ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

INFLUENCE OF CUTTING PARAMETERS ON DRY MACHINING OF INCONEL 625 ALLOY WITH COATED CARBIDE INSERT - A STATISTICAL APPROACH

K. Venkatesan, R. Ramanujam, Vimal Saxena, Nilendukar Chawdhury and Vikash Choudhary
School of Mechanical and Building Science, VIT University, Vellore, India
E-Mail: venkatesan.kannan@vit.ac.in

ABSTRACT
This paper investigates the influence of cutting parameters on machinability of a Ni-Cr alloy, Inconel 625, with coated carbide inserts (PVD AlTiN). In this work, a bar type Inconel 625 sample was chosen and based on Taguchi's L9 orthogonal array, turning experiments were conducted at different levels of cutting speed, feed rate and depth of cut. The performance measures, cutting force and surface roughness, were measured to analyze the machining effectiveness. The signal-to-noise (S/N) ratio, the analysis of variance (ANOVA), and regression analysis were employed to find the optimal levels and to analyze the effect of the cutting parameters for the objective of lower cutting force and better surface finish under dry cutting conditions. The obtained results indicated that PVD coated inserts performed better in terms of cutting force and surface roughness with designed cutting parameters. The relationship between the independent variables and dependent variables is determined through a quadratic multiple regression model. From the statistical analysis, the results show that surface roughness is greatly influenced by feed rate and followed by cutting speed. The feed rate exhibits the maximum influence on cutting force components as compared to the depth of cut and cutting speed.

Keywords: inconel 625, surface roughness, cutting force, Taguchi technique, coated carbide.

INTRODUCTION
Nickel based super alloys have found widespread applications in aerospace, nuclear, chemical and petrochemical industries due to their excellent thermo-mechanical properties. However, they pose serious challenges to the manufacturing sector due to their difficult to cut nature causing metallurgical damages to the workpiece due to the very high cutting forces which leads to work hardening, surface tearing and distortion in final machined components.

Among the different nickel alloys, Inconel 625 is generally known to be one of the most difficult materials to machine because of its high hardness, high strength at high temperature, affinity to react with the tool materials, and low thermal diffusivity [1-2]. Inconel 625 is a non-magnetic, corrosion and oxidation resistant super alloy and shows prominent strength and toughness in the temperature range cryogenic to 2000°F [3]. Inconel 625, a solid solution hardened alloy, comprising of refractory metals, columbium and molybdenum, in a nickel-chromium matrix, has widespread application in aeronautic, aerospace, chemical and petrochemical industries. Due to its inherent capability to resist creep and corrosion, the super alloy is of high importance in heavy water plant to withstand the cracked ammonia environment [4]. Even though these properties are desirable from design perspective, they pose serious challenges to the manufacturing sector. The surface quality generated during the machining operation has been the prime focus of researchers to investigate properties such as surface finish, surface alteration etc. [5-12]. During the machining process, intense friction is generated at the tool-workpiece interface and the lower thermal conductivity of the alloy results in severe plastic deformation in the local area of workpiece due to excessive heat generation. This effect coupled with work hardening results in debonding of the tool substrate leads to a series of flaws, such as surface finish, excessive tool wear, frequent tool change, short tool life, low productivity, and large amount of power consumption etc. [13, 14]. A. Devillez *et al*., [15] performed an experimental investigation to determine the optimal value for surface integrity during dry machining of Inconel using a coated carbide insert. Various cutting speeds were employed with a semi finishing condition (0.5mm depth of cut and 0.1mm/rev feed rate). Cutting speed of 60m/min was stated as to be optimal value in dry machining giving acceptable surface quality.

The surface quality of the machined part not only depends on the machining condition but also the type of cutting insert used. The behavior of the tool can be attributed to the type of coating used. Coatings increase the wear resistant properties of the tool and may also reduce cutting forces and temperatures. Jindal *et al*., [16] did a comparative investigation of PVD TiN, TiCN, and TiAlN coating on cemented carbides at a cutting speed of 46m/min and 76m/min. he found out that TiAlN have superior properties than TiCN or TiN as it possesses higher hardness at elevated temperature (T ≥ 750ºC). This is due to the fact that TiAlN forms a protective layer of Al203 and an intermediate layer comprising of Ti, Al, N and O_2 leading to higher oxidation resistance. Similar results were obtained by Prengel *et al*., [17]. It was concluded from his work that multi-layer coated carbide tool performed better than monolayer coated carbide at the higher speed of 76m/min.

In machining high temperature super alloys, the cutting fluid plays an important role. But the adverse effect of cutting fluids cannot be neglected. Cutting fluid waste must undergo proper treatment prior to its disposal.

ARPN Journal of Engineering and Applied Sciences

Also prolonged exposure can cause serious health problems to the machine operators. All these factors sum up a significant cost which is four times the cost of cutting tools used and 17% of the total manufacturing cost. Therefore the feasibility of dry cutting method or near dry cutting method has received a significant attention in the past decade as it is reduces the overall manufacturing cost as well as eliminates all the adverse negative effect associated with it [18].

Few research actions on taguchi based optimization of machining parameters on Inconel alloy were investigated. R.S. Pawade [19] studied the optimization of cutting force and surface roughness through the optimal setting of performance level of cutting speed, feed rate, depth of cut and tool cutting edge geometry in high-speed turning of Inconel 718 using PCBN tools has been discussed. The authors concluded that the effect of depth of cut and feed in variation of feed force were affected more as compare to speed. M. Nalbant *et al*. [20, 21] developed the linear regression model for cutting force and surface roughness in dry turning operation. The regression equation was developed by a single cutting parameter i.e. cutting speed were chosen for in-process surface roughness and cutting force prediction system.

By using Analysis of variance (ANOVA) and prediction model a strong linear relationship among the dominant parameters (feed rate and cutting tool) and the response (cutting force and surface roughness) was found. D. D'Addona *et al*., [22] studied for tool flank wear growth for optimal tool life estimation by utilizing the neural network model. The experimental data set from measured tool flank wear were employed to train the neural network models. Predictive neural network models were found to be capable of better predictions tool flank wear within the range.

The present work focuses on finding the optimal machining parameters setting for machining of Inconel 625 to achieve better surface finish and lower cutting force under dry machining conditions using coated carbide tool. Cutting force and the surface roughness was analysed for various cutting conditions. Taguchi based statistical approach is employed to investigate the relationship between various machining parameters and their response. By applying ANOVA and mathematical model, the response factors are modelled in terms of input machining parameters. The developed model describes the interaction i.e. either single/multiple parameters of various input parameters with respect to response factors. Statistical approach has been proven to be a very powerful tool for solving optimization problems in industrial manufacturing conditions.

EXPERIMENTAL WORK

TAGUCHI METHOD BASED DESIGN OF EXPERIMENT

The Taguchi method-based design of experiment involves selecting response variables, independent variables, their interaction and an orthogonal array. The levels of the process parameters were selected in order to cover a sufficiently wide range of possible cutting conditions. Table-1 shows the parameters and the corresponding levels chosen for this experimentation. In the present study, a standard Taguchi L_9 (3^3) orthogonal array, was chosen [23]. The use of orthogonal arrays gives a minimum number of experiments and does not have any mixed levels. Cutting speed, feed rate and depth of cut as control factors and varied for three levels each to adequately cover the entire range available by machine tool. ANOVA is employed to interpret experimental data and make necessary decisions. Table-2 shows the L_9 orthogonal array with the process parameters. Figure-1 shows the steps in the Taguchi's optimization Method for turning process.

Table-1. Parameters and their levels.

Parameter, symbol	Units	Levels		
		1	2	3
Cutting speed (v)	m/min	30	50	70
Feed rate (f)	mm/rev	0.103	0.206	0.294
Depth of cut (d)	mm	0.2	0.3	0.4

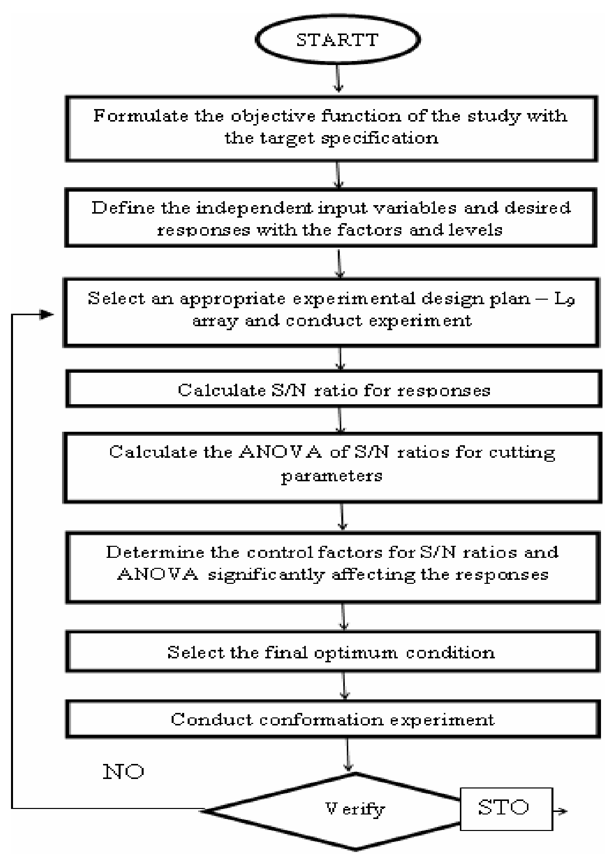

Figure-1. Taguchi's robust design for optimization of turning process.

VOL. 9, NO. 3, MARCH 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-2. L_9 orthogonal array.

Trial	Process Parameters		
	v	f	d
1	30	0.103	0.2
2	30	0.206	0.3
3	30	0.294	0.4
4	50	0.103	0.3
5	50	0.206	0.4
6	50	0.294	0.2
7	70	0.103	0.4
8	70	0.206	0.2
9	70	0.294	0.3

WORK MATERIAL AND CUTTING TOOL

The workpiece used in the experiment was Inconel 625 in the form of round bar of φ30mm and length 200mm. The chemical composition of given sample as Ni 61.6%, Cr 22.0%, Mo 9.0%, Cb+Ta 4.0%, Al 0.2% Tl 0.2%, Fe 3.0%, Mn 0.15, Si 0.30%, C 0.05%. The cutting tool used for dry machining of Inconel 625 was PVD coated carbide tungsten inserts (AlTiN) manufactured by Kennametal Grade KC5525 is an advanced PVD coated fine-grained tungsten carbide specifically designed for machining high-temperature alloys. Its substrate has 10% cobalt for excellent toughness and deformation resistance. The inserts used were of ISO coding CNMG 120408-MS (80˚ diamond shaped insert) with negative rake angle and nose radius of 0.8 mm. The inserts were rigidly mounted on a tool holder designated by ISO coding PCLNR 2525M12.

EXPERIMENTAL SETUP AND MEASURING INSTRUMENT

The dry turning experiments have been carried out on a medium speed lathe of spindle speed of 1600 rpm and a drive motor power of 7.5 kW. A view of the experimental setup used for the current study is shown in Figure-2. Cutting force was measured using 9121 type Kistler dynamometer with digital indicator connected to a data acquisition system. The dynamometer was mounted on the turret face of the medium duty lathe. The surface roughness was measured using Mahr surf test (Make-Japan –Model GD120) with the cut-off 1.75 mm. Figure-3 shows the experimental device for measurement of the surface roughness. The experimentations were conducted without the application of cutting fluids.

EXPERIMENTAL PROCEDURE

The purpose of this study is to investigate the effect of different cutting conditions on cutting force and surface quality. A skin cut thickness of 1.5mm of the workpiece is removed in order to avoid any adverse effect on surface and formation of residual stress after the machining trials. Each machining trail has been carried out on a new fresh cutting edge and total of nine cutting edges have been used in accordance with Taguchi's L_9 orthogonal array of experimental design. Each machining tests are carried out for a cutting length of 40 mm.

The three surface roughness parameters were measured for surface characteristics i.e., arithmetic surface roughness average (R_a), maximum peak-to-valley height within sampling length (R_z) and maximum peak-to-valley height within assessment length (R_t). To measure roughness of the surface formed while processing the workpiece, the cutoff length has been fixed as 1.75 mm and 4 mm assessment length. The measurement was taken at three locations (120˚ apart) around the circumference of the workpiece and repeated three at each point on the face of the machined surface and the average values were reported. The three components of cutting forces were measured using the dynamometer. The resultant cutting force was then calculated to evaluate the machining performance in this study. The average experimental results for surface roughness and cutting force responses are listed in Table-3.

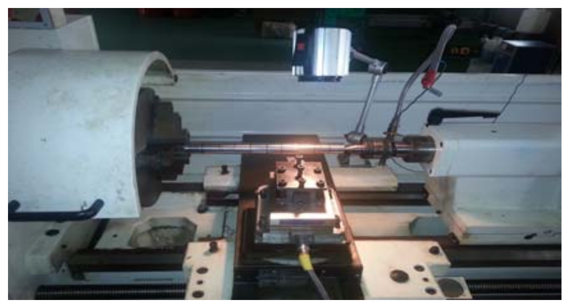

Figure-2. Experimental setup for turning operation.

Figure-3. Experimental setup for surface roughness measurement.

RESULTS AND DISCUSSIONS

In this section, the influence of machining parameters and its effects on surface roughness (R_a, R_t and R_z) and cutting force (F_z) on dry turning of Inconel 625 with PVD coated carbide inserts has been discussed. Table-3 shows the experimental results of surface roughness and cutting force. The surface roughness's were obtained in the range of 0.473 - 1.432, 2.744 -7.475 and 3.715 - 8.313μm for R_a, R_t and R_z, respectively. The cutting forces (F_z) were obtained in range of 75- 439.2 N, respectively.

VOL. 9, NO. 3, MARCH 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-3. Experimental results using L9 orthogonal array.

Trial No.	Process parameters and its levels			Experimental results			
	v m/min	f mm/rev	d mm	R_a	R_t	R_z	F_z
1	30	0.103	0.2	1.413	6.978	8.313	151.50
2	30	0.206	0.3	1.407	6.282	6.909	194.50
3	30	0.294	0.4	1.432	7.475	8.042	439.20
4	50	0.103	0.3	0.473	2.744	3.715	193.90
5	50	0.206	0.4	1.049	5.053	6.014	383.80
6	50	0.294	0.2	0.906	4.267	5.837	169.00
7	70	0.103	0.4	0.718	3.628	4.328	75.00
8	70	0.206	0.2	1.125	5.376	7.378	143.30
9	70	0.294	0.3	1.380	7.222	8.030	325.80

ANALYSIS OF S/N RATIO

In this research work, the collected experimental values of cutting force components as well as surface roughness obtained in the dry turning process at three different levels of feed rates, cutting speeds and depths of cut were analyzed by Minitab software. The main effects plots for S/N ratio were drawn. Analysis of variance (ANOVA) at 95% confidence level for all responses was performed to identify the influence parameters that have statistically significant effect on response variables as discussed below. The S/N ratio for cutting force (F_z) and surface roughness (R_a, R_t and R_z) are calculated by taking into the consideration of smaller-the-better characteristics. Tables 4, 5, 6 and 7 shows the response Table for Ra, Rt, Rz and Fz and the corresponding main effect plots in Figures 4, 5, 6 and 7. The plots show the variation of individual responses with the process parameters. The x-axis in the plot shows value of each parameter at three different levels and y-axis the response value (mean S/N ratio). The overall mean value is represented by the horizontal line. From the tables, it can been observed that the surface roughness is mainly influenced by cutting speed (rank 1 for R_a, R_t, and R_z in Tables 4, 5, 6) followed by feed rate as compared to depth of cut. The feed rates (rank1in Table-7) exhibit the maximum influence on the cutting force as compared to depth of cut and cutting speed. The main effect graph expresses the effect of cutting speed, feed rate and depth cut versus surface roughness criteria. According to the fundamental theory of metal cutting, the feed rate and nose radius is the most influence factor in the roughness of the machined surface [24], equation is given by $R_a = f^2/32r$ where *f* is feed rate and *r* is nose radius From the graph (Figures 4, 5 and 6), it can be observed that the surface roughness accelerates with increases in feed rate and lower cutting speed. It was observed in the few trials the surface roughness value is high due to the presence of hard carbide particle in the material. The increase in surface roughness at higher feed rates is due to the high friction between the work piece and the tool interface; consequently increase the cutting zone temperature [25]. For this reason, low feed rates and higher cutting speed have to be employing during turning operation. Depth of cut has little effect on the surface roughness values.

In this experiment, based on S/N ratio and main effect plot, better surface finish is obtained at cutting speed 50 m/min, feed rate 0.103mm/rev, and depth of cut, 0.3 mm. Similar results were reported by R.S. Pawade *et al*., [19] that when turning of Inconel 718 using PCBN cutting tool. The results show that the surface roughness is poor at low cutting speed and the better surface finish was achieved at low feed rate and higher cutting speed. M. Nalbant *et al*. [20] observed that improved surface roughness was obtained at elevated cutting speed and deteriorating with increase in the feed rate.

The main effect graph (Figure-7) expresses the effect of cutting speed, feed rate and depth cut versus cutting force criteria. From the graph, it can be observed that the cutting force decelerates with increases in cutting speed. At low cutting speed and higher feed rate, the cutting force value is higher when compared to higher cutting speed and low feed rate. This is due to higher friction between tool-work piece interfaces. From the experimental results, higher feed rate and higher cutting speed the cutting zone temperature is high and producing low cutting force. Thus for machining of Inconel 625, higher cutting speed is advisable. For this reason, higher cutting speed and low feed rate have to be employed during turning operation. This is due to low thermal conductivity and specific heat of the material and favourable to decrease in both cutting force and feed force [25].

In this experiment, based on S/N ratio and main effect plot, lower cutting force is obtained at high cutting speed (70 m/min), low feed rate (0.103mm/rev) and medium depth of cut (0.6 mm). Similarly, the author M. Nalbant *et al*., [21] concluded that increasing of cutting speed by 66.6% (150-250 m/min) causes the main cutting force to decrease by 14.6% and increasing cutting speed by 20% causes main cutting force to increase by10.4%. Similarly results were obtained while turning of Inconel 718 using multicoated Al_2O_3 carbide tools [15, 21].

ARPN Journal of Engineering and Applied Sciences

ANALYSIS OF VARIANCE (ANOVA)

The experimental results were analyzed using analysis of variance (ANOVA) for identifying the significant parameters affecting the performance measurers on the total variance of the results [23]. The Table ANOVA has the following components: Source of variation, degrees of freedom (DOF), sum of square (SS), mean square (MS), F-values (F), % contribution. Tables 7, 8 and 9 shows the results of ANOVA of R_a, R_t and R_z, respectively. The analysis was carried out for a confidence level of 95% (significance level of α = 0.05).

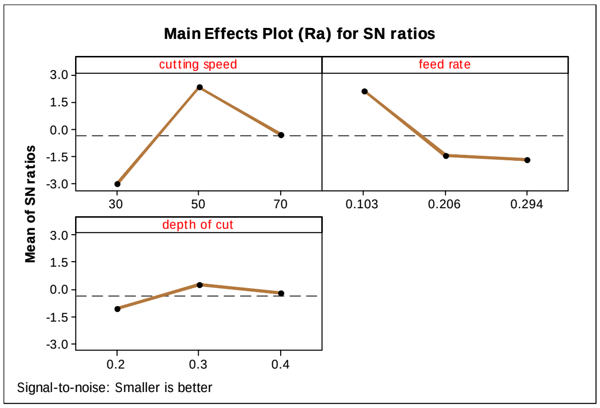

Figure-4. Main effect plot (Ra) for SN ratio.

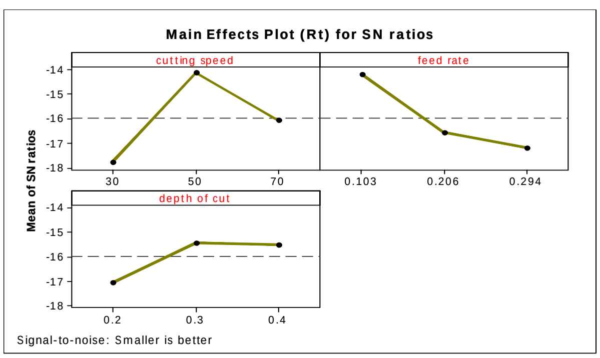

Figure-5. Main effect plot (Rt) for SN ratio.

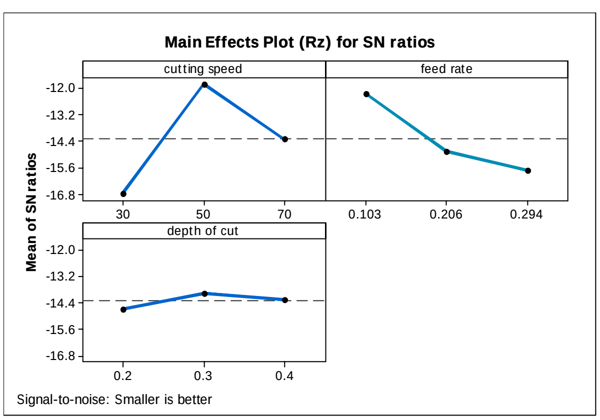

Figure-6. Main effect plot (Rz) for SN ratio.

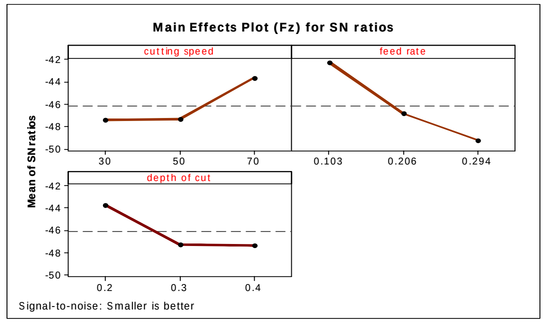

Figure-7. Main effect plot (Fz) for SN ratio.

Table-4. Response table for S/N ratio for R_a.

Levels	Cutting speed	Feed rate	Depth of cut
1	-3.0305	2.1188*	-1.0569
2	-2.3070	-1.4706	0.2399*
3	-0.3159*	-1.6876	-0.2224
Delta	5.3374	3.8064	1.2968
Rank	1	2	3

* Optimum levels

Table-5. Response table for S/N ratio for R_t.

Levels	Cutting speed	Feed rate	Depth of cut
1	-16.77	-12.28*	-14.33
2	-11.81*	-14.88	-13.97*
3	-14.33	-15.75	-14.25
Delta	4.96	3.47	0.73
Rank	1	2	3

* Optimum levels

Table-6. Response table for S/N ratio for R_z.

Levels	Cutting speed	Feed rate	Depth of cut
1	-17.76	-14.17*	-17.03
2	-14.10*	-16.58	-15.43*
3	-16.06	-17.18	-15.47
Delta	3.66	3.01	1.60
Rank	1	2	3

*Optimum levels

Table-7. Response table for S/N ratio for F_z.

Levels	Cutting speed	Feed rate	Depth of cut
1	-47.41	-42.29*	-43.76*
2	-47.33	-46.86	-49.22
3	-43.63*	-49.22	-47.35
Delta	3.78	6.94	3.58
Rank	2	1	3

*Optimum levels

ARPN Journal of Engineering and Applied Sciences

The principle of the F test is that the larger the F value for a particular parameter, the greater the effect on the performance characteristics due to the change in that process parameter. The other important factor is R^2 (determination coefficient) the ANOVA Table, which is defined as the ratio of the explained variation to the total variation. When R^2 approaches to unity, it indicates a good correlation between the experimental and the predicted values.

From the tables we can conclude that the F value for the factor cutting speed is larger than the other two cutting parameters, i.e., the largest contribution to the workpiece surface finish is due cutting speed. The percentage contribution of the most significant factor, cutting speed, shows that it contributed 58% for R_a, 55.7% for R_z and 44.8% for R_t. The percentage contribution for feed rate was 25.6% for R_a, 23.6% for R_z and 24.6% for R_t and that of depth of cut was 11.2% for R_a, 0.17% for R_z and 9.9% for R_z. M. Nalbant *et al.*, [21] reported that average surface roughness increases on dry of turning of Inconel 718, with increasing cutting speed. Increasing the cutting speed from 15 to 75 m/min by 400% average surface roughness increases by 27.5%. From the Table-11, it can conclude that the F value for the factor feed rate and is larger than the other two cutting parameters, i.e., the largest contribution to the cutting force is due feed rate. The percentage contribution of the most significant factor, feed rate, shows that it contributed 36.8% followed by depth of cut 26.2% and 9.2% for cutting speed.

Table-8. ANOVA for R_a.

Source	DF	SS	MS	F	P %
V	2	0.5569	0.2784	3.80	58.0
F	2	0.2457	0.1228	1.68	25.6
D	2	0.0107	0.0053	0.07	11.2
Error	2	0.1464	0.0732		
Total	8	0.9598			

Table-9. ANOVA for R_t

Source	DF	SS	MS	F	P %
V	2	12.537	6.268	2.74	55.7
F	2	5.320	2.660	1.16	23.6
D	2	0.040	0.020	0.01	0.17
Error	2	4.576	2.288		
Total	8	22.473			

Table-10. ANOVA for R_z.

Source	DF	SS	MS	F	P %
V	2	9.901	4.950	2.09	44.8
F	2	5.445	2.722	1.15	24.6
D	2	2.024	1.012	0.43	9.9
Error	2	4.727	2.363		
Total	8	22.096			

Table-11. ANOVA for F_z.

Source	DF	SS	MS	F	P %
v	2	11184	5592	0.34	9.2
f	2	44402	22201	1.33	36.8
D	2	31668	15834	0.95	26.2
Error	2	3337	1663		
Total	8	12058			

REGRESSION MODEL AND DEVELOPMENT

A linear regression model was carried on the dependent variable R_a, R_t, R_z and F_z and cutting speed, feed rate depth of cut are considered as predictor variable on the experimental data for selected PVD coated tungsten carbide inserts. The regression model is developed for both surface roughness and cutting force by applying the least square method to the experimental data to determine the regression coefficients of equation.

In addition to linear regression equations and coefficient of determination (R^2), normal probability plot has been utilized to study the significance of regression model developed. Usually, the R^2 value lies in the range of 0 to 1 (i.e. $0 \leq R^2 \leq 1$). When R^2 value approaches to unity, it is taken as better prediction of responses and fitting of the model with the experimental data. If R^2 value is 85%, it means that this model explains about 85% of the variability in predicting new observations. Therefore, the following regression equations are obtained for both cutting force and surface roughness. The normal probability plots are shown in the Figures 10, 11, 12 and 13 for F_z, R_a, R_t, and R_z, respectively. Also, the predicated values are very close to experimental value which indicated the model holds good for better machining performance such as lower surface roughness and cutting force (Figures 8, 9).

F_z = - 67 - 2.01 cutting speed + 899 feed rate + 724 depth of cut $R^2 = 85\%$

R_a = 1.25 - 0.00858 cutting speed + 1.98 feed rate - 0.41 depth of cut $R^2 = 84.75\%$

R_t = 7.58 - 0.0294 cutting speed + 9.78 feed rate - 5.24 depth of cut $R^2 = 80\%$

R_z = 5.58 - 0.0376 cutting speed + 9.83 feed rate - 0.77 depth of cut $R^2 = 80\%$

Figure-8. Experimental Vs predicted results for F_z.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

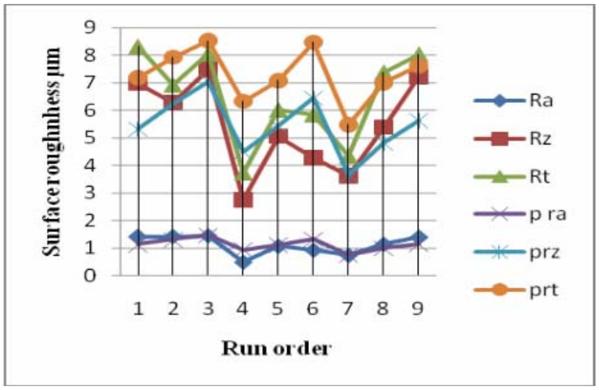

Figure-9. Experimental Vs predicted results for R_a.

CONCLUSIONS

This work discussed about the dry machining of Inconel 625 alloy using multi-layer coated tungsten carbide insert. Taguchi's L9 orthogonal array, S/N ratio and ANOVA were used for finding the optimal process parameters for cutting force and surface roughness. Linear regression model was developed for surface roughness and cutting force to check the model adequacy. The following conclusions are drawn from the analysis of results.

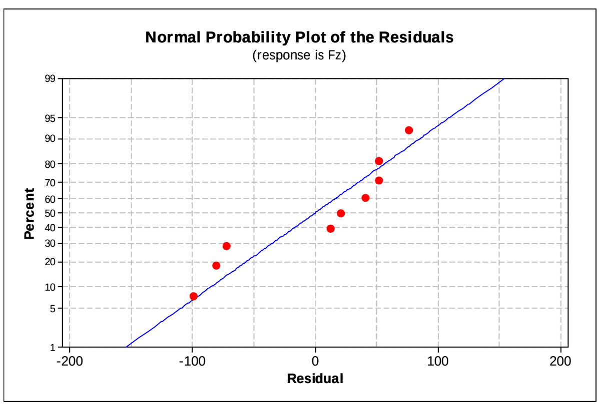

Figure-10. Normal probability plot of the residuals for Fz.

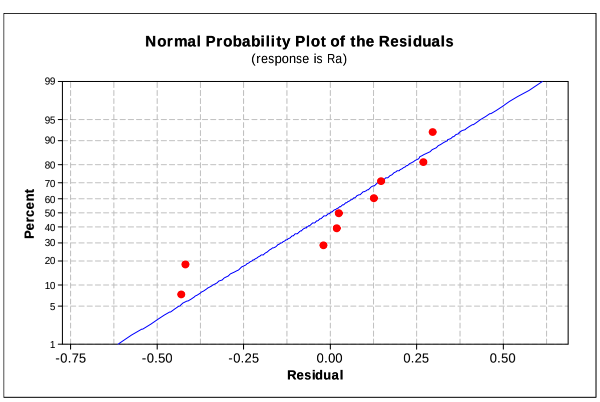

Figure-11. Normal probability plot of the residuals for Ra.

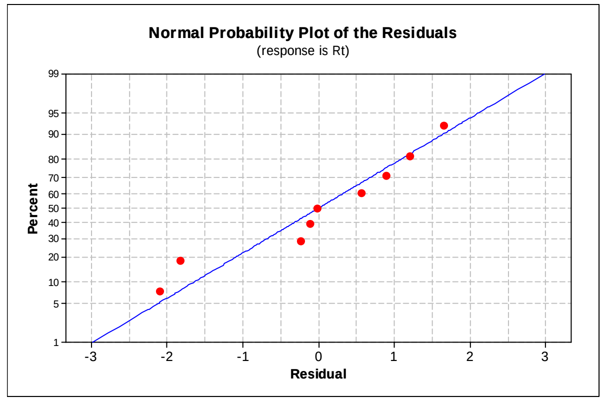

Figure-12. Normal probability plot of the residuals for Rt.

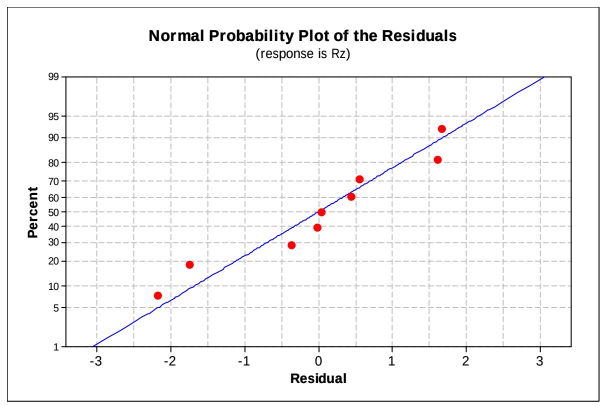

Figure-13. Normal probability plot of the residuals for Rz.

a) Based on the analysis of response graph and ANOVA analysis, the optimal cutting parameter for surface roughness and cutting force were A2B1C2 and A3B1C1 i.e. cutting speed at 50 m/min, feed at 0.103 mm/rev and depth of cut at 0.3 mm for R_a, cutting speed at 50 m/min, feed at 0.103 mm/rev and depth of cut at 0.3 mm for R_t, cutting speed at 50 m/min, feed at 0.103 mm/rev and depth of cut at 0.3 mm for R_z, cutting speed at 50 m/min, feed at 0.103 mm/rev and cutting speed at 70 m/min, feed rate at 0.103 mm/rev, depth of cut at 0.4 mm for F_z, respectively.
b) Cutting speed was found to be the most significant parameter for R_a, R_t, R_z which bags the maximum percent contribution of 58%, 55.7%, 44.8% followed by feed rate 25.6%, 23.6%, 24.6%. Depth of cut has the insignificant effect on surface roughness (R_a, R_t and R_z).
c) Feed rate and depth of cut was found to be most significant parameter for F_z which bags the maximum percentage contribution of 36.8% and 26.2%. Cutting speed has the insignificant effect of cutting force (F_z).
d) The developed regression equation for both cutting force and surface roughness shows that the developed model has high significant on the responses. Also, the predicated values are very close to experimental value

which indicated the model holds good for better machining performance.

e) From this research, within the experimental region, the potential and effectiveness of the PVD AlTiN coated carbide insert has been identified while dry turning of Inconel 625.

REFERENCES

[1] M. Field, "Machining Aerospace Alloys, Iron and Steel Institute", Special Report 94, pp. 151-160, 1968.

[2] P. Warburton, "Problems of Machining Nickel-Based Alloys", Iron and Steel Institute, Special Report 94, pp. 151–160, 1967.

[3] Vani Shankar, K. Bhanu Sankara Rao and S.L. Mannan, "Microstructure and Mechanical properties of Inconel 625 superalloy", Journal of nuclear materials, vol. 288, pp.222-232, 2001.

[4] H.L. Eiselstein and D.J. Tillack, "Superalloy 718, 625 and various derivatives", in: TMS, Warrendale, PA, E.A. Loria (Eds.), pp. 1, 1991.

[5] M.Y. Reddy, A.B. Sadat and B.P. Wang, "Plastic deformation analysis in machining of Inconel 718 nickel base superalloy using both experimental and numerical methods", International Journal Mechanical and Science, vol. 33 (10), pp. 829–842,1991.

[6] R.M. Arunachalam and M.A. Mannan, "High speed facing of age hardened Inconel 718 using silicon carbide whisker reinforced ceramic tools", Transaction NAMRI/SME, vol. 30, pp. 345-352, 2002.

[7] R.M. Arunachalam, M.A. Mannan and A.C. Spowage, "Residual stress and surface roughness when facing age hardened Inconel 718 with CBN and ceramic cutting tools", International Journal Machine Tools and Manufacturing, vol. 44, pp. 879–887, 2004.

[8] A. Mittal and M. Mehta, "Surface finish prediction models for fine turning", International Journal of Production Research, vol. 26 (12), pp.1861–1876, 1988.

[9] S.M. Darwish, "The impact of tool material and the cutting parameters on surface roughness of supermet 718 nickel superalloy", Journal of Materials Processing Technology, vol. 97, pp. 10–18, 2000.

[10] R. Bhat, H.K. Balakrishna and K. Ramachandra, B.K. Subhas, "Dimensional instability studies in machining of Inconel 718 nickel-based superalloy as applied to aero gas turbine components", Transaction of ASME, Journal of Engineering for Gas Turbine and Power, vol. 122, pp. 55–61, 2000.

[11] E.O. Ezugwu and S.H. Tang, "Surface abuse when machining cast iron (G-17) and nickel-base superalloy (Inconel 718) with ceramic tools", Journal of Material Processing Technology, vol. 55, pp. 63–69, 1995.

[12] A. Braghini Jr., A.A. Bezerra, R.T. Coelho and L.R. Silva, "Some effects of cutting edge preparation and geometric modifications when turning Inconel 718 at high cutting speeds", Journal of Material Processing Technology, vol. 148 (1), pp. 147–153, 2004.

[13] Chao Xue and Wuyi Chen, "Adhering layer formation and its effect on the wear of coated carbide tools during turning of a nickel based alloy". Wear, vol. 270, pp. 895-902, 2011.

[14] M. Field, J.F. Kahles and W.P. Koster, "Surface Finish and Surface Integrity", ASM Handbook, vol. 16, Machining, 9th ed., ASM Publication, ASM, Metal Park, Ohio, 1989.

[15] A. Devillez, G. Le Coz, S. Dominiak and D. Dudzinski, "Dry machining of Inconel 718, workpiece surface integrity", Journal of Materials Processing Technology, vol. 211, pp. 1590-1598, 2011.

[16] P.C. Jindal, A.T. Santham, Schleinkofer and A.F. Shuster, "Performance of PVD TiN, TiCN and TiAlN coated cemented carbide tools in turning", International Journal of Refractory Metals and Hard Materials, vol.17, pp.163-170, 1999.

[17] H.G. Prengel, P.C. Jindal, K.H. Wendt, A.T. Santhanam, P.L. Hedge and R.M. Penich, "A new class of high performance PVD coating for carbide cutting tools", Surface and Coating Technology, vol.139, pp.25-34, 2001.

[18] E.O. Ezugwu, "Key improvements in the machining of difficult-to-cut aerospace superalloys", International Journal of Machine Tools and Manufacturing, vol. 45, pp. 1353-1358, 2005.

[19] R.S. Pawade, Suhas S. Joshi, P.K. Brahmankar, and M. Rahman, "Cutting force and wear in dry machining of Inconel 718 with coated carbide tools", Wear, vol. 262, pp. 931-942, 2007.

[20] Muammer Nalbant, Abdullah Altın, and Hasan Go kkaya, "The effect of coating material and geometry of cutting tool and cutting speed on machinability properties of Inconel 718 super alloys", Materials and Design, vol.28, pp.1719-1724, 2007.

[21] Muammer Nalbant, Abdullah Altın, and Hasan Go kkaya, "The effect of cutting speed and cutting tool geometry on machinability properties of Inconel 718 super alloys", Materials and Design, vol. 28, pp. 1334-1338, 2007.

[22] D. D'Addona, T. Segreto, A. Simeone, and R. Teti, "ANN tool wear modeling in the machining of nickel super alloy industrial products", CIRP Journal of Manufacturing Science and Technology, vol.4, pp. 33-37, 2011.

[23] P.J Ross, "Taguchi techniques for quality engineering", McGraw-Hill, New York, USA.

[24] M.C. Shaw, "Metal Cutting Principles, Oxford University Press, London,UK, 1984.

[25] D.G Thakur, B. Ramamoorthy and L. Vijaraghavan, "Study on the machinability characteristics of super alloy Inconel 718 during high speed turning", Materials and Design, vol. 30, pp.1718-1725, 2009.