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Optimization Of Process Parameters During Dry Turning Of Inconel 625 By Using Sialon Ceramic Insert

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Abstract : *In present work, experimental investigation is done by using response surface methodology (RSM), for dry turning of inconel 625 using Sialon ceramic round shape insert. Effect of input cutting parameters such as Cutting speed, feed and depth of cut is studied for output response parameters as average surface roughness (Ra) and material removal rate (MRR) Statistical analysis is done by using analysis of variance (ANOVA) and it was observed that feed has most significant effect on average surface roughness whereas depth of cut is most significant factor affecting material removal rate (MRR) followed by cutting speed. Finally Multi response optimization is carried out by using RSM'S D- Optimal method, to find out optimal conditions of machining parameters were determined for minimization of average surface roughness (Ra) and maximization of Material Removal Rate (MRR).*

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I. Introduction

Super alloys are heat resistant alloys of nickel or cobalt which maintains structural, surface and property stability; at elevated temperatures usually 70% of the absolute melting temperature under high stress, and in severe environment. Super alloys usually have poor machinability due to their work hardening phenomenon. The especially characteristics that provide superior high-temperature strength also make them difficult to machine. Additionally, decreased cutting tool speeds can limit productivity. They have a low thermal conductivity, due to which heat generated during machining is neither transferred to the chip nor the work piece, but is heavily concentrated in the cutting edge area. While machining, consequently increases tool tip temperatures and tends to excessive tool wear, which can limit cutting speeds and reduce useful tool life.

High tensile, creep, and rupture strength, fatigue and thermal-fatigue strength, oxidation resistance and excellent weldability and brazeability are the properties of INCONEL alloy 625 , which are resposible for the wide applications in the field of aerospace and automobile. Strength of INCONEL alloy 625 is derived from the stiffening effect of molybdenum and niobium on its nickel-chromium matrix; thus precipitation hardening treatments are not required.Service temperatures range from cryogenic to 1800°F (982°C). Strong solution strengtheners and hard abrasive precipitates which makes it difficult for machining**.**

I. Literature Review

Machining of Nickel and Ni based alloy can be readily accomplished providing fundamental principles which affects their machinabilty.Consequently, use of powerful and rigid machine tool tends to best results. In accordance with these properties and machine requirements is that essential to select proper tooling in order to minimize cutting forces, to have maximum edge strength and to withstand highest possible cutting temperature.

N.H.Rafai et al 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 compa
red to the flood turning.

A .Kortabarria et al has studied Residual stress profiles induced by different dry face turning conditions are compared 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 used in this study.

R Ramanujam et al has optimized the dry turning parameters of Inconel 718 based on Taguchi L9 orthogonal array to evaluate the responses such as cutting force, surface roughness and tool wearBy the experimental analysis using RSM & ANOVA, the optimal cutting parameters for Ra, Rt, Rz and Fz were determined cutting speed at 50 m/min , feed at 0.103mm /rev and depth of cut 0.4 mm respectively. It was also observed that feed is the most significant factor for Ra, Rt and Rz where as feed rate and depth of cut was determined as most significant parameters affecting Fz. At cutting speed Vs=30 m/min, tool wear occurs since low cutting speed and short cutting length.

K.Venkatsen et al 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 & 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

A.R.Sharman et al (2014) has done the investigation of the effects of tool nose radius on the residual stress distribution developed in Inconel 718 by finish turning. Cutting force, microstructural alteration and residual stress distribution have been analysed for machining trials examining 2, 3, 4 and 6 mm radius tools at various feed rates and in both the new and worn tool condition. Machining was carried out by using carbide inserts with multilayer $TiCN/Al_2O_3/TiN$ coating. In general the results show that an increase in tool nose radius results in; increased radial cutting forces, increased microstructural deformation depth, higher near surface tensile stresses (up to 1550 MPa with a worn tool), and deeper tensile and compressive residual stress distribution.

From literarure review it is observed that very few resercher has done research work Inconel 625 alloy. It belongs to D-2 group of the Ni alloys which consist of Group D-1 in age hardened condition and other age hardenable alloys. Strong solution strengtheners and hard abrasive precipitates which makes them difficult for machining. Hence present work is done for the experimental analysis of dry turning process parameters for Inconel 625.

II. Experimental Work

3.1 Experimental Set Up

For the experimentation Inconel 625 round bar stock of 25 mm dia is selected as work piece material. It is used for its high strength, excellent fabricability (including joining), and outstanding corrosion resistance, within service temperatures range from cryogenic to 1800°F (982°C). Chemical Composition of material is given below in Table 3.1.

Table 3.1 – Chemical Composition (%) of Inconel 625 Super alloy

C%	Si %	Mn %	S%	P %	Cr %	Fe %	Mo %
0.015	0.255	0.126	0.005	0.008	22.890	2.774	9.275
Nb %	**Cu %**	**V%**	**Al %**	**Ti %**	**W%**	**Ni %**	
3.326	0.130	0.022	0.143	0.227	0.129	60.522	

For the machining of Ni based alloys high speed machining under dry condition is desirable. Performance of the carbide insert is not so effective for machining of Ni alloys. Sialon is a special type of ceramic which is a mixture of silicon nitride and aluminum oxide. It has the best chemical stability and resists notch wear. Hence for experimentation, round shape insert RNGN120700E 6060(Sandvik –Make) is used with tool holder CRSNR 2525. All the experiments are carried out on a high speed CNC lathe machine (Jobber Jr – ACE make).

3.2 Methodology

Design of experiment is carried out by using Response surface methodology (RSM) with the 5 levels of input process parameters i.e cutting speed, feed and depth of cut against the response parameters as average surface roughness and material removal rate. Table 3.2 shows the levels of input process parameters which are selected based on trial experiments within range of recommended conditions of machining parameters provided by manufacturers catalogue.

Table 3.2 – Levels of Input Process Parameters

Parameter	Unit	Levels				
		+ α	1	0	-1	- α
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

III. Results And Discussion

Table 4.1 shows the RSM'S CCD Design Matrix in coded value and the out response in terms of average surface (Ra) and material removal rate (MRR). Analysis of variance for the average surface roughness and material removal rate is carried out as shown in Table 4.3 and Table 4.4

Table 4.2 RSM's CCD Design Matrix in Coded Value

Experimental Run	Cutting Speed	Feed	Depth of Cut	MRR	Ra
	m/min	mm/rev	mm	gm/sec	μm
1	-1	1	-1	0.0049	0.30
2	1	-1	-1	0.0046	0.29
3	- α	0	0	0.0062	0.37
4	0	- α	0	0.0060	0.14
5	0	0	0	0.0056	0.24
6	0	0	0	0.0056	0.24
7	0	0	α	0.0064	0.41
8	-1	-1	1	0.0068	0.27
9	-1	-1	-1	0.0054	0.27
10	1	1	-1	0.0040	0.23
11	α	0	0	0.0052	0.26
12	0	0	0	0.0056	0.24
13	1	1	1	0.0058	0.34
14	0	0	0	0.0056	0.24
15	0	0	0	0.0056	0.24
16	0	0	- α	0.0039	0.32
17	0	0	0	0.0056	0.24
18	-1	1	1	0.0061	0.51
19	0	α	0	0.0050	0.29
20	1	-1	1	0.0062	0.19

The regression equation of model for average surface roughness (Ra) can be expressed in equation (1)

$$Ra = 0.23800 – 0.5854Vc + 0.07099F + 0.04550\ Ap + 0.07470Vc * Vc - 0.02533F*F + 0.12672\ Ap*Ap - 0.06048\ Vc * F - 0.06950Vc *Ap + 0.13989\ F*Ap \quad \_\_\_\ \_\_\_ \quad (1)$$

Table 4.3 - ANOVA for average surface roughness (Ra)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.123909	0.123909	0.13768	940.62	
Linear	3	0.053635	0.052450	0.017483	1194.49	
Cutting Speed	1	0.017225	0.016546	0.016546	1130.45	0.000
Feed	1	0.027439	0.025797	0.025797	1762.50	0.000
Depth of Cut	1	0.008971	0.010107	0.010107	690.52	0.000
Residual Error	10	0.000146	0.000146	0.000015		
Lack of Fit	5	0.000146	0.000146	0.000029		

From the analysis for Ra, it is observed that model adequacy is achieved with R-Sq = 99.88% and R-Sq (adj) = 99.78% with 95 % confidence level. Fig 4.1 shows residual plot for average surface roughness.

Contour plot for Ra Vs Cutting Speed and Feed as shown in fig 4.2 whereas Graph 4.4 shows the surface plot. From the Contour plot and surface plot it is observed that, Surface roughness is having increasing trend with the increase in feed rate and decreasing trend with increase in cutting velocity.

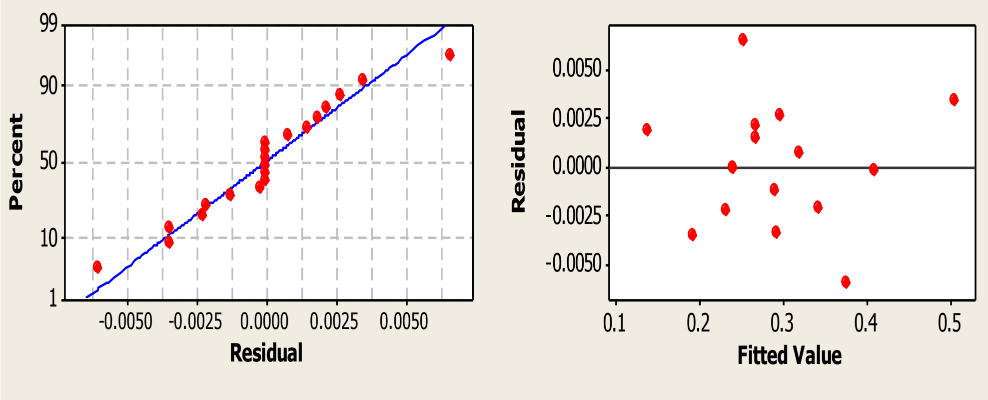


Fig 4.1 Residual Plot for average surface roughness (Ra)

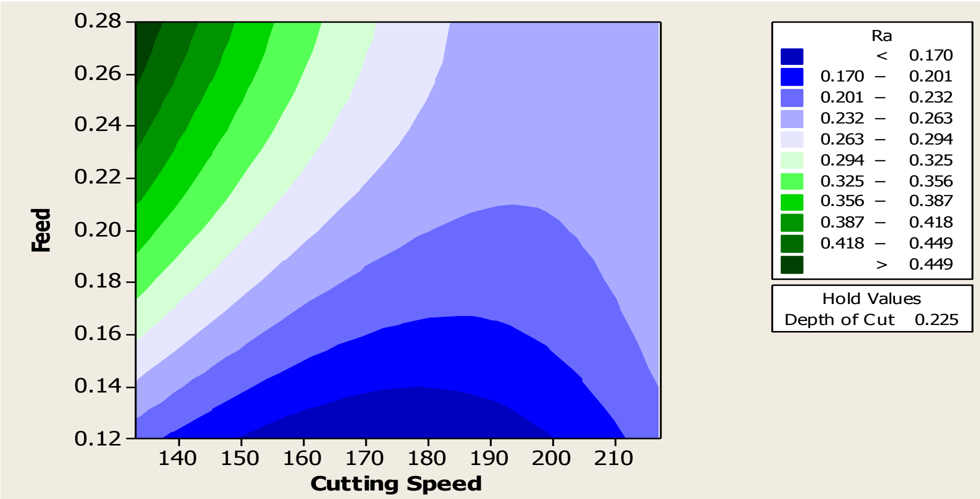
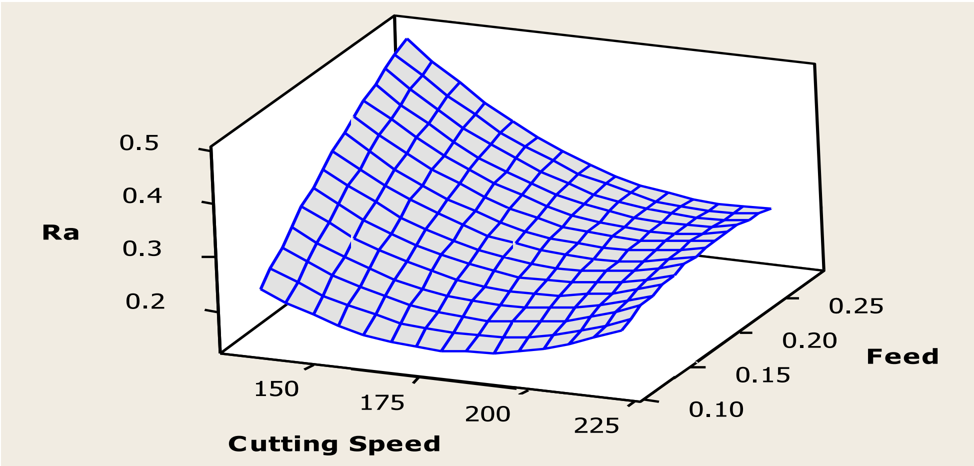


Figure 4.2 - Contour Plot for Ra Vs Cutting Speed and Feed



Graph 4.1 - Surface Plot for Ra Vs Cutting Speed and Feed

The regression equation of model for material removal rate (MRR) can be expressed in equation (2) , while the analysis of variance for material removal rate is given in table 3.5

MRR = 0.0107990 - 0.00672156F + 0.0105687Ap - 0.00628044F*F -0.0220274Ap*Ap - - - (2)

Table 3.5 - ANOVA for Material Removal Rate (MRR)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.000011	0.000011	0.000001	277.02	
Linear	3	0.000010	0.000010	0.000003	796.67	0.00
Cutting Speed	1	0.000001	0.000001	0.000001	323.61	0.00
Feed	1	0.000001	0.000001	0.000001	260.67	0.00
Depth of Cut	1	0.000008	0.000008	0.000008	1805.73	
Residual Error	10	0.000000	0.000000	0.000000		
Lack of Fit	5	0.000000	0.000000	0.000000	33.44	

From the analysis for MRR, also it is observed that model adequacy is achieved with R-Sq = 99.60% and R-Sq (adj) = 99.24% with 95 % confidence level. Fig 4.2 shows residual plot for material removal rate. Contour plot for MRR Vs Cutting Speed and Depth of cut as shown in fig 4.4 whereas Graph 4.2 shows the surface plot.

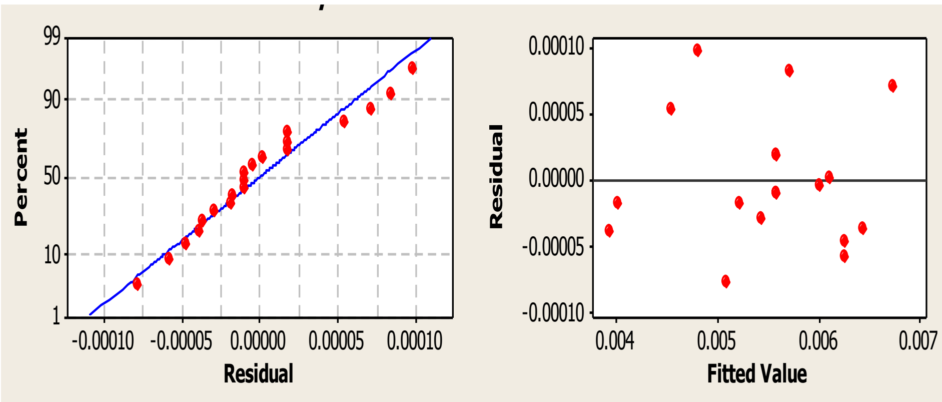


Fig 4.3 - Residual Plot for Material Removal Rate

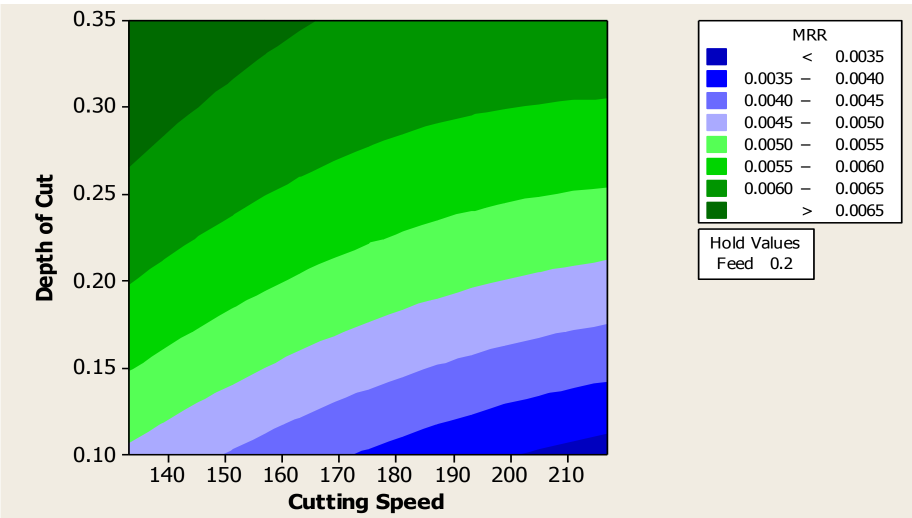
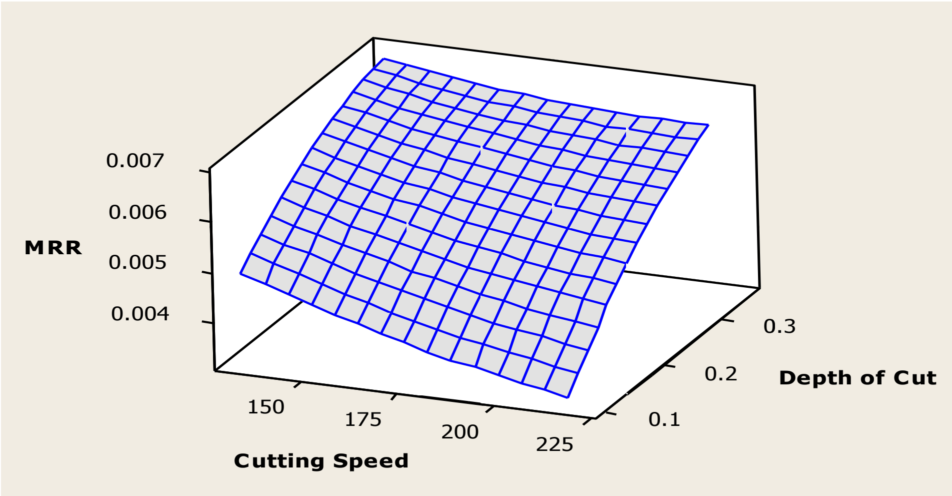


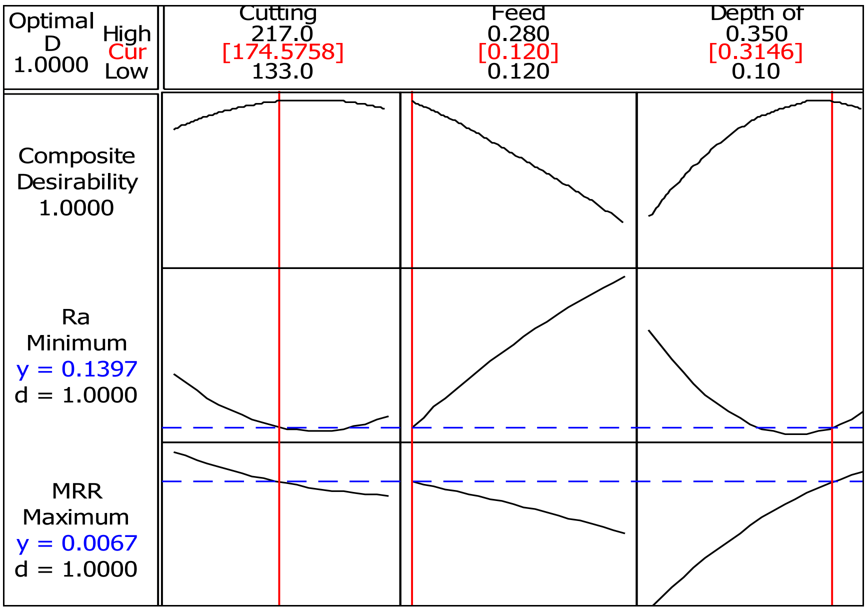
Fig 4.4 – Contour plot for MRR Vs Cutting Speed, Depth of Cut



Graph 4.2 - Surface Plot of MRR Vs Feed, Cutting Speed

From the Contour plot and surface plot for MRR, it is observed that the material removal rate (MRR) is having an decreasing trend with the increase in cutting velocity and feed rate.

Further the multi response optimization is carried out by using D Optimality method and response optimizer, in order to minimize Average surface roughness where as to maximize material removal rate. Optimization plot for Ra and MRR as shown in Graph 4.2.For the model composite desirability is achieved as 1. Average surface roughness can be achieved as 0.139 while Material removal rate as 0.0067 gm/sec



Graph 4.3 - Optimization Plot for Surface Roughness and Material Removal Rate

IV. Conclusion

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 by Cutting Speed where as Depth o cut is most significant factor affecting material removel rate. Also it is observed that better performance of Sialon Ceramic round shape insert (RNGN120700E 6060) , during high speed machining of the Heat resistant Super Alloy- Inconel625 under dry condition.

From the multi response optimization the optimal conditions for the input cutting parameters are achieved at Cutting speed as 174.57 m/min, feed as 0.12 mm /rev, Depth of cut as 0.31 mm for the output response parameters average surface roughness as 0.139 and material removal rate as 0.0067 gm/sec.

After performing confirmation experiment with these optimal conditions of input parameters, it was observed that the percentage variation between predicted values and confirmation experimental values for the responses less than 5%.

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