Journal of Mechanical Engineering *Vol SI 3 (2), 199-209, 2017*

Influence of Grinding Parameters on Surface Finish of Inconel 718

Nurul Afizan Yaakob
Hema Nanthini Ganesan
Nurul Hatiqah Harun
Raja Izamshah Raja Abdullah
Mohd Shahir Kasim
Department of Manufacturing Process,
Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

Jaharah A. Ghani
Che Hassan Che Haron
Department of Mechanical and Material Engineering,
Faculty of Engineering and Built Environment, Universiti Kebangsaan
Malaysia,43600 Bangi, Selangor, Malaysia

ABSTRACT

High-strength Inconel 718 is used for manufacturing critical parts of a turbine blade owing to its good mechanical properties. However, there is a drawback in the material removal process. In this paper, the grinding performance of surface finish was investigated under several cutting conditions. The variable parameters studied were traverse speed, depth of the cut and the number of passes. Historical data of the response surface methodology (RSM) was used to analyses the correlation between the variable input and output. In ANOVA, the traverse speed and depth of cut were found to be significant factors instead of the number of passes, in which the P-value is less than 0.05. The appropriate parameter settings for grinding of the Inconel 718 are 9,137 mm/min of traverse speed, 7 µm in depth of cut, and 10 passes.

Keywords*: Surface Grinding, Historical Data, Surface Roughness, Response Surface Methodology*

ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2016-09-22
Accepted for publication: 2017-03-03
Published: 2017-07-01

Introduction

Inconel 718, a nickel-based super alloy, exhibits remarkable characteristics because of which it has emerged as the material choice for products used in challenging environments. It finds applications in the manufacturing of reciprocating engines, stack gas preheater and aircraft gas turbines. However, Inconel 718 is a tough material to be machined because of its characteristics, such as high hardness and high strength at elevated temperatures [1]. Many previous studies have reported the poor machinability of this nickel-based alloy. Machinability refers to the ease with which a work material is machined under a given set of cutting conditions. The main parameters considered for the assesssment of machinability are surface roughness, cutting force and tool life [2].

Unfortunately, there is little literature available on the grinding process. Grinding is a chip-removal process that uses an individual abrasive grain as the cutting tool. It is a term used in modern manufacturing practices to describe machining with high-speed abrasive wheels, pads, and belts [3]-[5]. It is a machining process that employs an abrasive grinding wheel rotating at a high speed to remove material from a softer material [4]. It is one of the last steps in the machining operation chain and is highly developed to cater for specific products and process requirements. It is important for a product to attain the desired surface roughness to achieve optimum quality and endurance in the industry [6].

Aslan and Budak [7] stated that grinding can be a cost-effective alternative for roughing operations of some hard-to-machine materials. Due to the hardness of Inconel 718, with the type of grinding wheel, the depth of cut will affect the surface roughness [8]. It is important to know the relation between input parameters and its response or output characteristics. Input parameters that are usually varied in research studies are speed, feed rate, depth of cut, type of wheel, grit, usage of coolant and force. In this study, three parameters i.e., traverse speed, depth of cut and the number of passes, are varied. The surface roughness of the ground part is considered an important quality measure in the industry [9]. Hence, appropriate control of cutting parameters plays a key role in the manifestation of surface quality [10].

This paper focuses on identifying the significant and insignificant factors and optimum parameters that affect the surface roughness of Inconel 718. A regression model is developed based on the set of experiment data

Methodology

Experiments were carried out using a block of Inconel 718 with a hardness of 36 HRc. The size of 100 mm × 150 mm × 30 mm was used throughout the experiment, as shown in Figure 1. The controlling input parameters were the traverse speed, *Vc*; the depth of cut, *ap*; and the number of passes, *n*, in the range of 1.6–10.4 m/min, 0.003–0.007 mm and 2–10, respectively. Historical data of the response surface methodology was used to analyse the data from 19 runs. Analysis of variance (ANOVA) was used to evaluate the relative significance of the cutting parameters with regards to the surface roughness.

A gate surface grinding machine was used in this study as shown in Figure 2. Machine specifications are given detailed in Table 1. Workpiece surface roughness (*Ra*) was measured using a contact-type stylus profilometer, the Mitutoyo Surftest SJ-301 series. This machine has a diamond stylus that travels along a straight line over the surface and records periodic height measurements. The stylus traversing length L_t was set to 12.5 mm with cut off λ_c at 2.5 mm. Measurements were taken in pick and feed of the cutting wheel direction. For every experiment, 10 roughness measurements were taken at random locations. A total of 190 roughness measurements were taken. Figure 3 shows the flow diagram for this experiment.

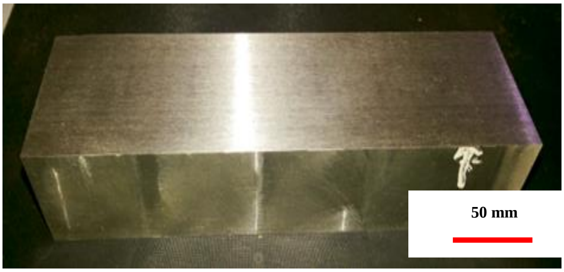


Figure 1: Specimen of Inconel 718

Figure 2: Surface grinding machine used in the experiment

Table 1: Specifications of surface grinding machine

Machine name	**Gate surface grinding machine**
Model number	PSGC 60220AHR
Serial number	0205J-01
Voltage	415 V
Frequency	50 Hz
Power	12 kW
Wheel speed	1,500–1,800 rpm
Table speed	5–25 m/min

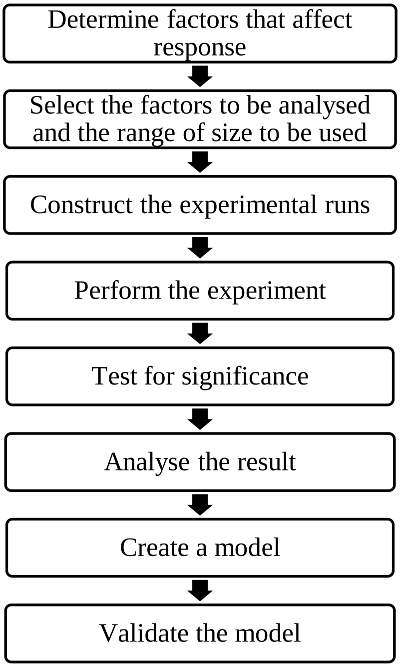


Figure 3: Flow diagram of the experiment

Results and Discussion

Figure 4 shows different readings for both the pick and feed directions. The roughness shows that there is a variation between these directions. The pick direction measurement is measured based on the waviness of the surface. It consists of widely spaced irregularities and is often produced by vibrations in the machine. Surface finish measured in the pick direction is found to be rougher than that of the feed direction, which is more consistent. This could be because the ground surface has a strong lay pattern on the pick direction, as mentioned by [11].

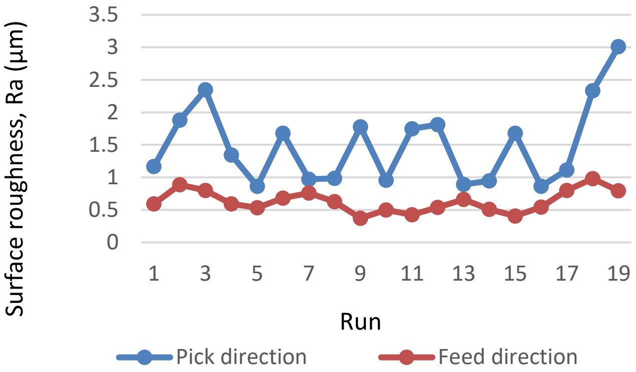


Figure 4: Graph of surface roughness, *Ra* of pick and feed directions

Figure 5 shows the surface of Inconel 718 with a high surface roughness of 2.350 µm. The difference can be seen by comparing the surface with that shown in Figure 6, which has a surface roughness of 0.863 µm. The rougher the surface, the higher the difference between the layers. On the other hand, the surface roughness is low with a small difference in the height of the layers.

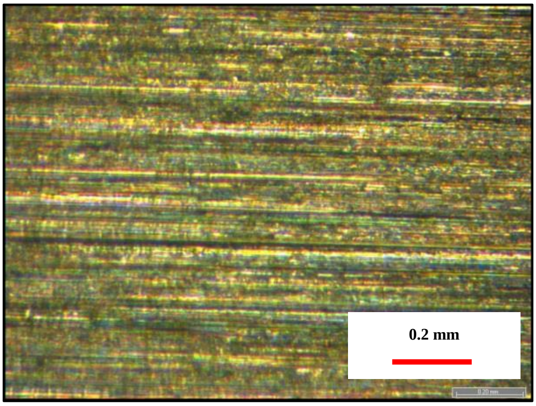


Figure 5: Surface of Inconel in experiment run number 3 (f 1622 m/min, ap 3 mm, n 6)

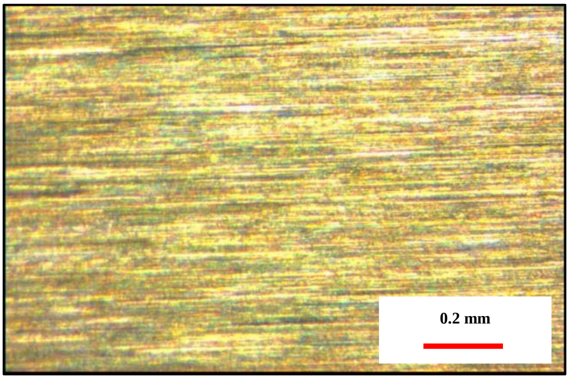


Figure 6: Surface of Inconel in experiment run number 5 (f 10375 m/min, ap 5 mm, n 2)

Table 2 shows the analysis of variance of the experiment. It shows that the traverse speed is the most significant parameter for surface finish, followed by the depth of cut. This is determined from the value of probability. A value less than 0.05 indicate that the factor is significant. Other research studies also support the result that both speed and depth of cut are significant factors for surface grinding [12], whereas the number of passes is not significant. A review of the ANOVA results show that the model is significant based on the F-test. The P-value is less than 0.05, which means the model is valid to be used to predict surface roughness.

Table 2: ANOVA of cutting parameters and surface roughness

Source	**Sum of squares**	**Degree of freedom**	**Mean square**	***F* value**	**Prob > *F***
Model	0.25	3	0.083	5.38	0.0103
Traverse speed	0.15	1	0.15	9.87	0.0067
Depth of cut	0.091	1	0.091	5.91	0.028
No. of passes	9.57E-03	1	9.57E-03	0.62	0.443
Residual	0.23	15	0.015		
Correlation total	0.48	18			

To focus on the model validation, model predictions and experimental observations in the grinding process were compared. The grinding process was carried out as per the selected parameters shown in Table 3. The output i.e., the surface roughness of these parameters is 1.260 µm. By substituting the values of the parameter into the model, the predicted surface roughness $\widehat{Ra}$ is obtained as 1.161 μm.

$$\widehat{Ra} = [0.347 + 3.185 \times 10^{-5}(A) + 0.048\ (B) + 8.653 \times 10^{-3}(C)]^{-2}$$

$$\widehat{Ra} = [0.347 + 3.18 \times 10^{-5}(9030) + 0.048\ (5) + 8.653 \times 10^{-3}(6)]^{-2}$$

$$\widehat{Ra} = 0.928^{-2}$$

$$\widehat{Ra} = \mathbf{1.161\ \mu m}$$

Table 3: Parameters considered for the validation of the model

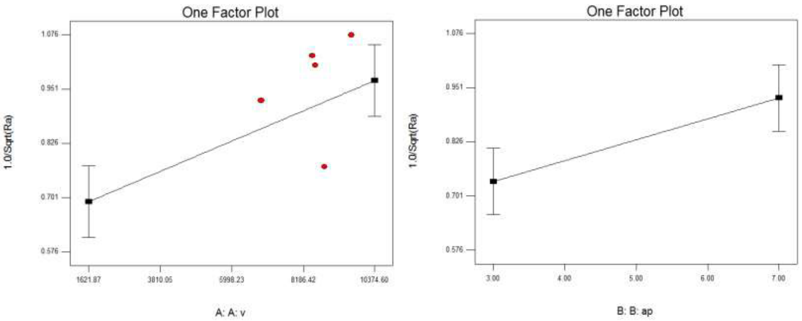
A: Traverse speed, f (mm/min)	**B: Depth of cut, ap (μm)**	**C: Number of pass, n**	**Surface roughness, Ra (μm)**
9,030	5	6	1.260

This shows that there is a difference between the actual value and the predicted value, which is 1.260 μm and 1.161 μm, respectively. The percentage of error is 9.86%, which is less than 10%, and hence considered an acceptable error [13]. The prediction model of surface roughness can be denoted as:

$$\widehat{Ra} = (0.347 + 3.185 \times 10^{-5}(A) + 0.048\ (B) + 8.653 \times 10^{-3}(C))^{-2} \quad (1)$$

Figure 7 (a) shows the effect of the traverse speed on the surface finish. From the graph of the inverse square root of *Ra*, it is clear that the higher the traverse speed, the lower the *Ra*. In other words, the surface is smoother if the traverse speed is higher. It was agreed by the other studies that found the higher the table speed, the lower the surface roughness [14]. This is because the ground surface is prone to undergo the maximum removing process at the opposite direction. This is because the total speed is composed by the linear traverse speed, *f* of the table and rotational speed, *N* of the grinding wheel.

Figure 7 (b) shows the trend of the depth of cut. The graph shows the inverse square root of surface roughness. It can be seen that an increase in the depth of cut increases the surface finish. Subsurface deformed region (<300 μm) experienced a work hardening from the past cutting process, which is harder than the bulk material. Therefore, it is evident that the grindability index becomes poor when the material hardness increases.



(a) (b)

Figure 7: Correlation between surface finish versus: (a) traverse speed and (b) depth of cut

The effect of number of passes is shown in Figure 8. The steep slope of the graph shows that the surface finish is not affected by this factor. The slope of the graph is almost horizontal. The number of passes has a very low effect on surface roughness [15]. As the number of passes does not affect the surface roughness, it is economical if the number of passes remains minimum. A lower number of passes will reduce the lead time, which in turn increases productivity. When there are a large number of passes, it results in more total machining time, which proves disadvantageous to the workpiece and production. Furthermore, the higher the number of passes, the higher the wheel wear produced [5]. An increase in the number of passes will lead to a rise in the grinding force due to the dulling of the grinding wheel [16].

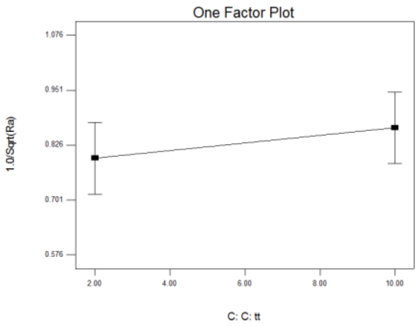


Figure 8: Graph of inverse square root of roughness against the number of passes

Optimization

The optimization of surface grinding of Inconel 718 is done by using the parameter that is preferred in design of experiment. The optimisation parameters set are 9,137 mm/min of traverse speed, 7 µm in depth of cut, and 10 passes. The result of the optimization parameters is shown in Table 4. From the calculation, the surface roughness is 0.986 µm with standard deviation of 0.014. The standard deviation shows that it is close to zero. From the Design expert software, it is predicted that this optimization parameter will got 0.886 µm, where the result is 10% of error.

Table 4 : Calculation of the reading of surface roughness

Readings	**Surface roughness (µm)**			
	First calculation	**Second calculation**	**Third calculation**	**Fourth calculation**
1	1.02	1.02	1.02	
2	1.03	1.03		
3	1.00	1.00	1.00	1.00
4	1.00	1.00	1.00	1.00
5	0.98	0.98	0.98	0.98
6	0.97	0.97	0.97	0.97
7	1.00	1.00	1.00	1.00
8	0.91			
9	0.98	0.98	0.98	0.98
10	0.97	0.97	0.97	0.97
Average	0.986	0.994444	0.99	0.985714
Minimum	0.91	0.97	0.97	0.97
Maximum	1.03	1.03	1.02	1.00
Different min and average	0.076	0.024444	0.02	0.015714
Different max and average	0.044	0.035556	0.03	0.014286
Stdev	0.0334	0.021279	0.017728	0.013973

Conclusion

Traverse speed and the depth of cut are significant factors that affect the surface roughness of Inconel 718. However, the number of passes does not seem to have any significant effect. The traverse speed is the most significant factor that affects the surface roughness of Inconel 718, followed by the depth of cut. The optimisation parameters set are 9,137 mm/min of traverse speed, 7 µm in depth of cut, and 10 passes. The surface roughness that resulted from this set of parameters was 0.986 µm. The percentage of error is 9.86%, which is below 10%.

Acknowledgements

The authors would like to thank PMG Research Facility, AMC, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka. This research is supported by the Ministry of Higher Education, Malaysia under project no. FRGS/2/2014/TK01/UTEM/03/2.

References

[1] M. Nalbant, A. Altin and H. Gökkaya "The effect of cutting speed and cutting tool geometry on machinability properties of nickel-base Inconel 718 super alloys," Materials and Design 28 (4), 1334–1338 (2007).

[2] I.A.Choudhury and M.A. El-Baradie, "Machinability assessment of Inconel 718 by factorial design of experiment coupled with response surface methodology," Journal of Materials Processing Technology 95(1-3), 30–39 (1999).

[3] S. Kalpakjian and R. S. Stevent, Manufacturing Engineering and Technology. Singapore: Pearson (2014).

[4] W.B Rowe, Principles of Modern Grinding Technology (First Edit). UK: Elsevier Publication. (2009).

[5] I. Marinescu, M. Hitchiner, and E.Uhlmann, Handbook of machining with grinding wheels. Vasa (2006).

[6] D. Whitehouse, Surface and Their Measurement: Butterworth Heinemann (2004).

[7] D. Aslan and E. Budak, "Semi-analytical force model for grinding operations," Procedia CIRP, 14, 7–12 (2014).

[8] D. Ulutan and T. Ozel, "Machining induced surface integrity in titanium and nickel alloys," International Journal of Machine Tools and Manufacture,51(3),250–280 (2011).

[9] J.P. Davim, Surface integrity in machining. Surface Integrity in Machining. New York: Springer-Verlag (2010).

[10] D.S. Mankar, and P.V. Jadhav, "Effect of Surface Roughness on Fatigue Life of Machined Component of Inconel 718," International Journal of Fatigue, 41(6), 141–149 (2007).

[11] T.V. Vorburger and J. Raja, Surface Roughness Metrology Tutorial (1990).

[12] R.Jamaludin and M.S. Kasim, "Experimental Investigation of Significance Parameters in Surface Grinding," Quality Evaluation, 403–406 (2001).

[13] R.Hills and T. Trucano, Statistical validation of engineering and scientific models, Background. Sandia National Laboratories, SAND99-1256, (May 1999).

[14] N.Sohal, C.S. Sandhu, and B.K. Panda, "Analyzing The Effect of Grinding Parameters on MRR and Surface Roughness of En24 and En353 Steel," 3, 1–6 (2014).

[15] T. Singh, K. Goyal and P. Kumar, "To Study the Effect of Process Parameters for Minimum Surface Roughness of Cylindrical Grinded AISI 1045Stee,"l,2(3),56–61 (2014).

[16] P.L. Tso, “Study on the grinding of Inconel 718,” Journal of Materials Processing Technology, 55(3-4), 421–426 (1995b).