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Application of Taguchi Method L_9 for Tool Life and Surface Roughness in Turning of Inconel 718 under Dry Cutting

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Abstract Taguchi method offers a simple and systematic approach to optimize performance, quality and cost in manufacturing process. Taguchi optimization methodology with orthogonal array of L_9 was applied to optimize cutting parameters in turning of inconel 718 with PVD coated cemented carbide tools. The turning parameters evaluated were cutting speed of (50, 70 and 80) m/min, of (0.20, 0.25 and 0.30) mm/rev and depth of (0.30, 0.40, and 0.50) mm. The results show that the most significant factor which effects on the tool life was the cutting speed with the significant value of 0.019%. The depth of cut also gave significantly on the tool life of machining of inconel 718 in dry cutting condition. And other hand, the most significant factor which influences the surface roughness was the . The percentage of significant value of the was 0.032% or the gave contribution of 93.61%. The optimal machining condition for the tool life was at the lowest cutting parameters. Then the optimal condition for the surface roughness was at cutting speed of 70 m/min, of 0.20 mm/rev, and depth of cut of 0.40 mm.

Keywords: Taguchi Method; inconel 718; tool life; surface roughness; turning.

1. Introduction

The nickel-based super alloys are known as a difficult to cut material and heat-resistant alloys with high melting temperatures. The ability to retain high mechanical and chemical properties at elevated temperatures makes these super alloys an ideal material for use in land-based power generators and aerospace aero-engine components. About 50 wt% of all aero-engine alloys are nickel-based alloys (Ezugwu, 2003). However, nickel-based super alloys are also used for other applications such as marine equipment, nuclear reactors, petrochemical plants, food processing equipment, and pollution control apparatus. They are generally used in aggressive environments because of their ability to maintain high resistance to corrosion, mechanical and thermal fatigue, mechanical and thermal shock, creep and erosion at elevated temperatures. Inconel 718 super alloy is one of the nickel-based super alloys mostly used in manufacturing of aero-engine components of the hot section, shown as 35% of all productions (Loria, 1988). This alloy is often used in a solution-treated and aged condition. Several problems that exist after machining nickel-based super alloys are reported in the literature, including surface tearing, cavities, cracking, metallurgical transformation, plastic deformation, increased microhardness, increased surface roughness and the formation of tensile residual stresses (Arunachalam et al., 2004; Sharman et al., 2006; Dudzinski et al., 2004).

The quality of products can be improved by improving the quality of design and process in company-wide activities (those activities concerned with quality, include in quality of product planning, product design and process design (Park, 1996; Ranjit, 2001). Robust design is an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs (Park, 1996). Taguchi's parameter design is an important tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost. Signal to noise ratio and orthogonal array are two major tools used in robust design. Signal to noise ratio, which measures quality with emphasis on variation, and orthogonal arrays, accommodates many design factors simultaneously (Park, 1996; Phadke, 1998).

Taguchi method offers the quality of product measured by quality characteristics such as: nominal is the best, smaller is better and larger is better (Park, 1996; Ranjjit, 2001). Optimization using Taguchi method in orthogonal cutting using conceptual S/N ratio approach and Pareto ANOVA is suitable to analyze the metal cutting problem. Gusri et al. (2009) found that the conceptual S/N ratio and ANOVA approaches for data analysis draw similar conclusion in process turning use at high cutting speed of 95 m/min, low of 0.15 mm/min and low depth of cut of 0.1 mm. For tool life, the main factor gave the most contribution was cutting speed.

Yang and Tarng (1998) applied Taguchi method for optimizing the cutting parameters in turning operations. The Taguchi method proved to be a systematic and efficient methodology for the design optimization of the cutting parameters with far less effect than would be required for most optimization techniques. They found that tool life and surface roughness can be improved significantly for turning operation. The improvement of tool life and surface roughness from the initial cutting parameters to the optimal cutting parameters is about 250%.

Application of Taguchi's method for parametric design was carried out to determine an ideal and desired force combination. Although small interactions exist between a horizontal and desired force, the experimental results showed that surface roughness decreases with a slower and larger grinding force, respectively (Liu and Andrian, 2005). Conceptual S/N ratio approach of Taguchi method provides a simple, systematic and efficient methodology for optimizing of process parameters and this approach can be adopted rather than using engineering judgment. Furthermore, the multiple performance characteristics such as tool life, cutting force, surface roughness and the over all productivity can be improved by useful tool of Taguchi method (Mohan et,al, 2005).

This paper describes the turning of inconel 718 with parameters of turning at three levels and three factors each. The main objective is to develop a study of Taguchi optimization method for high tool life and low surface roughness value in term of cutting parameters when turning of inconel 718 with PVD coated cemented carbide tools under dry cutting condition and high cutting speed.

2. Material and Method

The experiments were carried out with three factors at three levels each, as shown in Table 1. Three factors used in this experiment are cutting speed, feed rate and depth of cut. The fractional factorial design used was a standard L9 orthogonal array, which is calculated by using 3^{3-1} (level$^{(\text{factor-1})}$) (Kalpakjian and Schmid, 2001). This orthogonal array was chosen due to its capability to reduce the number experiment without interaction. The machining trials were carried out by using the lathe machine (Colchester T4, with maximum spindle rotation of 6000 rpm) in dry condition. The cutting tools (inserts) used were Phisycal Vapor Deposition (PVD) coated carbide tool with the coating layer of TiAlN. Chemical composition of substrate the cutting tool is 91.25% WC (wolfram carbide), 2.5% Ti/Ta/NbC (titanium/tantalum/niobium carbide) and 6% Co (cobalt).

The average flank wear land (*VB*) and maximum flank wear (Vbmax) were measured every one pass machining by using Mitutoyo Tool Maker Microscope with magnification up to 50x. The machining will be stopped when the VB reached 0.3 mm, whereas the surface roughness value of the machined surface was measured by using the surface roughness tester model Mpi Mahr Perthometer. The recordings of surface roughness were done every one pass machining and be done for three times.

Table 1. Factors and levels used in the experiment

Factors	Levels		
	0	**1**	**2**
A- Cutting speed (m/min)	60	70	80
B- (mm/rev)	0.20	0.25	0.30
C- Depth of cut (mm)	0.30	0.40	0.50

3. Result and Conclusions

Tool life

Table 2 shows the significant values and contribution of cutting parameters when turning Inconel 718 with PVD carbide tools in dry machining. The significant value of cutting speed (P) is 0.019 (lower than 0.05). It means that the cutting speed significantly influences on the tool life value (Park, 1996, Ranjit 2001). In addition to, the depth of cut and feed rate are insignificant factors on the tool life due to P values bigger than 0.05. The cutting speed has a contribution for the tool life of 45.47%, otherwise, for and cutting speed are 39.53% and 15.00%, respectively, as shown in Table 2. From this result, it can be concluded that the cutting speed is the most significant factor and give most contribution on the tool life. In line with the theory that the cutting speed is the main machining factor that generated temperature and high generated temperature contribute significantly on cutting tool failure (Trent, 2001). The higher cutting speed causes high temperature generated that influences on wear progression of tool (Gusri, et.al, 2011). He also reported cutting speed significantly influenced on flank wear of tool life when machining inconel 718 compared to the depth of cut and .

Meanwhile, the cutting speed and depth of cut were the most significant factor that affected the cutting force and the cutting force also gave a significant contribution on flank wear or tool life when cutting inconel 718 under dry condition. It can be seen clearly that the cutting speed is the most significant factor influences on the tool life at high cutting speed and dry machining. Some previous researchers also suggest similar results. They claimed that the tool life or flank wear well strongly depends on the cutting speed followed by the depth of cut and.

Table 2. Analysis variance of signal to noise ratio (ANOVA) for tool life

No	Variable Factors	DF	Sum of Square (S)	Variance (V)	F	Percent (P)	Contribution (%)
1	Cutting speed	2	26.7231	13.3360	51.60	0.019	45.47
2		2	8.8253	4.4126	17.03	0.220	15.00
5	Depth of cut	2	23.2434	11.6217	44.86	0.055	39.53
	Error	2	0.5181	0.2590			
	Total	**8**	**59.3188**				**100**

Table 3 shows response values of signal to noise ratio for tool life at each factors and levels. The signal to noise ratio for tool life has characteristic larger is better. Response factor which has higher value contributes more on tool life. Factor A (cutting speed) gave a delta value bigger than others factor. The delta value of cutting speed of 4.12, it is better than others factors. So this factor considered as factor which influences significantly on the tool life. Factor C (depth of cut) is the second factor which has delta value of 3.81. Its value is lower than factor A and bigger than factor B. The effect of each factor on tool life can be seen on Figure 1.

Table 3. Response table for signal to noise ratios (larger is better)

Level	A	B	C
1	22.32	21.36	21.63
2	19.49	19.03	20.56
3	18.20	19.62	17.82
Delta	4.12	2.33	3.81
rank	1	3	2

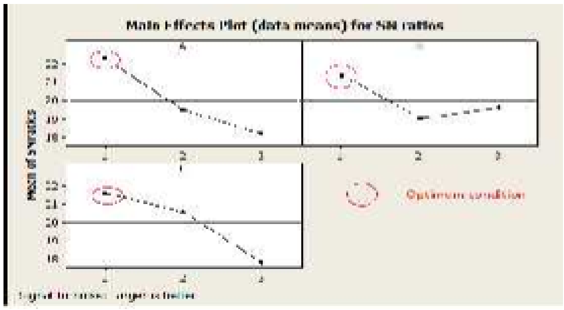

Figure 1. S/N response table for tool life

The optimum condition of turning process when machining inconel 718 for tool life can be shown in Table 3 and Figure 1. The maximum value of response at each factor indicates the optimum condition. It can be seen clearly that cutting speed at level 1 (60 m/min), feed rate at level 1 (0.20 mm/rev) and depth of cut at level 1 (0.3 mm) is the optimum condition. The lowest level of every factor produced the longest tool life. Theoretically, the low cutting speed selected while machining of super alloy materials resulted the low heat generated so that increasing in cutting time (Gusri, et.al, 2011). As found by Yazid et.al (2011) when cutting inconel 718 by lathe machine that the longest tool life achieved when cutting at low cutting parameters in term of cutting speed, feed rate and depth of cut. Therefore, it can be recommended that to get long tool life can be selected low main cutting parameters.

Surface Roughness

As shown in Table 4 that the significant values of cutting parameters while machining of Inconel 718 with PVD coated carbide inserts in dry machining. The is the most significant factor which influences on surface roughness. The significant value on the is 0.032 (lower than 0.05). In addition to, the cutting speed and depth of cut are insignificant factors on the surface roughness due to P values bigger than 0.05. The contribution of is 93.61%. In contrast with others parameters, cutting speed and depth of cut are not very insignificant, in which, its contribution values are 0.49% and 2.80%, respectively. From this result, it can be concluded that the feed rate is the most significant factor and give most contribution on the surface roughness values.

Surface roughness values are indicator in machining process, by which a good quality is presented by low surface roughness. Table 4 shows that the is the most significant factor in controlling the material surface roughness values when machining inconel 718 alloy under dry cutting condition. Classically, The surface roughness values related to equation h » $f^2/8R$ or h_{CLA} » $f^2/18\ (3R)^{1/2}$ [Bhattacharya 1991, Shaw 2005]. Where, h is the peak-to-valley height, h_{CLA} the centerline–average roughness, f the and R the nose radius of insert. The formula shows that surface roughness is primarily dependent on the and the geometry of nose radius. The higher feed rate causes high distance between peak to peak of machine (Gusri, et.al, 2010).

The previous researcher found that the surface roughness trends to become smoother when selected feed rate parameter at low level. This is probably due to short distance between peak to peak at texture of machine surface (Park, 1996). Whereas according to Bhattacharya (1994), decreases of the surface roughness values recorded were caused by using low feed rate. Gusri et al. (2009) found that Taguchi Method successfully applied in machining super alloys material as like titanium with orthogonal. By using orthogonal array L27 and four factors and three levels each, the was the most significant factor which influenced the surface roughness of new machined surface.

Table 4. Analysis variance of signal to noise ratio (ANOVA) for surface roughness

No	Variable Factors	DF	Sum of Square (S)	Variance (V)	F	Percent (P)	Contribution (%)
1	Cutting speed	2	0.2528	0.1264	0.16	0.864	0.49
2		2	48.5841	24.2920	30.15	0.032	93.61
5	Depth of cut	2	1.4505	0.7252	0.90	0.526	2.80
Error		2	1.6112	0.8056			3.10
Total		**8**	**51.8985**				**100**

The optimum condition while cutting inconel 718 for surface roughness can be shown in Table 5 and Figure 2. It can be seen clearly that cutting speed at level (70 m/min), feed rate at level 1 (0.20 mm/rev) and depth of cut at level 2 (0.4 mm) is the optimum condition. Even so, the feed rate demonstrates effect extremely on surface roughness as shown at Figure 2.

Table 5. Response table for signal to noise ratios (smaller is better)

Level	A	B	C
1	-8.013	-5.437	-8.138
2	-7.636	-7.161	-7.293
3	-7.954	-11.004	-8.171
Delta	0.377	5.567	0.88
Rank	3	1	2

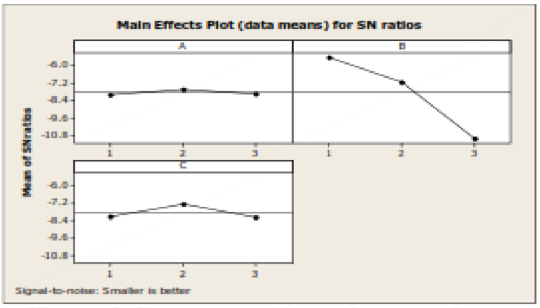

Figure 2. Response table surface roughness

Determination of the maximum tool life and surface roughness

Prediction of the optimum tool life performance using the cutting parameters at A1, B1 and C1.
Predicted S/N ratio (maximum) for tool life.

$$\begin{aligned} &= \eta+(\eta A1-\eta)+(\eta B1-\eta)+(\eta C1-\eta) \\ &= 20.23 + (22.32 - 20.23) + (21.36 - 20.23) \\ &\quad + (21.63 - 20.23) \\ &= 20.23 + 2.09 + 1.13 + 1.4 \\ &= 24.85 \text{ dB.} \end{aligned}$$

With this prediction, one could conclude that the machine creates the best tool life with optimum condition for S/N ratio value is 24.85 dB.
With similar method prediction of the optimum surface roughness can be found using A1, B3 and C3:

Predicted mean (minimum roughness):

$$\begin{aligned} &= \eta + (\eta A2-\eta) + (\eta B1-\eta) + (\eta C2-\eta) \\ &= -7.98 + (-7.636 + 7.98) + (-5.437 + 7.98) \\ &\quad + (-7.293 + 7.98) \\ &= -7.98 - 0.334 + 2.543 + 0.687 \\ &= -5.084 \text{ dB.} \end{aligned}$$

where η is the average value of S/N ratio. With this prediction, one could conclude that the machine creates the best S/N ratio value of surface roughness is – 11.228 dB.

4. Conclusions

Taguchi's robust design method and analysis of variance give similar results and it is suitable to optimize the tool life and surface roughness in turning inconel 718. The significant factors in turning of super alloys inconel 718 on tool life were cutting speed with contribution of 45.47%. In addition, the significant factors which influenced on the surface roughness were with contribution up to 93.61%. The optimal condition for the tool life is obtained at cutting speed of 60 mm/min, of 0.20 mm/rev and depth of cut of 0.30 mm, whereas the optimal condition for surface roughness at cutting speed of 70 mm/min, of 0.20 mm/rev and depth of cut of 0.40 mm.. Prediction of the optimum for signal to noise of tool life and surface roughness are 25,85 dB and -5.084 dB, respectively.

5. References

1. Arunachalam, R.M., Mannan, M.A., and Spowage, A.C. (2004), Surface integrity when machining age hardened Inconel 718 with coated carbide cutting tools, International Journal of Machine Tools and Manufacture, Vol. 44(14), pg. 1481-1491.
2. Dudzinski, D., Devillez, A., Moufki, A., Larrouquère, D., Zerrouki, V. & Vigneau, J. (2004), A review of developments towards dry and high speed machining of Inconel 718 alloy, International Journal of Machine Tools and Manufacture, Vol. 44(4), pg. 439-456.
3. Ezugwu, E.O., Booney,J., Yamane, Y. (2003), An overview of the machinability of aeroengine alloys, Journal of Material

Processing and Technology, Vol. 134, pp. 233-253.

4. Gusri, A.I., Che Haron, C.H., Ghani, J.A. (2011), Tool Wear Performance of CVD-Insert during Machining ofTi-6%Al-4%V ELI at High Cutting Speed, Key Engineering Materials Vol. 443 (2010) pp 371-375.
5. Gusri, A..I., Che Haron, C. H., and Ghani, J.A. (2009), Progression and Wear Mechanism of CVD Carbide Tools in Turning Ti-6Al-4V ELI, International Journal of Mechanical and Materials Engineering, Vol. 4 (1), pg. 35-41.
6. Liu, C.H., Andrian, C. (2005), Grinding Force Control in Automatic Surface Finish System, Journal of Materials Processing Technology, Vol. 170, pp. 367 – 373.
7. Loria, E.A. (1988), The status and prospects of alloy 718, Journal of Metal,pg. 36–41.
8. Mohan, N.S., Ramachandra, A., Kulkarni, S.M. (2005), Influence of Process Parameters on Cutting Force and Torque During Drilling of Glass-Fiber Polyester Reinforce composite, Journal of Composite Structure, Vol. 71, pp. 407-413, 2005.
9. Park, S.H. (1996), Robust Design and Analysis for Quality Engineering, (London, Chapman & Hall.
10. Ranjit, R. (2001), Design of experiment Using The Taguchi Approach, (New York, John Wiley & Sons Inc.
11. Phadke, M.S. (1998), Quality Engineering Using Design of Experiment, Quality Control, Robust Design and Taguchi Method (California, Warsworth & Books).
12. Sharman, A., Hughes, J., Ridgway, K. (2006), Workpiece surface integrity and tool life issues when turning Inconel 718TM nickel based superalloy, Machanical Sciemce and Technology, Vol. 8 (3), pg. 399–414.
13. Shaw, C.M. (1984), *Metal cutting principles* (Clarendon Press, Oxport).
14. Trent, E.M., (1995), Metal Cutting (Thirth Edition, Butterworth-Heinemann, Oxford).
15. Yang, W.H., Tarng, Y.S. (1998), Design Optimization of Cutting Parameters for Turning Operations based on Taguchi Method, Journal of Materials Processing Technology, Vol. 84, pp. 122-129.
16. Kalpakjian, S., Rchmid, S.R. (2001), Manufacturing Engineering and Technology (Fourth Edition. USA, Prentice Hall).