EXPERIMENTAL EVALUATION ON THE QUALITY OF MACHINED SURFACE AFTER TURNING OF MATERIAL INCONEL 625

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Study relates to machining of toughly-machined metal materials specifically turning of the Inconel 625. There had been planned an experiment to find out the impact of setting the individual parameters of machining(cutting speed, feed rate, depth of cut)onto the quality of machined surface. Such experiment was the type of 'box behnken'and contained 15 rounds. Following was the evaluation of the machined surface quality and their topography thanks to 3D profilometer Taylor Hobson Talysurf CCI Lite, based on which there were created 3D colour filtered pictures of the surface of the samples. Morphology of the surfaces was investigated by electron microscopy.

KEYWORDS

turning, Inconel 625, surface quality, box behnken, design of experiment

1 INTRODUCTION

From many perspectives, turning represents the basic way of machining, as well as the most useful work practice within the scope of mechanical engineering. Finishing operations such as grinding are replaced with turning which reduces production costs of individual parts. Apart from the others, there is necessary an optimal choice of cutting process parameters [Mishra 2014, Cheung 2014] to reach the high quality of machined surface. These parameters may be found through various methods [Blecha 2011a, Blecha 2011b]

However, [Nalbant 2007]obtained that the minimum average surface roughness was determined with single layer TiN coated cemented carbide tools, while maximum average surface roughness was observed with multicoated Al_2O_3 tools. The carbide insert used by [Thakur 2009]during turning of the Inconel 718 shows that the surface finish was optimal in the cutting speed range of 45 to 55 m/min for low feed rate and depth of cut; cutting force magnitude was found higher than feed force. However, the surface roughness could be also affected by the cutting conditions. The increase of the cutting speed v_c should improve the surface roughness by softening the surface. At the high cutting speed, the deformation rate in the workpiece surface was increased by increased temperature, causing the surface softening, and by consequence, improved surface roughness and the surface roughness were also affected by the feed rate [Ståhl 2011]. During a study of machinability assessment of Inconel 718 accomplished by[Choudhury 1999], it was revealed that the surface roughness generated by the uncoated and coated tools was mostly influenced by the change in feed, and the increase in the depth of cut improved the surface finish produced by the coated carbide tools whilst it was the opposite when the uncoated tools were used while cutting force was decreased when the speed was increased and increased when the feed or depth of cut was increased.

Although the optimal setting of the cutting parameters is significant, the relevant impact onto final surface quality has also the combination of mechanical and physical properties of the machined material, especially its hardness.

2 EXPERIMENTAL SETUP AND MATERIAL

2.1 *Experimental material*

Samples suitable for the experiment had been made from the nickel-based alloys calledInconel 625with their chemical composition according to Tab. 1.

Contents	Ni	Cr	Fe	Mo	Nb	Co	Mn
Max. wt. %		23	5	10	4.15	1	0.5
Min. wt. %	58	20		8	3.15		

Table 1. Chemical composition of Inconel 625specified by the Standard

Inconel isnon-magnetic metal resistant to both corrosion and acids, with high welding characteristic. Due to its high tensile strength, in tension up to 880 MPa, hardness from 20 to 30 HRC and excellent resistance to fatigue fracture is this material suitable for turbine engine, thermal shields, turbine blades, gas supply pipes and any special usage in sea water.

Material Inconel is of very low thermal conductivity (9.8 W/m/K), which results into excessive wear of the tools. At the same time it causes hardening of the surface layer and due to that excessive wear of the tools. [Choudhury 1999].

2.2 *Turning machine setup*

Experimental samples had been made by lathe SQT 200, produced by company called MAZAK, and coated insert marked as WNMG060404N-SUfrom companySumitomowith relevant tool holder AC405K of the same brand Sumitomo. This insert is coated with TiAlN, reason being the higher resistance to high temperatures as they are created when machining.

To find out the impact of parameters such as cutting speed (v_c), feed (f) and depth of cut (a_p) onto the machined surface there was used planned experiment (DoE).This experiment had been designed by methodology called'box behnken'and contained 15 rounds [Tebassi 2016]. Individual settings of the machine for each sample are specified in Tab.3. There were made randomise runs to limit the external influence.

Parametr / Sample	v_c (m/min)	f (mm/rev)	a_p (mm)
1	60	0.275	0.8
2	45	0.050	0.8
3	45	0.275	0.5
4	60	0.275	0.2
5	30	0.500	0.5
6	45	0.275	0.5
7	45	0.050	0.2
8	30	0.275	0.2
9	30	0.275	0.8
10	30	0.050	0.5
11	60	0.050	0.5
12	45	0.500	0.8
13	60	0.500	0.5
14	45	0.275	0.5
15	45	0.500	0.2

Table 3. Machining parameters for each sample.

3 RESULTS OF EXPERIMENT

3.1 *Evaluation of the profile parameters of the machined surfaces*

Examined surfaces created by turning were analysed with 3D profilometer Taylor Hobson Talysurf CCI Litebased on the principle of coherent correlation interferometry. Profile parameters were evaluated on 1024 profiles of a single evaluation length lr=0.8 mm obtained from S-F surfaces of measurements made with the 10x objective.

Assessed profile parameters of the surface quality were following: arithmetical mean deviation of profile (*Ra)* and root mean square deviation (*Rq*).

The values of the examined parameters of the surface quality *Ra* and*Rq*were put into spreadsheet Tab. 5.Sample with the highest value of the examined parameter*Ra*was no. 15 (9.01 µm) and the lowest value was obtained by number 7 (1.17 µm).

Parametr Sample	Ra (µm)	Rq (µm)
1	4.58	5.48
2	1.27	1.63
3	2.93	3.71
4	4.81	5.55
5	6.34	7.57
6	3.69	4.55
7	1.17	1.46
8	3.49	4.25
9	3.84	4.59
10	1.66	2.12
11	1.30	1.67
12	7.01	8.48
13	7.27	8.32
14	4.04	4.83
15	9.01	10.54

Table 5. Evaluated parameters of the surface quality of individual samples.

In the picture(Fig. 1)is shown topography of the surface with the highest value of the parameter *Ra*.There are obvious deep lines created by the tool with its feed rate 0.5 mm/rev.

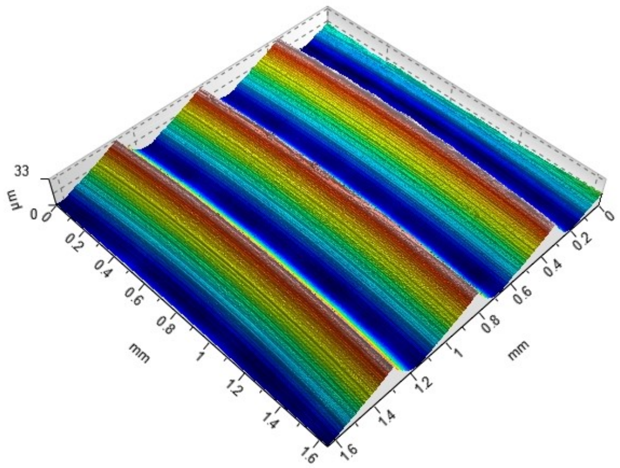

Figure 1. 3D colour filtered picture of the surface of the sample no. 15

Topography of the surface of the sample which resulted in the lowest value of Ra is presented in the picture (Fig. 2).It is more difficult to diversify individual lines of the tool which is caused by significantly lower feed rate 0.05 mm/rev.

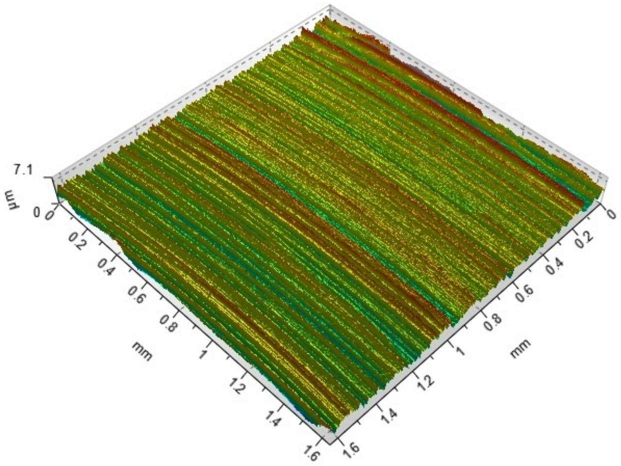

Figure 2. 3D colour filtered picture of the surface of the sample no. 7

3.2 *Morphology of the surfaces*

Machined surfaces of the samples had been cleaned in ultrasonic cleaner and were analysed by scanning electron microscope (SEM) LYRA3 brand nameTescan.

Structure of the surfaces, when examined by electron microscopy, was different to analyses from coherent correlation interferometry. Reason being, the usage of higher magnification, where there was impossible to watch deep grooves made by the tool in the sample 15. Conversely, on the surface of the sample 7, with 300x magnification, there are obvious grooves made with the nose of the tool.

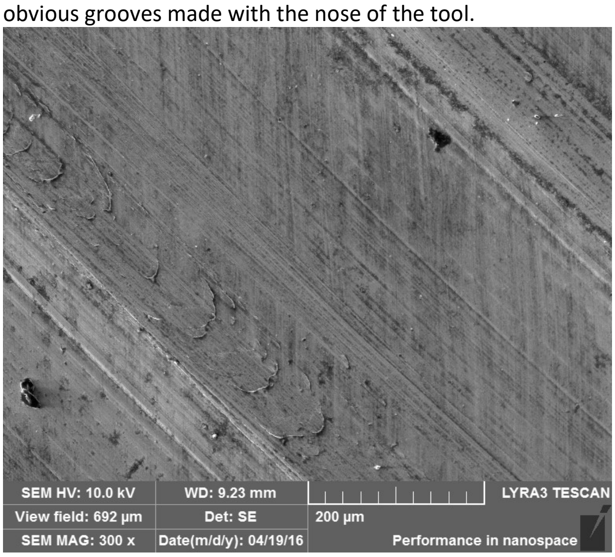

Figure 3. Morphology of surface sample 15 (SEM), 300x magnification

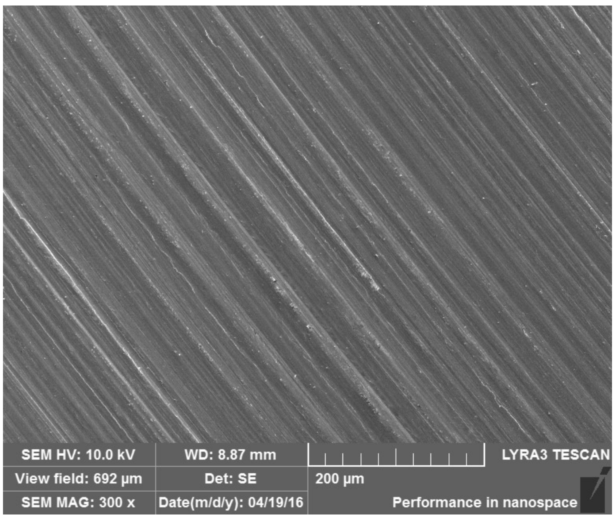

Figure 4. Morphology of surface sample 7 (SEM), 300x magnification

3.3 Evaluation of the planned experiment

Used experiment for examination of the dependence of the quality of the machined surface to specific parameters of the process was type ‘box-behnken’containing 15 rounds(Tab. 5). ‘Box-behnken’ itself is efficient version of response surface experiment thanks to which there was allowed lower number of samples[Kim 2014].

Final model for parameter *Rq* (Fig. 5) is created on the level of importance α=95 %, after deleting statistically insignificant parameters (P value > 0.05) there it represents c. 91 % of experimentally founded values.

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Source          P-Value
Model       0.000
    Linear      0.000
    f (mm/rev)   0.000
  Lack-of-Fit 0.362

Model Summary
        S     R-sq  R-sq(adj)  R-sq(pred)
0.816147  91.90%     91.28%      88.71%
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Figure 5. Anova for Rq(μm)

To find out the type of distribution the residues values, there was used Andersen darling test and its graph is presented in Fig. 6. P-value for test was higher than 0.05 and that is why there mustn’t be refused null hypothesis aboutnormal distribution of the residues.

Due to fulfilling the assumption of the normal distribution of the residues, it was possible to make regression model for parameter *Rq*.

Lower value P-value has been caused by distance value on the level Residual = 2.

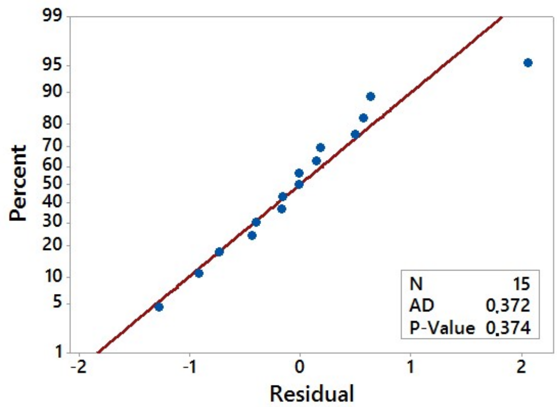

Figure 6. Normal probability plot

With the help of linear regression there was established equation (1) of the dependence *Rq*parameter to statistically significant parameters of the process:

$$Rq = 0.704 + 15.58 f \qquad (1)$$

where :*Rq* (μm) isroot mean square deviation a f (mm/rev) isfeed.

Linear regression of parameter *Rq*to*Ra* (Fig. 7) is expressed by equation (2) gained by the regression analysis:

$$Rq = 0.2003 + 1.4149 Ra \qquad (2)$$

where: *Ra* (μm) arithmetical mean deviation of profile. While equation (2) represents c. 99.8 % of the values of the experiment.

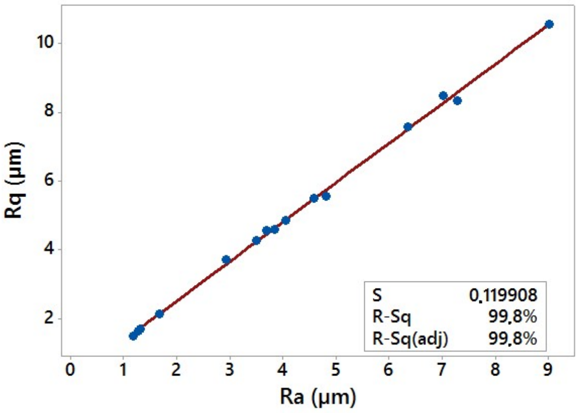

Figure 7. Dependence Rqto Ra

4 CONCLUSIONS AND DISCUSSION

Morphology of the surface was made by parallel grooves created by turning [Gao 2016] at all examined samples. Size of the grooves was depended not only on cutting parameters but also on the parameters of the tool itself. Meanwhile there must not be omitted interaction of the machined material with the toll [Sahu 2015], [Hao 2015], [Thakur 2016].

The highest values of the parameter *Rq*were evaluated at the samples with high feed rate and that is confirmed by linear regression and equation (1).The lowest values of the parameter *Rq*was reached when setting of machining parameters v_c=45 m/min, f=0.05 mm/rev anda_p=0.2 mm. The highest values *Rq*were evaluated at the sample no. 15, which was machined by cutting conditions v_c=45 m/min, f=0.5 mm/rev anda_p=0.2 mm.

Above described information confirm that the final parameter of the surface roughness *Rq*is significantly depended on the feed rate of the tool.

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REFERENCES

[Blecha 2011a]Blecha, P., Blecha, R.,Bradac, F. (2011). Integration of Risk Management into the Machinery Design Process. In Mechatronics Springer Berlin Heidelberg, pp. 473-482.

[Blecha 2011b]Blecha, P., &Prostrednik, D. (2011). Influence on the failure probability. Annals of DAAAM & Proceedings, pp. 11-13.

[Hao 2015] Hao, Z., Fan, Y., Lin, J., & Yu, Z. (2015). Wear characteristics and wear control method of PVD-coated carbide tool in turning Inconel 718. The International Journal of Advanced Manufacturing Technology, 78(5-8), pp. 1329-1336.

[Cheung 2014]Cheung, C. F., & Lee, W. B. (2000). A multi-spectrum analysis of surface roughness formation in ultra-precision machining. Precision Engineering, 24(1), pp.77-87.

[Choudhury 1999]Choudhury, I. A., & El-Baradie, M. A. (1999). Machinability assessment of inconel 718 by factorial design of experiment coupled with response surface methodology. Journal of Materials Processing Technology, 95(1), pp. 30-39.

[Gao 2016] Gao, Y., Sun, R., Chen, Y., & Leopold, J. (2016). Analysis of chip morphology and surface topography in modulation assisted machining. International Journal of Mechanical Sciences, 111, pp. 88-100.

[Kim 2014] Kim, D. H., & Lee, C. M. (2014). A study of cutting force and preheating-temperature prediction for laser-assisted milling of Inconel 718 and AISI 1045 steel. International Journal of Heat and Mass Transfer, 71, pp. 264-274.

[Mishra 2014]Mishra, V., Khan, G. S., Chattopadhyay, K. D., Nand, K., &Sarepaka, R. V. (2014). Effects of tool overhang on selection of machining parameters and surface finish during diamond turning. Measurement, 55, pp. 353-361.

[Nalbant 2007] Nalbant, M., Altın, A., &Gökkaya, H. (2007). The effect of coating material and geometry of cutting tool and cutting speed on machinability properties of Inconel 718 super alloys. Materials & design, 28(5), pp. 1719-1724

[Sahu 2015] Sahu, S., & Choudhury, B. B. (2015). Optimization of Surface Roughness Using Taguchi Methodology & Prediction of Tool Wear in Hard Turning Tools.Materials Today: Proceedings, 2(4), pp. 2615-2623.

[Ståhl 2011]Ståhl, J. E., Schultheiss, F., &Hägglund, S. (2011). Analytical and experimental determination of the R a surface roughness during turning.Procedia Engineering, 19, pp. 349-356.

[Tebassi 2016]Tebassi, H., Yallese, M., Khettabi, R., Belhadi, S., Meddour, I., &Girardin, F. (2016). Multi-objective optimization of surface roughness, cutting forces, productivity and Power consumption when turning of Inconel 718. International Journal of Industrial Engineering Computations, 7(1), pp. 111-134.

[Thakur 2009]Thakur, D. G., Ramamoorthy, B., &Vijayaraghavan, L. (2009). Study on the machinability characteristics of superalloy Inconel 718 during high speed turning. Materials & Design, 30(5), pp. 1718-1725.

[Thakur 2016]Thakur, A., &Gangopadhyay, S. (2016). State-of-the-art in surface integrity in machining of nickel-based super alloys. International Journal of Machine Tools and Manufacture, 100, pp. 25-54.

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