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Optimization of Cutting Force, Feed Force and Material Removal Rate (MRR) in Turning of Inconel 718

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Abstract: ***Inconel 718 plays very important role in the field of high temperature and high pressure applications but due to difficult machining of this alloy, machining analysis is quite being necessary before fabrication. In this paper, machining analysis of Inconel 718 is performed with the help of three process parameters namely, cutting speed, feed rate, and depth of cut along with PVD(physical vapordeposition) coated carbide insert in turning operation. The machining characteristics Cutting force, Feed force, and Material removal rate (MRR) are optimized by the using of Taguchi method.***

Keywords: Taguchi method, Cutting force, Feed force, MRR.

1. Introduction

Inconel 718 is one of the most nickel based superalloy, widely used materials due to its high strength that is maintained at the elevated temperature and its high corrosive resistance property. Inconel 718 possessing high strength and work hardening is usually known to create major challenges during its machining. Friction between tool and material and its low thermal conductivity results in high temperature generation. Turning is the traditional machining method that could be effectively used for the cost effective machining of Inconel 718.There are three principal forces during a turning process and these are cutting or tangential force, axial or feed force and radial or thrust force (Koepfer et al, 2010).

The cutting force components are very sensitive even to the very smallest changes in the cutting process; therefore, instead of calculating the cutting forces theoretically, measuring them in process by Dynamometers is preferred (Sanglam, H et al., 2007).Oscillations in cutting forces and high temperatures on the rake face in the contact area can cause rapid tool wear. High pressures developed during segmented chip formation retards further machining and increase power requirements of the process. The method of minimizing work hardening during machining is to use sharp tools with a positive rake angle, control feed rate and depth of cut to avoid burnishing [Hua J et al. 2002]. According to[Ezugwu et al.1999], the chip segmentation phenomena significantly limits the material removal rates and causes cyclic variation of force. The combination of a low Young'smodulus (114 GPa). Coupled with a high yield stress ratioallows only small plastic deformations and encourages chatter and work piece movement away from the tool.

In this study, optimization of feed force, cutting force and material removal rate have been performed for Inconel 718 through PVD coated carbide insert in turning operation.

2. Experiment Setup

Turning of Inconel 718 has been done on centre lathe using PVD coated carbide inserts available at Workshop.

2.1 Insert Type

In the experimental work we use the PVD coated carbide insert with grade CNMG 120404 MF 1025.It consists a 4µm PVD coating of TiAlN-TiN.

2.2 Tool Type

We used DCLNR 25 25 M12 Holder for turning of Inconel 718 material.

2.3 Work-piece Specification

Inconel 718 is a nickel-chromium-molybdenum alloy that is made to offer resistance to the variety of corrosive conditions, pitting and crevice corrosion as shown in table

2.4 Selection of process parameters

The fallowing parameter were selected for the study based on the availability of these parameter on the machine .**a.**spindle speed, **b**. Feed, **c**. Depth of cut. The other parameter during experiment is to be fixed based on the literature survey.

Table 1 Work-piece Specification

Work-piece specification	
Work-piece Material	Inconel 718
Work-piece size	Length 300 mm , diameter 60 mm
Shape	Round bar (cylindrical)

2.5 Levels for Various Control Factor

The Experimentation consists of turning of Inconel 718 superalloy on a lathe machine. The Control factors along with their 3 levels are given in table 2.

Table 2: Levels for Various Control Factor

Sr. No.	Factor	Level 1	Level 2	Level 3	Unit
A	Spindle speed	250	400	640	rpm
B	Feed	0.05	0.10	0.15	mm/rev
C	Depth of Cut	0.5	0.7	0.9	mm

3. Results and Analysis

In this work L9 array was used to carry out the experiment. The response, Cutting Force, Feed Force and MRR were measured by varying the machining parameters and the corresponding values are shown in table 3. MINITAB version 18 software is used.

Table 3: Experimental Results of Cutting force Feed Force, MRR and S/N Ratio

Exp. No.	Control Parameter Levels			Cutting Force (N)	S/N Ratio of cutting force (dB)	Feed Force (N)	S/N Ratio of feed force (dB)	Material Removal Rate (mm3/sec)	S/N Ratio of MRR (dB)
	Speed(s) (rpm)	Feed (f) (mm/rev)	Depth of cut (d) (mm)						
1	250	0.05	0.5	153	-43.69	110	-40.82	18.31	25.25
2	250	0.1	0.7	320	-50.1	185	-45.34	51.28	34.19
3	250	0.15	0.9	515	-54.23	318	-50.04	98.9	39.9
4	400	0.05	0.7	150	-43.52	135	-42.6	43.22	32.71
5	400	0.1	0.9	300	-49.54	213	-46.56	50.34	34.03
6	400	0.15	0.5	220	-46.84	130	-42.27	87.9	38.87
7	640	0.05	0.9	180	-45.1	240	-47.6	84.37	38.52
8	640	0.1	0.5	160	-44.08	118	-41.43	93.75	39.43
9	640	0.15	0.7	325	-50.23	225	-47.04	196.94	45.88

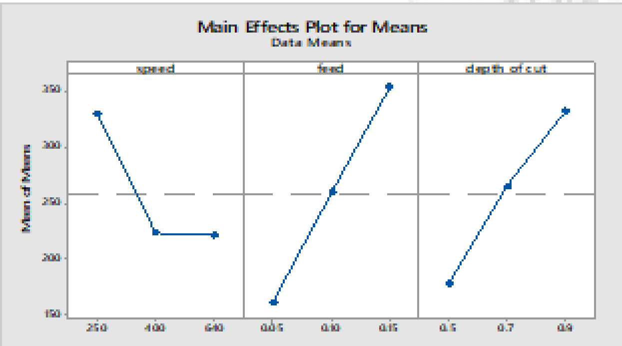
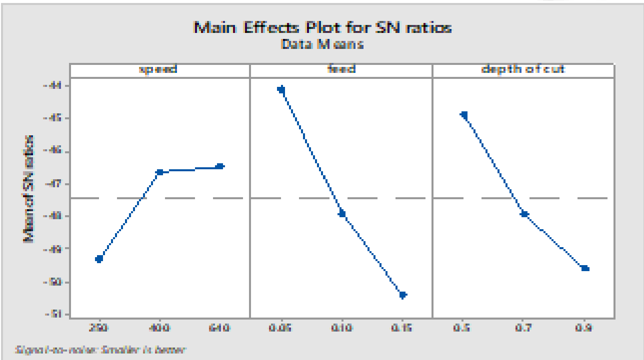


Figure 1: Effects of process parameters on Cutting Force (Raw data)

From Figure 1, it is clear that during cutting speed increment from 250 to 400rpm, the cutting force would be decreased sharply because of thermal softening occurs in this region. Beyond 400 rpm, cutting force was slightly decreased due to dominating role of strain hardening.Increment in feed causes higher cutting force because friction. When depth of cut was increased cutting force also increased due to high material removal rate.



2. Effects of process parameters on Cutting Force (S/N Ratio data)

For optimization of various process parameters signal to noise ratio smaller is better.As in figure 2, cutting speed 250 rpm, feed 0.05 mm/rev and depth of cut 0.9 mm are optimise parameters.

Table 4 .Analysis of Variance Cutting fore (Raw data)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
speed	2	22831	19.69%	22831	11415.4	12.38	0.075
feed	2	55504	47.86%	55504	27752.1	30.10	0.032
depth of cut	2	35788	30.86%	35788	17893.8	19.41	0.049
Error	2	1844	1.59%	1844	922.1		
Total	8	115967	100.00%				

Table 5: Analysis of Variance Cutting force(S/N ratio)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
speed	2	15.585	13.92%	15.5849	7.7925	29.70	0.033
feed	2	60.981	54.46%	60.9814	30.4907	116.20	0.009
depth of cut	2	34.876	31.15%	34.8757	17.4379	66.45	0.015
Error	2	0.525	0.47%	0.5248	0.2624		
Total	8	111.967	100.00%				

It is clear as shown in Table 4, the percentage contribution of depth of cut is 30.68% and feed 47.86% so these are the most significant factor. The spindle speed is in insignificant factor with percentage contribution of 19.69 %.

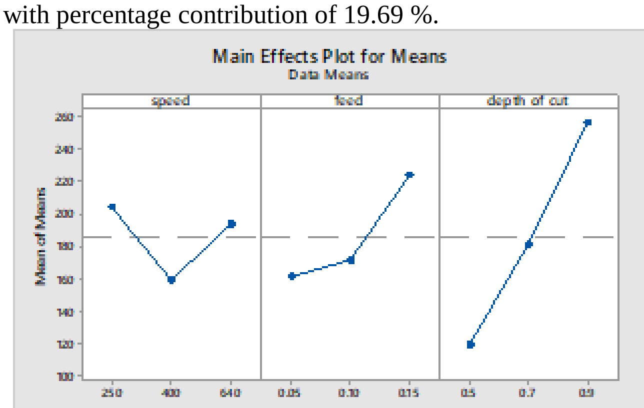


Figure 3: Effects of process parameters on Feed Force (Raw data)

In Figure 3, feed forces firstly decreased up to 400 rpm then it was observed that feed force was increased.Feed force was increased as increment in feed and depth of cut.

Figure 4: Effects of process parameters on Feed Force (S/N Ratio data)

From figure 4, cutting speed 250 rpm, feed 0.15 mm/rev and depth of cut 0.9 mm are optimise parameters according to principle of optimization, “signal to noise ratio smaller is better”.

Table 6: Analysis of Variance Feed Focre (Raw data)

Soure	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
speed	2	15.585	13.92%	15.5849	7.7925	29.70	0.033
feed	2	60.981	54.46%	60.9814	30.497	116.20	0.009
depth of cut	2	34.876	31.15%	34.877	17.4379	66.45	0.015
Error	2	0.525	0.47%	0.5248	0.2624		
Total	8	111.967	100.00%				

Table 7: Analysis of Variance Feed force(S/N ratio)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
speed	2	4.9109	5.98%	4.9109	2.4555	21.82	0.044
feed	2	12.3369	15.03%	12.3369	6.1685	54.83	0.018
depth of cut	2	64.6072	78.71%	64.6072	32.3036	287.12	0.003
Error	2	0.2250	0.27%	0.2250	0.1125		
Total	8	82.0801	100.00%				

The percentage contribution of depth of cut is 31.15% , feed 54.46% and speed 13.92% so these are the most significant factor as shown in Table 6 .

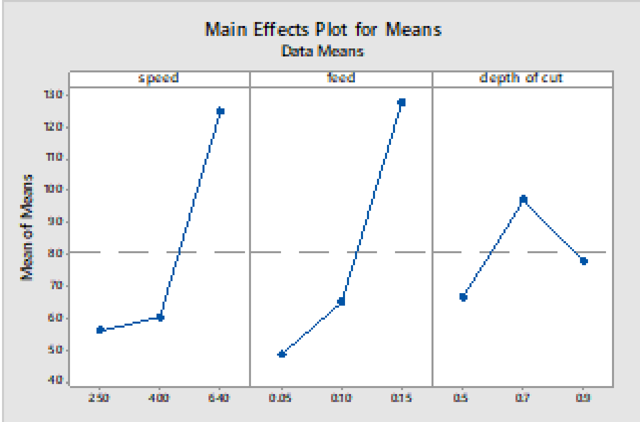


Figure 5: Effect of process parameter on MRR Raw data

In Figure 5,Material removal rate is increased as increment in cutting speed and feed rate.Material removal rate is increased upto 0.7 mm depth of cut. Beyond 0.7 mm depth of cut, material removal rate is decreased.

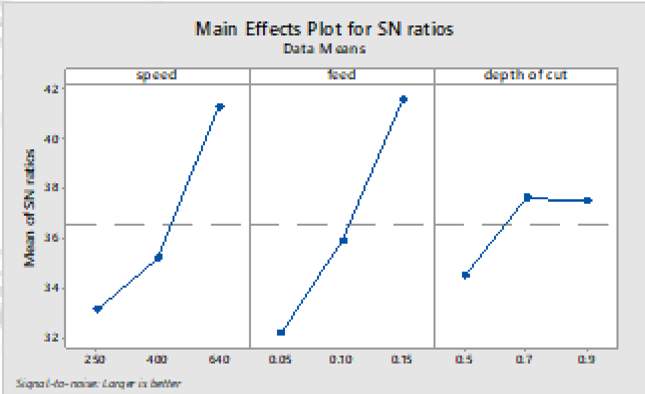


Figure 6: Effect of process parameter on MRR (S/N Ratio data)

In this study, higher material removal rate is desirable so “signal to noise ratio larger is better” considers for optimized parameter. Cutting speed 640 rpm, feed 0.15 mm/rev and depth of cut 0.7 mm are optimized parameter for maximum material removal rate as shown in figure 6.

Table 8: Analysis of Variance MRR (raw data)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
speed	2	8924.5	42.17%	8924.5	4462.2	28.66	0.034
feed	2	10499.8	49.61%	10499.8	5249.9	33.72	0.029
depth of cut	2	1427.2	6.74%	1427.2	713.6	4.58	0.179
Error	2	311.4	1.47%	311.4	155.7		
Total	8	21162.9	100.00%				

Table 9: Analysis of Variance MRR (S/N ratio)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
speed	2	107.910	39.93%	107.910	53.955	10.94	0.084
feed	2	134.218	49.66%	134.218	67.109	13.61	0.048
depth of cut	2	18.258	6.76%	18.258	9.129	1.85	0.351
Error	2	9.865	3.65%	9.865	4.932		
Total	8	270.252	100.00%				

The percentage contribution of speed 42.17% and feed 49.61% so these are the most significant factor. The depth of cut is insignificant factor with percentage contribution of 6.74% as shown in Table 8.

4. Conclusion

This study concludes optimized process parameters such that speed, feed and depth of cut in turning operation of Inconel 718 for getting high material removal rate.

1) Input parameter setting of spindle speed 640 rpm ,feed 0.05 mm/rev , and depth of cut 0.5 mm has been given the optimum result for the cutting force.
2) Input parameter setting of spindle speed 400 rpm ,feed 0.05 mm/rev, and depth of cut 0.5 mm has been given the optimum result for the feed force.
3) Input parameter setting of spindle speed 640 rpm ,feed 0.15 mm/rev , and depth of cut 0.7 mm has been given the optimum result for the MRR when Inconel 718 was turned on lathe .

This study is based on Dry machining of Inconel 718 superalloy. Minimum Quantity Lubricant (MQL) can be used in machining of Inconel 718 for better control on heat generation and cutting forces which will provide better results in terms of tool life as well as material removal rate. Other optimization technique such as Response Surface Methodology can be used for this study.

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