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Surface of Inconel X-750 alloy after turning with different CBN inserts under various cooling conditions

SUMMARY

High-performance machining of aircraft Ni-based alloys is possible due to the use of modern cutting materials such as regular boron nitride and optimization tools enabling the selection of the cutting conditions. This study discusses the effect of the cutting speed vc and the concentration of waterborne synthetic cutting fluid on the parameters of surface roughness after turning of the Ni-based superalloy Inconel X-750 (AMS 5668). Two cutting materials made from fine-grained regular boron nitride in a ceramic binder differing in the contents of the CBN were used. Variable cutting speeds vc in the range between 150-300 m/min were investigated. The measurements of roughness parameters Ra, Rz, and RSm were made on surfaces after turning without the use of cooling liquid and after machining with flood cooling 2.5% and 5% emulsion.

Key words: turning, surface roughness, Inconel X-750, CBN inserts.

Introduction

Inconel X-750 is a Ni-Cr superalloy that has been made precipitation-hardenable by the additions of Al and Ti. This material have good resistance to corrosion and oxidation along with high tensile and creep rupture properties at temperature up to 700°C. Due to its excellent relaxation resistance it has a wide range application in high-temperature springs and bolts but also on gas turbines, rocket engines, nuclear reactors and other aircraft structures[1].

[1] http://www.steelforge.com; access on 24/02/2018.

Good mechanical properties cause problems in machining of Inconel X-750. Its machinability has been ranked 12% to relative cutting speed based on B-1112 steel as 100%[2]. Although area of machining optimization of Ni-based superalloys such as Inconel 625, Inconel 718 or Waspaloy has been widely investigated[3], still it is a problem of effective turning parameters selection for Inconel X-750. For example there is a lack of information according cutting parameters influence on surface roughness. In addition, the widely described problems associated with shaping the roughness in the range of small feeds f<0.1 mm/rev for the alloy of such Inconel 718[4] can also be enhanced during the treatment of the X-750 alloy.

One of the emerging filed in metal machining technology is new materials development for cutting tools[5]. Recently, researches have focused on new material grade such as regular boron nitride in various types of binders. A strong correlation between the percentage of binder and CBN content on tool life of cutting inserts during Inconel 718 was proven[6]. It was shown that dominant form of tool wear is adhesion and diffusion[7]. The development of superhard materials such as CBN in various types of binder is the main area of the development of tool for machining of Ni-based superalloys.

It is widely known that insert wear form and behaviour are influenced by factors such as type of coating, pre-coating preparations technologies and tool micro- and microgeometry[8]. Various insert preparation technologies leads to different edge geometry. Cutting edge geometric parameters have important impact on material decohesion. One of the most interesting aspects of metal machining is relationship between cutting edge radius and minimal depth of cut[9].

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[2] Ibidem.

[3] J.P. Costes, Y. Guillet, G. Poulachon, M. Dessoly, *Tool-life and wear mechanisms of CBN tools in machining of Inconel 718*, „International Journal of Machine Tools & Manufacture" 2007, 47, pp. 1081–1087; R.S. Pawde, S.S. Joshi, P.K. Brahmankar, M. Rahmanc, *An investigation of cutting forces and surface damage in high-speed turning of Inconel 718*, „Journal of Materials Processing Technology" 2007, 192–193, pp. 139–146; B. Słodki, *Wpływ temperatury i siły na postać wióra przy toczeniu wzdłużnym stopów Inconel 625 i Inconel 718*, „Inżynieria Maszyn" 2013, R. 18, z. 4, pp. 28–41.

[4] T. Chwalczuk, M. Kawalec, P. Szablewski, *Wybrane właściwości warstwy wierzchniej po toczeniu tradycyjnym i ukośnym ostrzami ceramicznymi nadstopu niklu Inconel 718 po nagrzewaniu laserowym*, „Mechanik" 2012, 7–8, pp. 409–414.

[5] P. Niesłony, K. Żak, R. Chudy, *Ocena energetyczna wybranych parametrów stereometrii ostrza CBN na kształtowanie powierzchni po toczeniu stali o podwyższonej twardości*, „Mechanik" 2016, 10, pp. 1384–1385; P. Twardowski, S. Legutko, G.M. Królczyk, S. Hloch, *Investigation of wear and tool life of coated carbide and cubic boron nitride cutting tools in high speed milling*, „Advances in Mechanical Engineering" 2015, Issue 6, Vol. 7, pp. 1–9.

[6] J.P. Costes, Y. Guillet, G. Poulachon, M. Dessoly, op. cit.

[7] R.S. Pawde, S.S. Joshi, P.K. Brahmankar, M. Rahmanc, *An investigation of cutting forces and surface damage in high-speed turning of Inconel 718*, „Journal of Materials Processing Technology" 2007, 192–193, pp. 139–146; A. Thakur, S. Gangopadhyay, A. Mohanty, *Investigation on some machinability aspects of Inconel 825 during dry turning*, „Materials and Manufacturing Processes" 2015, 30, pp. 1026–1034.

[8] B. Denkena, D. Biermann, *Cutting edge geometries*, „CIRP Annals – Manufacturing Technology" 2014, 63, pp. 631–653; B. Stroch, A. Zawada-Tomkiewicz, *Distribution of unit forces on the tool edge rounding in the case of finishing turning*, „The International Journal of Advanced Manufacturing Technology" 2012, vol. 60, 5–8, pp. 453–461.

[9] B. Stroch, A. Zawada-Tomkiewicz, op. cit.

The machining process is connected with the formation of large quantity of heat. The increase in temperature during the process result in increased tool wear, loos of mechanical properties due to microstructure changes. What is more a geometrical dimensions of final element may change when heat expansion will influence on cutting zone parameters. Constant thermal conditions of the cutting process can be ensured by the use of cooling lubricants. Current development trends of cooling methods relate to lubrication with a minimum quantity of lubrication (MQL) or cooling with gases. The use of CO_2 in gaseous form makes it possible to reduce the process temperature by more than 50% compared to dry turning[10]. Bearing in mind the modern problems of ecology a significant factor should be the reduction of the impact of conventional processing emulsions on the environment. Minimal lubrication of the treatment zone is not only the fulfilment of this postulate but also brings important technological benefits. It was proven that various methods of MQL allows to reduce friction coefficient when turning stainless steel[11]. Despite many works both in the fields of MQL and gas cooling those techniques have limited industrial applications in the aircraft industry.

Considering the previously mentioned areas of development in the field of metal cutting, the problem of surface roughness shaping with the use of different cutting emulsions and CBN tools was investigated.

Experimental details

External turning was carried out on the CTX 310 ECOLINE lathe. The investigated material was Ni-based superalloy Inconel X-750 according to AMS 5668 (Table 1.). Two cutting materials were used from fine-grained regular boron nitride ceramic binder by Sandvik with the designations CB7015 and CB7025. Those two materials is differing mainly in CBN density, respectively 50% and 60% volume fraction. A different manufacturing process involves forming a different form of the cutting edge, including, but not limited to, rounding radius r_n. This fact strongly effects on surface quality and cutting edge performance. Radius measurements carried out in the area of cutting edge radius on the device of Alicona EdgeMaster at ITA Polska showed that for the insert with the designation 7015 the value of $r_n = 18.3$ μm and for the blade 7025 $r_n = 27.5$ μm. Measurements of the geometric surface structure parameters were carried out using the Hommelwerke Tester T500 profilometer in accordance with the ISO standard for the adopted measuring section $Lt = 4.8$ mm.

The cutting fluids Cimtech M21-02 and Cimtech A31F by Cimcool were investigated. In the further research they have been coded respectively CF1 and CF2. In addition, the percentage value of emulsion was evaluated. Concentration of CF1 was studied of 2.5% and 5%.

Statistical analysis was based mean values after performing four measurements. Confidence interval based on *t*-Student distribution for $\alpha = 0{,}05$ was shown in figures. The Design of experiment and its analysis were performed with Statistica 13.3 software by Statsoft.

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[10] Ł. Żyłka, R. Babiarz, M. Płodzień, P. Sułkowicz, M. Pasierb, *Zastosowanie CO_2 jako chłodziwa w procesie toczenia*, „Zeszyty Naukowe Politechniki Rzeszowskiej" 2017, 295, „Mechanika" 89, „RUTMech", t. XXXIV, z. 89 (3/17), pp. 401–408.

[11] R.W. Maruda, G.M. Królczyk, P. Niesłony, J.B. Królczyk, S. Legutko, *Chip formation zone analysis during the turning of austenitic stainless steel 316L under MQCL cooling condition*, „Procedia Engineering" 2016, 149, pp. 297–304.

Table 1. Chemical compositions limits of Inconel X-750

%	Ni+(Co)	Cr	Fe	Ti	Nb+(Ta)	Al	Mn	Co	Cu	Si	C	S
min.	70	14	5	2,25	0,7	0,4	–	–	–	–	–	–
max.	balance	17	9	2,75	1,2	1	1	1	1	0,5	0,08	0,01

Source: own elaboration based on http://www.steelforge.com; access on 24/02/2018.

Results and discussion

The *Ra* parameter is one of the most frequently studied surface roughness indicators. Figure 1a shows the effect of the cutting speed on the value of the *Ra* and figure 2b value of the *RSm* parameter after turning with two different tool materials. It can be noticed that the influence of the cutting speed on the values of the analysed parameters is not monotonic. The lowest recorded value of *Ra* was noted for a cutting speed equal to 300 m/min when turning with insert of material 7025 (60% CBN content). For the same speed value, the 7015 insert showed several dozen times worse surface quality. The smaller values of the *Ra* parameter for lower content CBN insert were found at 200 m/min. Probably this phenomenon is related to the edge of the cutting edge.

Mean peak width *RSm* parameter is associated with the feed value. For the assumed value of $f = 0.08$ mm/rev, the values of *RSm* should be consistent with the feed. Due to the progressive wear of the cutting insert the cutting edge geometry changes. All kinds of notch wear and flank wear can reduce mean peak width of roughness profile.

Taking into interpretation both *Ra* and *RSm* values, it can be concluded that the most favourable arrangement has place for the value of $v_c = 150$ m/min and $v_c = 250$ m/min. The turning process was the most stable. There were no anomalies associated with the rapid breakaway of build-up material on a rake face of cutting insert. The macrogeometry of the cutting edge remained unchanged. These anomalies can be observed at speeds of 200 and 300 m/min and they are illustrated by the height of the error bar.

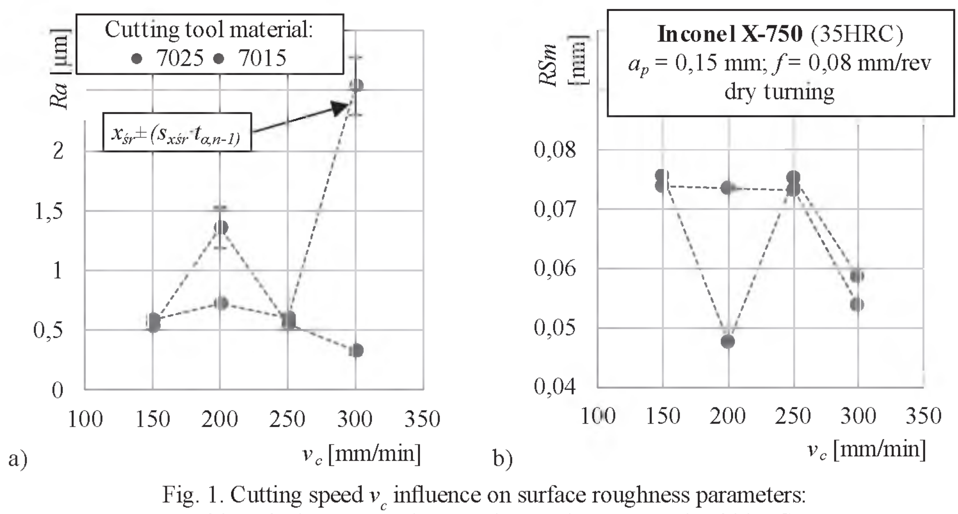

Fig. 1. Cutting speed v_c influence on surface roughness parameters:
a) arithmetical mean roughness value *Ra*, b) mean peak width *RSm*

Source: own elaboration.

Taking into account the values of the cutting edge radius, it can be concluded that the smaller radius of the insert allowed shaping the more favourable roughness. Undoubtedly, this is related to the phenomenon of the minimum thickness of the machined layer.

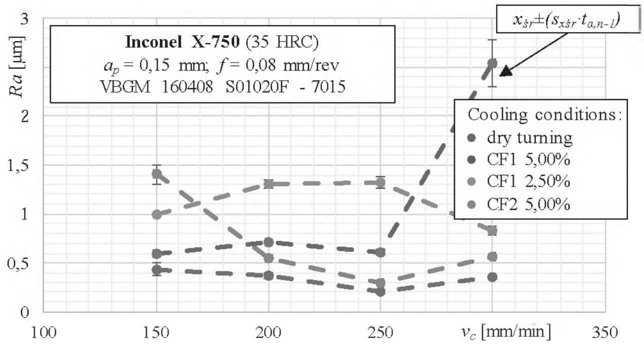

Fig. 2. Cutting speed v_c influence on surface roughness parameters *Ra* for different cooling conditions

Source: own elaboration.

Figure 2 shows the effect of cutting speed and the type of coolant on the value of parameter *Ra*. The fact that the highest value of the roughness parameter was recorded for the parameter 300 m/min for turning without cooling (dry turning) is noticeable. The use of coolant with a concentration of 2.5% generated the least measurable effects. In addition, it is necessary to take into account the fact that for a lower concentration of emulsion may cause a corrosion in the machine. The CF1 coolant with increased concentration resulted in the smallest values of *Ra* roughness parameters in the entire range of analysed cutting speed. The use of CF2 coolant did not significantly improve the roughness *Ra*. The reduction of roughness values might be connected with thermal conditions of adhesion process appearance when cutting fluids are added. Lack of adhesion build ups leads to the tool geometry stabilization and wear growth reduction of cutting insert. In addition the effect of thermal balance changes between tool-machined surface-chip in the function on increasing cutting speed might occurs in a favour for chip. Better thermal condition might be reflected in lower values of roughness parameters (Fig. 2 and Fig. 3 a).

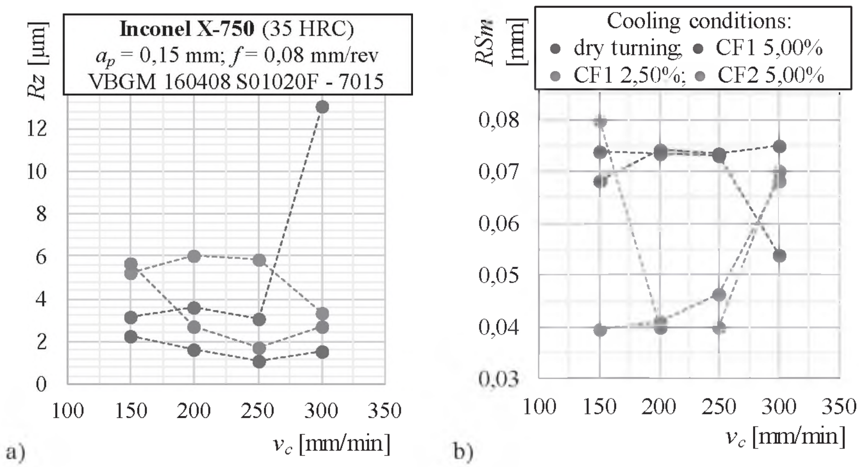

Fig. 3. Cutting speed v_c influence on surface roughness parameters for different cooling conditions a) greatest height of the roughness profile *Rz* and b) mean peak width *RSm*

Source: own elaboration.

Figure 3 shows the values of the parameter *Rz* and *RSm* after turning with various cooling emulsions. Again the *RSm* value should be close to the feed value *f*. The most stable form in mean peak with is observed for coolant coded CF1 at a concentration of 5%. As mentioned earlier, reducing the value of the *RSm* parameter may be related to the condition of the cutting edge and its charting in the roughness profile.

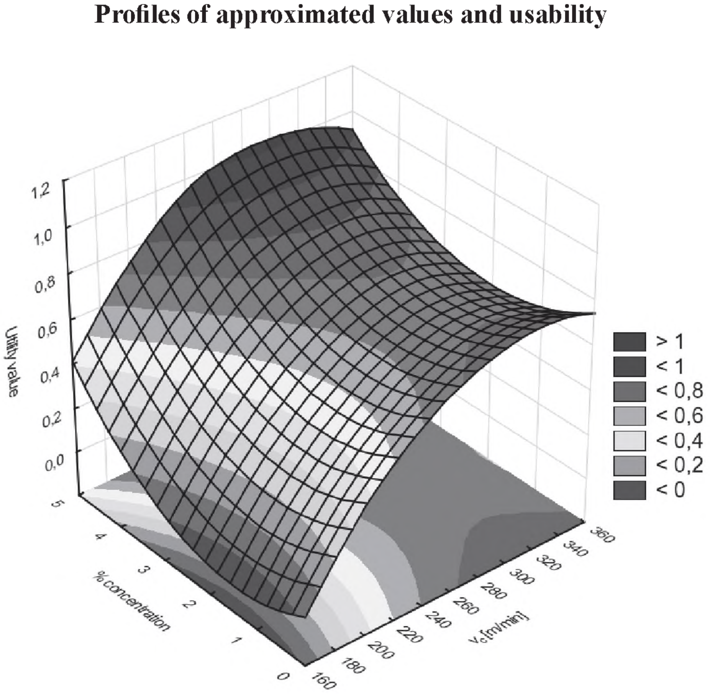

Fig. 4. Cutting speed v_c influence on surface roughness parameters for different cooling conditions a) greatest height of the roughness profile *Rz*

Source: own elaboration.

The analysis of many input factors and the assessment of their interdependencies influencing the result can be a technical challenge. One of the simple optimization methods is the method of utility profiles. Defining low values of roughness parameters as the most desirable, we assign them a value of 1. The useless in terms quality of the machining process is surface with high roughness parameters values. In this method the usability of such combinations of input parameters it has been assigned with 0. Representation of date with this method allows to formulate general conclusion about combinations of input parameters.

The effect of cutting speed and cooling conditions (defined as concertation of emulsion) on usability of surface is presented in the fig. 4 and 5. It was found that in terms of cutting parameters optimization with utility value functions the best range of cutting parameters might be found for higher value of cutting emulsion concentration and higher cutting speeds. This fact is important due to the possibility of high-speed turning of CBN inserts. It is possible to effectively machining of Inconel 718 with proper roughness parameters in higher ranges of cutting speed values.

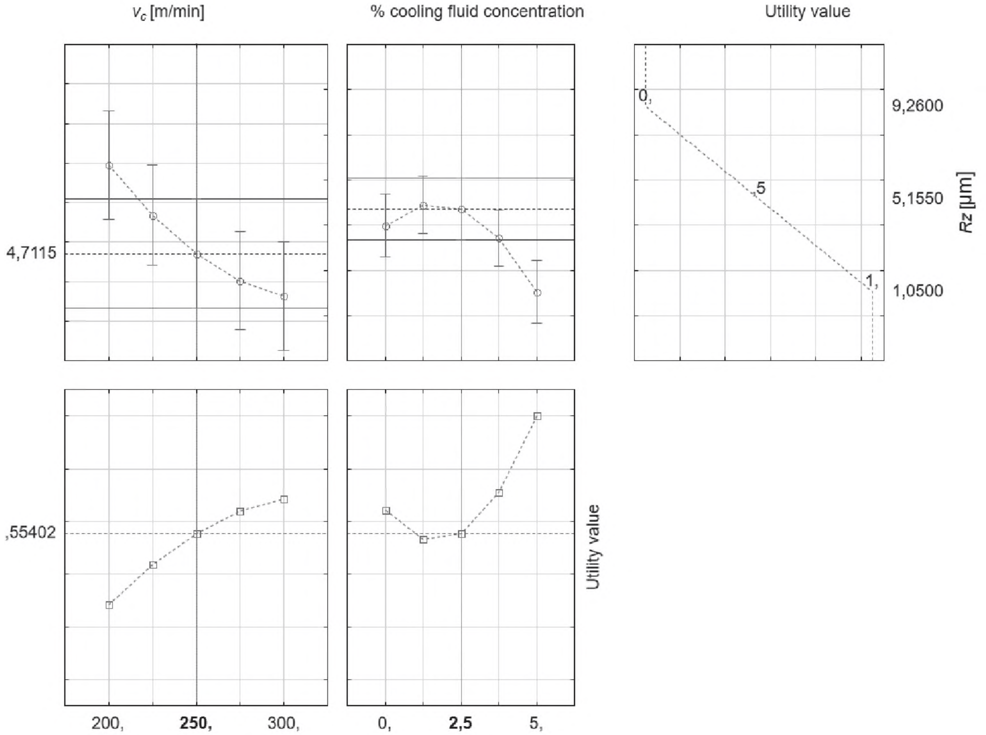

Fig. 5. Profiles of approximate values of *Rz* parameters and usability for cutting speed and cutting fluid concentration

Source: own elaboration.

Conclusions

Analysis of the obtained results allows to formulate the following conclusions:

- cutting with a 60% contents of CBN inserts allows obtaining more favourable roughness parameters than an insert with a content of 50% boron nitride. This might be related to such factors as the value of cutting edge radius r_n.
- optimization of cutting parameters using the utility function showed that the smallest values of the *Ra* and *Rz* parameters can be obtained for a cutting speed of 300 m/min with simultaneous flooding at 5% concentration of the emulsion.
- values of roughness parameters after dry turning are statistically comparable with parameters after turning under cooling conditions in the range of cutting speed 150-250 m/min,
- the concentration value of the used cooling lubricant affects the values of the surface parameters, low concentration contributes to the deterioration of surface quality expressed by roughness parameters.

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Bibliography

Chwalczuk T., Kawalec M., Szablewski P., *Wybrane właściwości warstwy wierzchniej po toczeniu tradycyjnym i ukośnym ostrzami ceramicznymi nadstopu niklu Inconel 718 po nagrzewaniu laserowym*, „Mechanik" 2012, 7–8, pp. 409–414.

Costes J.P., Guillet Y., Poulachon G., Dessoly M., *Tool-life and wear mechanisms of CBN tools in machining of Inconel 718*, „International Journal of Machine Tools & Manufacture" 2007, 47, pp. 1081–1087.

Denkena B., Biermann D., *Cutting edge geometries*, „CIRP Annals – Manufacturing Technology" 2014, 63, pp. 631–653.

Maruda R.W., Królczyk G.M., Niesłony P., Królczyk J.B., Legutko S., *Chip formation zone analysis during the turning of austenitic stainless steel 316L under MQCL cooling condition*, „Procedia Engineering" 2016, 149, pp. 297–304.

Niesłony P., Żak K., Chudy R., *Ocena energetyczna wybranych parametrów stereometrii ostrza CBN na kształtowanie powierzchni po toczeniu stali o podwyższonej twardości*, „Mechanik" 2016, 10, pp. 1384–1385.

Pawde R.S., Joshi S.S., Brahmankar P.K., Rahmanc M., *An investigation of cutting forces and surface damage in high-speed turning of Inconel 718*, „Journal of Materials Processing Technology" 2007, 192–193, pp. 139–146.

Słodki B., *Wpływ temperatury i siły na postać wióra przy toczeniu wzdłużnym stopów Inconel 625 i Inconel 718*, „Inżynieria Maszyn" 2013, R. 18, z. 4, pp. 28–41.

Stroch B., Zawada-Tomkiewicz A., *Distribution of unit forces on the tool edge rounding in the case of finishing turning*, „The International Journal of Advanced Manufacturing Technology" 2012, vol. 60, 5–8, pp. 453–461.

Thakur A., Gangopadhyay S., Mohanty A., *Investigation on some machinability aspects of Inconel 825 during dry turning*, „Materials and Manufacturing Processes" 2015, 30, pp. 1026–1034.

Twardowski P., Legutko S., Królczyk G.M., Hloch S., *Investigation of wear and tool life of coated carbide and cubic boron nitride cutting tools in high speed milling*, „Advances in Mechanical Engineering" 2015, Issue 6, Vol. 7, pp. 1–9.

http://www.steelforge.com, dostęp: 24.02.2018 r.

Żyłka Ł. Babiarz R., Płodzień M., Sułkowicz P., Pasierb M., *Zastosowanie* CO_2 *jako chłodziwa w procesie toczenia*, „Zeszyty Naukowe Politechniki Rzeszowskiej" 2017, 295, „Mechanika" 89, „RUTMech", t. XXXIV, z. 89 (3/17), pp. 401–408.

STRESZCZENIE

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Struktura geometryczna powierzchni stopu Inconel x-750 po toczeniu ostrzami CBN w różnych warunkach chłodzenia

Wysoko wydajne skrawanie stopów lotniczych na osnowie niklu jest możliwe dzięki zastosowaniu nowoczesnych materiałów narzędziowych, takich jak regularny azotek boru, oraz narzędzi optymalizacyjnych umożliwiających dobór warunków skrawania. W badaniach oceniono wpływ prędkości skrawania v_c oraz stężenia wodorozcieńczalnego, syntetycznego chłodziwa obróbczego na parametry struktury geometrycznej powierzchni (SGP) podczas toczenia nadstopu niklu Inconel X-750 (AMS 5668). Zastosowano dwa materiały narzędziowe z drobnoziarnistego regularnego azotku boru w osnowie ceramicznej różniącego się zwartością CBN. Stosowano zmienne wartości prędkości skrawania w zakresie v_c = 150–300 m/min. Pomiarów parametrów chropowatości *Ra*, *Rz* oraz *RSm* dokonano na powierzchniach po toczeniu bez udziału cieczy chłodzącej oraz po obróbce z chłodzeniem zalewowym chłodziwem o stężeniu 2,5% oraz 5% emulsji.

Słowa kluczowe: toczenie, struktura geometryczna powierzchni, Inconel X-750, ostrza CBN.

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