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Optimizing the Machining Parameters and study the Effect for Super Alloy Inconel 718 by using Factor Analysis Method

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Abstract

This paper presents a novel approach for the optimization of machining parameters on Super Alloy Inconel 718 machining with Factor analysis method. In this experiment, machining parameters like speed, feed, depth of cut and cutting force are optimized with the considerations of multi responses such as material removal rate and surface roughness. L9 Orthogonal array was taken to conduct the experiments. The method shows a good convergence with the experimental and the optimum process parameters where the maximum material removal rate and the minimum surface finish are obtained.

Keywords: Alloy, Inconel 718, Factor Analysis, Material Removal Rate, Surface Roughness, MiniTab

Introduction

Inconel 718 is the most frequently used of the nickel-base super alloys; Some important applications of nickel based super alloys are gas turbines, reciprocating engines, metal processing, space vehicles heat treating equipments, nuclear power plants, chemical and petrochemical industries, and heat exchangers and they also used for manufacturing disks, combustion chambers, casings, shafts, exhaust systems, blades, vanes, burner cans, reheaters, turbochargers, exhaust valves, hot plugs, valve seat inserts, hot work tools and dies, aerodynamically heated skins, rocket engine parts, trays, fixtures, conveyor belts, baskets, fans, furnace mufflers.

The nickel based super alloys are complex materials as that contain 10 to 12 elements as shown in the table 1.The major phase in these alloys are gamma phase (γ), gamma prime phase (γ'), and gamma double prime phase (γ'') phase. γ phase is a continuous matrix of an fcc nickel-based non-magnetic phase. γ' phase contains an addition of aluminum and titanium in amounts required to precipitate fcc γ' Ni3 (Al, Ti) phase coherent with austenitic γ phase. This phase gives the properties of high temperature strength and creep resistance.

Table 1: Nominal chemical composition of Inconel 718 (% wt)

Ni	Fe	Cr	Mo	Nb	Ti	Al	C	Mn	Si	Cu	Co	Vd
54.39	15.11	19.499	3.08	5.30	1.11	0.74	0.03	0.08	0.11	0.38	0.05	0.03

The γ'' phase contains a combination nickel and niobium combined in the presence of iron, as a catalyst, to form body centered tetragonal (bct) Ni3Nb, which is coherent with γ phase. This phase enables high strength at low and intermediate temperatures but it is unstable above 650°C.

Machining of Nickel-based Super Alloys

Inconel 718 is very much difficult to machine; not many cutting tools can cut this material easily. Nickel-based alloys work-harden rapidly. Work hardening results in strengthening of the material. Plastic deformation during machining leads to heat generation. High temperature gradients are localized in narrow bands along shear plane due to poor thermal properties of Inconel 718, leading to weakening the material in the deformation zone. When the rate of thermal softening is greater than that of strain hardening, material deforms locally, termed as adiabatic shear failure.

Design of Experiment

The assignment of the levels to the factors and the various parameters used are given in table 2. Taguchi's L9 orthogonal array was used to design the experiments with four factors and three levels. Experiments were conducted based on the Taguchi's method which is a powerful tool used in design of experiments. Taguchi advocates use of orthogonal array designs to assign the factors chosen for the experiment. The advantage of Taguchi method is that it uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Compared to the conventional approach of experimentation, this method reduces drastically the number of experiments that are required to model the response functions. The experimental results for L9 orthogonal array are given in table 3.

Table 2: Machining Parameters and Domain of Experiments

S. No	Operating parameter	Symbol	Unit	Levels		
				Low	Medium	High
1	Speed	A	rpm	40	45	50
2	Feed	B	mm/rev	0.05	0.06	0.07
3	Depth of Cut	C	mm	0.20	0.25	0.30
4	Cutting Force	D	N	175	200	238

Table 3: Experimental Results for L9 Orthogonal Array

Trial. No	Speed A (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Cutting Force (N)	MRR (mm^2/min)	Surface Roughness (micron meter)
1	40.0	0.05	0.2	175.0	399.0	0.34
2	40.0	0.06	0.25	200.0	480.0	0.41
3	40.0	0.07	0.3	238.0	500.0	0.4
4	45.0	0.05	0.25	238.0	515.0	0.42
5	45.0	0.06	0.3	175.0	535.0	0.35
6	45.0	0.07	0.2	200.0	550.0	0.17
7	50.0	0.05	0.3	200.0	540.0	0.23
8	50.0	0.06	0.2	238.0	575.0	0.22
9	50.0	0.07	0.25	175.0	600.0	0.27

Factor Analysis:

In factor analysis principal component method (PCM) is a mathematical procedure that summarizes the information contains in a set up of original variables into a new and smaller set of uncorrelated combinations with a minimum loss of information. These analysis combine the variable that account for the largest amount of variance to form the first principal component .Second principal accounts for the next largest amount of the variance and so on, until the total sample variance is combined into components groups.

PCM of factor analysis is used for solving the multi –response Taguchi problems. Chao-Ton and Lee-Ing Tong (1997) have developed and effective procedure to transform a set of responses into a set of uncorrelated component such that the optimal conditions in the parameters design stage for the multi-response problem can be determined. They have proposed an effective procedure on the basis of PCM to optimize to multi- response problems in the Taguchi method (Pananeerselvam, 2004). Statistical software is used to perform factor analysis.

Step 1: Transform the original data from the Taguchi experiment into S/N ratio. S/N ratio for Material Removal Rate is computed form the following formula

S/N ratio = $-10 \log (1/n) \sum (1/Y_{ij})^2$

S/N ratio for Surface roughness is computed form the following formula

S/N ratio = $-10 \log (1/n) \sum (Y_{ij})^2$

Step 2: Normalized the S/N ratio are computed and presented in the table 4.

Table 4:. S/N ratio and Normalized S/N ratio Values

TRIAL	S/N Ratio Values		Normalized S/N Ratio Values	
	MRR	SR	MRR	SR
1	52.01	9.37	0	0.765
2	53.62	7.77	0.453	0.969

3	53.97	7.95	0.552	0.946
4	54.23	7.55	0.625	1
5	54.56	9.11	0.718	0.798
6	54.8	15.39	0.785	0
7	54.64	12.76	0.74	0.334
8	55.19	13.15	0.895	0.28
9	55.56	11.37	1	0.511

Step 3: Factor analysis is performed based on principal component method. Here the component that are having Eigen value more than one are selected for analysis .The component values obtained after performing factor analysis based on PCM are given in the table 5.

Table 5: Component Matrix and Eigen Values for Response

Component Matrix[a]

	Component
	1
MRR	.870
SR	.870
Eigen Values	1.514

Using the values from the table 5, the following MRPI equation is obtained, $MRPI_{i,j} = 0.870\ Z_{i1} - 0.870\ Z_{i2}$. The MRPI values are computed and tabulated in table 6.

Table 6: Normalized N/S Ratio and MRPI for Response

Trial	Normalized S/N Ratio Values		MRPI
	MRR	SR	
1	0	0.765	-0.66555
2	0.453	0.969	-0.44892
3	0.552	0.946	-0.34278
4	0.625	1	-0.32625
5	0.718	0.798	-0.0696
6	0.785	0	0.68295
7	0.74	0.334	0.35322
8	0.895	0.28	0.53505
9	1	0.511	0.42543

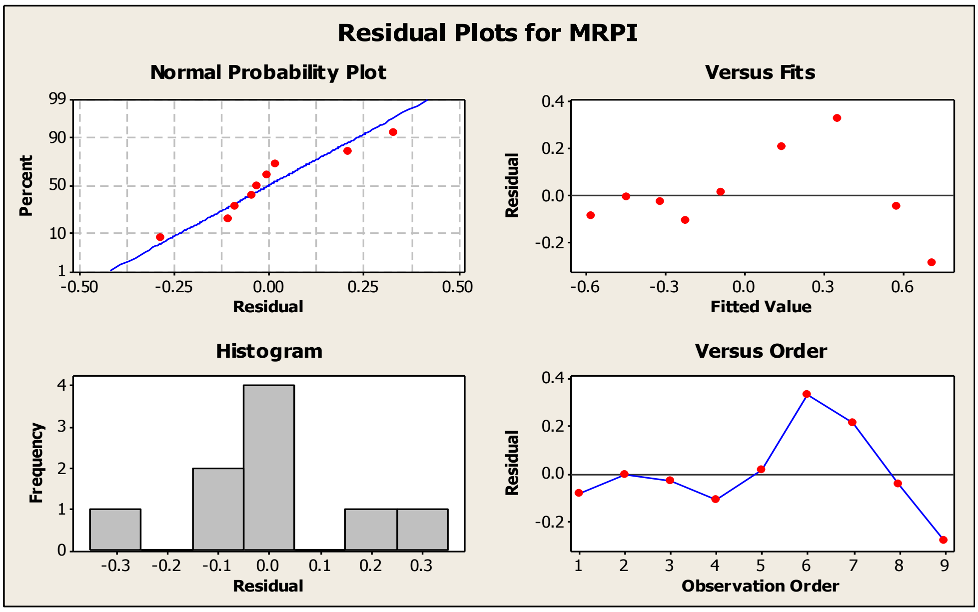

Figure 1: Residual plot for Gi (grey grade)

Conclusion

The controllable factor on MRPI value in the order of significance are A, B, C and D. The larger MRPI value implies the better quality .Consequently the optimal condition is set as A3, B3, C1 and D2.

Table 7: Main Effect on MRPI

A1	-0.48575	B1	-0.21286	**C1**	**0.18415**	D1	-0.10324
A2	0.0957	B2	0.000005	C2	-0.11658	**D2**	**0.19575**
A3	**0.4379**	**B3**	**0.26071**	C3	-0.01972	D3	-0.04466
Max– Min	0.92365	Max Min	0.47357	Max - Min	0.30073	Max - Min	0.29899

Table 8: ANOVA Results on MRPI Values

Source	DF	Seq SS	Adj SS	Adj MS	F	p	% contribution
Speed	1	1.27969	1.27969	1.27969	24.7262	0.004203	66.33
Feed	1	0.32862	0.32862	0.32862	6.3496	0.053185	17.03
Depth of Cut	1	0.06234	0.06234	0.06234	1.2046	0.322423	3.23
Error	5	0.25877	0.25877	0.05175			
Total	8	1.92943					100

S = 0.227496 R-Sq = 86.59% R-Sq (adj) = 78.54

From ANOVA analysis, it is revealed that speed, Feed and Depth of Cut are prominent factors which affect the performance of machining operation. The speed (A= 66.33 %) is the most influencing factor followed by Feed (B=17.03%) and Depth of Cut (C=3.23%)

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