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Experimental Investigation of Dry Turning Process Parameters for Inconel 625 Super Alloy by Response Surface Methodology

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ABSTRACT

Inconel 625 is a Nickel-Chromium-Molybdenum; heat and corrosion resistant super alloy developed for components widely used in aerospace, automobile, chemical and petrochemical industry. It is one of the most difficult to cut material due to its microstructure, high strength and work hardening phenomenon. It is preferable to machine this alloy at high speed with dry condition, which results in the decreased region of plastic deformation and ultimately lowers the cutting force required. In present work experimental investigation is done by using response surface methodology (RSM), for dry turning of inconel 625 using ceramic insert. Statistical analysis is done by using analysis of variance (ANOVA) and it was observed that feed has most significant effect on average surface roughness. Finally optimal conditions of machining parameters were determined for minimization of average surface roughness

Keywords : *Ceramic Insert, Dry Turning, Inconel 625, RSM*

1. Introduction

Inconel 625 is a nickel based heat resistant super alloy. Due to the properties viz. high tensile, creep, and rupture strength; high fatigue and thermal-fatigue strength, oxidation resistance, excellent weldability and brazeability, there is wide application of material in the field of aerospace and automobile industry. Strength of inconel alloy 625 is derived from the stiffening effect of molybdenum and niobium on its nickel-chromium matrix; hence precipitation hardening treatments are not essential. This combination of elements is also responsible for improved resistance to a wide range of corrosive environments of unusual severity as well as to high-temperature effects such as oxidation and carburization. Its allowable design strength at elevated temperatures usually ranges between 1200°-1400°F (649-760°C).

Due to high strength to weight ratio, components produced by using super alloys are comparatively smaller and lighter than conventional steel. Hence finds greater significance of the material in the field of aerospace and automobile industry [10].

Nickel based super alloys have few characteristics which are accountable for its poor machinabilty. They have presence of an austenitic matrix and hard abrasive carbides in their microstructure. They also have a characteristic to weld with the tool material at elevated temperature which is being generated during machining, further it tends to form a Built up edge (BUE).These characteristics of the alloy results in the generation of high temperature greater than 1000 °C in the cutting zone which leads to increased rate of flank wear, cratering and notching for the respective cutting tool material and machining conditions applied. Usually the machining of Nickel based super alloy is carried out in dry conditions at high speed, it results in the decreased region of the plastic deformation because of the less contact period of cutting tool and work piece material which decreases the required cutting force.

2. Literature Review

Altin et al. [1] has investigated the effect of cutting tool coating material and cutting speed on cutting forces and surface roughness by using Taguchi experimental design for the Hastelloy X & Inconel 625 material. From the results of analysis of variance (ANOVA) and signal-to-noise(S/N) ratio, effects of parameters on both average surface roughness and cutting forces were statistically investigated.

It was found that feed rate and cutting speed has higher effect on cutting force for the Hastelloy X where as feed rate & cutting tool material had higher effect on cutting force for Inconel 625.The average surface roughness is affected by the cutting tool and feed rate for both materials [1].

Jahanbaksh, et al. [2] were studied that, as per the machinability aspects of the nickel based super alloys, rapid tool wear is one of the major factor. Effect of process parameters on material removal rate and tool wear while turning of Inconel 625 by using whisker ceramic insert was studied. The whisker reinforced alumina oxide based ceramic insert having round geometry was used. Highest desirability was achieved at cutting speed 200 m/min, feed 0.2 mm/rev and depth of cut 1.14 mm. It was found that when there is equivalent significance of the tool wear as well as material removal rate, depth of cut should be preferred at the middle range [2].

Soo, et al. [3] studied of five different coatings and two PCBN grades during high speed turning of Inconel 718.The workpiece material Inconel 718 was solution treated & aged condition with a bulk hardness 44 HRC. Design of experiment is carried out by Taguchi L18 orthogonal array.From the experimentation it was found that during machining at 200m/min, TiSiN coating provides better tool life by 40% as compare to uncoated PCBN. At higher speed depth of cut notching was the most important mode of tool wear where as uniform flank and crater wear were dominant. While using medium CBN content & high cutting fluid pressure, greater subsurface compressive residual stresses were obtained [3].

Marimuthu, et al. [4] has optimized the process parameters during the dry turning of Inconel 625 by Taguchi method. For the optimization of turning parameters Desirability function analysis was implemented. Optimal machining parameters for the minimization of surface roughness, tool wear and maximization of Material Removal Rate were found at Cutting speed of 100m/min, feed at 0.3 mm/rev and depth of cut of 0.75 mm. By the ANOVA results, feed and cutting speed are significant for affecting surface roughness whereas feed and depth of cut are significant for MRR and tool wear [4].

Palakudtewar and Gaikwad [5] have discussed regarding the capabilities of dry machining of super alloys by using specially coated carbide tool inserts. Dry machining is usually associated with high speed machining results in amount of heat dissipate with the chip is more and has less contact time of chip to transfer heat to tool material. As the cutting speed increases the region of plastic deformation decreases, which results in the lower force required for the chip formation. During machining in dry conditions, surface roughness decreases with the increase in cutting speed. They have investigated the response parameters as surface roughness, material removal rate and cutting force during dry turning of Inconel 718 by using Taguchi method. From experimental results observed that machining of Inconel 718 was not possible at very high speed 120 m/min due to tool tip wear occurs suddenly [5].

Venkatsen et al. [6] investigated the effect of process parameters on machinability of a Ni- Cr alloy, inconel 625 by using PVD AlTiN coated carbide inserts. Experimental design was done by using Taguchi L9 Orthogonal array for the response parameters as cutting force and surface roughness. Machining is performed under the dry cutting conditions. For the optimal parameters the analysis is done by using ANOVA and regression analysis. It was observed that performance of the PVD coated inserts is better in terms of cutting force and surface roughness. Quadratic multiple regression model is implemented to develop the relationship between the independent variables and dependent variables. From the statistical analysis it was also found out that surface roughness is highly influenced by feed rate and followed by cutting speed. As compared to depth of cut and cutting speed, feed rate is the most significant parameter for affecting the cutting force components. From his research, within the experimental region, the potential and effectiveness of the PVD Al TiN coated carbide insert has been identified while dry turning of Inconel 625 [6].

Kortabarria et al. [7] studied residual stress profiles induced by different dry face turning conditions which were compared by employing X-ray diffraction method, Hole-Drilling method and Finite Element Modeling. It is well known that the surface integrity condition has a great influence on the machined parts fatigue life, specially the residual stress profile. This issue is important when machining aeronautical critical parts, even more due to the difficulty of machining of nickel based super alloys, such as Inconel 718. Research work is focused on the identification of the residual stress profile uncertainty of experimental and numerical measurements. For this proposal, several measurements were carried out on a set of Inconel 718 samples machined with different conditions of cutting speed and feed rate under dry conditions. Although residual stress profiles are similar, differences are found between the three measurements techniques user in this study [7].

Rafai et al. [8] has done the comparative study of dry and flood turning in terms of the response parameters as dimensional accuracy and surface roughness. Experimentation and statistical analysis is done by traditional analysis, Pareto ANOVA analysis and Taguchi method. Machining of hardened alloy steel AISI 4340 with 30 HRC is done by using square shaped inserts with cobalt coating. From the experimental results, it was observed that Utilization of a low feed rate improves the surface roughness of the turned part. At a low cutting speed, dry turning gives better quality in terms of he circularity of turned parts. For the certain combinations of the cutting parameters, dry turning gives better dimensional accuracy compared to the flood turning [8].

From literature review it is found that, very few researchers have done research work on machining of Inconel 625 super alloy by different conditions of the machining parameters and cutting tool inserts. Present work is carried out to determine the influence of different process parameters on average surface roughness during machining of Inconel 625 under dry conditions.

3. Experimental Work

3.1 Experimental Set Up: Inconel 625 is a nickel based heat resistant alloy .It is widely used for various applications in the field of Automotive, Aeronautics & Chemical process industries because of the excellent mechanical properties at extremely high temperature. For the experimentation Inconel 625 round bar is selected as work piece material. Detail chemical composition of the Inconel 625 alloy is as shown in Table 1.

While machining of super alloys, main factors affecting the performance of cutting tool are high hardness, resistance to wear, chemical inertness, fracture toughness. Ceramic tools retain hardness due to their hot hardness. Hence ceramic insert with round geometry is used [9]. For conducting the experiment a high speed CNC machine is used.

Table 1. Chemical Composition (%) of Inconel 625 Super alloy

Ni	Cr	Mo	Nb	Fe	Ti	Al
58	22	9	3.5	2	0.2	0.2

3.2 Methodology : Response Surface methodology is used for the design of experiments. It is a collection of mathematical and statistical techniques which are useful for modeling and analysis of the problems in which a response is affected by several variables and objective is to optimize the desired response. Regression model is developed to define the relationship between response and independent variables.

In present study, the independent variables viz. Cutting Speed, Feed, Depth of cut is considered against the response as average surface roughness. Five different levels of the input parameters are considered, to develop the design matrix by using Central Composite Design. From literature review and trial experiments the different five levels of the input parameters are finalized as given in Table 2.

4. Result & Discussion

Table 3 shows the RSM'S Central Composite Design Matrix in the coded values and their output response as average surface roughness. Further analysis is done with coded units by using Minitab software.

Table 2. Levels of Input Process Parameters

Parameter	Unit	Levels				
		1.68	1	0	-1	-1.68
Cutting speed (Vc)	m/min	217	200	175	150	133
Feed (f)	mm/rev	0.28	0.25	0.20	0.15	0.12
Depth of Cut (ap)	mm	0.41	0.27	0.23	0.15	0.10

Table 3. RSM's CCD Design Matrix in Coded Value

No. of Run	Cutting Speed	Feed	Depth of Cut	Ra
	m/min	mm/rev	mm	µm
1	-1	1	-1	0.30
2	1	-1	-1	0.29
3	-1.68	0	0	0.37
4	0	-1.68	0	0.14
5	0	0	0	0.24
6	0	0	0	0.24
7	0	0	1.68	0.41
8	-1	-1	1	0.27
9	-1	-1	-1	0.27
10	1	1	-1	0.23
11	1.68	0	0	0.26
12	0	0	0	0.24
13	1	1	1	0.34
14	0	0	0	0.24
15	0	0	0	0.24
16	0	0	-1.68	0.32
17	0	0	0	0.24
18	-1	1	1	0.51
19	0	1.68	0	0.29
20	1	-1	1	0.19

5. Analysis of Variance for Ra

From the analysis of variance for the average surface roughness (Ra) it is observed that, adequacy of the model is achieved with the R –Sq = 99.88% and R-Sq (adj) = 99.78% at the 95 % confidence level.

It is also found that, feed is affecting most significantly for the average surface roughness followed by cutting speed. The residual plots for the results are as shown in Figure 1.

Table 4 – ANOVA Table for Ra

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.123	0.123	0.137	940.62	
Linear	3	0.053	0.052	0.017	1194.49	
Cutting Speed	1	0.017	0.016	0.016	1130.45	0.000
Feed	1	0.027	0.025	0.025	1762.50	0.000
Depth of Cut	1	0.008	0.010	0.010	690.52	0.000
Residual Error	10	0.000	0.000	0.000		
Lack of Fit	5	0.000	0.000	0.000		
Pure Error	5	0.000	0.000	0.000		
Total	19	0.124				
S = 0.0038258		**PRESS** =0.00113867				
R-Sq = 99.88%		**R-Sq(adj)** = 99.78%				

The regression equation for the model can be expressed as follows:

$$Ra = 0.23800 - 0.5854Vc + 0.07099f + 0.04550\,ap + 0.07470Vc^2 - 0.02533Feed^2 + 0.12672\,ap^2 - 0.06048\,Vc * f - 0.06950\,Vc * ap + 0.13989\,f * ap$$

The ANOVA is given in Table 4. Surface plots for the average surface roughness as shown in Fig 2(a) shows that the nature of surface plot for Surface Roughness verses cutting speed (Vc) and feed (f) where as Fig 2(b) shows the surface plot for Average Surface Roughness verses Depth of Cut (ap) and Cutting Speed (Vc).From both Fig 2(a) and Fig 2(b) it is observed that , Average surface roughness value increases with minimum level cutting speed and maximum level of feed, depth of cut.

Further for the present Response Surface Experimental Design, response optimization is carried out to find out optimal condition of the input parameters to minimize the output response as average surface roughness. Optimization plot for Ra is as shown in Fig. 3. For the model composite desirability is achieved as 1 while minimum average surface roughness can be achieved as 0.12 µm.

6. Conclusion

For the machining of Incomel 625, dry turning at high speed is desirable. From the Response surface Methodology experimental Design and analytical analysis it has been found that, Feed is most significant factor affecting the average surface roughness followed

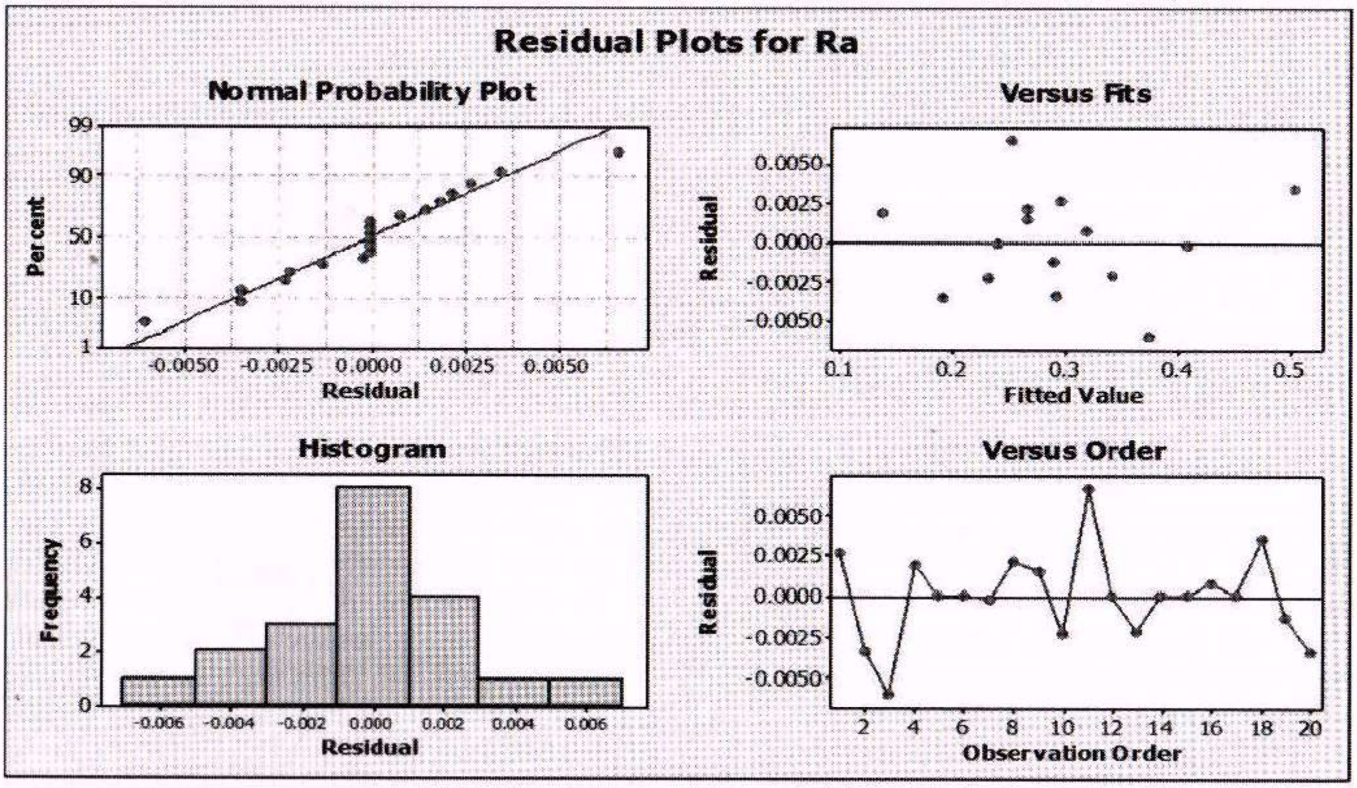
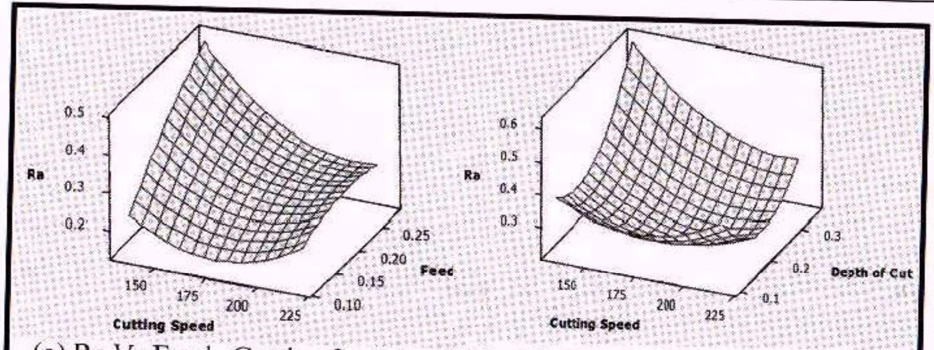


Fig.1. Residual Plots for Ra



(a) Ra Vs Feed , Cutting Speed (b) Ra Vs Depth of Cut, Cutting Speed

Fig. 2. Surface Plots for Ra

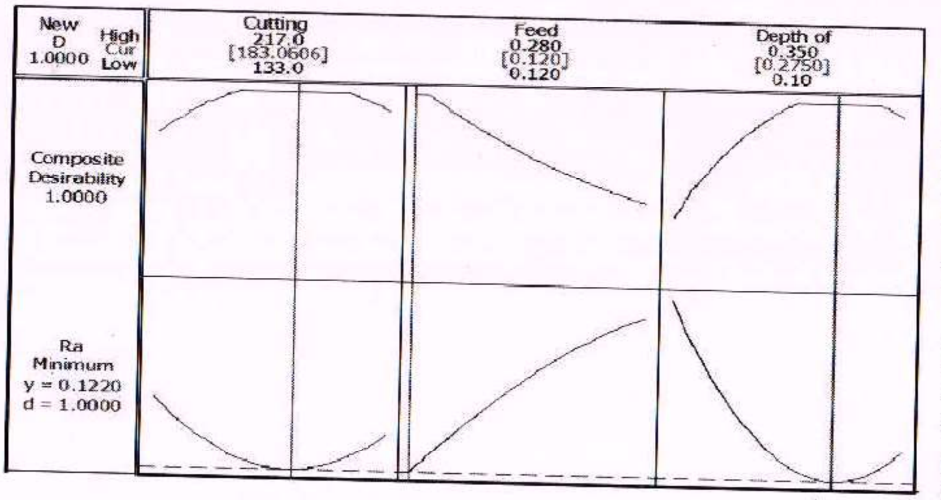


Fig. 3. Optimization Plot for Ra

by Cutting Speed. Optimization of cutting parameters is done by D Optimality and Response Optimizer. Optimal condition of process parameters is achieved as cutting speed at 183.06 m/min, Feed at 0.12 mm /rev, depth of cut 0.275 mm and output response in terms of average surface roughness (Ra) is achieved as 0.12 µm.

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