Experimental Investigations on Surface Topography in CNC Machining of Nickel-200 Alloy

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ABSTRACT
Now a day's Nickel material have growing applications in the manufacturing of various components and structure due to their inherent properties, the Nickel alloys are widely used in aerospace, marine, and nuclear power generation, chemical, petrochemical and process industries. Nickel is a versatile element and will alloy with most metals. At present very few researchers developed manufacturing technology for the production of highly precise Nickel products. Better surface topography can be achieved by the CNC turning process than with conventional grinding technique. The need of finding out machining characteristics of Nickel using high quality machine tools like CNC turning, the experiments were done according to Taguchi DOE. Present paper focuses the CNC turning experiments were conducted on one of the alloy of Nickel i.e. Nickel-200 for analyzing surface characteristics.

***Keywords** - Nickel-200, CNC turning, Carbide tool, Surface roughness, Taguchi DOE*

1. INTRODUCTION
Nickel alloys are widely used in the manufacture of various components and structures for aerospace, marine, and nuclear power generation, chemical, petrochemical and process industries. In the aerospace industry these alloys are used in the rotating parts of gas turbines such as blades and disks, housing components such as turbine casing, engine mounts and in components for rocket motors and pumps. They are also used as structural material for various components in the main engine of space shuttles, in cryogenic tank age and for pressure vessels of Nickel-hydrogen batteries used in the space station [1]. All these applications of Nickel alloys are made possible on account of properties such as high yield strength and ultimate tensile strength, high fatigue strength, corrosion and oxidation resistance even at elevated temperatures, non-magnetic characteristics and low creep [2].

Nickel alloys are widely employed in the aerospace industry, in particular in the hot sections of gas turbine engines, due to their high temperature strength and high corrosion resistance. They are known to be among the most difficult-to-cut materials. In turning Nickel alloy, it is well known that the tool temperature rises easily due to its poor thermal properties. In addition, precipitate hardening of secondary phase (Ni_3Nb) together with work hardening during machining makes the cutting condition even worse. All these difficulties lead to high tool wear less material remove rate (MRR) and poor surface finish [3,5]. Considerable research has been done on selection and optimization of machining parameters for coated and uncoated carbide cutting tools using wet and dry cutting conditions. However understanding the wear mechanism of turning and turning operations, are very important in the aerospace industry for desired surface roughness and economic manufacturing of the product. Surface finish is a very important aspect for designing mechanical elements and also presented as a quality indicator of manufacturing processes [6]. The present investigation aims at quantitative as well as qualitative analysis of surface topography of the machined surface produced using CNC turning operation on pure Nickel alloy by carbide inserts. The analyzed results could help prescribe suitable machining techniques that produce most favorable and acceptable surfaces for precision applications.

2. EXPERIMENTAL

2.1 Process, Equipment and Tooling

Precision CNC turning process was employed for investigation on surface roughness of Nickel alloy. Table 1 shows the specifications of CNC turning machine used for carrying out the experiments.

2.2 Experimental Design

A Taguchi experimental design L9 orthogonal array was used for designing the parameter combinations for each experimental trial (See Table 2). In this orthogonal array, number of factors are 4 and number of levels are 3. Hence total numbers of runs are 9. The response variable chosen is the arithmetic average of surface roughness for the experiments in CNC turning of Nickel-200 alloy. The input control factors selected for CNC turning of Nickel are: depth of cut (50-100-150 µm), feed rate (0.15-0.20-0.25 mm/rev), spindle speed (1000-2000-3000 rpm) and rake angle (0-5-7 degrees). Table 3 shows the experimental runs with the assigned factors to each of the columns of OA for CNC turning process respectively.

2.3 Experimental Procedure and Measurements

The preparation of experiments began with the cutting of nine work pieces to the required length from a long rod of Nickel-200. These substrates of Nickel are exactly made to size Ø25 x 10 mm thickness. The single substrate of Nickel is hold in three jaw chuck of CNC machine (see Fig. 1). Initially, rough cut of 60 µm was taken on each substrate and finish cut was taken on surface of 24 mm diameter. Finally each substrate was machined as per data, which is fixed in L9 array. For protection of CNC faced surface from dust and swarf each substrate was stacked by a plastic sticky paper called as food wrapped paper.

Table 1 Specifications of CNC Turning Machine

Sr. No.	Machine parts	Details	Dimensions/Sizes
1	Capacity	Swing over bed	ø300 mm
		Std. Turning Diameter	ø165 mm
		Max. Turning Diameter	ø250 mm
		Dist. Between Centre	350 mm
		Max. turning length	300 mm
2	Slides	Cross (X axis) Travel	140 mm
		Longitudinal (Z axis) Travel	300 mm
		Rapid Feed (X & Z axis)	24 m/min
3	Main Spindle	Spindle Motor	5.5/7.5 KW (15 min. rating)
		Spindle Bore	ø38 mm
		Spindle Nose	$A_2 5$
		Max. Bar Capacity	ø25 mm
		Chuck Size	ø165 mm
		Speed Range	50-4000 rpm
		Full Power Speed Range	1000-3000 rpm
4	Turrent	No. of Stations	8
		Tool Size	20 x 20 mm
		Max. Boring Bar Capacity	Ø 50
5	Other Data	Weight (Approx)	2500 Kg.
		Machine Dimensions (L x B x H)	2200 x 1400 x 1550
6	Accuracy	Positioning Accuracy	0.015
		Repeatability	± 0.003
7	Tail Stock	Quill Diameter	ø70 mm
		Quill Stroke	80 mm
8	Control System	Fanuc Oil Mate TC/Siemens 802D	

3. RESULTS AND ANALYSIS

The experiment was performed according to Taguchi L9 orthogonal array. Based on the experimental work, the results were analyzed and are presented in this section.

Table 2 Standard experimental design of L9 (3^4) orthogonal array

Expt. Run	Column Factor A	Factor B	Factor C	Factor D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3 Experimental layout using L9 array for Nickel-200

Expt. runs	Depth of cut (µm)	Spindle speed (rpm)	Feed (mm/rev)	Rake Angle (Degrees)
1	50	1000	0.15	0
2	50	2000	0.20	5
3	50	3000	0.25	7
4	100	1000	0.20	7
5	100	2000	0.25	0
6	100	3000	0.15	5
7	150	1000	0.25	5
8	150	2000	0.15	7
9	150	3000	0.20	0

analysis was done to determine the significant factors influencing output variables using statistical software known as 'Minitab R-16'. An analysis was done to predict the response variable for the unknown value of the input factors. In this investigation the response variable was selected as surface roughness of the machined surfaces.

All CNC turned machined surfaces were measured by contact type of measurement in a controlled environment temperature. The instrument is used for measuring the surface roughness of machined surfaces is Surface Roughness Tester (see Fig. 2) Model RT10G made by Strumentazione having LC of 0.001µm. Table 4 shows the Ra and Rz values of turned surfaces.

3.1 Statistical Analysis of Surface Roughness

The main effect plot for surface roughness

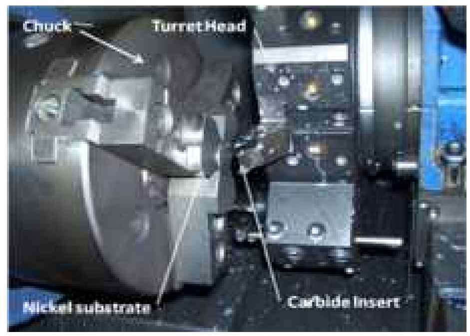

Fig. 1 A close up photograph of CNC turning of Nickel-200 substrate

Fig. 2 Surface roughness tester

Table 4 Results of CNC turning of Nickel-200

Substrate No.	Ra Value (µm)	Rz Value (µm)
1	0.689	3.734
2	1.956	8.352
3	1.009	4.210
4	1.210	6.493
5	1.428	4.673
6	1.574	9.331
7	1.936	10.141
8	0.771	4.401
9	1.020	4.993

(ANOM) and the table of analysis of variance (ANOVA) are shown in Fig. 3 Table 5. It is observed from the ANOVA that the input variable, rake angle has statistically significant effect on the surface roughness obtained during CNC turning of Nickel-200. Since the P-value in the ANOVA table for rake angle is less than 0.05, there exist statistically significant relationship between the rake angle and the response variable at 95.0% confidence level. Other variables chosen in this investigation are not statistically significant on the surface roughness. The percentage contribution of the input variables influencing the surface roughness are depth of cut: 3.50 %, spindle speed: 2.92 %, feed rate: 24.69 %, rake angle: 73.52 %. The effect of each input variables on the surface roughness in detail using ANOM plots.

Table 5 ANOVA table for surface roughness in CNC turning of Nickel-200 for experiment

Source	DF	SS	MS	F	P
Depth of cut	2	0.06132	0.030662	0.07	0.929
Spindle Speed	2	0.05121	0.025607	0.06	0.940
Feed	2	0.35055	0.175277	6.23	0.059
Rake Angle	2	1.28627	0.643135	22.86	0.006*
Error	0	0	-	-	-
Total	8	1.74936	-	-	-

* Statistically significant factor

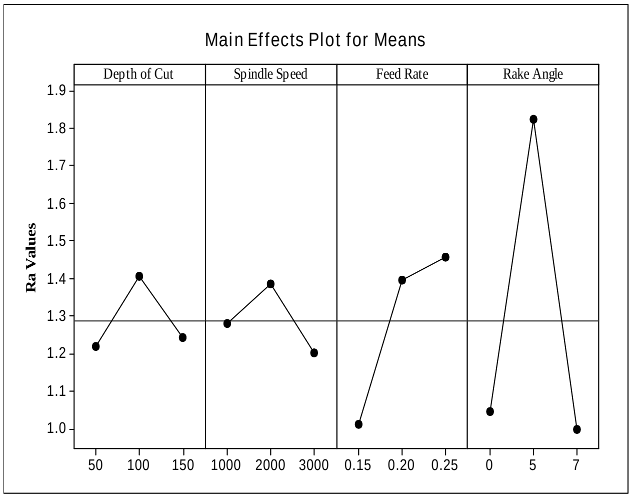

Fig. 3 Main effect plot for surface roughness

3.2 Effect of Machining parameters

Main effect plot shows the significant effect of various machining parameters on surface roughness obtained by CNC machining process.

Effect of Depth of Cut

In CNC turning operation depth of cut shows non linear effect on the surface roughness generated. From the main effect plot it is shown that the surface roughness is minimum when depth cut was taken as 50 µm, the surface roughness is about 1.22 µm. However, at 100 µm the surface roughness is maximum and it is nearly above 1.4 µm. At 150 µm depth of cut, surface roughness is about 1.2 to 1.3 µm. As the depth of cut is increases from 50 µm to 100 µm there is an increase in the surface roughness. From main effect of plot shows that there is reduction in surface roughness when depth of cut is ranges from 100 µm to 150 µm. Change in depth of cut changes the cross sectional area of the deformation of the work piece. As the depth of cut increases the material removal during turning will be higher.

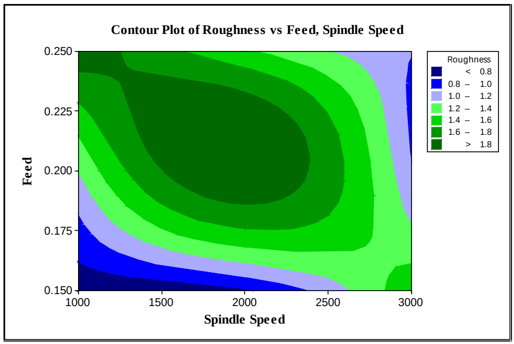

Fig. 4 Contour plot of surface roughness vs feed rate and spindle speed

Effect of Spindle Speed

In CNC turning operation spindle speed show non linear effect on the surface roughness. From the main effect plot it is shown that the surface roughness is minimum at 3000 rpm is about 1.2 µm. However, at 2000 rpm the surface roughness is maximum it is about 1.37 µm. At 1000 rpm surface roughness about 1.25 to 1.30 µm. Fig. 4 shows that contour plot of surface roughness vs feed rate and spindle speed. Contour plots are generally used to define the particular region of output variable, which is achieved in different values of parameters during the process. It is observed from the contour plot the minimum surface roughness is obtained. When the feed rate is about 0.150 mm/rev to 0.165 mm/rev and spindle speed is about 1000 rpm to 2050 rpm.

Effect of Feed Rate

It is observed from the main effect plot that feed rate shows non linear effect on machined Nickel-200 substrates. At 0.15 mm/rev the surface roughness is less. The surface roughness nearly 1 µm is obtained. However, further increasing feed rate to 0.20 mm/rev increases the surface roughness by a higher magnitude. The surface roughness is raised about 1.4 µm. There is slightly increase in the surface roughness when the feed rate changes from 0.20 mm/rev to 0.25 mm/rev.

Effect of Rake Angle

It is observed from the main non linear effects plot that rake angle shows effect on machined Nickel-200 substrates. Rake angle is statistically significant factor in this experiment. At 7° the surface roughness is quite less. It is about less than 1.0. However, when 0° rake angle is used for turning of substrate it is observed that surface roughness value about 1.0 µm to1.1 µm is obtained. There is sudden increase in surface roughness value when rake angle is changed to 5°. When 5° rake angle is used for turning of substrate surface roughness value about 1.8 µm to 1.9 µm is obtained.

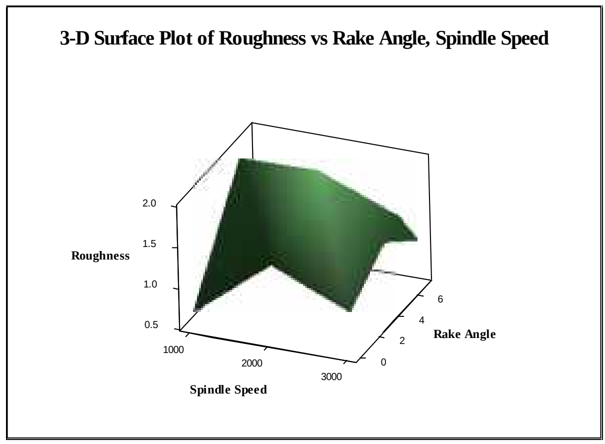

Fig. 5 3-D Surface plot of surface roughness vs rake angle and spindle speed

From the Fig. 5 it is observed that when spindle speed increases from 1000 rpm to 2000 rpm there is an increase in surface roughness value. Further increase in spindle speed, surface roughness value is decreases. It is shown when rake angle increase from 0° to 5° there is an increase in roughness value. Further increase in rake angle surface roughness value is decreases.

4. CONCLUSION

The present work include the extensive experimental analysis of CNC turning processes to understand the ability of the process to generate high degree of surface roughness on Nickel-200 surface. The experiment was carried out to explore the effect of process parameters on machinability of Nickel-200 during CNC turning operation. From the experimental results and subsequent Taguchi's analysis the following conclusions for surface roughness value can be deduced from the study:

- In the experiment on Nickel-200 in CNC turning process, it was observed from ANOVA that the input factor rake angle has statistically significant effect at 95% confidence level on the surface roughness. It was found that the feed rate has secondary effect on surface roughness on Nickel 200.
- It was observed that in the experiment, minimum surface roughness obtained 0.9 μm when rake angle of 7° was used. Therefore, CNC turning of Nickel alloys with high rake angle is most suitable to achieve better surface quality.
- It was also observed that the minimum values of depth of cut gives the good surface quality in CNC turning of Nickel-200 alloy.

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