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Procedia Engineering 100 (2015) 853 – 860

Procedia Engineering

www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

The Research of the Surface Profile after Profiling of Superalloys

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Abstract

Production of so-called superalloys is increasing in the present. This paper is about milling of Inconel 738 LC and Inconel 718. There are main mechanical properties as well as chemical composition of Inconel 738 LC and Inconel 718 in this paper. Special properties of superalloys cause, that they are very hard machining materials, mainly thanks to their high thermal stability during machining. For this reason it was necessary to measure the surface roughness after machining turbine blades made of Inconel 738LC and Inconel 718 depending on profiling. For roughing and finishing of Inconel 738 LC and Inconel 718 were used the best cutting parameters from previous research.   After machining of turbine blades were measured parameters of the surface roughness and wear of the cutting tools.

Peer-review under responsibility of DAAAM International Vienna

Keywords: Inconel 718; Inconel 738LC; surface quality; milling direction

1. Introduction

In the present, as well as in the future is expected to increase production of products made of so-called superalloys. Among the superalloys can be sorted materials such as Inconel, Hastelloy, Waspaloy, Nimonic or Titat. The main advantages of these materials are used in the air industry, in the manufacture of turbines, in the space industry and in manufacturing of components that are working in high temperature. Due to its special properties superalloys are very hard machining materials, mainly due to their high thermal stability during machining. There is a lot of requests for products made of superalloys. One of the most common request is for surface integrity, mainly for roughness. For this reason it was necessary to design machining experiment and measure the surface roughness

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Peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2015.01.441

after machining turbine blades made of Inconel 738LC and Inconel 718 depending on profiling and tool wear.

The number of studies were carried out for evaluating the best cutting conditions of Nickel-based superalloys and Inconel 718 in particular. H.R. Krain et al.[1] showed that increasing of the immersion ratio leads to reduction of tool life. It is possible a decreasing of tools wear by using good choosing tool geometry [2]. Another study [3] showed influence of different cutting strategies on the surface quality and cutting forces, researchers had better surface quality when used horizontal downward cutter orientation. For the better surface quality and material removal rate it is recommended to use larger speed velocity, smaller feed rate and middle depth of cut [4]. Nickel-based alloys could also be machined by laser cutting technology [5] but for getting complex shaped surfaces it necessary to use multi axis milling machines. Some of studies about machining of Inconel 738 LC have already been published [6, 7]. The main aim of the presented research was to evaluate influence of milling direction on the surface roughness and tool wear and compare them between two materials during the machining of a real part.

2. Inconel 738 LC

Inconel 738 LC is a high-strength, corrosion-resistant polycrystalline Ni-based superalloy, which is stabilized by coherent precipitates on the basis of A_3B (Ni_3Al, Ni_3AlTi).

It is a modification of a low-carbon alloy Inconel 738. This superalloy is used for the production of high-temperature stressed components in the aerospace and energy industries, mainly because of its excellent mechanical properties and structural stability at high temperatures and resistance to oxidation and corrosion. Products made of Inconel 738LC are can operate in temperature up to 750 ° C.

Mechanical properties (at 20°C) are $R_m \geq 927$ MPa, $R_{p0,2} \geq 772$ MPa, $A_5 > 4$ %. Furthermore, the creep characteristics are measured at the temperature of 870 °C. ($R_{mT} \geq 309$ MPa with minimal time to fracture 50 hours) [8].

There is chemical composition of Inconel 738 LC in the Table 1.

Table 1. Chemical composition of Inconel 738 LC [9].

Element	C	Mn	Si	Cr	Ti	Al	Fe	B	Zr	Nb	Ta	Mo	W	Co	Cu	P	S	Ni
Min.(%)	0,09			15,7	3,2	3,2		0,007	0,03	0,6	1,5	1,5	2,4	8,0				
Max.(%)	0,13	0,2	0,3	16,3	3,7	3,7	0,35	0,012	0,08	1,1	2,0	2,0	2,8	9,0	0,1	0,01	0,015	rest

Machining of Inconel 738 LC is difficult, technically demanding, especially because of the high temperature of cutting at the edge of the tool, that cause deformation during machining and also increasing wear of tool. Another negative phenomenon in machining of this material is hardening during the mechanical deformation, which makes the vibrations, which also affect the quantity of the tool wear.

3. Inconel 718

Superalloy Inconel 718 is used for the high-temperature stressed components, mainly in the aerospace and energy industries. Mechanical properties (at 20°C) are $R_m \geq 1205$ MPa, $R_{p0,2} \geq 1105$ MPa, $A_5 > 17$ %. [8]

There is chemical composition of Inconel 718 in the Table 2.

Table 2. Chemical composition of Inconel 718 [10].

Element	C	Mn	Si	Cr	Ti	Al	Fe	B	Nb	Mo	Co	Cu	P	S	Ni
(%)	0,08	0,35	0,35	17-21	0,3	0,65-1,15	R	0,006	4,75-5,5	2,8-3,3	1	0,2-0,8	0,015	0,015	50-55

4. Experiment

The aim of the experiment is to verify the influence of cutting conditions and tool wear on the surface roughness of turbine blades made of Inconel 738 LC and Inconel 718.

For this experiment was chosen turbine blade, which contains the geometry of the complex shaped and planar surfaces. The technology used for the production of blades is to produce cast parts using the investment casting and finish this part by machining technologies.

In this experiment it was necessary to define the part of the area to be machined, because of the working range of the instrument is not unlimited. Selected area for machining is shown in Fig. 1. The defined area for the experiment is machinable by 4 axes milling, where angle between cutter and normal of the turbine blade was 14°.

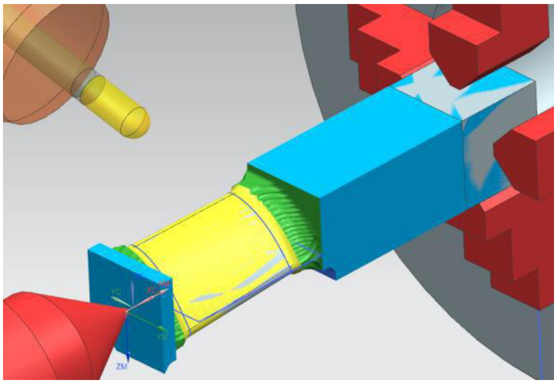

Fig. 1. 3D model of the milling process (NX software).

The experiment was realized on CNC machining centre MCFV 1260 STANDARD at the company PBS Velká Bíteš a.s.. For this experiment the company Gühring recommended tool marked as 3563 DIN 6527L R-NH 10,000x72x22 R1. Drawing of the cutting tool is shown in Fig. 2 and specifications are shown in Table 3.

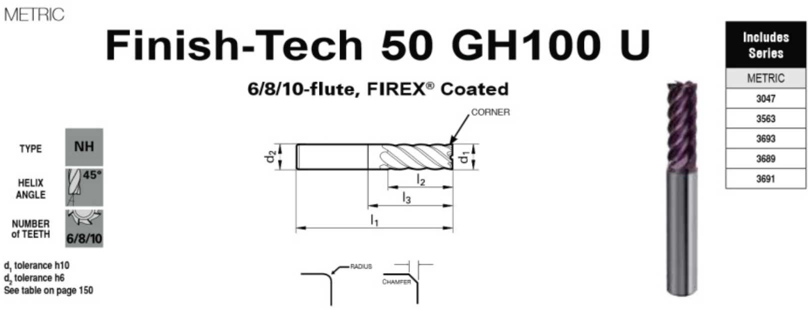

Fig. 2. 3563 DIN 6527L R-NH 10,000x72x22 R1 cutting tool [10].

Table 3. Guhring 3563 cutting tool parameters [10].

d1 h10 [mm]	d2 [mm]	l1 [mm]	l2 [mm]	l3 [mm]	Corner radius [mm]	Flutes
10	10	72	22	32	1	6

5. Results

Measurement of surface roughness parameters was carried out on Profilemeter MAHR MarSurf XCR 20 equipped with a drive unit PGK and sensor MFW-250 tracing arm 6851805 (Fig. 3). Calibration was carried out by using the caliber MAHR W-Nr: 11416/03 with the filter selected λC = 0.8 μm with a deviation of 4.8% (Fig. 3).

a b

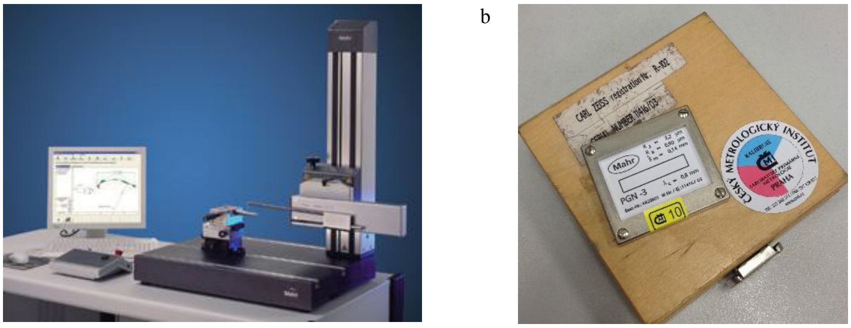

Fig. 3. (a) MAHR MarSurf XCR 20, (b) Caliber MAHR W-Nr: 11416/03.

There were measured parameters of surface roughness on a total of 4 blades cast from Inconel 718 and Inconel 738 LC, which were machined by different cutting parameters (Table 4), in this experiment. Parameters of surface roughness were measured on the convex (on the figure) and concave sides of the turbine blades three times on each different place on (see Fig. 4 for details).

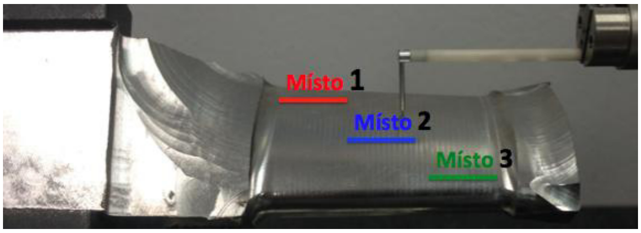

Fig. 4. Section of the measurement.

Results of measurement of the parameters of surface roughness on machined blades are shown in Table 4.

Table 4. Results of roughness measurement.

Material	Program	Side	R_a [μm]	R_Z [μm]
Inconel 718	Climb	Concave	0,561	2,861
Inconel 718	Climb	Convex	0,442	2,165
Inconel 718	Conventional	Concave	0,58	2,66
Inconel 718	Conventional	Convex	0,587	3,035
Inconel 738LC	Climb	Concave	0,621	2,582
Inconel 738LC	Climb	Convex	0,501	2,288
Inconel 738LC	Conventional	Concave	0,668	3,317
Inconel 738LC	Conventional	Convex	0,502	2,293

Fig. 5 shows boxplot of roughness parameter Ra, where data are grouped by material, program and side. Ra values vary from 0.4 μm to 0.8 μm. It is seen, that turbine blades do not have the same roughness in different places. In the most cases, Ra is larger on the concave side of the blade. Milling of Inconel 718 by conventional manner leaded to the smallest variability. In the most cases conventional manner of milling caused larger average values of Ra, except convex side of Inconel 738LC, so climb manner leads to the better surface quality (see Fig. 6).

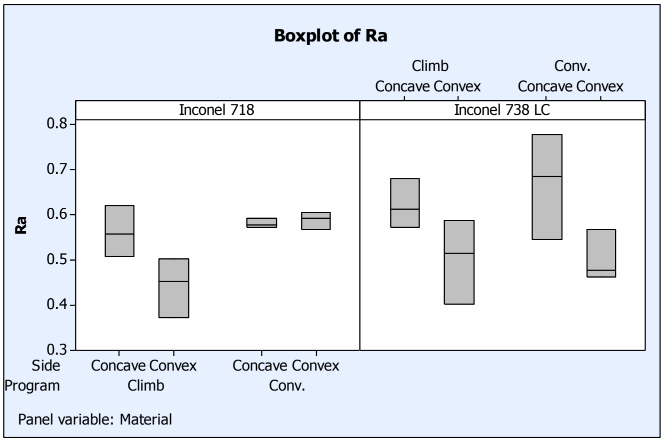

Fig. 5. Boxplot of Ra values.

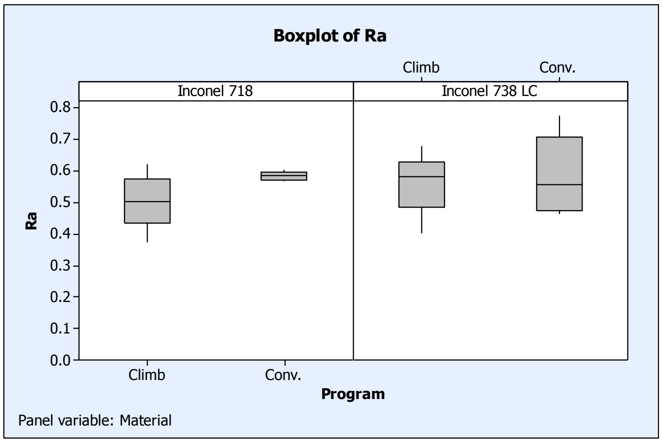

Fig. 6. Boxplot of Ra values, average for both sides.

Fig. 7 shows individual values of Rz parameter in µm. In the 3 of 4 cases concave side had the larger value of Rz, except machining of Inconel 718 in conventional manner. Another observation is that machining in the climb direction caused slightly smaller values of Rz than machining in the conventional direction.

Tool wear measurement was carried out on the multi-sensor measuring machine O-INSPECT from Carl Zeiss where the tool was clamped on a self-aligning vise. VB parameter was measured. Fig. 8 shows the graph of tool wear. Average values of VB are plotted on the graph. It is seen that VB values for Inconel 738LC are significantly larger than VB values for Inconel 718 due to machinability of the material. The program as well has an influence on the tool wear: smaller tool wear follows to conventional milling. Comparing in individual edges showed that larger tool wear occurred on the main edges.

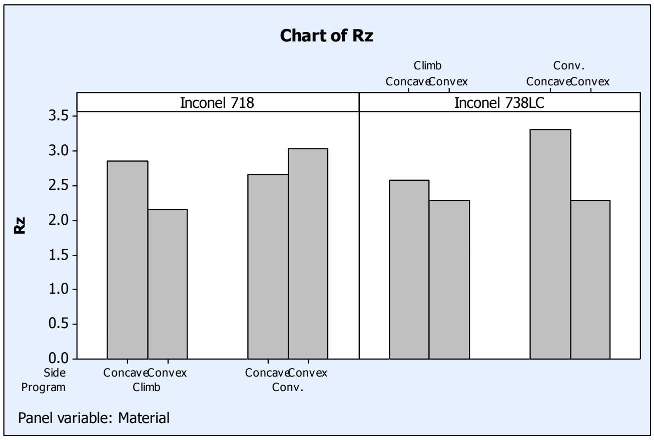

Fig. 7. Individual values of Rz parameter.

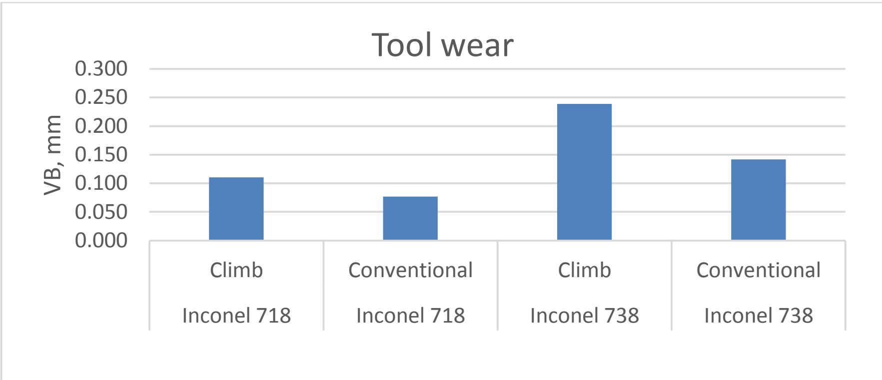

Fig. 8. Tools wear measured values (VB).

Fig. 9 shows that there is no significant correlation between tool wear and roughness. It is possible to declare that there is no correlation between these factors in the given conditions. Fig. 10 and Fig. 11 contains enlarged photos of used cutting tools.

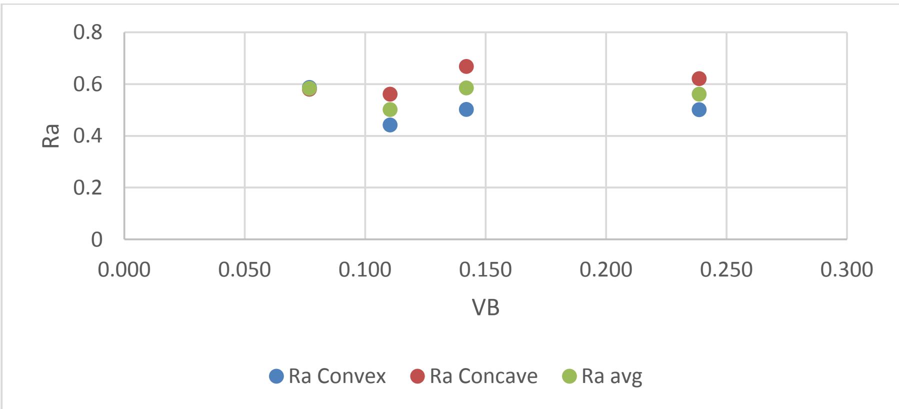

Fig. 9. Correlation between tool wear and average roughness.

a b

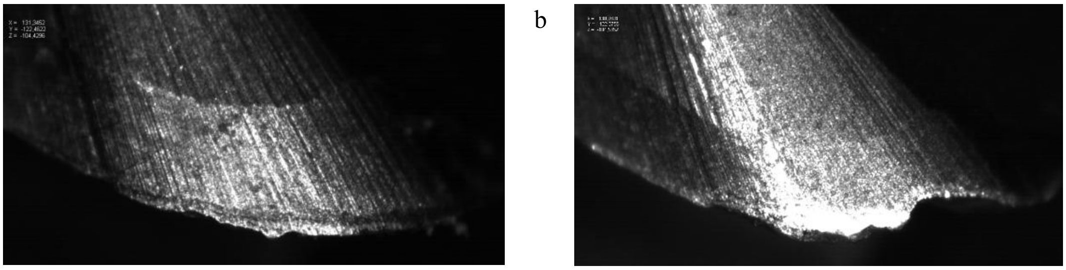

Fig. 10. (a) Cutting tool after Inconel 718 conventional machining (b) Cutting tool after Inconel 738 LC conventional machining.

a b

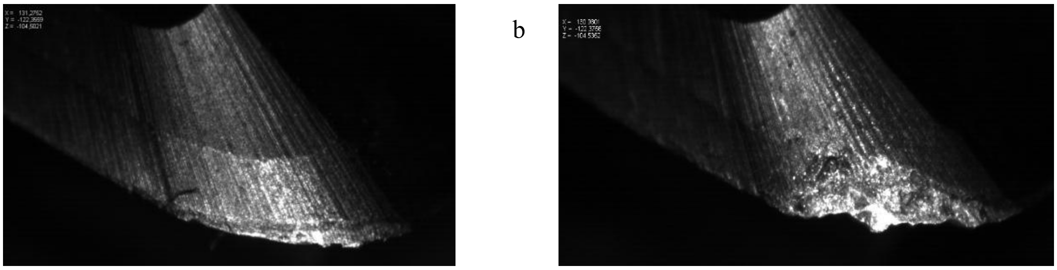

Fig. 11. (a) Cutting tool after Inconel 718 climb machining (b) Cutting tool after Inconel 738 LC climb machining.

6. Conclusion

The main aim of the research was to compare surface quality and tools wear after milling operations of turbine blades made of two materials (Inconel 718 and Inconel 738LC) by two milling directions (conventional and climb). Both of factors had influences on the surface integrity. After machining roughness parameters Ra and Rz were measured on the two sides of turbine blades: convex and concave. Tools wear was also evaluated and measured.

Climb milling caused smaller Ra and Rz values in average. Roughness in the most cases was not homogeneous on the entire surface and greater on the concave side. Ra parameter achieved values about 0.8 μm. Inconel 738 LC showed little greater values of roughness than Inconel 718. Due to the features of turbine blade milling, convex side has better surface quality.

Greater impact on the tools wear parameter had the material. **VB parameters were measured greater for the Inconel 738LC**. Another impact on the tool wear is a milling direction. Climb milling is characterized by larger thickness in the beginning of cutting process, so the cutter is more loaded, what leads to the faster tools wear. So conducted research had confirmed that material Inconel 738 LC is more hard-machinable than Inconel 718.

Machining of the super alloys is associated with the number of problems due to hardness of materials. In the future studies research team is going to focus on the improving of multi-axis milling strategy for obtaining better characteristics of surface quality, tools wear and cutting time.

Acknowledgements

This work was supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS13/188/OHK2/3T/12.

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