

Evaluation of Optimal Cutting Parameters in CNC Milling Of NIMONIC 75 Using RSM

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ABSTRACT: NIMONIC 75 is one of the important materials in the group of nickel based super alloys. It has wide applications in marine, aircraft, aerospace and chemical industries as they can withstand at very high temperatures. But NIMONIC 75 is very hard material to machining, so it is essential to estimate the optimum cutting parameters to machine it for desired output responses. CNC milling is widely used in machining operations due to it offers flexibility in producing complex shapes. In this paper the optimal machining parameters such as feed, depth of cut and spindle speed in CNC milling of NIMONIC 75 are estimated for the minimum Surface Roughness(R_a) and for maximum Material Removal Rate (MRR) by using Response Surface Methodology(RSM) with the help of DESIGN EXPERT 9 soft ware.

KEYWORDS: NIMONIC 75, RSM, CNC end mill, surface roughness R_a , Material Removal Rate (MRR).

I. INTRODUCTION

Computer numeric control (CNC) machine (i.e. mill, lathe, sheet metal brake etc) used for controlling the motion in one or more axes with the help of computers. It is first originated in 1950s able to manufacture complex jet air craft parts. Now a day's CNC machines utilizes software programmes for generating instructions to control the axis motions, tool changers, spindle speeds etc .

End milling is one of the types of face milling. In the end milling process, small cutter is used to remove material from the stock, to get slots over the cutting surface explained by Ming-Yung Wang et.al, 2004; A. monsour et.al, in[1][2]. The basic end milling operation is shown in Fig. 1; here a_e is radial depth of cut in mm , f_z is feed per tooth in mm/tooth, a_p is axial depth of cut in mm.

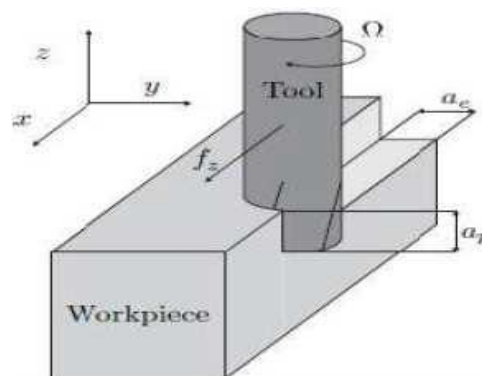


Fig.1 End Milling Operation

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For machining of hard materials like nickel alloys (NIMONIC), CNC milling is suitable. But it is required to analyze the cutting parameters to overcome machining problems and to forecast the machinability conditions.

Machinability is estimated by the analysis of outputs like R_a , material removal rate (MRR). Machining should provide accurate individual desired outputs such as shape, MRR, surface roughness etc. The index which determines the quality of machined products is surface roughness and it depends on cutting parameters. The average roughness (R_a) can be defined as the area between the roughness profile and its mean line or the integral of the absolute value of the roughness profile height over the evaluation length. The R_a is expressed by the following equation (1)

$$R_a = \frac{1}{L} \int_0^L |Z(x)| dx \quad \dots (1)$$

Where R_a is the arithmetic average deviation from the mean line, L is the sampling length and Z is the coordinate of the profile curve. The profile curve is shown in Fig.2.

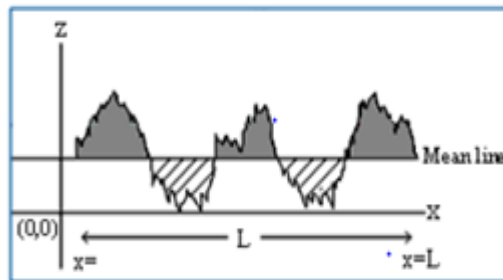


Fig. 2 Surface Roughness Profile

For desired conditions of output or response, the cutting parameters should be optimized before machining and thus the cost of machining and manufacturing time explained by Behnam Davoodi et.al, 2015; U. Natarajan et.al, 2011.[3][4].

Ming-Yung Wang et.al, 2004 explains that Response surface methodology (RSM) is an accumulation of statistical as well as mathematical methods useful for establishing optimized conditions in [1]. The majority of extensive applications of RSM will be in the distinct situations where exactly several input variables potentially influence a number of performance measures or excellent characteristics in the process. By the RSM the input parameters (speed, depth of cut, feed) be analysed and optimized for the desired outputs or responses such as surface roughness R_a and material removal rate (MRR) explained by U.Natarajan et.al, 2011; M.Numan Durakbasa et.al, in [4][5].

NIMONIC 75 alloy is selected as work piece material. NIMONIC 75 is a non ferrous nickel based alloy and it is a heat resistant super alloy. NIMONIC 75 chemical composition is shown in Table 1.

Table .1 Chemical Composition of NIMONIC 75

| Element | Percentage |
|-----------|----------------|
| Carbon | 0.08 to 0.15%, |
| Chromium | 18.0 to 21.0% |
| Copper | 0.5% max |
| Iron | 5.0% max |
| Manganese | 1.0% max |
| Silicon | 1.0% max |
| Titanium | 0.2to0.6% |
| Nickel | Balance |

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For turbine blades machining it is introduced in 1940s due to its mechanical stability at high temperatures, non reactive and resist to corrosion. It has wide scope in many areas such as chemical, marine, aerospace industries etc., explained by Dr Kevin Bradley, President, in [7]. The work piece before machining is shown in Fig.3.



Fig. 3 Work piece before Machining

A fully automated CNC vertical milling machine (HAAS 2F) is used as machine tool to do end milling operation on work piece as shown in Fig.4, with the help of CNC programming.

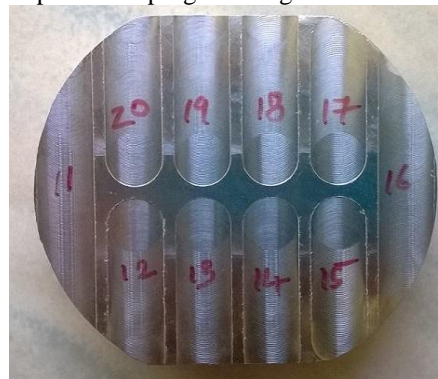


Fig. 4 Work Piece after Machining

Taguchi method, the L_{27} (3^3) orthogonal array (full factorial design) was taken to frame the design of experiments, with three factors (speed, feed, and depth of cut) with three levels explained by Hamzeh Shahrajabian et.al, in [6]. Machining parameters and their levels are given in the Table 2.

Table.2 Machining Parameters and their levels

| S.NO | Factor | Units | Level 1 | Level 2 | Level 3 |
|------|------------------------|--------|---------|---------|---------|
| 1 | Spindle Speed(X_1) | Rpm | 1000 | 1100 | 1200 |
| 2 | Feed Rate (X_2) | mm/min | 300 | 350 | 400 |
| 3 | Depth of Cut(X_3) | Mm | 0.1 | 0.125 | 0.15 |

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II. EXPERIMENTAL DETAILS

Solid carbide cutter of 10mm diameter with 4 flutes was used as cutting tool for the end mill operation and shown in Fig.5.



Fig.5 Solid Carbide Cutter

In the presence of coolant the end milling operation was carried. The machining operation is shown in Fig.6. The machining parameters ranges are spindle speed: 1000-1200 rpm, feed: 300-400 mm/min and depth of cut: 0.1-0.15mm.



Fig.6 Machining Operation

Responses Measurements:

1) Surface Roughness R_a Measurement:

The surface roughness (R_a) values of each machined slots are measured by using a portable surface roughness measuring device called SURFTEST-SJ210 as shown in Fig.7. The measured R_a values are given in the Table.3.



Fig.7 Measuring Surface Roughness R_a with Surf test Apparatus

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2) Material Removal Rate (MRR) Calculation:

Material removal rate (MRR) was calculated by using the equation (2) and values are given in the Table.3.

$$MRR = \text{Depth of Cut} \times \text{Width of Cut} \times \text{Feed Rate} \quad \dots (2)$$

Table.3 Observation table

| | Factor 1 | Factor 2 | Factor 3 | Response 1 | Response 2 |
|------------|-------------------------|----------------------|--------------------------|----------------|------------|
| Experiment | x ₁ :spindle | x ₂ :feed | x ₃ :depth of | R _a | MRR |
| Order | Rpm | mm/min | Mm | Microns | mm3/min |
| 1 | 1000 | 300 | 0.1 | 0.791 | 300 |
| 2 | 1000 | 300 | 0.125 | 1.254 | 375 |
| 3 | 1000 | 300 | 0.15 | 0.962 | 450 |
| 4 | 1000 | 350 | 0.1 | 1.469 | 350 |
| 5 | 1000 | 350 | 0.125 | 1.983 | 437.5 |
| 6 | 1000 | 350 | 0.15 | 1.786 | 525 |
| 7 | 1000 | 400 | 0.1 | 1.932 | 400 |
| 8 | 1000 | 400 | 0.125 | 2.047 | 500 |
| 9 | 1000 | 400 | 0.15 | 1.112 | 600 |
| 10 | 1100 | 300 | 0.1 | 1.408 | 300 |
| 11 | 1100 | 300 | 0.125 | 0.952 | 375 |
| 12 | 1100 | 300 | 0.15 | 1.383 | 450 |
| 13 | 1100 | 350 | 0.1 | 1.232 | 350 |
| 14 | 1100 | 350 | 0.125 | 1.258 | 437.5 |
| 15 | 1100 | 350 | 0.15 | 1.883 | 525 |
| 16 | 1100 | 400 | 0.1 | 1.265 | 400 |
| 17 | 1100 | 400 | 0.125 | 1.828 | 500 |
| 18 | 1100 | 400 | 0.15 | 1.456 | 600 |
| 19 | 1200 | 300 | 0.1 | 1.033 | 300 |
| 20 | 1200 | 300 | 0.125 | 1.229 | 375 |
| 21 | 1200 | 300 | 0.15 | 0.834 | 450 |
| 22 | 1200 | 350 | 0.1 | 1.133 | 350 |
| 23 | 1200 | 350 | 0.125 | 1.211 | 437.5 |
| 24 | 1200 | 350 | 0.15 | 2.704 | 525 |
| 25 | 1200 | 400 | 0.1 | 3.559 | 400 |
| 26 | 1200 | 400 | 0.125 | 2.63 | 500 |
| 27 | 1200 | 400 | 0.15 | 3.015 | 600 |

III. RESULTS AND DISCUSSION

1. Effect of Process Parameters on Surface Roughness R_a:

The ANOVA table for Surface Roughness R_a is given in Table.4; from the ANOVA table of R_a the following points are observed.

1. Here the quadratic model was suggested in the fit summary so that the analysis was done for quadratic model.
2. The model F-value 9.75 indicates that the model is significant.
3. The Prob > F less than 0.0500 indicates the model terms are significant. Here x₁, x₂, x₃, x₁² are significant.
4. R² value is 0.6394 for surface roughness indicates that the total variations of 63.94% explained by the model.

The final equation in terms of actual factors is given in the equation (3).

$$R_a = +56.79151 - 0.11078 \times X_1 + 7.49278E - 003 \times X_2 + 13.94378 \times X_3 + 5.13183E - 005 \times X_1^2 \quad \dots (3)$$

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Table.4 ANOVA Table for Surface Roughness (R_a)

| Source | Sum of squares | d. f. | Mean Square | F-Value | P-value Prob > F |
|--------------|----------------|-------|-------------|------------|------------------|
| Model | 7.10 | 4 | 1.78 | 9.75 | 0.0001 |
| x_1 -Speed | 0.81 | 1 | 0.81 | 4.44 | 0.0468 |
| x_2 -Feed | 2.53 | 1 | 2.53 | 13.88 | 0.0012 |
| x_3 -DOC | 2.19 | 1 | 2.19 | 12.01 | 0.0022 |
| x_1^2 | 1.58 | 1 | 1.58 | 8.68 | 0.0075 |
| Residual | 4.01 | 22 | 0.18 | | |
| Cor Total | 11.11 | 26 | | | |
| Std. Dev. | 0.43 | C.V | 24.60 | R^2 | 0.6394 |
| Mean | 1.73 | Pred | 0.4577 | Adj. R^2 | 0.5738 |

a) Model graphs plotted for R_a :

The one factor graphs for R_a with respect to cutting parameters speed, feed, and depth of cut are given in the Fig.8, Fig.9 and Fig.10 respectively. The surface roughness R_a value decreases with increases in speed at intermediate level but finally surface roughness increases with increase in speed.

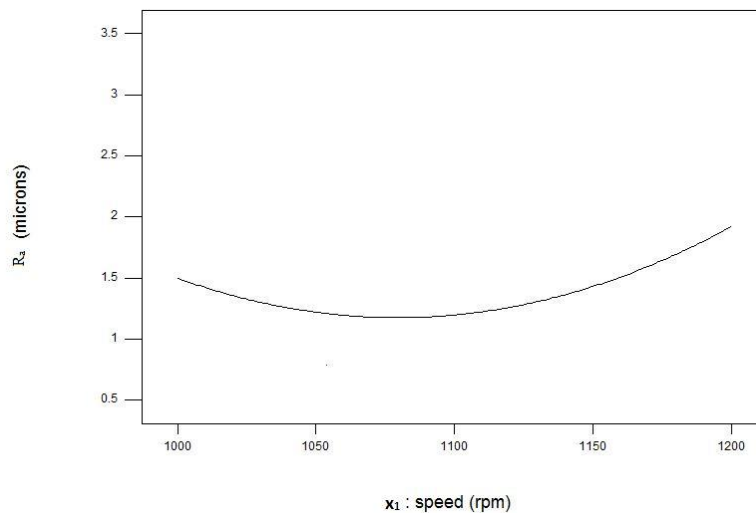


Fig.8 Graph between Speed and Surface Roughness R_a

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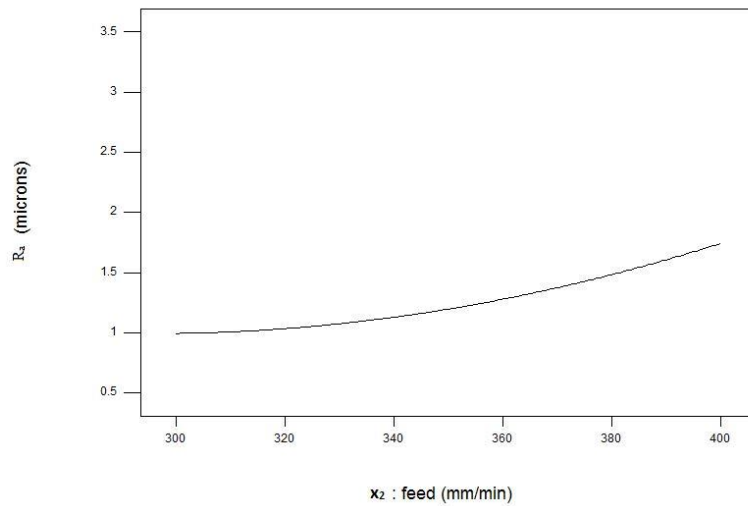


Fig. 9 Graph between feed and Surface Roughness R_a

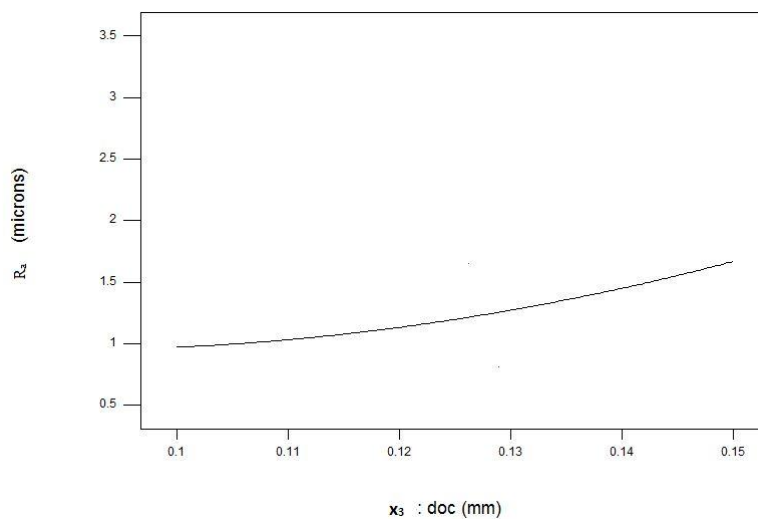


Fig. 10 Graph between depth of cut and Surface Roughness R_a

2. Effect of Process Parameters on MRR:

The ANOVA table for MRR is given in the Table.5; from the ANOVA table for MRR the following points are observed.

1. For Material Removal Rate (MRR), the linear model was suggested in the fit summary so that the analysis was carried out on the linear model only.
2. The model F-value of 851.00 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise.
3. Values of Prob > F is less than 0.0001 means the terms are significant. Here terms x_2 and x_3 are significant. The term x_1 is insignificant term.
4. R^2 value is 0.9911 that means for material re. The surface roughness R_a value increases with increment in feed. With increase in depth of cut the surface roughness R_a value increasing moval rate (MRR), the total variations explained by the model are 99.11%.

The final equation in terms of actual factors for material removal rate (MRR) is generated and given in equation 4.

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$$MRR = -437.50000 + 3.27618E - 0 \times x_1 + 1.25000 \times x_2 + 3500.00000 \times x_3 \quad \dots (4)$$

Table.5 ANOVA table for Material Removal Rate (MRR)

| Source | Sum of Squares | Dof | Mean Square | F-Value | P-value |
|--------------|----------------|---------------------|-------------|---------------------|-----------|
| Model | 2.081E+005 | 3 | 69375.00 | 851.00 | < 0.0001* |
| x_1 -Speed | 0.000 | 1 | 0.000 | 0.000 | 1.0000 |
| x_2 -Feed | 70312.50 | 1 | 70312.50 | 862.50 | < 0.0001 |
| x_3 -DOC | 1.378E+005 | 1 | 1.378E+005 | 1690.50 | < 0.0001 |
| Residual | 1875.00 | 23 | 81.52 | | |
| Cor Total | 2.100E+005 | 26 | | | |
| Std. Dev. | 9.03 | C.V% | 2.06 | R ² | 0.9911 |
| Mean | 437.50 | Pred R ² | 0.9865 | Adj. R ² | 0.9899 |

a) Model graphs plotted for MRR: the model graphs for Material Removal Rate (MRR) with respect to significant factors feed, depth of cut are given in the Fig.11 and Fig.12 respectively. The Material Removal Rate (MRR) increases with increase in feed rate. The Material Removal Rate (MRR) is increasing with increase in depth of cut.

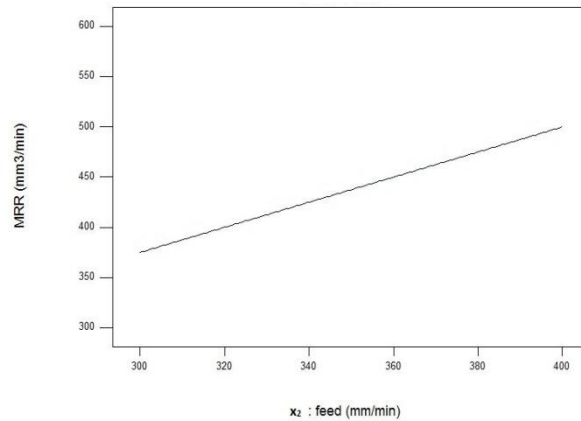


Fig.11 Graph between Material removal rate (MRR) and feed

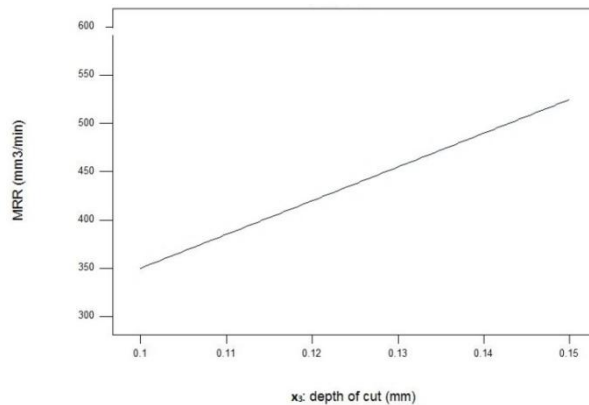


Fig.12 Graph between Material Removal Rate (MRR) and depth of cut

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3. Optimization:

The optimization carried for surface roughness R_a and material removal rate (MRR) separately and multi response optimization done for both R_a and MRR combine. The optimized values are shown Table.6.

Table.6 Optimization Parameters with their corresponding Responses

| Response | Optimum cutting parameters | | | Predicted responses | Desirability |
|----------------|----------------------------|------------|---------------|---------------------|--------------|
| | x_3 :spee | x_2 :fee | x_3 : D O C | | |
| R_a minimize | 1007.74 | 300 | 0.1 | 1.07617 | 0.962 |
| MRR | 1100 | 400 | 0.15 | 587.5 | 0.958 |
| R_a minimize | 1102.71 | 300 | 0.15 | 1.06498,462.5 | 0.828 |
| Moderate R_a | 1000 | 400 | 0.15 | 1.52085,587.5 | 0.840 |

IV. CONCLUSIONS

The experimental work involves analysis of surface roughness R_a and Material Removal Rate (MRR) in CNC end milling operation of NIMONIC 75 with RSM leads to the following conclusions:

1. The surface roughness R_a follows the quadratic model and Material Removal Rate (MRR) follows the linear model. For R_a the speed, feed, depth of cut parameters are significant and for MRR the feed and depth of cut are significant.
2. The final equations for R_a and MRR were generated.
3. Optimum cutting parameters to minimize the R_a , speed=1007.74 rpm, feed rate=300 mm/min, depth of cut=0.1.
4. Optimum cutting parameters to minimize the R_a are speed=1100 rpm, feed rate=400 mm/min and depth of cut=0.15.
5. Optimum cutting parameters to optimize the multiple responses by using desirability function on giving same importance for both surface roughness R_a and material removal rate (MRR) are speed = 1000 rpm, feed rate = 400 mm/min, depth of cut = 0.15.
6. From the Table.9, the parameters and predicted responses in different combinations of surface roughness R_a and material removal rate (MRR) will give an idea while selecting the cutting parameters on the basis of priority levels set.

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