Optimization of process parameters on Inconel 718 using Taguchi's technique

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Abstract – *Super alloy, Inconel 718 has sophisticated applications due to its unique properties which are desired for various engineering applications. Due to its peculiar characteristics machining of Super alloy Inconel 718 is difficult and costly. Hence Taguchi optimization technique is used to optimize cutting parameters during turning of Inconel 718 using tungsten carbide cutting tool. Analysis of variance (ANOVA) is used to study the effect and contribution of process parameters like cutting speed, feed and depth of cut on output parameters like surface roughness (Ra) and material removal rate (MRR).*

Key Words: **Turning, MRR, Surface Roughness, Signal-to-Noise Ratio, ANOVA.**

1. INTRODUCTION

To provide satisfaction to customers and to deliver in a competitive market, a producer has to acknowledge that considerable advantage can be obtained by controlling quality at the design stage itself instead of at the manufacturing stage or by the inspection of the products. This is the basic idea of off-line quality control; Taguchi's method is one of the most comprehensive and effective systems of off-line methods and statistical tool for determining the influential parameter of the process. The work is carried out to understand turning of Inconel718 super alloy material, experiments were carried out on a CNC lathe in order to obtain the optimal setting of turning machining parameters i.e. MRR and surface roughness. Super alloy, Inconel718 is widely used in sophisticated applications due to its unique properties desired for the engineering applications. Due to its peculiar characteristics machining of super alloy inconel718 is difficult and costly. Thus the study proposes to characterize the influence of the machining parameters over the part quality characteristics [1]. An orthogonal array of experiment has been developed which has the least number of experimental runs and desired machining parameter settings with Taguchi's Signal to noise ratio. In order to determine the effect of control factors on response variable had been determined by ANOVA (Analysis of Variance) or MINI TAB (Statistical / Graphical software). The prediction of the optimal process parameter with respect to the response variable i.e., the physical part characteristics which are used to obtain the optimal process parameter for the MRR and surface roughness, are the end result of the project work.

2. INCONEL718 APPLICATION FIELD

The elevated temperature strength, excellent corrosion resistance and workability at 700°C properties made it use in a wide range of high requirement environments.

- Steam turbines
- Liquid-fuel rocket
- Cryogenic engineering
- Acid environment
- Jet engines
- Rocket motors and thrust reversers
- Nuclear fuel element spacers
- Nuclear engineering

3. INTRODUCTION TO CNC TURNING

Turning is one of the most widely used metal cutting operations in the engineering industries. Mostly the cutting parameters are selected based on the experience or by referring to the handbook. Selection of wrong or not optimal parameters leads to the wastage of raw material, man power, electricity, cutting fluid, cutting tools etc. adds to the cost of the product. CNC turning is a method of machining a part in which a pointed cutting tool is fed parallel onto the surface of a material being rotated [2]. The lathe secures and spins the part being machined, allowing for a simple single-point cutting tool to remove and shape the material, creating the desired part. Turning allows for the creation of varying complex shapes including plain, tapered, contoured, filleted, threaded and radius profiles. Advances in technology have led to the creation of CNC lathes and turning processes. Beyond programming commands into the CNC lathe, the operator is taken out of the equation.

3.1 Tool insert used

Uncoated carbide cutting tool inserts (VNMG) were used for turning tests. The inserts were rigidly attached to a tool holder. Double-sided 35° rhombic inserts are used for turning applications. Low cutting forces are employed due to very sharp edge and positive rake.

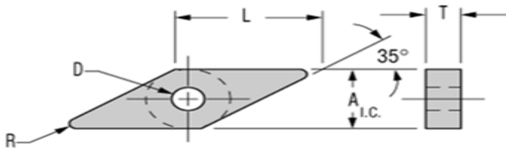


Fig 1. Double-sided 35° VNMG rhombic insert

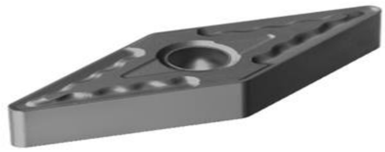


Fig 2. VNMG tool insert

3.2 Factors affecting quality of turning process

- Cutting Speed
- Feed
- Depth of cut
- Material removal rate (MRR):

The material removal rate of the work piece is the volume of the material removed per minute. It can be calculated using the following relation.

MRR = ((Wi – Wf))/(Dw × t)
Wi - Initial weight of work piece (gm.)
Wf - Final weight of work piece (gm.)
Dw - Density of the work piece (gm. /mm3)
t - Period of trial (min)

- Surface roughness (Ra): Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. The parameter mostly used for general surface roughness is “Ra”. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging them all over the entire cut-off length.

4. TAGUCHI TECHNIQUE

Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently applied to Engineering, Biotechnology, Marketing and Advertising. The Taguchi design is used to determine optimal cutting parameters and to find the relationships between independent variables and surface roughness and MRR. The Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only [3]. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi recommends the use of the ratio to measure the quality characteristics deviating from the desired values.

Usually, there are three categories of quality characteristic in the analysis of the ratio,

Larger the better (for eg: MRR, agricultural yield, mechanical strength)

$$S/N = -10\log \mathbf{1/n} \left(\sum \mathbf{1/y^2}\right)$$

Smaller the better (for eg: surface roughness, Co2 emission)

$$S/N = -\ 10\log \mathbf{1/n} \left(\sum \mathbf{y}^2\right)$$

Nominal the better (for eg: a mating part in an assembly, castings)

$$S/N = 10\log \bar{y}/\mathbf{sy}^2$$

Where ‘y’ is the average of the observed data, ‘sy^2’ is the variance of y and ‘n’ is the number of observations.

4.1 ANOVA (ANALYSIS OF VARIANCE)

The purpose of the analysis of variance is to investigate which cutting parameters significantly affect the quality characteristics. ANOVA is accomplished by separating the total variability of the S/N ratios. It is used to determine whether the parameter has a significant effect on the quality characteristics.

4.2 Methodology

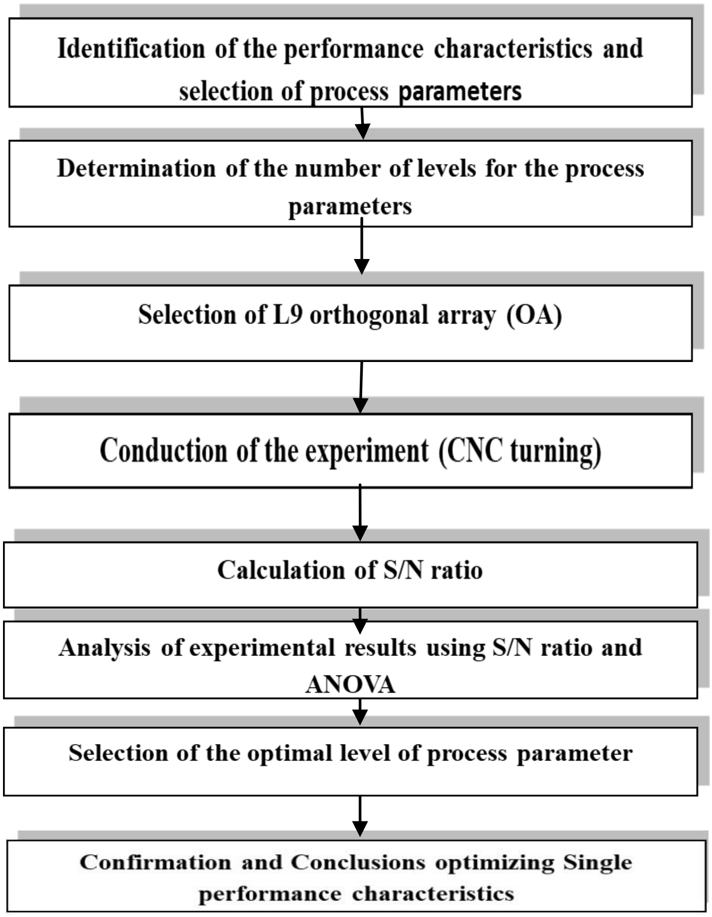


Fig 3. Flowchart indicating methodology

4.3 Experimental analysis for MRR and surface roughness

Identification of process parameters

Fig 4. Interrelations between the processing conditions and the output variables

Table 1. Levels for the parameters choosen

Parameter	Level 1	Level 2	Level 3
Speed (Vc)	60	70	80
Feed (f)	0.15	0.2	0.25
DOC (d)	0.1	0.15	0.2

4.4 Selection of orthogonal array

1. Degree of freedom (D): The selection of which OA to use depends on these elements:

   1. The number of factors and interaction of interests.
   2. The number of levels for the factor of interest.

These two items determine the total degree of freedom required for the entire experiment i.e.,

$$D = n-1$$

Here we have three parameters therefore, D = 3-1 = 2
Hence we have two DOF for each parameter for a Vc, f, d = 6

i.e, Orthogonal array should be chosen, in such a way that the total number of experimental runs in main experiment should be greater than the total DOF of the experiment. So 9 levels of trial runs were chosen and L9 orthogonal array was taken into consideration [4].

4.5 Design of Orthogonal array (L9)

Test no	Cutting speed	Feed	DOC
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 2. L9 orthogonal array

Cutting speed(m/min) (A)	Feed (mm/rev) (B)	Depth of cut(mm) (C)
60	0.15	0.1
60	0.2	0.15
60	0.25	0.2
70	0.15	0.2
70	0.2	0.1
70	0.25	0.15
80	0.15	0.15
80	0.2	0.2
80	0.25	0.1

Table 3. Orthogonal array for main experiment

Experiment no.	A (Vc)	B (f)	C (d)	MRR (mm³/min) ×10³	S/N ratio for MRR (dB)	Surface roughness (Ra) (μm)	S/N ratio for Ra (dB)
1	1	1	1	0.6549	-3.676	0.51	5.848
2	1	2	2	1.3252	2.44	1.36	-2.67
3	1	3	3	1.9723	5.903	2.99	-9.513
4	2	1	2	1.1671	1.341	2.88	-9.188
5	2	2	3	1.8847	5.505	1.26	-2.0
6	2	3	1	1.2883	2.2	1.62	-4.19
7	3	1	3	1.6258	4.22	0.63	4.013
8	3	2	2	1.1806	1.443	0.76	2.384
9	3	3	1	2.1562	6.673	2.4	-7.604

Table 4. L9 Orthogonal array with experimental results and calculated S/N ratios

- Larger the better for MRR,
  S/N = -10log $1/n\ (\sum 1/y^2)$
- Smaller the better surface roughness,
  S/N = - 10log $1/n\ (\sum y^2)$

Where, n = no. of repetition of experiments (n = 1), y = response variable [5].

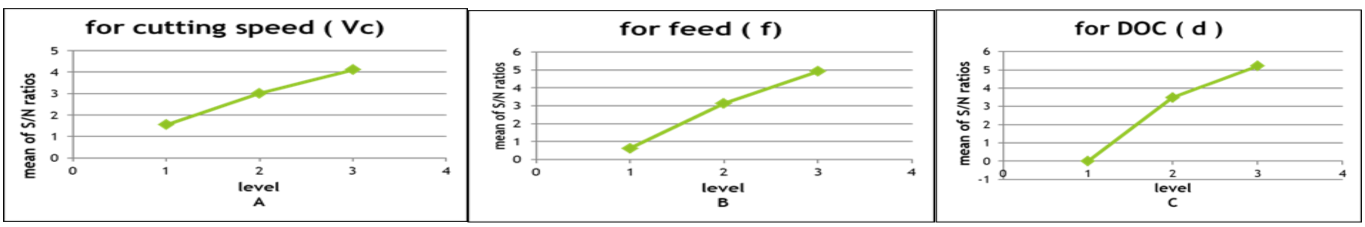
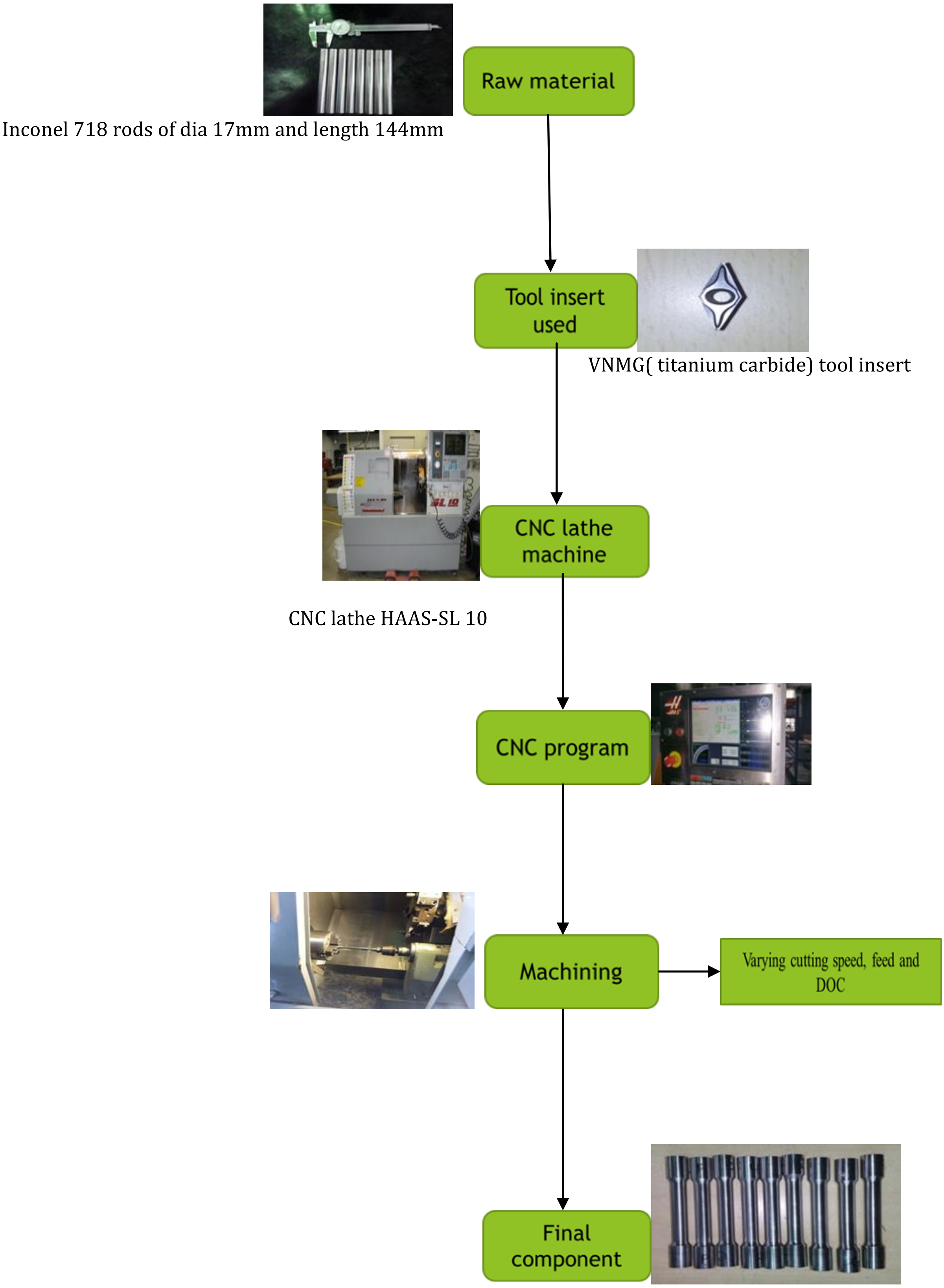


Fig 5. Influence of control factors on S/N ratios (MRR)

4.6 Flow chart indicating the fabrication of the test specimen



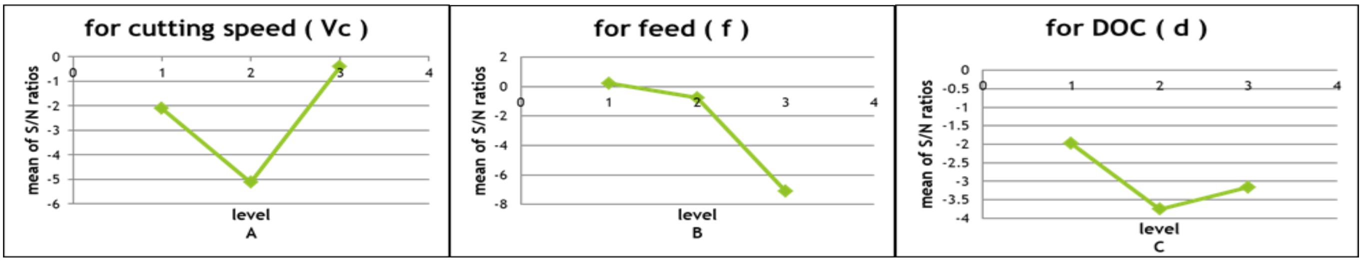


Fig 6. Influence of control factors on S/N ratios (Ra)

Table 5. % of contribution of three parameters to the MRR along with the estimated ANOVA parameters [6].

Parameter 'i'	Sum of squares SSi	DOFi	Mean sum of squares MSSi	Fstatistics	Fα (for V1,V2)	% of Contribution
Vc	0.1718	2	0.0859	9.4917		9.48
f	0.645	2	0.3225	35.6354	19	35.596
d	0.959	2	0.4795	52.9834		52.925
Error	0.0362	2	0.0181			1.99
Total	1.812	8	0.906			

Pvc = 9.48%
Pf = 35.596%
Pd = 52.925%

Table 6. % of contribution of three parameters to the Ra along with the estimated ANOVA parameters.

Parameter 'i'	Sum of squares SSi	DOFi	Mean sum of squares MSSi	Fstatistics	Fα (for V1,V2)	% of Contribution
Vc	0.6484	2	0.3242	0.7537		8.982
F	2.503	2	1.2515	2.9095	3	34.673
D	2.3467	2	1.1734	2.7278		32.51
Error	1.7206	2	0.8603			23.835
Total	7.2187	8	3.6094			

Pvc = 8.982%

Pf = 34.673%
Pd = 32.51%

4.7 ANOVA Analysis for MRR (MATERIAL REMOVAL RATE)

One-way ANOVA: MRR versus Cutting speed

Source	DF	SS	MS	F	P
Cutting speed	2	0.173	0.087	0.32	0.740
Error	6	1.640	0.273		
Total	8	1.813			

S = 0.5228 R-Sq = 9.55% R-Sq(adj) = 0.00%

One-way ANOVA: MRR versus Feed

Source	DF	SS	MS	F	P
Feed	2	0.647	0.323	1.66	0.266
Error	6	1.167	0.194		
Total	8	1.813			

S = 0.4410 R-Sq = 35.66% R-Sq(adj) = 14.21%

One-way ANOVA: MRR versus Depth of Cut

Source	DF	SS	MS	F	P
Depth of Cut	2	0.954	0.477	3.33	0.106
Error	6	0.859	0.143		
Total	8	1.813			

S = 0.3784 R-Sq = 52.61% R-Sq(adj) = 36.81%

4.7 ANOVA analysis for Ra (SURFACE ROUGHNESS)

One-way ANOVA: Ra versus Cutting speed

Source	DF	SS	MS	F	P
Cutting speed	2	0.65	0.32	0.30	0.754
Error	6	6.57	1.10		
Total	8	7.22			

S = 1.046 R-Sq = 8.98% R-Sq(adj) = 0.00%

One-way ANOVA: Ra versus Feed

Source	DF	SS	MS	F	P
Feed	2	2.503	1.251	1.59	0.279
Error	6	4.716	0.786		
Total	8	7.219			

S = 0.8865 R-Sq = 34.67% R-Sq(adj) = 12.90%

One-way ANOVA: Ra versus Depth of Cut

Source	DF	SS	MS	F	P
Depth of Cut	2	2.347	1.173	1.45	0.307
Error	6	4.872	0.812		
Total	8	7.219			

S = 0.9011 R-Sq = 32.51% R-Sq(adj) = 10.01%

5. CONCLUSIONS

In this project work, the material used is a super alloy Inconel718 which is a costly material and has got a peculiar characteristics which makes it difficult to machine. Therefore, the selection of optimal parameters is important to minimize the higher unit cost per machined part and service life [7]. Analysis of result showed that in the turning of Inconel718 using conceptual S/N ratio approach. In this work, Taguchi method is used to provide an efficient design of experiment (DOE) technique to obtain simple, systematic and efficient methodology for the optimization of the process parameters and their interaction effect.

For MRR,
The parameters Vc, f, d influence much on the response factor MRR by S/N ratio.
Speed (Vc) = 80 m/min; Feed (f) = 0.25 mm/rev; DOC (d) = 0.2 mm
The significance of each parameter is identified by ANOVA tool
Vc – 9.48%; f – 35.596%; d – 52.925%
Of the 3 process parameters, DOC(d) has the major contribution on MRR.

For surface roughness (Ra),
The parameters Vc, f, d influence much on the response factor Ra by S/N ratio.
Speed (Vc) = 80 m/min; Feed (f) = 0.15 mm/rev; DOC (d) = 0.1 mm
The significance of each parameter is identified by ANOVA tool
Vc – 8.982%; f – 34.673%; d – 32.51%
Of the 3 process parameters, Feed (f) has the major contribution on Ra.

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