INVESTIGATION OF THE INFLUENCE OF MACHINING PARAMETERS OF GRINDING PROCESS USING MULTI-GRANULAR WHEELS ON THE SURFACE ROUGHNESS OF INCONEL 718

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Abstract

Successive development of new difficult-to-machine materials requires the adaptation of new efficient methods of their treatment, especially in finishing machining stage, which are of great importance in manufacturing processes. One of the most common finishing treatments is grinding. In order to increase the efficiency of the grinding process and improve the quality of the surface finish, it began to produce grinding wheels with varied granulation. The following article presents the results of a reconnaissance research of the grinding process in which multi-granular grinding wheels made of green silicon carbide were used. The purpose of the experimental research was to investigate the influence of input parameters on surface roughness parameters. The workpiece material used in the present investigation was Inconel 718. The study was carried out with an experimental methodology design. Input parameters were: cutting speed V_c, cross feed rate F_p, longitudinal feed rate F_w. In order to characterize the surface texture after grinding process, surface roughness *St* and *Sz* parameters were described. Using the obtained results, statistical models of the grinding process were developed, which will enable selection of the most favorable processing parameters depending on the quality of the surface finish.

Keywords: Grinding process, abrasive grains, Inconel 718, regression equations

1. INTRODUCTION

Intensive development of numerous material technologies gives the opportunity for creation of new alloys. These materials are frequently characterized by high mechanical properties and they are widely used in innovative constructions of air propulsion units or in gas turbines. Due to the increased mechanical properties of these materials, nickel based super alloys (e.g. Inconel 718) are included in the group of materials which are difficult to machine. It creates a necessity to conduct research in scientific centers which will focus on developing methods for effective shaping of their geometry, especially in finishing machining stage, which are of great importance in manufacturing processes. Currently, the implementation of complex expectations of high-quality surface finish of difficult-to-machine alloys is possible with the use of unconventional machining processes, for instance: electrochemical treatment [1,2,3], electrical discharge machining or hybrid machining [4,5]. It should pay particular attention to an important area of research, focusing on the analysis of finishing treatments of surfaces of elements which cooperate with each other. Finishing machining affects the element and creates a specific condition of the surface layer, which determines the tribological properties of the workpieces. One of such finishing treatments that determines the functional properties of the surface layer is the grinding process [6].

The emergence of new materials which are difficult to machine poses new challenges for the constructors of machine tools and it makes necessary to modify tools for their treatment. Therefore, the successive development of the grinding process is observed nowadays and the wide changes occurring in the production of abrasive grinding wheels [7]. In the issue of abrasive materials used to build grinding wheels up to the 30s of the last century, no intensive development was noted. 3M (1981) and Norton (1986) companies presented the world with a new type of abrasive grains made of microcrystalline sintered corundum. The grinding process is mainly limited to the determination of the effects that are obtained by the applied machining parameters as well as the characteristics of the grinding machine and the abrasive tool. The treatment consists in removing certain material fractions, which constitute a machining allowance resulting from previous machining operations. The material removed in the process is often mechanically and thermally damaged. The state of destruction of the material in the grinding process often determines the dimensional and shape accuracy, as well as affects the condition of the surface layer of the workpiece. The area in which the tool touches the machined surface is characterized by variable distribution of unit pressures, temperature as well as velocity and relative strain of removed material portions [8,9].

2. METHODOLOGY OF EXPERIMENTAL RESEARCH

The purpose of the experimental research was to investigate the influence of input parameters of the grinding process on surface roughness parameters using single-granular and multi-granular grinding wheels. The workpiece material used in the present investigation was Inconel 718.

The experimental research carried out according to the rotatable, five levels, statically determined plan. There are additional experiments in the starry arms in the plan that has been applied. They are equidistant on each axis and equal +/- α. In the used experiment plan there are three repetitions in the central point (0.0.0), which allow to verify whether the tests are repeatable [4,5]. The plan of the experiment is schematically shown in **Figure 1**.

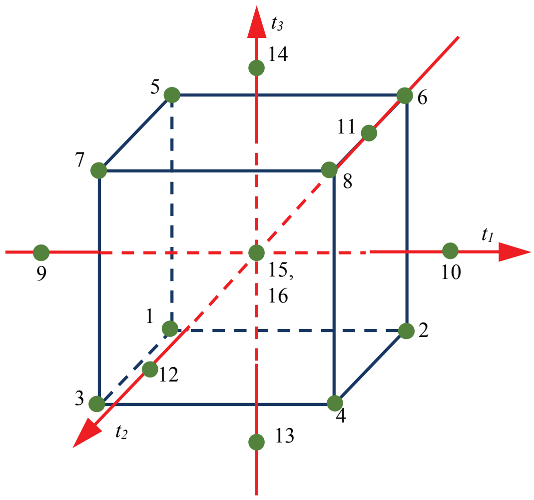


Figure 1 Adopted experimental model

The experimental research carried out using two abrasive grinding wheels measuring 80 x 15 x 32 mm made by NORTON SAINT-GOBAIN company. The first of them: conventional grinding wheel with the granulation of 120 and the second, hybrid grinding wheel with the granulation mixture of 120/150. Used abrasive tools are recommended for machine Inconel 718.

The abrasive tool is made of green silicon carbide with a ceramic binder. In the abrasive wheel, the existing grains have a rhombohedral shape with sharp edges, they are harder than the grains of an electro-corundum. The used abrasive material according to the Mohs scale is 9.5. Due to the fact that it is a hard material, it is also brittle. Green silicon carbide has good thermal conductivity and is characterized by low thermal capacity and is included in the group of refractory materials. The characteristic feature of SiC is its colourlessness and transparency when the crystals of the material are free of impurities. Otherwise, these crystals appear blue-green, green or black. The material is also resistant to adverse chemical environments. Two basic types of silicon carbide are used in abrasive tools: green silicon carbide SZ, black silicon carbide SZ.

The use of both grain species enables the machining of hard or brittle materials. SiC is used not only for the production of abrasive wheels, but also in the manufacture of lightning arresters [7].

In order to carry out the research, ranges of individual input variables were determined, which take part in the experiment and are presented below:

- abrasive grinding wheels:
  - conventional grinding wheel: 01 - 80x15x32 39C120-LVS,
  - hybrid grinding wheel: 01 - 80x15x32 39C120/150-LVS,
- cutting speed V_c = 15 ÷ 40 obr/min,
- longitudinal feed rate F_w = 50 ÷ 300 mm/s,
- cross feed rate F_p = 1 ÷ 10 mm/s,
- cutting depth a_p = 0.03 mm,
- number of grinding passes z = 3.

In order to characterize the surface texture after grinding process the following roughness parameters were designated:

- *Sz* - the largest height of the surface unevenness profile,
- *St* - the total height of the surface unevenness profile.

The reconnaissance research was started with setting of individual sizes of characteristic parameters on the grinding machine. The grinding tests were carried out in such a way that the surface to be tested was first machined with the conventional grinding wheel. After the first stage of research, on the machine the multi-granular grinding wheel was installed, and then the experiment was repeated, setting the same machining parameters on the grinding machine.

3. ANALYSE OF RESULTS

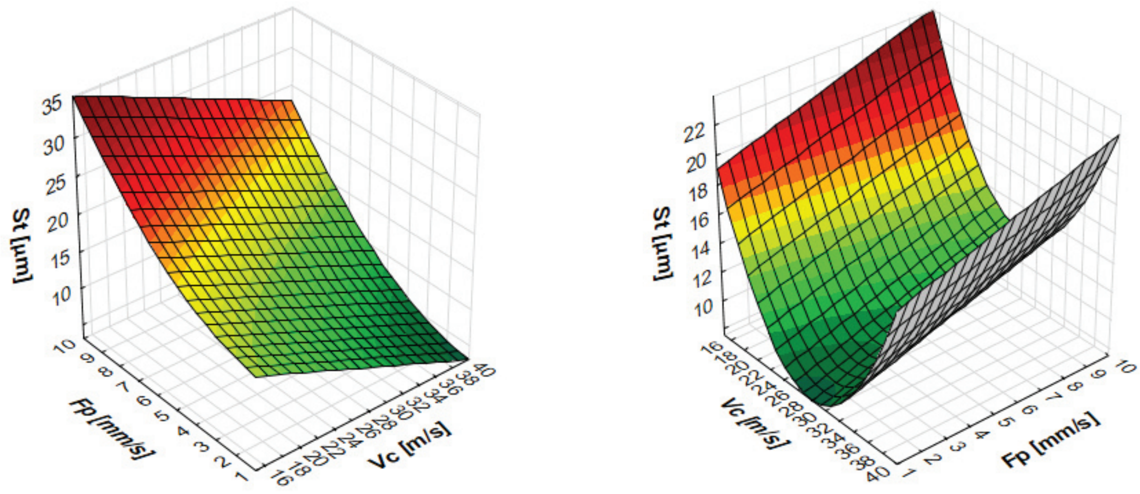
Surface roughness was measured on a Taylor Hobson FORM TALYSURF Series 2 scanning profilometer. For each sample area of 2 x 2 mm was measured. On the basis of the test results obtained statistical models describing the influence of input grinding parameters on the surface roughness parameters. The obtained regression equations are described by the function of the second degree polynomial (the relationship between the cutting speed V_c, cross feed rate F_p, longitudinal feed rate F_w and roughness parameters *St* and *Sz* is shown). Using the STATISTICA program, regression equations were designated. The significance of individual coefficients in the regression equation was tested with the t-student test (at the significance level α = 0.15). In each equation, the multiple correlation coefficient *R* was determined, which shows the variability of a given feature. The *R* coefficient is closer to the unity, the more faithful representation of the variability of the examined feature. Then, the adequacy of the multiple correlation coefficient was verified using the Fisher-Snedecor test. The obtained test value *F* was compared to the critical value F_{kr}. The *R* factor is significant if $F/F_{kr} > 1$.

The designated equations are characterized by a high degree of *R* correlation. The ratio F/F_{kr} is greater than unity (**Table 1**).

Table 1 Regression summary

Abrasive wheel	Regression equations	*R*	F/F_{kr}
Conventional (single-granular) wheel	$St = 22.8 - 0.5 \cdot V_c + 0.2 \cdot F_p^2$	0.73	1.9
	$Sz = 21.4 - 0.5 \cdot V_c + 0.1 \cdot F_p^2$	0.73	1.86
hybrid (multi-granular) wheel	$St = 61.3 - 3.9 \cdot V_c + 0.07 \cdot V_c^2 + 0.528 \cdot F_p$	0.77	1.61
	$Sz = 55.7 - 3.6 \cdot V_c + 0.06 \cdot V_c^2 + 0.352 \cdot F_p$	0.77	1.64

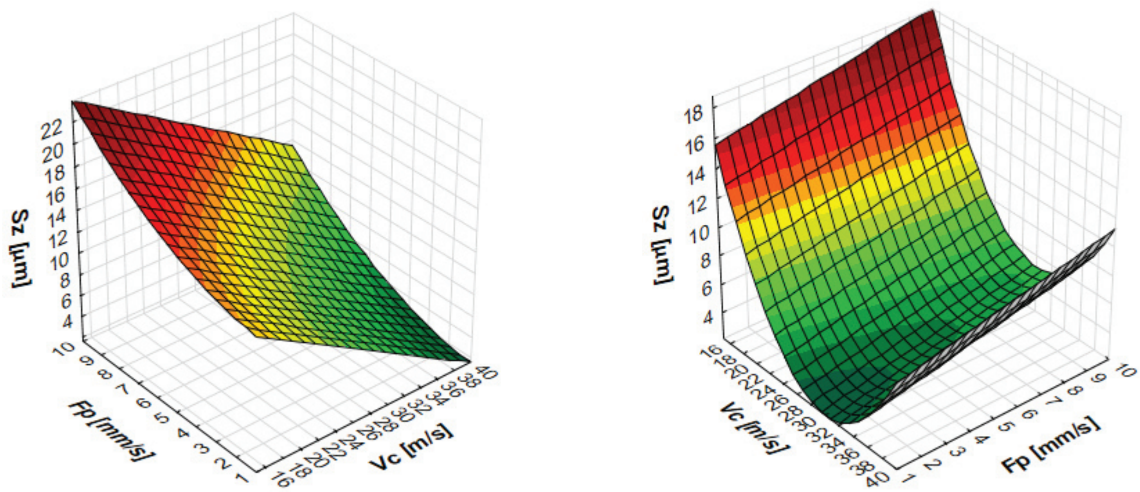
The following part of the article is accompanied by a graphical interpretation of the designated regression equations (**Figure 2**). The statistical analysis carried out shows for both the parameter *Sz* and *St*. The influence of longitudinal feed rate F_w is negligible, therefore it does not appear in the regression equations.



(a) (b)

Figure 2 Dependences of surface roughness parameters *St* from cross feed rate F_p and cutting speed V_c for: a) conventional (single-granular) grinding wheel, b) hybrid (multi-granular) grinding wheel

Analyzing the influence of input parameters on the *St* parameter, it can be perceived that in the case of a multigrain wheel, two quantities exist in the regression equation: cutting speed V_c and cross feed rate F_p. The chart indicates the cutting speed range for which it is possible to obtain the *St* parameter value below 10 µm. Increasing the cross feed rate F_p at a constant cutting speed V_c results in an increase in the parameter *St*. On the other hand, the cutting speed V_c and cross feed rate F_p prove to be important for the single-granular wheel. Obtaining the *St* parameter value below 3 µm in accordance with the graph is possible when the cutting speed V_c above 35 m/s is achieved and the cross feed rate F_p is below 3 mm/s. However, carrying out the process in such conditions becomes inefficient. In the following part of the article, the parameter *Sz* was analyzed, which is shown in **Figure 3**.



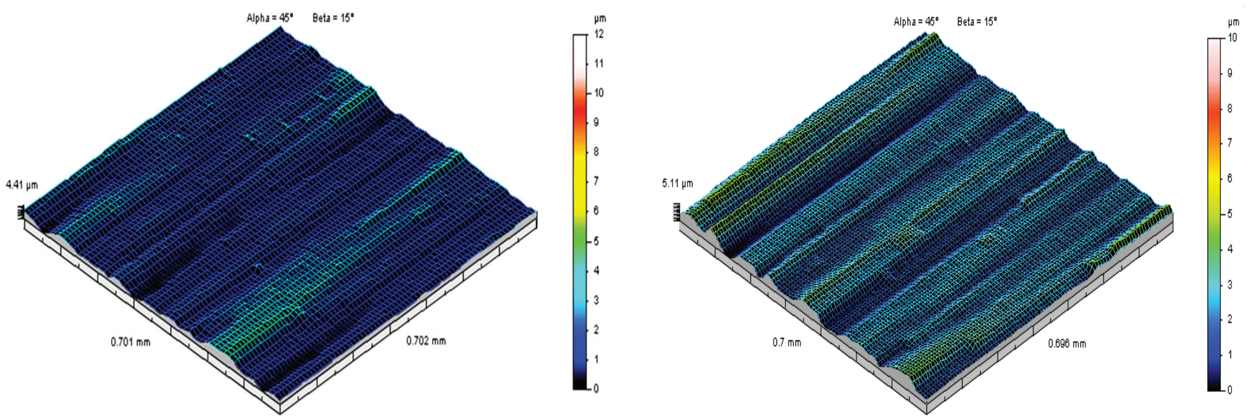
(a) (b)

Figure 3 Dependences of surface roughness parameters *Sz* from cross feed rate F_p and cutting speed V_c for: a) conventional (single-granular) grinding wheel, b) hybrid (multi-granular) grinding wheel

On the basis of the analysis of the influence of input parameters on the *Sz* parameter, similarly as for the *St* parameter, it can be noticed that grinding the surface of Inconel 718 with multigranular wheel two values in the regression equation are significant: cutting speed V_c and cross feed rate F_p. *St* and *Sz* parameters give information about the stability of the grinding process. The measured values of *St* and *Sz* parameters after the grinding process should be close to each other. It should be noticed that the *Sz* parameter, by definition, is the average of the five largest heights of the roughness profile. In turn, the *St* parameter is the maximum height of the profile. Similar values of these parameters may indicate the stability of the process. In the case under consideration, the parameter *Sz* and *St* for the multigranular grinding wheel shows that deviations of these values are in the order of a few micrometers. Small differences give information about the possibility of occurrence of certain inhomogeneous areas where there are larger height of surface irregularities in relation to the average. In the conventional grinding wheel, by contrast, this relationship is not visible. The results obtained for the multigranular wheel indicate the speed range for which the grinding process is effective.

Figure 4 shows the images of the surface texture obtained in the grinding process for single-granular and multi-granular wheels with the following machining parameters:

- cutting speed V_c = 27.5 m/s,
- longitudinal feed rate F_w = 300 mm/s,
- cross feed rate F_p = 5.5 mm/s.



(a) (b)

Figure 4 Surface texture after grinding with: a) multi-granular grinding wheel, b) single-granular grinding wheel

Surface texture after the grinding process is characterized by a clear directionality of machining marks. The visible scratches on the surface result from the mechanical contact of abrasive grains with the machined surface. The surface resulting from the machining with a conventional grinding wheel is shown by a greater number of scratches. The number of scratches is smaller for the hybrid grinding wheel. It is related to the construction of the abrasive wheel. The multigranular abrasive wheel is made of abrasive grains with smaller and larger granulation. During the grinding process, larger abrasive grains are responsible for the efficient material removal, while grains with smaller granulation result in smoothing the surface.

4. CONCLUSIONS

In the article presented the results of the reconnaissance research of grinding Inconel 718 with single-granular and multi-granular grinding wheels made of green silicon carbide. The theoretical assumption was verified that the use of a multi-granular wheel improves roughness and condition of the machining surface layer. The experimental research was consistent with Hartley's five-level, three-dimensional plan. Conducted research based on a planned experiment made it possible to determine the mathematical function sought. The obtained results show a large influence of the cutting speed V_c on the surface roughness parameters of the workpiece.

Regression equations for grinding with multigranular wheel made it possible to determine the range of machining parameters for which the roughness parameters obtain the lowest values (V_c = 26 ÷ 34 m/s). This dependence is not identical to the conventional (single-granular) wheel obtained in the grinding process, for which obtaining low values of roughness parameters is possible with a low cross feed F_p and a relatively high cutting speed V_c (over 35 m/s).

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