# Optimization of Cutting Parameters in Turning of NIMONIC 80A by using Taguchi Method

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***Abstract*** **-** The main objective of this study is to analyze the effect of cutting speed, feed, and depth of cut on response variables such as surface roughness, tool wear. Turning of NIMONIC 80A was carried out at three levels of cutting speed, feed, and depth of cut. S/N ratio analysis is used to find the optimum cutting parameters. Smaller the better criteria is used for surface roughness and flank wear and larger the better for MRR. It was observed that the cutting speed is most significant parameter for flank wear. Feed is most influencing parameter to get better surface finish. It is found from experimental results that ceramic inserts gives better surface finish compared to carbide inserts.

***Keywords*** - *NIMONIC 80A, surface roughness, Taguchi method*.

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## I. INTRODUCTION

NIMONIC 80A is nickel based super alloy which contains mainly nickel and chromium. It is strengthened by the addition of titanium and aluminium. It has good oxidation and corrosion resistance at higher temperature. The tensile and creep rupture point is large at elevated temperature (815°C). It is widely used in gas turbine engines, automobile exhaust valves, die casting inserts and cores, and nuclear boiler tube parts. The NIMONIC 80A is difficult to cut material because of its combined mechanical and corrosion resistance at higher temperature.

To overcome the above difficulties while machining of nickel based super alloys the selection of machining parameters is an important task. Many researchers carried out the machining of NIMONIC alloys. Danish khan et al. [1] investigated influence of cutting parameter such as cutting speed and feed on surface roughness and MRR. It was found that surface roughness follows quadratic trend for given range of cutting speed, feed, DOC. Feed rate was most important factor to determine surface roughness. Feed rate was contributing 58.69% to the surface roughness. P. Subhash et al. [2] described the multi response optimization using desirability function in conjunction with RSM. PVD TiAlN coating carbide tool. They found that surface roughness has an increasing trend with increase in feed and at the same time, it first decreases and then increases with increase in speed. MRR is directly proportional to feed, cutting speed and depth of cut. M.V.R.D. Prasad et al. [3] investigated the effect of process parameters on surface roughness of NIMONIC 80A by using CBN inserts. ANN was used to find which parameter has significant effect on output parameter. Surface roughness was decreased at certain cutting speed and increased with increase in cutting speed. Feed rate is directly proportional to surface roughness. Surface roughness decreases as depth of cut increases. From the sensitivity analysis, it was found that feed rate is the most significant factor affecting the surface roughness. Bin Zou et al. [4] studied the surface damages caused by turning NiCr20TiAl nickel based super alloy for different cutting speed, feed rate and depth of cut. It was found that, at cutting speed of 100 m/min, feed rate of 0.15 mm/rev and depth of cut of 1 mm, good surface finish is obtained with less work-hardening layer, also lower cutting forces are generated.

## II. EXPERIMENTAL DETAILS

### A. *Work piece Material*

The material used for the experiment is NIMONIC 80A round bar of 80 mm diameter and 250 mm length. The chemical composition is given in Table I.

TABLE I
CHEMICAL COMPOSITION OF NIMONIC 80A

| Ni | Cr | Ti | Al | Co | Fe | Si | Cu | C | Mn |
|---|---|---|---|---|---|---|---|---|---|
| Bal | 18.88 | 1.98 | 1.33 | 1.34 | 1.99 | 0.68 | 0.11 | 0.045 | 0.77 |

### B. *Tool material*

The turning experiments were conducted using SiAlON ceramic inserts. Grade SN800 is used. SiAlON ceramic inserts of CNGA120408 geometry is used. It has 0º clearance angle, –5 º side cutting edge angles and 80º rhombus shape with nose radius of 0.8 mm. The tool holder used for clamping the insert is MCLNL 2525 M12 (Make- WIDIA). It has 95º approach angle and – 6º back rake angle.

 ISSN: 2321-8169
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Fig. 1 NIMONIC 80A round bar


Fig. 2 Ceramic insert

### C. *Machines and Equipment used*

Fig. 3 Experimental set up

The machine used for turning of NIMONIC 80A is ACE CNC LATHE JOBBER XL. The instrument used for measuring surface roughness is SJ 301stylus type surface roughness tester developed for shop floor use. Nikon measuring microscope is used to measure flank wear.

### D. *Taguchi Method*

The Taguchi method, which uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments, only is a suitable substitute. To obtain better machining performance in turning, the parameter design proposed by the Taguchi method is adopted in this experimental work.

Selection of Input Parameter and their Level used for an Experiment

Mainly for NIMONIC 80A has recommended cutting speed in range of 100 to 500 m/min for ceramic insert. Hence, Keeping this in mind as well as reference of research literature the turning parameters for this work (cutting speed, feed and depth of cut) were selected after screening test. From the data obtained from screening experiment, we select cutting speed, feed rate and depth of cut. The levels of cutting parameters are given in Table II.

TABLE II
LEVELS OF CUTTING PARAMETERS

| Cutting parameters | Level1 | Level2 | Level3 |
|---|---|---|---|
| Cutting speed (m/min) | 400 | 450 | 500 |
| Feed (mm/rev) | 0.10 | 0.15 | 0.20 |
| Depth of cut (mm) | 0.25 | 0.50 | 0.75 |

## III. RESULTS AND DISCUSSION

L9 orthogonal array was used to find out the effect of cutting speed, feed, and depth of cut on surface roughness and flank wear. Table III illustrates the experimental results for surface roughness and flank wear.

TABLE III
EXPERIMENTAL RESULTS FOR $R_A$ AND FLANK WEAR

| Expt. no. | Factors | | | Performance measures | |
|---|---|---|---|---|---|
| | Cutting speed (m/min) | Feed (mm/rev) | Depth of cut (mm) | Surface roughness Ra (μm) | Flank wear Vb (μm) |
| 1 | 400 | 0.10 | 0.25 | 0.43 | 109.54 |
| 2 | 400 | 0.15 | 0.50 | 0.49 | 114.52 |
| 3 | 400 | 0.20 | 0.75 | 1.03 | 121.01 |
| 4 | 450 | 0.10 | 0.50 | 0.31 | 122.93 |
| 5 | 450 | 0.15 | 0.75 | 0.60 | 130.38 |
| 6 | 450 | 0.20 | 0.25 | 0.85 | 125.55 |
| 7 | 500 | 0.10 | 0.75 | 0.42 | 170.17 |
| 8 | 500 | 0.15 | 0.25 | 0.48 | 145.3 |
| 9 | 500 | 0.20 | 0.50 | 0.52 | 150.94 |

### A. *S/N Ratio Analysis of Surface Roughness*

Smaller the better criteria is used to find out the best optimum cutting parameters in turning of NIMONIC 80A. The formula for smaller the better S/N ratio is [5].

S/N ratio (smaller the better) = $-10\log [1/n * \sum y^2]$

Where y is the observed data and n is the number of observation. The S/N ratio of surface roughness for each factor was given in Table IV.

TABLE IV
S/N RATIO OF SURFACE ROUGHNESS

| Expt. No | Cutting Speed (m/min) | Feed (mm/ rev) | Depth of cut (mm) | Surface Roughness (μm) | S/N ratio |
|---|---|---|---|---|---|
| 1 | 400 | 0.10 | 0.25 | 0.43 | 7.33 |
| 2 | 400 | 0.15 | 0.50 | 0.49 | 6.20 |
| 3 | 400 | 0.20 | 0.75 | 1.03 | -0.26 |
| 4 | 450 | 0.10 | 0.50 | 0.31 | 10.08 |
| 5 | 450 | 0.15 | 0.75 | 0.60 | 4.39 |
| 6 | 450 | 0.20 | 0.25 | 0.85 | 1.41 |
| 7 | 500 | 0.10 | 0.75 | 0.42 | 7.53 |
| 8 | 500 | 0.15 | 0.25 | 0.48 | 6.37 |
| 9 | 500 | 0.20 | 0.50 | 0.52 | 5.68 |

TABLE V
S/N RESPONSE TABLE FOR SURFACE ROUGHNESS

| Symbol | Cutting | Mean S/N ratio |
|---|---|---|

| | parameter | | | | |
|---|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 | Max-min |
| A | Cutting Speed | 4.423 | 5.293 | **6.553** | 2.130 |
| B | Feed | **8.338** | 5.653 | 2.278 | **6.060** |
| C | Depth of cut | 5.039 | **7.319** | 3.912 | 3.407 |

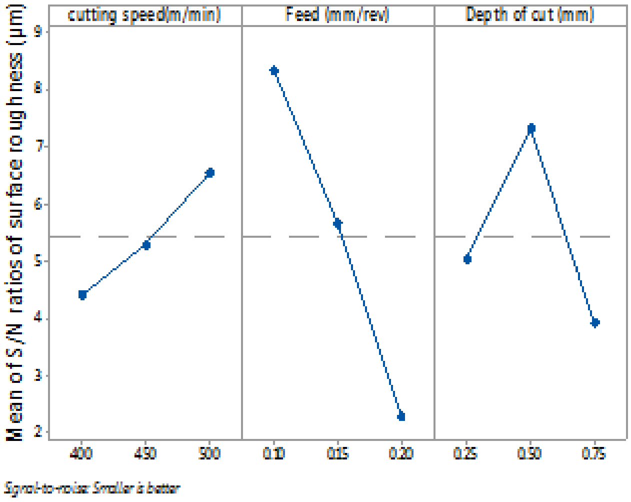


Fig. 4 Main effects plot for means of surface roughness

Fig.4 shows the main effects plot for means of surface roughness. Main effect plot gives the trend of surface roughness with cutting speed, feed, and depth of cut. The mean of S/N ratios of surface roughness increases with increase in cutting speed and decreases with increase in feed. It first increases then decreases with increase in depth of cut. The level of factor, which has highest value of S/N ratio, is selected as optimum level. From the Fig. 4, it is clear that the optimum parameter for best surface roughness is A3B1C2. The optimum parameter to give best surface roughness is cutting speed of 500 m/min, feed of 0.10 mm/rev, and depth of cut of 0.50 mm. The surface roughness decreases with increase in cutting speed. The minimum surface roughness was observed at cutting speed of 500 m/min. As the cutting speed is increased, the conditions promoting the built up edge formation is also reduced due to a rise in temperature, which leads to a corresponding reduction in the height of the micro irregularities (roughness). Along with the rise in temperature, the reduced friction and plastic deformation could also have caused the reduction in the surface roughness when the cutting speed is increased.

The surface unpleasantness first reductions then increments with expansion top to bottom of cut. The base surface was seen at profundity of cut of 0.50 mm. This may be because of an expansion in the disfigurement volume with the increment top to bottom of cut. Along these lines, serious distortion of work material prompts era of more inconsistencies at first glance and thus poor surface completion.

The ideal parameters for better surface completion acquired from S/N proportion are cutting velocity of 500 m/min, food of 0.10 mm/rev and profundity of cut of 0.50 mm.

## B. Analysis of flank wear

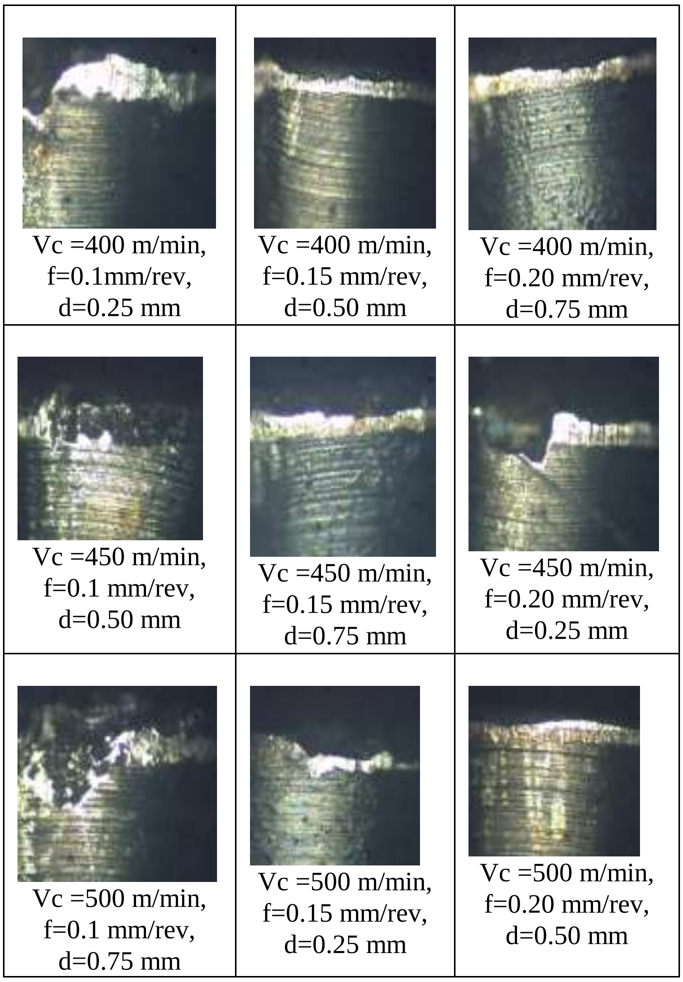


Fig. 4 Photographic view of tool wear at different cutting conditions [Nikon microscope at 10X magnification.]

## *C. S/N Ratio Analysis of Flank Wear*

Smaller the better criterion is used to find out the best optimum cutting parameters in turning of Nimonic 80A. The formula for smaller the better S/N ratio is given as [5]

S/N ratio (smaller the better) = $-10\log [1/n * \sum y^2]$

Where y is the observed data and n is the number of observation.

The S/N ratio of flank wear for each factor was given in Table VI.

TABLE VI
S/N RATIO OF FLANK WEAR

| Expt. No | Cutting Speed (m/min) | Feed (mm/ rev) | Depth of cut (mm) | Flank wear (µm) | S/N ratio |
|---|---|---|---|---|---|
| 1 | 400 | 0.10 | 0.25 | 109.54 | -40.79 |
| 2 | 400 | 0.15 | 0.50 | 114.52 | -41.18 |
| 3 | 400 | 0.20 | 0.75 | 121.01 | -41.66 |

ISSN: 2321-8169
01 - 04

| | | | | | |
|---|---|---|---|---|---|
| 4 | 450 | 0.10 | 0.50 | 122.93 | -41.79 |
| 5 | 450 | 0.15 | 0.75 | 130.38 | -42.30 |
| 6 | 450 | 0.20 | 0.25 | 125.55 | -41.98 |
| 7 | 500 | 0.10 | 0.75 | 170.17 | -44.62 |
| 8 | 500 | 0.15 | 0.25 | 145.30 | -43.24 |
| 9 | 500 | 0.20 | 0.50 | 150.94 | -43.58 |

TABLE VII
S/N RESPONSE TABLE FOR FLANK WEAR

| Symbol | Cutting parameter | Mean S/N ratio | | | |
|---|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 | Max-min |
| A | Cutting Speed | **-41.21** | -42.02 | -43.81 | **2.60** |
| B | Feed rate | -42.40 | **-42.24** | -42.40 | 0.16 |
| C | Depth of cut | **-42.00** | -42.18 | -42.86 | 0.86 |

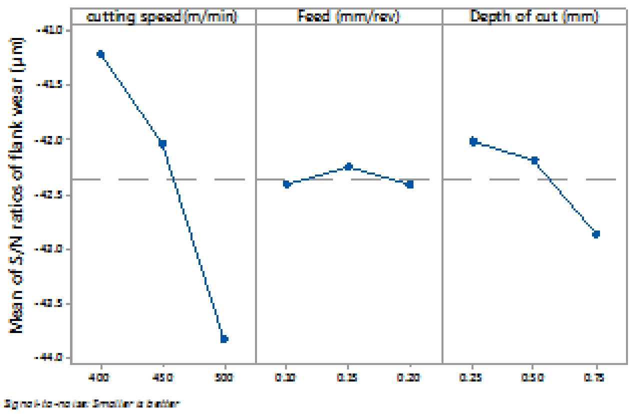


Fig. 5 Main affects plots for S/N ratios of flank wear

Table VI gives the experimental results for flank wear and its S/N ratio. From S/N response table it is clear that cutting speed is most significant parameter that affects the flank wear. Fig. 5 gives the variation of mean of S/N ratios of flank wear with cutting speed, feed, and depth of cut. S/N ratio decreases with increase in cutting speed, same trend is observed for depth of cut with less change in S/N ratio. S/N ratio first increases then decreases with increase in feed. Maximum S/N ratios are observed at cutting speed of 400 m/min, feed of 0.15 mmm/rev and depth of cut of 0.25 mm. Thus, the optimum cutting parameters for flank wear are A1B2C1.

Flank wear increases with increase in cutting speed and has greater change as compared to feed and depth of cut. Highest flank wear is seen at cutting speed of 500 m/min. Due to poor thermal conductivity of NIMONIC 80A the temperature in the cutting region goes up to 1200 ºC and accumulates at the rake face at higher cutting speed. Besides, the nickel based super alloys have high chemical affinity for many tool materials, which prone to generation of diffusion wear. Hence, increase in cutting speed results higher tool wear.

Flank wears first decreases then increases with increase in feed. Minimum flank wear is observed at feed of 0.15 mm/rev. Initially flank wear decreases with increase in feed because chip cross section area increases hence more heat is dissipated through the chips which reduces the temperature at cutting zone. Further increase in feed leads to increase in flank wear because as the feed increases, there will be increase in force on the cutting edge of the tool. This heavy force produces higher stress on the cutting edge of tool. Due to this stress the flank wear increases rapidly.

Flank wears increases with increase in depth of cut. The rate of change in flank wear is more when depth of cut changes from 0.50 mm to 0.75 mm. Minimum flank wear is measured at depth of cut of 0.25 mm. As depth of cut increases, very high stresses developed at the tool nose because in higher cutting force. In order to get minimum flank wear cutting speed should be taken at lower level, feed at medium level and depth of cut at lower level. The optimum cutting parameters to get minimum flank wear are cutting speed of 400 m/min, feed of 0.15 mm/rev and depth of cut of 0.25 mm.

## IV. CONCLUSIONS

The experiments were carried out to analyze the effect of process parameters on machinability of NIMONIC 80A turning process. From the experimental investigations based on Taguchi's method and considering the limits of the variables employed, the following conclusions are drawn:

- It is observed that ceramic inserts gives better results for surface roughness compared to carbide insert. At lower cutting speed, notching is predominant and it is decreasing as cutting speed increases.
- Optimum parameters for better surface roughness are cutting speed of 500 m/min, feed of 0.1 mm/rev and depth of cut of 0.50 mm.
- It is found that the tool wear progresses rapidly during machining of NIMONIC 80A. The optimum condition to get lower flank wear is cutting speed of 400 m/min, feed of 0.15 mm/rev and depth of cut of 0.25 mm.

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