on 16 random combinations of variables presented in Table 1 was repeated twice for each combination – that gives 32 tries. Design of experiment and its analysis were performed with Statistica 13.3 software by Statsoft.

The study adopted two technological criteria related to the presented research program. The first was the wear indicator VB_c measured on the flank face. The second was the height of the burr produced inside the technological gap measured in the plane consist the vector of cutting speed on the exit edge of processed material.

Table 1. Cutting parameters applied in the research.

Level of research program and variables values	f [mm/rev]	a_p [mm]	v_c [m/min]	γ_0 [deg]	κ_r [deg]
-1	0,13	0,10	30	5	45
1	0,28	0,50	88	12	75

In the second stage of research the new program was implemented involving only one variable that have the most significant influence on analysed parameters. The linear correlation was estimated. The research program is based on mathematical regression where investigated parameters has four levels and tests were repeated three times.

3 Results and discussion

The graphs presented in Figure 2 illustrates the results of Pareto's analysis. Taking into concern the analyzed input variables from the statistic point of view, the most important is technological parameters is the depth of cut. The values of a_p affect both the value of wear after machining and the height of the burr. Other input factors with the assumption of no interaction between them are statistically insignificant.

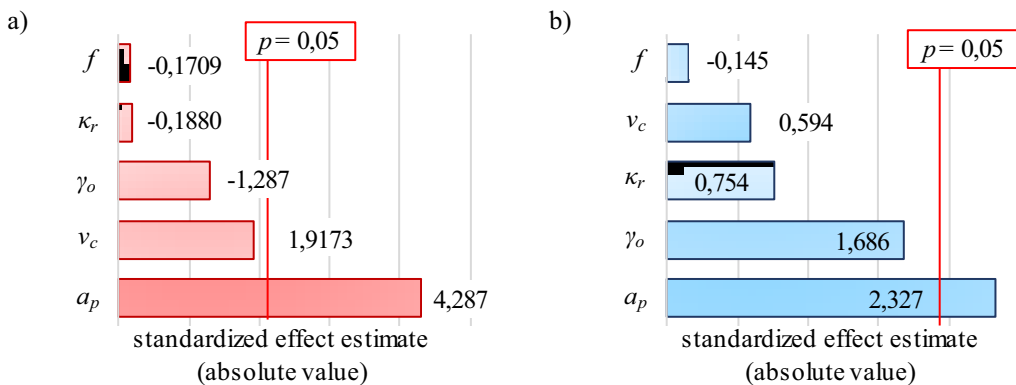


Figure 2. Pareto effects charts for input variables on a) wear indicator VB_c and b) burr high h .

Figure 3 presents the impact of the analyzed parameters on the VB_c wear after the same cutting time. The largest estimated wear value is achieved for test where $a_p = 0,5$ mm. The difference in VB_c in the studied range of a_p reaches over 1,2 mm. Despite the lack of statistical influence of the cutting speed and rake angle in the quantitative mean analysis, the differences between the boundary values

reach 0.45 mm and 0.25 mm, respectively. Such differences are significant for technological reasons. The low effect of feed f on the VB_c value might be found surprising. Both the change in a_p and f is related to the change of the cross-sectional area of the cutting layer and thus to the value of the cutting force. So that the affect of those parameters should be similar. However, it must be that the change of the a_p increases the share of the rake face during cutting and consequently also the chip breaker on this surface.

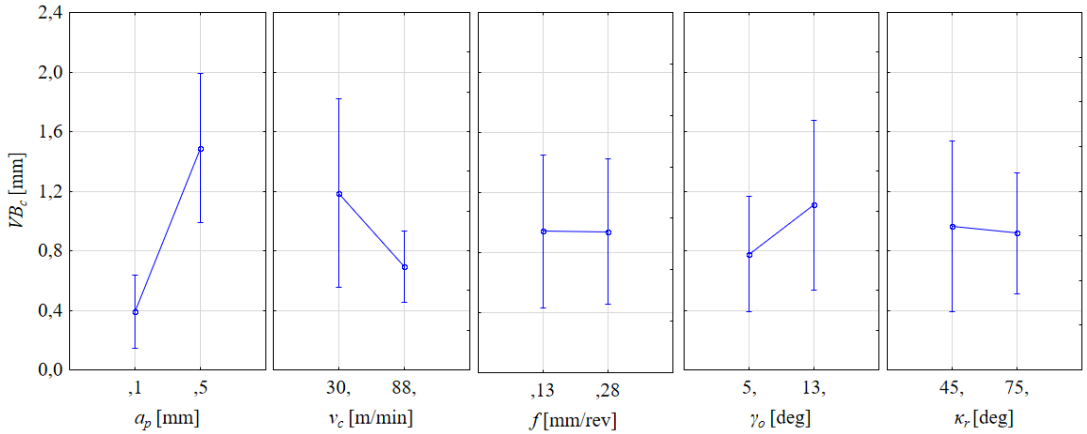


Figure 3. Input parameters (tool geometry and cutting parameters values) influence on a wear VB_c .

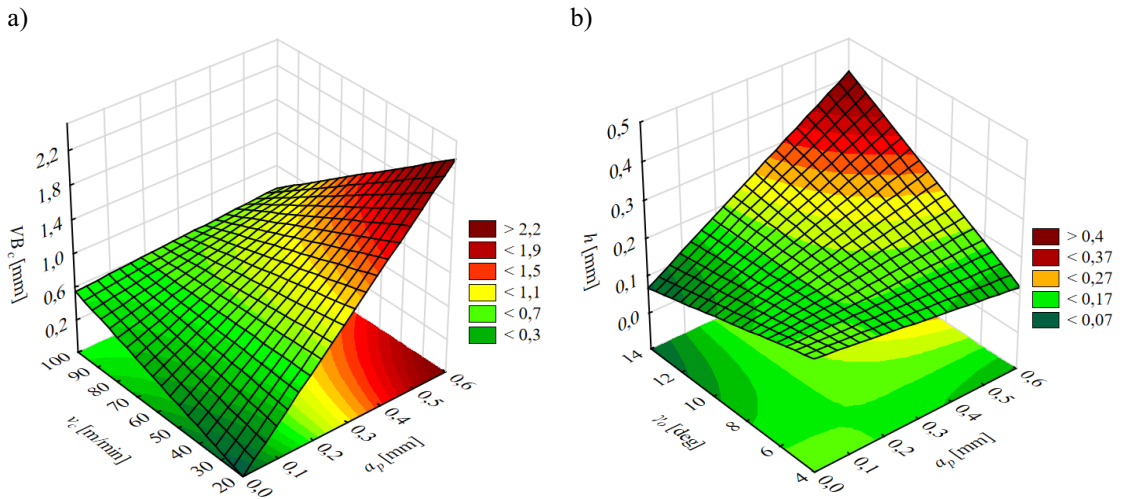


Figure 4. Plot functions of influence of a) cutting speed v_c and depth of cut a_p on cutting wear indicator VB_c , b) orthogonal rake angle γ_0 and depth of cut a_p on burr high h .

The next stage of conducted research focused on determination of cutting parameters values a_p and v_c and tool angle γ_0 impact on wear and burr high. The effects are presented in the Figure 4. The burr high vary from 0.1 mm to 0.4 mm. Smaller values of VB_c are obtained for small a_p values and higher values of γ_0 angle. It is possible to reduce the negative impact of depth of cut on burr high by using smaller γ_0 angle values.

The analysis of force variability in the interrupted turning is based on the analysis of the difference in mean values between the cutting phase and the entry into the spacing. The increasement in cutting force and thrust force was analysed in this way. The mean values of cutting force F_c and thrust force F_p were chosen for discussion. Cutting force good indicator of material decohesion velocity and plastic deformation changes in the cutting zone. The thrust force is directly connected

with depth of cut values. It was found that there is no linear correlation between force increment, wear or burr high (Table 2). The dependence and influence between those parameters might be more complex. Figure 5 represent the quadratic plot functions of approximation between analysed factors. Low wear values and burr are generated at low increments of both cutting and thrust forces. To obtain small values of ΔF_c and ΔF_p the proper parameter selection should be conducted. Such basic optimization was shown in previously discussion. In further researches the temperature and dynamic aspect of interrupted cutting will be investigated to minimize the burr high and cutting tool wear.

Table 2. Matrix of correlations; $N=12$; $r \in \langle -1; 1 \rangle$

Variable	h [mm]	VB_c [mm]	ΔF_c [N]	ΔF_f [N]	ΔF_p [N]
h [mm]	1,00	0,31	0,36	0,36	0,15
VB_c [mm]	0,31	1,00	0,19	0,26	0,58
ΔF_c [N]	0,36	0,19	1,00	0,96	0,81
ΔF_f [N]	0,36	0,26	0,96	1,00	0,86
ΔF_p [N]	0,15	0,58	0,81	0,86	1,00

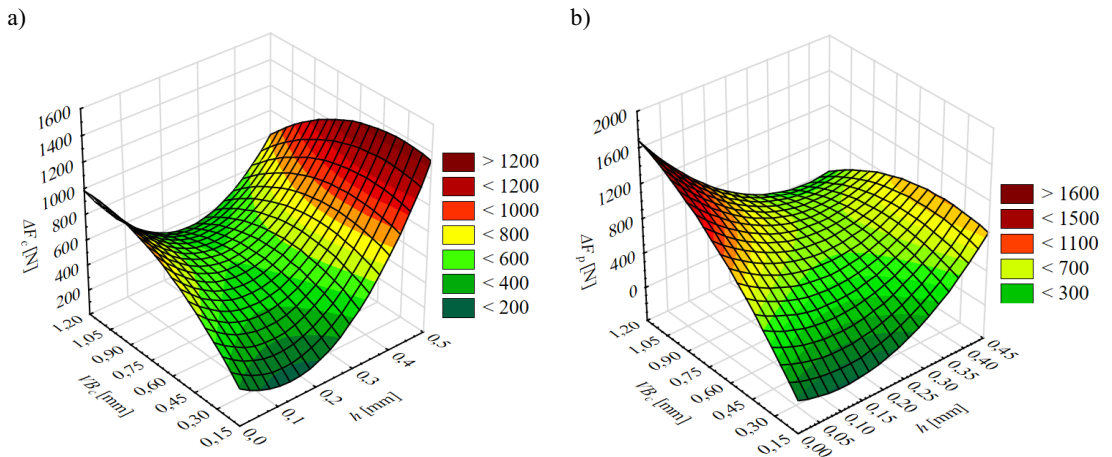


Figure 5. Quadratic plot function of force increment of a) cutting force ΔF_c and b) thrust force ΔF_p and their dependency between cutting insert wear VB_c and burr high h .

4 Conclusions

On the basis of the carried out investigations, the following conclusion are formulated:

- Tool geometry during interrupted cutting has lower impact on its performance then cutting parameters value.
- Plastic deformation on the edge of machined component is mainly influenced by the value of depth of cut. Feed per revolution and cutting speed have lower influence because decreased interaction area of rake face plane on analysed indicators.
- There is no significant correlation between cutting forces increase during interrupted turning of Inconel 718 on wear indicator VB_c and burr high h .

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