Optimization of Process Parameters of Inconel 600 Using Taguchi's Technique

Raju B.S[1], Suman.V, Sunil. K[2], Supreeth C.D.S[3], Syed S.A.K[4]
[1, 2, 3, 4] Dept of Mechanical Engineering
[1, 2, 3, 4] REVA University

Abstract- *Inconel 600 is a nickel base super alloy comprising of high temperature withstanding property, highly corrosion resistant and high strength because of its unique properties which is desired in various engineering and marine applications such as components of gas and jet engines, steam turbines and nuclear reactors. In our work an attempt is made to determine the optimal process parameters such as speed, feed, DOC on the response variable which are MRR, Tensile strength (Ts) and Surface Roughness (Ra) during the turning operation on Inconel 600. An L9 orthogonal array has been used with different levels of input parameters in order to minimize the experimental trials. The signal to noise ratio is determined w.r.t to the quality characteristics in order to determine the optimal parameters for the response variables. The Analysis of Variance is performed in order to predict the most significant parameter which affects the response variables and the end results, are validated with Minitab software.*

Keywords- Inconel 600, Taguchi Technique, Orthogonal array, SN ratio, ANOVA.

I. INTRODUCTION

Super alloy, Inconel series 718,600,700 is widely used in sophisticated applications due to its unique properties desired for the various engineering and marine applications. Due to its special characteristics, machining of super alloy is difficult and also costlier. Hence the present work mainly deals with the determination of optimal process parameters during the turning of Inconel 600 using carbide tool insert as shown in the Fig.1. Inconel 600 material is a nickel based super alloy [1].

Taguchi method is one of the Design of experiment (DOE) tool for optimization of the process and also to identify the critical parameters with their optimal setting of it. Analysis of variance (ANOVA) is used to determine the effect of process parameters on the response variables. The input parameters such as speed, feed, degree of freedom on response variables tensile strength (Ts), material removal rate (MRR) and surface roughness (Ra).

INCONEL 600 is non-magnetic nickel-chromium-iron high temperature alloy having high strength, high corrosion resistance, hot and cold workability and free from stress corrosion. The high chromium content raises its oxidation resistance and the presence of high nickel content provides good corrosion resistance. The alloy shows very good levels of resistance to chloride stress-concentration cracking, ammonia. It has a good performance level at cryogenic temperatures. Since machining is a basically a finishing process with specified dimensions, stability, tolerance and surface finish, type of surface and its characteristics are very much important in manufacturing. Carbide cutting tools are the oldest amongst the hard cutting tool materials in order to machine nickel based super alloys with the speed range of 30-80m/min.

Table .1- chemical composition of Inconel 600

Element	Percentage
Nickel	72.0
Chromium	17.0
Iron	10.0
Manganese	01.0
Silicon	0.50
Copper	0.50
Carbon	0.10

Table .2- Mechanical properties of Inconel 600

Melting point	1354-1413°C
Thermal conductivity	14.9W/m-k
Ultimate tensile strength	550-690MPa
Ultimate yield strength	170-345MPa
Density	8470kg/m³
Hardness	65-85BHN
Young's modulus at 22°C	214GPa
Shear modulus at 22°C	80.8GPa

Applications

The elevated temperature strength, excellent corrosion resistance and workability at 700°C properties had made it uses in a wide range of applications. They are,

- Used in blades of gas turbines.
- Boilers of incinerators.
- Cryogenic storage tanks.
- High temperature fasteners
- Turbocharger rotors and seals.
- Used under carburizing environment [2].

II. LITERATURE SURVEY

1. "Wear Behaviour in dry sliding of inconell600 alloy using Taguchi Method and Regression analysis" authored by VishalBanker, Jitendra.M.Mistry, Malhar.R.Thakor. They have considered the input parameters as load, speed, wire track diameter and pin heating temperature for the determination of optimum combination. Orthogonal array is used to reduce the no of experiments. Then with the use of signal to noise ratio results showing smaller the better was opted for minimization of wear. The wear behaviour of the Inconel 600 is directly proportional to the applied load and inversely proportional to the pin heating temperature, most important parameter affecting wear was speed and wire track diameter [3].

2. "Optimization of process parameters of wire electrical discharge machine by response surface methodology on inconel600" authored by C D Shah, JR Mahadeva, B C Khatri. The parameter selected for experiments are wire speed, peak current, pulse on time and pulse off time. Therefore, after selecting these parameters in order to determine the MRR ANOVA was performed. The ANOVA analysis is carried in Minitab software for the optimum results, the machining parameters on material removal rate is determined by ANOVA technique. With the help of S/N, ratio optimum combination of parameters is obtained to maximize the material removal rate [4].

3. "Determining the cutting parameters on surface roughness in hard turning using Taguchi method" authored by llhan Asilturk and Harun Akkus. We optimize turning parameters based on the Taguchi method to minimize the surface roughness. Coated carbide cutting tool are used. The statistical methods of signal to noise ratio (SNR) and analysis of variance (ANOVA) are applied to investigate effect of cutting speed, feed rate, and depth of cut on surface roughness. The major result is feed rate has most significant effect on surface roughness [5].

4. "Comparison of wear performance of hardened Inconel 600 by different nitriding process" authored by F.Mindivan, H.Mindivan. This paper describes the structure and properties of nitride layer produced on Inconel 600 alloy. The characteristics of the nitride layer at the surface were investigated by microscopic examination, hardness measurement and wear test. It was found that the nitrite layer produced on the alloy surface greatly decrease the wear rate and slightly increases the surface hardness [6].

5. "Characterization of white layer generated when turning aged Inconel 718" authored by V Bushlya J M Zhou, F.Lenrick. A white layer is going to form on the surface of Inconel 718 components, which are under regular stressed areas because of that the fatigue strength of the component get reduced. After experimenting under transmission electron, scanning electron and atomic force microscopy technique the causes for the formation of white layer are tool wear, dry machining and cutting speed majorly and the layer will due to the plastic deformation of the near surface region [7].

Literature review

From the review of literature, it is observed that only a few investigations have been carried out for the optimization and statistical modeling of process parameter in turning of inconel600 using carbide insert tool. To overcome the above shortcoming, the present work has been focused to attain the following objectives:

- Planning of experimental design according to the choice of factors and its levels.
- To conduct the machining experiments on inconel600 under turning using carbide insert tool.
- To predict the optimum process parameters using Taguchi's experimental design procedure.
- To develop a statistical model and validate the results obtained using Taguchi method.
- To conduct the confirmation test at optimum levels to compare the predicted results and to analyze the optimum response parameters.

III. OBJECTIVES AND STUDY

The objective of the project is identified as below “OPTIMIZATION OF PROCESS PARAMETERS ON INCONEL 600USING TAGUCHI’S TECHNIQUE”.

1. The main objective is to analyze the machining parameters of Inconel 600 Turing operation.
2. To obtain the optimal setting process parameters such as cutting speed, feed and depth of cut in order to yield the optimal tensile strength, material removal rate and surface roughness while machining Inconel 600.
3. To identify the influential parameter on the response variable using ANOVA and validation of end results using Minitab 17/18 software.

Factors affecting the quality of turning

The key mechanical input in material removal operation are speed, feed, depth of cut, tool insert, cutting force, coolant used etc. The choice of feed, speed and depth of cut is based on the customer objectives

Independent Variable

- **Cutting Speed**

In general, speed (V) is the primary cutting motion, which relates the velocity of the rotating work piece with respect to the stationary cutting tool.

- **Feed**

Feed is the relative velocity at which the cutter is advanced along the work piece. Its vector is perpendicular to the vector of cutting speed. Feed rate units depend on the motion of the tool and work piece.

- **Depth of cut**

Cutting speed and feed rate come together with depth of cut to determine the material removal rate, which is the volume of work piece material that can be removed per time unit. It is the distance that cutting tool penetrates into the work piece

Response variables

- Material removal rate

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

$$MRR = \frac{(Wi - Wf)}{Dw \times t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

MRR – Material Removal Rate (mm3/min)
W_I– Initial weight of work piece (gm)
W_f– Final weight of work piece (gm)
D_w– Density of the work piece (gm/mm3)
t - Period of trial (min)

- Tensile Strength

The tensile strength of the material is the maximum amount of tensile stress that a material can take before the failure

$$Ts = \frac{load}{area} \ in \ N/mm^2 \quad \ldots\ldots\ldots\ldots\ldots(2)$$

- Surface roughness

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.

IV. TAGUCHI TECHNIQUES

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.

Taguchi’s work includes three principal contributions to statistics:

- A specific loss function
- The philosophy of off-line quality control
- Innovations in the design of experiments

The Taguchi design was used to determine optimal cutting parameters and to find the relationships between independent variables and response variables. The Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (SN) 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,

1. Larger the better (for e.g., MRR, agricultural yield, mechanical strength)

$$\frac{S}{N} = -10log\frac{1}{n}\left(\sum\frac{1}{y^2}\right)\ldots\ldots(3)$$

2. Smaller the better (for e.g., surface roughness, Co2 emission)

$$\frac{S}{N} = -10log\frac{1}{n}\left(\sum y^2\right)\ldots\ldots(4)$$

3. Nominal the better.(for e.g., a mating part in an assembly, castings)

$$\frac{S}{N} = 10\log\frac{\bar{y}}{sy^2}\ldots\ldots(5)$$

Main experiment

The various parameters considered for the experiments with their various levels is as shown in the table 3

Table.3-Levels of various parameters

Parameter	Level 1	Level 2	Level 3
Speed in m/min	60	70	80
Feed in mm/rev	0.1	0.15	0.2
DOC in mm	0.15	0.2	0.25

Selection of Orthogonal Array

Orthogonal Array is selected based on number of factors and interaction between them and the number of levels of here each factors the two way interaction effect of the three parameters to be analyzed with the plots drawn between Vc/f/d and parameters MRR/Ra/Ts with different settings of other parameters. L9 Orthogonal Array was taken into consideration. In order to reduce the number of experimentations with various parameters with their levels, the Orthogonal Array plays a very important role. The L9 Orthogonal Array was selected since 3 parameters with 3 different levels were selected. The L9 Orthogonal Array is as shown in table 4

Table.4 orthogonal array for main experiment

Exp no.	Vc in mm/min	Feed in mm/rev	DOC in mm
1	(1)60	(1)0.10	(1)0.15
2	(1)60	(2)0.15	(2)0.20
3	(1)60	(3)0.20	(3)0.25
4	(2)70	(1)0.10	(2)0.20
5	(2)70	(2)0.15	(3)0.25
6	(2)70	(3)0.20	(1)0.15
7	(3)80	(1)0.10	(3)0.25
8	(3)80	(2)0.15	(1)0.15
9	(3)80	(3)0.20	(2)0.20

IV. RESULTS AND DISCUSSION

Table.5- L9 orthogonal array with experimental results

Exp no.	Vc in mm/min	Feed in mm/rev	DOC in mm	MRR $*10^3$in mm^3/min	S/N ratio for MRR
1	1	1	1	0.281	-11.02
2	1	2	2	0.355	-8.99
3	1	3	3	0.60	-4.73
4	2	1	2	0.293	-10.64
5	2	2	3	0.584	-4.73
6	2	3	1	0.492	-6.19
7	3	1	3	0.418	-7.57
8	3	2	1	0.424	-7.53
9	3	3	2	0.703	-3.06

Table.6-- L9 orthogonal array with experimental and calculated results for MRR
results and calculated results for Ts

Exp no.	Vc in mm/min	Feed in mm/rev	DOC in mm	Ts in N/mm^2	S/N ratio for Ts
1	1	1	1	685.19	56.723
2	1	2	2	688.19	56.754
3	1	3	3	695.68	56.848
4	2	1	2	685.66	56.722
5	2	2	3	686.09	56.727
6	2	3	1	686.90	56.737
7	3	1	3	739.23	57.375
8	3	2	1	741.32	57.4
9	3	3	2	743.41	57.425

Table.7- L9 orthogonal array with experimental results and calculated results for Ra

Exp no.	Vc in mm/min	Feed in mm/rev	DOC in mm	Ra in micro meter	S/N ratio for Ra
1	1	1	1	4.89	-13.78
2	1	2	2	3.69	-11.34
3	1	3	3	4.33	-12.72
4	2	1	2	3.51	-10.90
5	2	2	3	3.41	-10.65
6	2	3	1	4.09	-12.23
7	3	1	3	3.97	-11.97
8	3	2	1	3.15	-9.96
9	3	3	2	4.09	-12.23

Effect of parameters on MRR

Effect of parameters on Tensile Strength

Effect of parameters on Surface Roughness

Table 8 shows the % contribution of three parameters to the MRR along with the estimated ANOVA parameters

Parameter	Sum of squares(SS_i)	DOF_i	Mean sum of Squares(MSS_i)	$F_{Statistics}$	Fα (For v1 & v2)	%of contribution
Vc	0.016	2	0.008	0.7334		9.237
F	0.1077	2	0.0538	4.93		62.1002
D	0.0279	2	0.0139	1.275	3	16.0681
Error	0.0281	2	0.0109			12.594
Total	0.1797	8	0.0867			100

Table 9- shows the % contribution of three parameters to the Tensile strength along with the estimated ANOVA parameters

Parameter	Sum of squares(SS_i)	DOF_i	Mean sum of Squares(MSS_i)	$F_{Statistics}$	Fα (For v1 & v2)	%of contribution
Vc	5714.419	2	2857.21	386.07		98.825
F	43.505	2	21.752	2.939		0.752
D	9.602	2	4.801	0.648	3	0.166
Error	15	2	7.4			0.2559
Total	5782.526	8				100

Table 10- shows the % contribution of three parameters to the surface roughness along with the estimated ANOVA parameters

Parameter	Sum of squares(SS_i)	DOF_i	Mean sum of Squares(MSS_i)	$F_{Statistics}$	Fα (For v1 & v2)	%of contribution
Vc	0.7266	2	0.3633	2.219		32.428
F	1.069	2	0.5345	3.264		47.709
D	0.1176	2	0.0588	0.3597	3	5.248
Error	0.3274	2	0.1637			14.613
Total	2.2412	8	1.1203			100

V. CONCLUSION

In this project work, the material used is a super alloy Inconel 600 which is costly material and possess a peculiar characteristics which makes it difficult to machine. Therefore, the selection of optimal parameters are important in order to minimize the higher unit cost per machined part and its service life. Analysis showed that in the turning of Inconel 600 using conceptual S/N ratio approach. In this work, Taguchi method is used to provide the efficient and more effective design of experiment (DOE) technique to obtain simple, systematical and procedural methodology for the process optimization and their interaction effects.

- For MRR,
  - The parameters Vc, f , Doc influence much on the response factor MRR by S/N Ratio are, Speed (Vc)=80m/min; feed=0.2mm/rev; DOC=0.25mm
  - The significance of each parameter is identified by ANOVA tool

Speed (Vc)=9.237% ; feed=62.1%; DOC=16.06% of these three process parameters, Feed (f) has the major contribution on MRR

- For Tensile strength
  - The parameters Vc, f , Doc influence much on the response factor TS by S/N Ratio are, Speed (Vc)=80m/min; feed=0.2mm/rev; DOC=0.25mm
  - The significance of each parameter is identified by ANOVA tool

Speed (Vc)=98.825% ; feed=0.752%; DOC=0.166% of these three process parameters, Speed (Vc) has the major contribution on TS.

- For Surface roughness
  - The parameters Vc, f , Doc influence much on the response factor Ra by S/N Ratio are, Speed (Vc)=60m/min; feed=0.2mm/rev; DOC=0.15mm
  - The significance of each parameter is identified by ANOVA tool

Speed (Vc)=32.428% ; feed=47.709%; DOC=5.248% of these three process parameters, Feed (f) has the major contribution on Ra.

REFERENCES

[1] P.Ross, Taguchi Technique for Quality Engineering, McGraw-Hill, New-York,1984

[2] Quality engineering by Mahadev.s.Padhke 2004

[3] Vishal.Banker, Jitendra.M.Mistry, Malhar.R.Thakor. “Wear Behavior in dry sliding of inconell600 alloy using Taguchi Method and Regression analysis”. 2016, ICIAME, Procedia engineering. (2016)383-390, Vol 23.

[4] C D Shah, JR Mahadeva, B C Khatri. “Optimization of process parameters of wire electrical discharge machine by response surface methodology on inconel600”. April 2013, International Journal of emerging technology and advance energy ISSN 2250-2459, volume 3 issue 4.

[5] Asilturk and Harun Akkus.“Determining of the cutting parameters on surface roughness in hard turning using Taguchi method”. November 2011, Measurements, volume 44 issue 9, page 1697-1704.

[6] F.Mindivan, H.Mindivan. “Comparison of wear performance of hardened Inconel 600 by different nitriding process”. 2013, Procedia engineering, page 730-735.

[7] V Bushlya,J MZhou,F Lenrick. “Characterization of white layer generated when turning aged Inconel 718” 1st CIRP on Surface Integrity. Procedia Engineering 19(2011)60-66.