Optimization of CNC Turning Process Parameters on INCONEL 718 Using Genetic Algorithm

K.Saravanakumar,
Assistant Professor,
Department of Mechanical Engineering,
Karpagam University, Coimbatore-641021,
Tamil Nadu, India.

M.R.Pratheesh Kumar,
Assistant Professor,
Department of Production Engineering,
P.S.G College of Technology, Coimbatore,
Tamil Nadu, India.

Dr.A.K.Shaik Dawood
Professor,
Department of Mechanical Engineering,
Karpagam University, Coimbatore-641021,
Tamil Nadu, India.

Abstract

This paper is aimed at conducting experiments on Inconel 718 and investigation the influence of machining process parameters such as cutting speed (X_1, m/min), feed rate(X_2, mm/rev), and depth of cut (X_3, mm) on the output parameters such as material removal rate and surface roughness. Cost effective machining with generation of good surface finish and maximum material removal rate on the Inconel 718 material by turning operation is a challenge to the manufacturing industry. Major advantages of high-speed machining are high material removal rates, more dissipation of heat, high chip removal rate and better surface finish. Therefore, by optimizing input parameters such as cutting speed, feed rate, and depth of cut, etc., the output parameters like surface finish and metal removal rate can also be optimized for economical production. Machining process is done in Computer Numerical Control (CNC) turning lathe. Several techniques are available for optimizing the input parameters to get optimized output parameters and in this research genetic algorithm is used. The chemical composition and hardness test are carried out for Inconel 718 material. Number of experiments had been conducted with suitable combinations of input parameters. Relationship between material removal rate and input parameters and between surface roughness and input parameters are arrived through Minitab software. These regression equations are solved using genetic algorithm tool called user interface method and the optimum combinations of input parameter for input parameters for maximum material removal rate (MRR) and minimum surface roughness (Ra) had been arrived using mat lab software.

Key words: CNC, MRR, Ra, GA.

I. INTRODUCTION

Inconel 718 a high strength thermal resistance nickel based alloy, is mainly used in aircraft industries, chemical processing industry, aircraft engine parts, medical applications and Steam turbine power plants. But the problem of machining inconel 718 is one of ever increasing magnitude due to extreme toughness and work hardening characteristics of the alloy.

Genetic algorithms are computerized search and optimization algorithms based on the mechanics of natural genetics and natural selection. Genetic algorithms are good at taking larger, potentially huge, search spaces and navigating them looking for optimal combinations of things and solutions. Genetic algorithms work with a coding of variables. The advantage of working with a coding of variable space is that coding discretizes the search space even though the function may be continuous. The main difference between GA and other traditional an optimization method is that GA uses a population of points at one time in contrast to the single point approach by traditional optimization methods. This means that GA processes a number of designs at the same time. Generally to solve a problem it is worked out towards some solution which is the best among others. The space for all possible feasible solutions is called search space.

Regression analysis may be broadly defined as the analysis of relationships among variables. It is one of the most widely used statistical tools because it provides a simple method of establishing a functional relationship among variables. The relationship is expressed in the form of an equation connecting the response or dependent variable (y), and one or more independent variables, x_1, x_2, x_3,……..x_p. The regression equation takes the form

$$y = b_0+b_1x_1+b_2x_2+\ldots\ldots..+b_px_p.$$

Where b_0, b_1, b_2……..b_p, called the regression coefficients, are determined from the data.

II. LITERATURE REVIEW

[1] Machinability characteristics of super alloy Inconel 718 during high speed turning using tungsten carbide tool inserts. Inconel 718 is used in many applications like space vehicles, marine applications owing to have unique properties of high oxidation resistance, corrosion resistance. The optimization of certain parameters in machinability like production rate, surface finish, and low cutting forces can be obtained by conventional machining method. The machining process involves continuous high speed turning by varying cutting parameters like cutting speed, feed rate and depth of cut, etc. The effect of machining parameters on the cutting forces, specific cutting pressure, cutting temperature, tool wears and surface roughness (Ra) criteria were investigated during the experimentation. The magnitude of cutting force and feed force are found to be somewhat linear cutting speed range of 45-55 m/min at medium level of feed rate and also gives optimum surface finish. Specific cutting pressure was used one of the important process parameters to understand status of the cutting edge. The authors concluded that the machining condition for Inconel 718 using tungsten carbide (k20) selected for the medium cutting speed range, feed rate range at low depth of cut.

[3] The effects of the feed rate on the cutting tool stresses in machining of Inconel 718. Since, cutting force affect the cutting tool during machining in metal cutting they are considered as important parameter for economical machining. In this experiment, Inconel 718 having initial hardness of 40-45 HRC was used as work piece material and tool inserts were Whisker reinforced ceramics. The tests were carried out without coolant at five levels of cutting speeds and feed rates and two levels depth of cut. Kistler piezoelectric dynamometer was used to measure principal cutting force F_c, feed force F_f and passive force F_p. The distribution of stresses on the cutting tool was analyzed by ANSYS 6.1 based on the FEM using the cutting forces (F_c, F_f, and F_p) measured during the machining. The authors concluded that the stresses on ceramic cutting inserts increases with increases in feed rate and it are influenced by feed force and passive force values.

[6] tool-life and wear mechanisms of CBN tools in machining of Inconel 718. Nickel super alloys of Inconel 718 extensively used by the automotive industry in hard turning, and also in aerospace materials. CBN tool material is one of the hardest materials as like diamond and has a cubic atomic structure and super abrasive material as like diamond. In their experiment, the material Inconel 718 was treated and aged to obtain hardness of 40-45HRc. Thus, the authors made their investigation on CBN tools and concluded that tool wear is obtained between 45-60% of CBN content. The authors did not mention about the effect of grain size on tool life.

[7] Real coded genetic algorithm optimization of machining parameters in order to obtain better surface quality. Since, surface quality is one of the important indicators of customer requirement in machining process. There are various methods available for optimization problems like calculus based, dynamic programming, artificial neural network, simulated annealing, etc. the authors concluded from experimental analysis that surface roughness decreases with increase in cutting speed and decrease in feed rate.

[8] A multi-objective optimization technique, based on genetic algorithms. In any optimization procedure identifying the output parameter is of chief important. Many of authors have determined the optimization in single objective approaches only and it has limited value to fix optimal cutting conditions. The objectives are maximization of tool life and maximization of production rate using genetic algorithm method. The proposed genetic algorithm was implemented in C++. By using of Pareto frontier graphics, several different situations may be considered, facilitating the choice of right parameters for any condition. The proposed micro-GA has obtain several, uniformly distributed points, in order to arrange the Pareto front, at a reasonably low computational cost. Cost analysis can complement the Pareto front information, and it helps the decision-making process.

III. METHODOLOGY

A. FOR EXPERIMENTAL WORK

i) The material and tool inserts are selected based on the problem identification study.

ii) Identifying different ranges of input parameters and their levels

iii) Testing of hardness and chemical composition.

iv) Measuring surface roughness (Ra) using surface roughness tester SJ-201.

B. FOR THEORETICAL WORK

i) Calculation of material removal rate

ii) Formation of regression equation using minitab software.

C. FOR ANALYSIS WORK

i) Developing algorithm for optimization using Mat lab.

ii) Comparing the optimization results with the experimental results and finding out the percentage error between them.

iii) Validation of results.

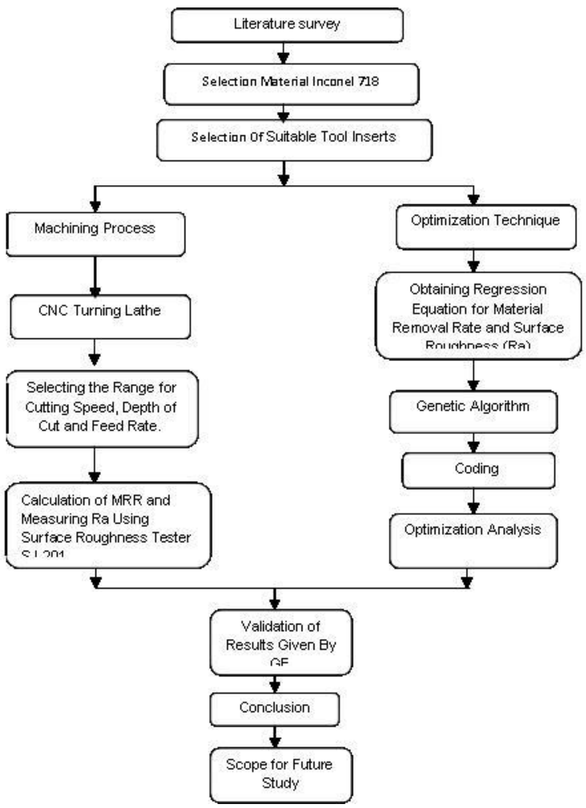


Figure 1 Flow Chart Methodology

IV. EXPERIMENTAL DETAILS

A WORK PIECE MATERIAL

The work material used was Inconel 718 and its chemical composition and hardness are tested and hardness value is found to be 43 HRC. The table below shows the chemical composition of Inconel 718.

Table 1 chemical composition for Inconel 718

C	Si	S	P
0.062%	0.12%	0.004%	0.033%
Mn	Cr	Mo	V
0.0002%	18.01%	3.75%	0.027%
Cu	W	Ti	Co
0.11%	0.12%	0.97%	0.17%
Al	B	Nb	Ta
0.47%	0.002%	5.345	5.34%
Mg	Fe	Sn	Zr
0.02%	18.51%	0.011%	0.001%
Ca	Ni		
0.0003%	52.21%		

B. CUTTING TOOL

Coated carbide tool inserts M30 was used for turning.

C. EXPERIMENTAL SET UP AND CUTTING CONDITIONS

Machining process was carried out in CNC lathe. The machining process involved various cutting parameters such as cutting speed, depth of cut, feed rate. The measurements of average surface roughness (Ra) were made on surface roughness tester SJ-201.Two measurements of surface roughness were taken at different locations and average value is used in the analysis and material removal rate is calculated using empirical formula.

D. MATERIAL REMOVAL RATE

The material removal rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in mm^3/min. For each revolution of the work piece, a ring shaped layer of material is removed.

$$MRR= ((\pi D^2/4)-(\pi d^2/4)) \times f \times N \qquad (1)$$

Where

D=Diameter of work piece before cutting in mm.

d= Diameter of work piece after cutting in mm.

f=Feed rate mm/rev.

N= spindle speed in rpm.

E. SURFACE ROUGHNESS TESTER SJ-201

The MITUTOYO Surface roughness tester used for measuring surface roughness (Ra) given below

Figure- 2 Surface roughness Tester SJ-201

F.COMBINATION OF PARAMETERS AND THEIR LEVELS

Table 2 Combination of Parameters and their levels

S.No	Parameters	Level		
		I	II	III
1	Cutting Speed (m/min)$\mathbf{X_1}$	60	70	80
2	Feed rate (mm/rev) $\mathbf{X_2}$	0.15	0.2	0.25
3	Depth of cut (mm) $\mathbf{X_3}$	0.1	0.2	0.25

G.CNC LATHE

The CNC Lathe used for machining Purpose shown below

Figure-3 CNC Lathe

H. EXPERIMENTAL VALUES

1) Input parameters

$\mathbf{X_2}$ -Cutting speed (m/min)

$\mathbf{X_2}$ -Feed rate (mm/rev)

$\mathbf{X_3}$-Depth of cut (mm)

2) Output parameters

$\mathbf{Y_1}$ -material removal rate (mm^3/min)

$\mathbf{Y_2}$ -surface roughness Ra (µm)

Table 3 Experimental values

Exp.no	**Input Parameters**			**Output Parameters**	
	$\mathbf{X_1}$	$\mathbf{X_2}$	$\mathbf{X_3}$	$\mathbf{Y_1}$	$\mathbf{Y_2}$
1	60	0.15	0.1	449.6	1.85
2	60	0.15	0.2	896.78	0.86
3	60	0.15	0.25	1116.34	1.28
4	60	0.2	0.1	593.46	1.42
5	60	0.2	0.2	1183.62	0.91
6	60	0.2	0.25	1473.34	1.91
7	60	0.25	0.1	734.26	1.59
8	60	0.25	0.2	1464.41	1.52
9	60	0.25	0.25	1822.79	1.07
10	70	0.15	0.1	503.3	1.42
11	70	0.15	0.2	1003.74	0.89
12	70	0.15	0.25	750.31	0.99
13	70	0.2	0.1	665.35	1.12
14	70	0.2	0.2	1326.9	1.96
15	70	0.2	0.25	1651.5	1.73
16	70	0.25	0.1	822.97	0.99
17	70	0.25	0.2	1641.19	1.17
18	70	0.25	0.25	2042.57	0.85
19	80	0.15	0.1	580.46	0.86
20	80	0.15	0.2	1157.5	0.94
21	80	0.15	0.25	1440.55	0.87
22	80	0.2	0.1	765.65	0.95
23	80	0.2	0.2	1526.79	1.12
24	80	0.2	0.25	1900.01	0.74
25	80	0.25	0.1	2363.24	2.12
26	80	0.25	0.2	1882.11	0.95
27	80	0.25	0.25	1874.58	1.16

I. REGRESSION EQUATIONS

Regression equations were formed using Minitab software for Material removal rate ($\mathbf{Y_1}$) and surface roughness Ra ($\mathbf{Y_2}$)

The regression equation for Material Removal Rate ($\mathbf{Y_1}$) is

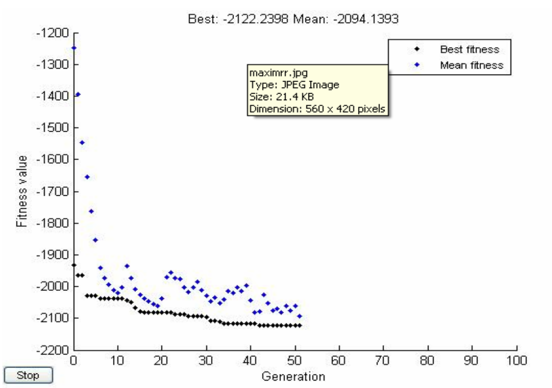
$\mathbf{Y_1} = 19158 - 298\,\mathbf{X_1} - 112136\,\mathbf{X_2} - 91493\mathbf{X_3} + 1749\mathbf{X_1}*\mathbf{X_2} + 1417\mathbf{X_1}*\mathbf{X_3} + 537343\,\mathbf{X_2}*\mathbf{X_3} - 7880\mathbf{X_1}*\mathbf{X_2}*\mathbf{X_3}$

The regression equation for Surface Roughness Ra ($\mathbf{Y_2}$) is

$\mathbf{Y_2} = 23.6 - 0.331\,\mathbf{X_1} - 110\,\mathbf{X_2} - 88.0\,\mathbf{X_3} + 1.66\,\mathbf{X_1}*\mathbf{X_2} + 1.29\,\mathbf{X_1}*\mathbf{X_3} + 463\,\mathbf{X_2}*\mathbf{X_3} - 6.93\,\mathbf{X_1}*\mathbf{X_2}*\mathbf{X_3}$

V.RESULTS AND DISCUSSIONS

A. MAXIMIZATION MATERIAL REMOVAL RATE USING GA TOOL



Best fitness for maximization of material removal rate is shown below using genetic algorithm tool.

Population 100, Current generation 52

Optimization value

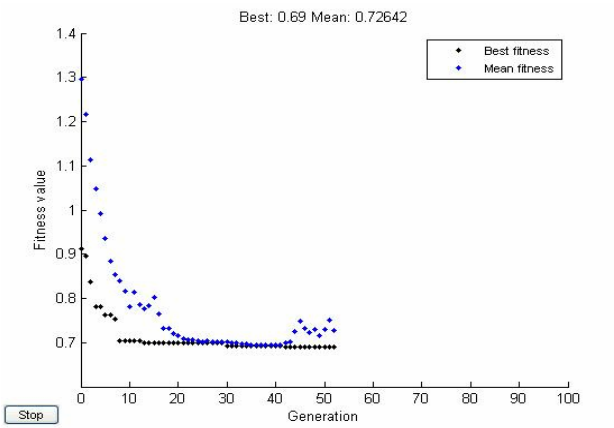
Cutting speed= 79.99m/min, feed rate=0.25mm/rev, depth of cut=0.1mm

Best fitness for maximization of Material removal rate is 2122.23 mm^3/min.

Figure 4 Graph for Material removal rate

B. MINIMIZATION OF SURFACE ROUGHNESS USING GA TOOL

Best fitness for minimization of surface roughness is shown below using genetic algorithm



tool.

Population 100, Current generation 52 Optimization value

Cutting speed= 79.9m/min, feed rate=0.15mm/rev, depth of cut=0.1mm

Best fitness for minimization of surface roughness is 0.69 µm

Figure 5 Graph for Surface roughness

VI. CONCLUSION

The optimum combination of input parameters for maximization of material removal rate is found to be cutting speed 79.99m/min, feed rate 0.25mm/rev, depth of cut 0.1mm and best fitness value is 2122.23 mm^3/min. and the optimum combination of input parameters for minimization of surface roughness found to be cutting speed 79.9m/min, feed rate 0.15mm/rev, depth of cut 0.1mm and Best fitness for minimization of surface roughness is 0.69 µm. This paper has presented a comprehensive literature review of various state-of-the-art methodologies for optimizing material removal rate and surface roughness which are obtained using genetic algorithm.

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K.Saravanakumar is post graduate in Production Engineering from PSG College of Technology, Coimbatore which is affiliated to Anna University of Technology, Coimbatore. Presently working as an Assistant Professor in Department of Mechanical Engineering, Karpagam University, Coimbatore. He has 2 years of experience in teaching. He published 3 papers in National Conference.

M.R.Pratheesh Kumar is a post graduate in Manufacturing Engineering, did his post graduation at Anna University-Chennai, Madras Institute of Technology campus-Chromepet, Chennai. Presently he is working as an Assistant Professor in Department of Production Engineering, PSG College of Technology, Coimbatore. He has 12 years of experience in teaching. His publications include one international conference, eight national conferences, and one national journal.

Dr.A.K.Shaik Dawood is doctorate in Mechanical Engineering from PSG College of Technology, Coimbatore which is affiliated to Anna University. Presently working as Professor in Mechanical Engg, Karpagam University, Coimbatore. He has got 13 years of teaching experience. He has published 10 papers in international journals and also has published 15 papers in international & national conference. His research interests include Robotics, CFD, Industrial Engg, Metallurgy and Production. He is a Registered PhD supervisor of Anna University and Karpagam University. He is currently guiding 8 PhD research scholars.