Optimization of Chip Load for Improved Surface Finish In Milling Inconel718

Faisal .M. Ali [1], S.C.Borse [2]

P.G. Student, Department of Mechanical Engineering, DIEMS Engineering College, Station Road, Aurangabad, India[1]

Assistant Professor, Department of Mechanical Engineering, DIEMS Engineering College, Station Road, Aurangabad, India[2]

Abstract: High quality and productivity are two important but major criteria in several machining operations. Vertical End Milling Machining process operated by CNC is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. In the End milling process, the material is removed by parent material from the end mill cutter. The effects of numerous parameters of end milling process like Chip load, cutting speed and depth of cut have been examined to reveal their Impact on surface finish using Taguchi Methodology. In this study, an attempt has been conducted to investigate the effects of cutting parameters on surface roughness during End milling of Inconel718 material By taking into account the taguchi method .The experimental results have revealed that the Chip load and cutting speed has most significant effect on surface roughness. The present approach and results will be helpful for understanding the machinability and surface characteristics of Inconel718 during End milling for the manufacturing engineers. Analysis of variance is used to study the effect of process parameters and established correlation among the chip load, speed and depth of cut with respect to Ra. The results are further confirmed by experiments.

Keywords: Chip load, End Milling, surface Finish

1 Introduction

The focus on this project is to obtain an optimum process parameter consider as Chip load, cutting speed and depth of cut which provides the optimum value of surface finish. The experimentation plan was created using Taguchi‟s L9 Orthogonal Array (OA) and Minitab 14.0 statistical software is employed. Optimal values of process parameter with regard to desired performance characteristic are received by Taguchi design of experiment. Milling is often a versatile in addition to useful machining operation. End milling is the main milling operation which is widely used in a lot of the manufacturing industries automobile capability involving producing complex geometric surfaces with reasonable accuracy in addition to surface finish. However, with the inventions of CNC milling machine, the flexibility may be adopted in addition to versatility within end milling process.

Milling processes comprise a very big portion of metal cutting process in industry. For the determination of ideal machinability properties, those parameters such as mechanical material properties, machine tool rigidity, Chip load, cutting speed and cutting tool geometry play an important role in machining. Chip load is the main parameters that affect machinability properties of the material .Although Inconel718 can be machined by using cemented carbide tools at low cutting speeds, it must be machined by ceramic tools at higher cutting speeds. But the problem of machining inconel718 is one of ever increasing magnitude due to extreme toughness and work hardening characteristics of the alloy.

Super alloy, Inconel718 is used for manufacturing components in most of the advanced and critical application due to its superior properties .Surface quality of machined component play a vital role in function characteristics and life of product .Due to its peculiar characteristics machining of super alloy Inconel718 is difficult and costly .Inconel718 material is widely used in as aircraft engine parts, steam turbine power plants, space vehicles, medical applications, marine applications, pollution control equipment, automotive sector etc. Since machining is basically a finishing process with specified dimensions, tolerances and surface finish, the type of surface that a machining operation generates and its characteristics are of great importance in manufacturing. Carbide cutting tools are the oldest amongst the hard cutting tool materials. Tungsten carbides are mainly used for continuous cutting operations Carbide tools are used to machine nickel-base super alloys in the speed range of 800-5000 Several research efforts have been conducted in order to improve the machined surface accuracy. which directly affects to the cost of machining and productivity.

Taguchi Proposed that the engineering optimization of a process should be carried out in a three steps approach ; system design parameters design and tolerance design Taguchi method is a powerful design of experiment tool for engineering optimization of a process. The application in which the concept of S/N ratio is the useful are the improvement of quality through variability reduction and improvement of measurement.

2 Literature Review

The challenge and difficulty to machine Inconel718 are due to its profound characteristics such as high sheer strength, tendency to weld and form build-up edge low thermal conductivity and high chemical affinity. Inconel718 also has the tendency to work harden and retain major part of its strength during machining .Due to these characteristics, Inconel718 is not easy to cut and thus has been regarded as difficult-to-cut material. Inconel718 are widely employed in aerospace industry .In particular for the hot sections of gas turbine engines due to their high temp strength and high corrosion resistance. we focus our study on the inconel718 alloys.

Yung-kuang yang (2009) This investigation applied the designs of experiments approach to optimize parameters of CNC end milling for high purity graphite under dry machining .The analysis variance anova was adopted to identify the most influential factors on the cnc end milling process. By applying regression analysis a mathematical predications of the groove difference and roughness average has been developed in terms of cutting speed, feed rate , depth of cut .The feed rate is found to be most significant factor affecting the groove difference & the roughness average in end milling process for high purity graphite. Additionally the tool worn surfaces after machining were examined by the optical zoom scope.

Bala murugan gopalsamy (2009) In this investigation ,Taguchi method is applied to find optimum process parameters for end milling while hard machining of hardened steel. A L 18 array signal to noise ratio & analysis of variance(ANOVA) are applied to study performance characteristics of machining parameters (cutting speed ,feed rate Depth of cut) with consideration of surface finish & Tool wear .chipping & adhesion are observed to be main cause of wear . Results obtained taguchi method match closely with ANOVA & cutting speed is most important parameter..

Domnita Fratila (2010) This work outlines the Taguchi optimization methodology, which is applied to optimize the cutting parameters in face milling when machining AlMg3 (EN AW 5754) with HSS (high speed steel) tool under semi-finishing conditions in order to get the best surface roughness and the minimum power consumption. Beside the conventional flood lubrication, the investigations include the minimal quantity lubrication and the dry milling. These environment-friendly cutting techniques are considered two practical ways to the cleaner manufacturing in the context of the sustainable production. The parameters evaluated are the cutting speed, the depth of cut, the feed rate and the cooling lubrication techniques (cutting fluid flow).The appropriate orthogonal array, signal to noise (S/N) ratio and Pareto analysis of variance (ANOVA) are employed to analyze the effect of the mentioned parameters on the good surfacefinish (surface roughness).

Nilrudra Mandal (2011) In this experiment, Taguchi method and Regression analysis have been applied to assess machin- ability of AISI 4340 steel with newly developed Zirconia Toughened Alumina (ZTA) ceramic inserts. Several experiments have been carried out based on an orthogonal array L9 with three parameters (depth of cut feed rate, cutting speed) at three levels (low, medium and high). Based on the mean response and signal to noise ratio (SNR), the best optimal cutting condition has been arrived at A2B1C1 i.e. cutting speed is 280 m/min, depth of cut is 0.5 mm and feed rate is 0.12 mm/rev considering the condition smaller is the better approach. Analysis of Variance (ANOVA) is applied to find out the significance and percent- age contribution of each parameter. It has been observed that depth of cut has maximum contribution on tool wear.

P.Chockalingam,(2012) This research deals with the effect of different coolant conditions on milling of AISI 304 stainless steel. Cooling methods used. In this investigation were flooding of synthetic oil, water-based emulsion, and compressed cold air. Cutting forces and the surface roughness were studied and tool flank wears observed. In this study, the comparison between different coolants' effect to the milling of AISI 304 stainless steel is done and the results from the study can provide very useful information in manufacturing field. The experiment results showed that water-based emulsion gave better surface finish and lower cutting force followed by synthetic oil and compressed cold air. Different cooling condition required different parameters in order to obtain lower surface roughness and cutting force. Chipping was the initial wear mode in the milling of AISI 304 stainless steel.

N.N. Bhopale (2012) This work addresses the effects of cutting speed and feed on the work piece deflection and surface integrity during milling of cantilever shaped Inconel718 plate under different cutter orientations. The experiments were conducted on a CNC vertical milling machine using 10 mm diameter TiAlN coated solid carbide ball end milling cutter. Surface integrity is assessed in terms of micro hardness beneath the machined surface. The micro-hardness profile shows different patterns at various cutting parameters. It is observed that at large cutting speed as well as feeds, thicker work piece with larger work piece inclination shows higher micro hardness as compared to the other machining conditions.

M.Z.A. Yazid,(2013) In this experimental works, Inconel718, a highly corrosive resistant nickel-based super alloy was finish- turning with CNC lathe using PVD coated carbide tools under Minimum Quantity Lubrication (MQL) conditions. The machining process was performed initially with two levels of cutting speed (Vc=90 and 150 m/min), two levels of cutting depth (d=0.30 and 0.50 mm), two levels of feed rate (f=0.10 and 0.15 mm/rev) and two levels of MQL volume flow rate (MQL 50 and MQL 100 mL/h). The levels of design were then augmented by adding center point and axial point runs as in Central Composite Design (CCD). This paper describes the development of a Tool-Life modeling using Factorial Design of Experiments and Response Surface Methodology (RSM) in terms of machining parameters: cutting speed, feed, cutting depth and MQL volume flow rate. Tool life data, which is measured based on flank wear, from the experimental runs were analyzed and processed using statistical method into first-order model, at 95% confidence level.

W. Li, Y.B. Guo (2014) In this work, the effect of tool wear on surface integrity and its impact on fatigue performance of Inconel 718 alloy (45 ± 1 HRC) by end milling using PVD coated tools are studied. The evolutions of surface integrity including surface roughness, microstructure, and microhardness were characterized at three levels of tool flank wear (VB = 0, 0.1 mm, 0.2 mm). At each level of tool flank wear, the effects of cutting speed, feed, and radial depth-of-cut on surface integrity were investigated respectively. End milling can produce surface finish between 0.1 μm and 0.3 μm under most of the conditions. Roughness is generally higher in step-over direction than feed direction.

Mohamad Amir shafique (2014) This work proposes several architectures of single and multi-layer back propagation neural network methods, to predict tool wear progression within the end milling process of Inconel 718. The end milling process was carried out in a cryogenic environment, with cutting parameters of cutting speed, Vc (140 - 170 mm/min), feed rate, Fz (0.05 - 0.1 mm/tooth), axial depth of cut, ap (0.3 - 0.5 mm), and radial depth of cut, ae (0.2 - 1 mm). A coated carbide end ball nose, with a diameter of 5 mm, was used as a cutting tool. The cutting forces exerted during the milling process were measured using a strain gauge based dynamometer in x, y, and z directions. In order to apply a feed forward back propagation neural network method to predict tool wear; Vc, Fz, ap, ae, and the resultant force (FR), were taken as inputs, and tool wear was obtained as an output.

Sourabh Kuamr Soni (2015) In this work the effect of machining parameters speed, feed, depth of cut, are studied on surface roughness for milling operation. For surface roughness, our observation is based on smaller is better for s/n ratio. Cutting speed has Optimization of Milling Process Parameter for Surface Roughness of Inconel718 By Using Taguchi Method .Greater effect than feed and depth of cut, our observation is based on smaller is better for s/n ratio. The lowest surface roughness (Ra) of 0.80 μm was achieved corresponding to: f: 0.12 mm/rev, Vc: 55m/min. and d: 1.6 mm. Taguchi robust design is suitable for modeling surface finish in CNC milling.

3. Experimental Procedure

The work piece material used in the machining test was Inconel718.Its chemical composition confirms to the following specification in table 1

Table 1 Chemical Composition of inconel718

Elements	Percentage (%)
Ni (+Co)	50 – 55
Fe	Bal
Mo	2.3 – 3.3
Ti	0.65 – 1.15
C	0.08
Si	0.35
Cu	0.3
Cr	17 – 21
Co	1
Nb (+Ta)	4.75 – 5.5
Al	0.2 – 0.8
Mn	0.35
B	0.006

4 Design of Experiment

For the experimentation three levels of cutting speed, Chip load and depth of cut are chosen. The experiment was conducted by considering orthogonal array of Taguchi design.

4.1 Taguchi method

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community.

Taguchi method are the most recent additions to the tool kit of design, process and manufacturing engineers, and quality assurance experts. In contrast to statistical process control, which attempts to control the factors that adversely affect the quality of production, Taguchi methods focus on design – the development of superior performance designs (of products and manufacturing processes) to deliver quality. Taguchi's orthogonal arrays, in general, are available in various sizes like L4, L9, L12, L16, L18 and L27.

4.2 Signal to Noise Ratio

The S/N ratio developed by Dr. Taguchi is a performance measure to choose control levels that best cope with noise. The S/N ratio takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The S/N equation depends on the criterion for the quality characteristic to be optimized. There are three standard types of SN ratios depending on the desired performance response.

1   Smaller the better characteristics;

$$S/N = -10\log\frac{1}{n}\left(\sum y^2\right)$$

2   larger the better characteristics;

$$S/N = -10\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right)$$

3   Nominal the best characteristics;

$$S/N = 10\log\frac{\bar{y}}{sy^2}$$

4.3 Taguchi L9 Orthogonal Array

 To perform the experimental design, three levels of the machining parameters were selected as shown in table 2. An L9 orthogonal array table is used to specify the experiments. This array table has 3 columns and 9 rows. Therefore, only 9 experiments are required to investigate the entire machining parameters space using the L9 orthogonal array shown in table3.

Table 2 Cutting parameters

Level	Cutting speed (rpm)	Chip Load (μ)	Doc (mm)
1	800	0.020	0.5
2	1000	0.024	0.75
3	1200	0.027	1

Table 3 Orthogonal array and experimental result

Speed(rpm)	Chip load (μ)	Doc(mm)	RA (μ m)
800	0.020	0.5	0.13
800	0.024	0.75	0.14
800	0.027	1	0.16
1000	0.020	0.75	0.137
1000	0.024	1	0.15
1000	0.027	0.5	0.17
1200	0.020	1	0.147
1200	0.024	0.5	0.166
1200	0.027	0.75	0.18

5. Result and Discussions

The purpose of the statistical analysis of variance is to investigate which design parameter significantly effects the surface roughness. Based on the ANOVA the relative importance of machining parameter with respect to surface roughness was investigated to determine to obtain combination of machining parameter table 4 show the result of the ANOVA analysis of surface roughness. The purpose of the ANOVA is to determine the process parameters which significantly affect the performance characteristic .It has absorbed that the depth of cut has insignificant effect on surface roughness It has found that Chip load and cutting speed has significant effect on Ra. Based on ANOVA analysis the optimum cutting parameters for surface roughness are the cutting speed, Chip load and depth of cut.

Table 4 ANOVA table for surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed(rpm)	2	0.000666	0.000666	0.000333	111.00	0.009
Chip load (µ)	2	0.001544	0.001544	0.000772	257.33	0.004
DOC (mm)	2	0.000018	0.000018	0.000009	3.00	0.250
Residual error	2	0.000006	0.000006	0.000003		
Total	8	0.002234				

5.1 Regression analysis

A various regression analysis was performed to know the effectiveness an application of the experimental result. To array out the regression analysis MINITAB statistical software is used an imperial equation is derived between the roughness and cutting parameter is given in equation 1 The obtain equation is as follows

RA µ = - 0.0015 + 0.000052 Speed (rpm) + 4.51 Chip load (µ) - 0.00600 Doc(mm)……………1
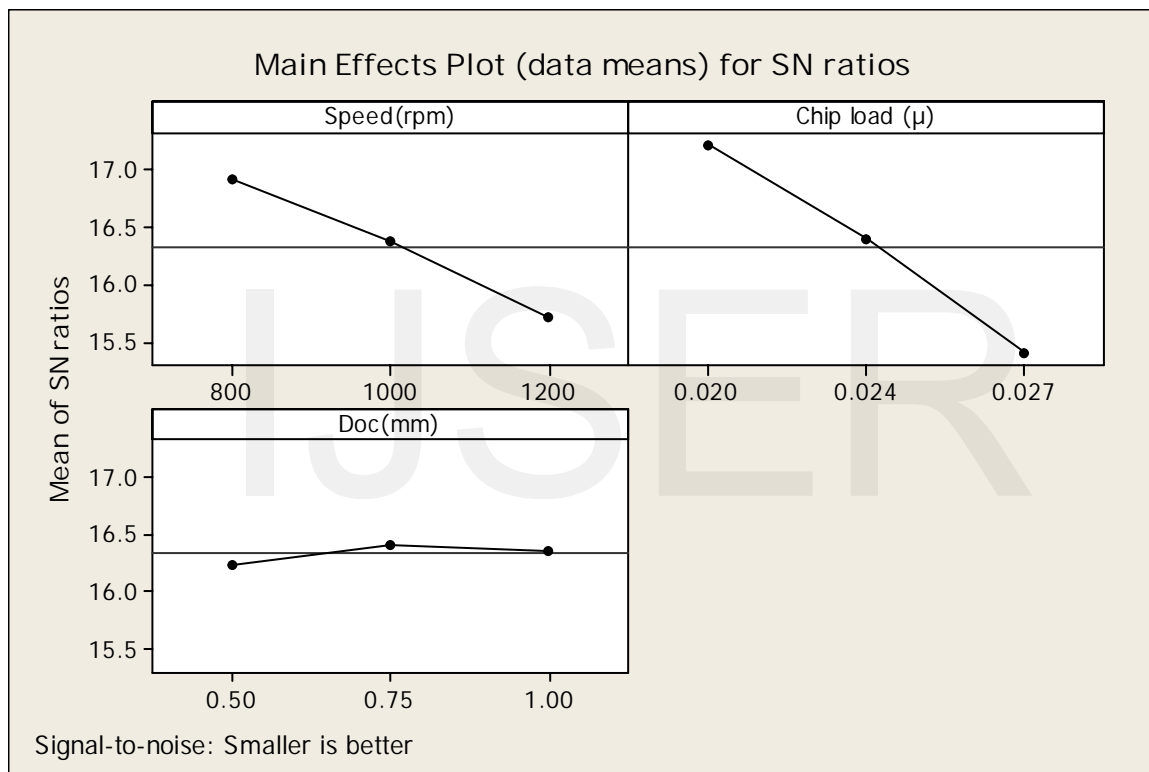
5.2 Taguchi optimization analysis of surface roughness

Taguchi recomendates analyzing means of S/N ratio using conceptual approach that involves graphical method for study the effect the surface roughness are analyzed using statistical software the mean S/N ratio for each level of the machining parameter were calculated based upon the data present in table the optimal performance for the surface roughness of milling process was obtain at a cutting speed (800 rpm) chip load (0.020 µ) DOC (0.5 mm) ranking of machining parameter are also calculated based of difference in S/N ratio. The rank indicate the dominant machining parameter that effects surface roughness. Figure 1 shows the plot for surface roughness which indicate that the surface roughness increases with increases of Chip load, cutting speed and very low influence on the depth of cut since delta value is very low.

Table 5 Response Table for Signal to Noise Ratios Smaller is better

Detail	Machining parameters Mean SN ratio		
	Speed(rpm)	Chip Load (µ)	Doc (mm)
Level 1	16.19	17.21	16.24
Level 2	16.38	16.38	16.41
Level 3	15.72	15.40	16.35
Delta	1.19	1.81	0.18
Rank	2	1	3

Fig 1 Mean effect plot for SN ratios

Signal-to-noise: Smaller is better

Conclusion

An L9 orthogonal array table is used to specify the experiments and taguchi optimization
analysis were carried out for selecting the optimum machining parameter.

1. Based on the taguchi design of experiments an analysis the Chip load and cutting speed is
   the main factor that has highest influence on surface roughness.
2. Optimum machining parameter for minimum surface roughness was determined.
3. For surface roughness, our observation is based on smaller is better for s/n ratio.

4. The lowest surface roughness (Ra) of 0.13µm was achieved corresponding to cutting speed
   (800 rpm) chip load (0.020 µ) DOC (0.5 mm.

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