EFFECT OF CUTTING PARAMETERS ON SUPER ALLOY IN TURNING OPERATION UNDER DRY CONDITION

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Abstract- Ni-base super alloys are widely used in several industrial sectors, like petrochemical and power generation due to their high performance in aggressive environments. Inconel625 is primarily a Ni–Cr–Mo alloy used in different applications for its strength, excellent fabric ability and outstanding corrosion resistance. Machining of super alloy has been found to be a challenging task it has attracted considerable research. So, it is essential to know the cutting parameters for effective machining of super alloys. The present work focuses on finding the optimal cutting parameters for turning Inconel625 to achieve minimum surface roughness (SR), tool wear (TW) and maximum material removal rate (MRR) in CNC turning under dry conditions using TiAlN coated cutting tool. Single response optimization is performed by Taguchi method and multi response optimization is performed by desirability function analysis.

Keywords- Inconel625, CNC turning, Surface roughness, Material removal rate, Taguchi's techniques, Desirability functional analysis.

I. INTRODUCTION

High performance nickel based super alloys are in increasing demand within the aerospace and power generation as combustion engines reach ever higher temperatures in the search for greater efficiency. However their high hardness, low thermal conductivity and high work hardening rates result in alloys which are classed as difficult to machine [1]. In current practice for forged parts, forgings are rough turned in the age hardened and finished in the hard state. Cutting speeds are limited to roughly 50 surface meters per minute for carbide tooling and 300 surface meters per minute for ceramic and CBN tooling. In rough machining, feeds are limited and tools are indexed frequently to avoid potential breakage, resulting in long cycle times and high machine investment and tooling costs. There has long been interest in improving material removal rate and reducing machining costs for Inconel625 applications. Much research has focused on the development of coolant strategies, in current practice Inconel alloys are most commonly machined using neat oil or low pressure water-based flood coolants. Su et al [2] have investigated machining of recalcitrant materials using liquid nitrogen-based cryogenic coolant systems. Hybrid systems combining water-based coolants with a chilled gas such as air, as investigated by Obikawaet al [3], or CO2 as investigated by Biermann et al [4] have also been tried to improve Inconel machinability. While all of these strategies can increase MRR and are likely suitable for some range of applications, they all increase fixed costs and maintenance requirements, reduce system flexibility, and in some cases require a recirculation coolant system more complex than common current systems. But the cost of cutting fluid is 17% of the total manufacturing cost and tool with coating is important to improve the performance [5].

In almost all of this research the machining has been examined from the manufacturing technology point of view for the improvement of tool materials, geometries and machining parameters. The main reasons for the machining difficulties are due to its high strength and ductility at high temperatures, the austenitic matrix and its low thermal conductivity. The material can also adhere and weld onto the tool, the influence of the stress and temperature along tool- chip and tool- work interfaces. All these effects finally lead to poor surface integrity if the working conditions are not properly selected. Therefore, it is important to know the machining parameters [6], [7]. Taguchi method is a traditional approach for robust experimental design that seeks to obtain the best combination set of factors/levels with the lowest societal cost solution to achieve customer requirements. Taguchi method is a powerful tool for optimization and this method is limited to solve single response problems and the multi response problems received less attention. Desirability function analysis is one of the most widely used methods in industry for the optimization of multi responses problems. Desirability function analysis is used to convert the multi responses problems into single response problems. As a result, optimization of the complicated multi response problems can be converted into optimization of a single response problem termed composite desirability [8], [9]. So in this investigation TiAlN coated cutting tool was used to CNC turning on Inconel625 under dry condition and best cutting conditions were obtained using Taguchi Techniques and desirability function analysis.

II. MATERIAL AND METHODS

The work material used for the present investigation is Inconel625. The diameter of the material is 24 mm and machined length is 30 mm for all trials. The chemical composition of the work piece materials is given in Table I.

TABLE I
Chemical composition of the Inconel 625

Ni	Cr	Mo	Nb	Fe	Other
58.0-63.0	20.0-23.0	8.0-10.0	3.0-5.0	≤5.0	≤2.0

A. Taguchi method

Taguchi proposed that the engineering optimization of a process or product should be carried out in a three-step approach, that is, system design, parameter design, and tolerance design. In the system design, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design. This prototype design includes the product design stage and the process design stage. In the product design stage, the selections of materials, components, tentative product parameter values, etc., are involved. As to the process design stage, the analysis of processing sequences, the selections of production equipment, tentative process parameter values, etc., are involved. Since the system design is an initial functional design, it may be far from optimum in terms of quality and cost. Following the system design is the parameter design. The objective of the parameter design is to optimize the settings of the process parameter values to improve quality characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is intended that the optimal process parameter values obtained from the parameter design are insensitive to the variation of environmental conditions and other noise factors. There are three categories of quality characteristic in the analysis of the S/N ratio, (1) the-lower-the-better, (2) the-higher-the-better and (3) the-nominal-the-better. Since the quality characteristic is to be minimized, the-lower-the-better category is used to calculate the S/N ratio for SR, TW and MRR Eq.1 and Eq.2 shows the lower the better and larger the better characteristic [10].

$$\text{S/N ratio } (\eta) = -10 \log_{10} \left(\frac{1}{n} \sum_{i=1}^{n} {y_{ij}}^2 \right) \quad (1)$$

$$\text{S/N ratio } (\eta) = -10 \log_{10} \left(\frac{1}{n} \right) \sum_{i=1}^{n} \frac{1}{{y_{ij}}^2} \quad (2)$$

Where: η = Signal to noise ratio, n = Number of repetitions of experiment, y = Measured value of quality characteristic.

B. Desirability function analysis

Desirability function analysis is used to convert the multi responses problems into single response problems. A composite desirability value is obtained for the multi responses from the DFA. Using composite desirability value, the optimum levels of parameters have been identified and significant contribution of parameters is determined by ANOVA [11].

Step 1: Calculate the individual desirability index (d_i) for the corresponding responses using the larger better and smaller the better. The The individual desirability index of all the responses can be combined to form a single value called composite desirability (d_G).

Step 2: Determine the optimal parameter and its level combination: The higher the composite desirability value implies better product quality. Therefore on the basis of the composite desirability (d_G), the parameter effect and the optimum level for each controllable parameter are estimated.

Step 3: Perform ANOVA: Perform ANOVA for identifying the significant parameters. ANOVA establishes the relative significance of parameters in terms of their percentage contribution. The calculated total sum of square values is used to measure the relative influence of the parameters.

Step 4: Calculate the predicted optimum condition: Once the optimal level of the design parameters has been selected, the final step is to predict and verify the quality characteristics using the optimal level of the design parameters.

Table-II
Experimental results for SR and MRR

Trial	v	f	a	SR (μm)	S/N for SR	MRR	S/N for MRR	TW (μm)	S/N for TW
1	75	0.1	0.25	0.680	3.35	0.500	-6.021	42.88	-32.64
2	75	0.1	0.5	0.653	3.70	0.522	-5.647	61.06	-35.71
3	75	0.1	0.75	0.587	4.62	0.609	-4.308	63.19	-36.01
4	75	0.2	0.25	1.650	-4.35	0.593	-4.539	51.91	-34.30
5	75	0.2	0.5	1.587	-4.01	0.429	-7.351	51.94	-34.31
6	75	0.2	0.75	1.627	-4.22	0.609	-4.308	138.01	-42.79
7	75	0.3	0.25	3.413	-10.66	1.000	0.000	92.61	-39.33
8	75	0.3	0.5	3.563	-11.03	0.923	-0.696	112.85	-41.05
9	75	0.3	0.75	3.360	-10.52	1.333	2.497	449.03	-53.04
10	100	0.1	0.25	0.493	6.14	0.526	-5.580	36.11	-31.15
11	100	0.1	0.5	0.827	1.65	0.632	-3.986	54.17	-34.67
12	100	0.1	0.75	0.500	6.02	1.053	0.449	97.12	-39.74
13	100	0.2	0.25	1.653	-4.36	0.923	-0.696	24.83	-27.89
14	100	0.2	0.5	1.670	-4.45	0.615	-4.223	29.4	-29.36
15	100	0.2	0.75	1.537	-3.73	1.077	0.644	415.44	-52.37
16	100	0.3	0.25	4.190	-12.44	0.727	-2.769	148.96	-43.46
17	100	0.3	0.5	3.853	-11.71	1.091	0.757	189.59	-45.55
18	100	0.3	0.75	3.663	-11.27	0.909	-0.829	203.57	-46.17
19	125	0.1	0.25	0.353	9.04	0.353	-9.045	31.83	-30.05
20	125	0.1	0.5	0.360	8.87	0.471	-6.540	60.94	-35.69
21	125	0.1	0.75	0.770	2.27	0.941	-0.528	444.68	-52.96
22	125	0.2	0.25	1.620	-4.10	0.667	-3.517	54.2	-34.68
23	125	0.2	0.5	1.480	-3.40	1.000	0.000	63.19	-36.01
24	125	0.2	0.75	1.757	-4.89	1.500	3.522	489.89	-53.80
25	125	0.3	0.25	3.663	-11.27	1.000	0.000	112.85	-41.05
26	125	0.3	0.5	3.557	-11.02	1.000	0.000	162.51	-44.21
27	125	0.3	0.75	2.907	-9.26	0.800	-1.938	581.05	-55.28

III. EXPERIMENTAL DETAILS

The experiments were conducted in Fanuc CNC lathe. TNMG 120408 coated with TiAlN is used as the insert for all machining operation. The range of cutting parameters were selected based on past experience, data book and available resources. SR is measured by the Mitutoyo surface roughness tester. TW was measured by an optical tool maker's microscope with image optic plus version 2.0 software designed to run under Microsoft widow's 32 bit system, which can be captured by the area of the tool wear. The three cutting parameters selected for the present investigation is cutting speed (75, 100, 125 m/min), feed (0.1, 0.2, 0.3 mm/rev) and depth of cut (0.25, 0.5, 0.75 mm). Taguchi's orthogonal array of L_{27} is most suitable for this experiment. This needs 27 runs and has 26 degrees of freedoms. The values of machining parameters and S/N ratio for all the responses are presented in Table II. The Taguchi analyses for all the responses are given in Table 4. The average value of S/N ratio has been calculated to find out the effects of different parameters and their levels.

IV. RESULT AND DISCUSIONS

A. Taguchi analysis for turning Inconel625

Signal to noise ratio: Analysis of the influence of each control factor (v,f and a) on the SR, TW and MRR has been performed with a so-called signal to noise ratio of response table. A response table for all the responses are given in Table III. It shows the S/N ratio at each level of control factor and how it is changed when settings of each control factor are changed from one level to another. According to the rank value for each control factor that the feed has the strongest influence on SR followed by cutting speed. Thus in order to minimum level of SR, Feed should be set to 0.1mm/rev, depth of cut set to 0.25 mm and cutting speed set to 125 m/min. In order to minimum level of TW, cutting speed set to 75 m/min, feed set to 0.1 mm/rev and depth of cut set to 0.25 mm. Similarly maximum level of MRR is cutting speed set as 100 m/min, feed set as 0.2m/rev and depth of cut set as 0.75 mm.

Table III
Taguchi analysis for all responses

Taguchi Analysis for SR			
Level	A	B	C
1	-3.682	**5.076**	**-3.195**
2	-3.797	-4.181	-3.491
3	**-2.652**	-11.026	-3.446
Delta	1.145	16.101	0.296
Taguchi Analysis for TW			
1	**-38.80**	**-36.52**	**-34.95**
2	-38.93	-38.39	-37.40
3	-42.64	-45.46	-48.02
Delta	3.84	8.95	13.07
Taguchi Analysis for MRR			
1	-3.374	-4.578	-3.574
2	**-1.803**	-2.274	-3.076
3	-2.005	**-0.331**	**-0.533**
Delta	1.571	4.2473	3.040

A. Desirability function analysis for turning Inconel625

The individual desirability (di) is calculated for all the responses depending upon the type of quality characteristics. Since the SR, TW are possessing minimization objective and MRR is possessing maximization objective, the equation corresponding to smaller and larger the better type is selected. The computed individual desirability for each quality characteristics using Equation 3 and Equation 4 are shown in Table IV. The composite desirability values (dG) are calculated using Equation 6. Finally, these values are considered for optimizing the multi-response parameter design problem. The results are given in the Table V. Optimal cutting condition for turning Inconel625 is cutting speed set as 75 m/min, feed set as 0.2 mm/rev and depth of cut set as 0.75mm. In addition, a statistical ANOVA was performed to see those process parameters that significantly affect the responses. The experimental results were analyzed with ANOVA which is used for identifying the factors which significantly affecting the performance measures. The results of the ANOVA for all the responses are given in Table VI. This analysis was carried out for significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%. It can be found that feed and cutting speed are the significant parameters for affecting SR with p-value of 0.000 and 0.144. Similarly found that depth of cut and feed are the significant parameters for affecting TW with p-value of 0.000 and 0.042 and feed and depth of cut are the significant parameters for affecting MRR with p-value of 0.013 and 0.034.

Table IV
Individual desirability (d_i) and Composite desirability (d_G)

Trial No.	**Individual Desirability (d_i)**			**Composite desirability (d_G)**
	SR	MRR	TW	
1	0.916	0.128	0.968	0.843
2	0.923	0.147	0.935	0.874
3	0.941	0.223	0.931	0.846
4	0.663	0.209	0.951	0.771
5	0.680	0.066	0.951	0.839
6	0.669	0.223	0.797	0.827
7	0.203	0.564	0.878	0.802
8	0.164	0.497	0.842	0.773
9	0.217	0.855	0.237	0.852
10	0.965	0.151	0.980	0.876
11	0.878	0.243	0.947	0.946
12	0.963	0.610	0.870	0.912
13	0.662	0.497	1.000	0.855
14	0.658	0.229	0.992	0.845
15	0.693	0.631	0.298	0.000
16	0.000	0.326	0.777	0.766
17	0.088	0.643	0.704	0.775
18	0.138	0.485	0.679	0.000
19	1.002	0.000	0.987	0.824
20	1.000	0.103	0.935	0.835
21	0.893	0.513	0.245	0.866
22	0.671	0.274	0.947	0.922
23	0.708	0.564	0.931	0.830
24	0.635	1.000	0.164	0.798
25	0.138	0.564	0.842	0.803
26	0.165	0.564	0.752	0.000
27	0.335	0.390	0.000	0.843

Table V
Parameters effects for composite desirability (dG)

Parameters	**Levels**		
	1	**2**	**3**
v	**0.823**	0.759	0.653
f	0.765	**0.854**	0.616
a	0.660	0.829	**0.746**

Table VI
ANOVA for all responses

ANOVA for SR					
Source	DF	SS	MS	F	P
A	2	0.211	0.105	2.13	0.144
B	2	41.592	20.796	419.68	0.000
C	2	0.0648	0.032	0.65	0.531
Error	20	0.9911	0.049		
Total	26	42.859			
ANOVA for TW					
A	2	57065	28532	2.77	0.086
B	2	76639	38320	3.72	0.042
C	2	35767	178803	17.38	0.000
Error	20	205762	10288		
Total	26	697072			
ANOVA for MRR					
A	2	0.09545	0.04772	0.92	0.414
B	2	0.56391	0.28195	5.45	0.013
C	2	0.41596	0.20798	4.02	0.034
Error	20	1.03402	0.05170		
Total	26	2.10933			

V. CONCLUSION

The present investigation is focused on optimization of CNC turning Inconel 625 during dry conditions. Taguchi's technique and Desirability function analysis were used for solving Turning parameter optimization. The following can be concluded from the present study.

1. Optimization of the single response problem using Taguchi method provided an effective methodology for the design optimization of turning parameters. Optimum parameter setting for minimization of SR is obtained at a cutting speed of 125 m/min, feed 0.1 mm/rev and depth of cut 0.25 mm, ie, $v_3f_1d_1$. Optimum parameter setting for minimization of TW is obtained at a cutting speed of 75 m/min, feed 0.1 mm/rev and depth of cut 0.25 mm, ie, $v_1f_1d_1$. Optimum parameter setting for maximization of MRR is obtained at a cutting speed of 100 m/min, feed 0.3 mm/rev and depth of cut 0.75 mm, ie, $v_2f_3d_3$.
2. Desirability function analysis for the optimization of multi-response problems is a very useful tool for turning Inconel625. Optimum cutting condition for minimization of SR, TW and maximization of MRR is cutting speed set as 75 m/min, feed set as 0.2 mm/rev and depth of cut set as 0.75mm
3. The results of ANOVA, the feed and cutting speed are the significant cutting parameters for affecting the SR. similarly feed and depth of cut are the significant cutting parameters for affecting the MRR and TW.

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