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Face Milling Process Parameters Optimization for Inconel 718 by Taguchi Method

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Abstract- Every day scientists are developing new materials and for each new material, we need economical and efficient machining process. The main objective of industries are producing better quality product at minimum cost and increase productivity. Though, CNC milling is most commonly used in industry and machine shops for machining parts to precise sizes and shapes with desire surface quality and higher productivity within less time and cost. Face milling is very common method used for finishing of new materials and machined materials. Inconel 718 is one of the most commonly used nickel based super alloy having a high temperature applications such as aerospace industries and gas turbines in aviation. It is known as the most difficult to cut materials due to its high strength even at high temperatures, low thermal conductivity, and rapid work hardening. The purpose of this paper is that an experiment will be performed to find out the set of optimum values of process parameters in order to reduce surface roughness (SR) and increase material removal rate (MRR) for the purpose of machining Inconel 718 Super Alloy. Also, To analyze effect of Process parameters on surface roughness (SR) and material removal rate (MRR) by plotting the various graphs. The cutting tool material used for this purpose is Carbide. The experiments are conducted by using Taguchi L9 orthogonal array method. By using ANOVA (Analysis of variance) Method, find out the significant factor and percentage contribution of each input parameter for obtaining optimal conditions. Using the signal to noise ratio and mean ANOVA calculations, the optimum output characteristics will be predicted by MINITAB 17.0 statistical software.

Index Terms- CNC Milling Machine (VMC), Inconel 718 Super Alloy, Process parameters, Machining characteristics- SR and MRR, Carbide cutting tool, Taguchi method, ANOVA**.**

1. INTRODUCTION

Machining is process of producing work piece by removing unwanted material from in the form of chips. This process is very important since almost all the products get their final shape and size by metal removal. Machining offers a important benefits such as excellent dimensional tolerances, surface finish, external and internal geometrical features, Removal of heat treat distortion. The machining efficiency is improved by reducing the machining time with high speed machining. Milling is the process of removing the extra work piece material with a rotating multi-point cutting tool, called milling cutter. The machine tool used for milling is called milling machine. So, Milling is a multipoint cutting tool machining operation used for removing a layer of material from complete surface of workpiece and also producing slots in the components. The axis of rotation of the cutting tool is perpendicular to the direction of feed, either parallel or perpendicular to the machined surface. Milling is the operation of machining flat, curved, irregular and complex surface by feeding the workpiece against a rotating cutter.

CNC (Computer Numerical Control) is a material removal process used to manufacture components with complicated shapes as well as profiles. In present time, improved significantly to meet advance requirements in various manufacturing fields, especially in precision metal cutting industry. This experiment gives effect of different machining parameters (spindle speed, feed, and depth of cut) on surface finish in face milling. CNC Milling machine is superior to other machines as compared to its accuracy and better surface finish. Every manufacturing industry is trying to achieve the high quality products in a very short period with less input. In milling machine, there are many process parameters like spindle speed, feed rate, depth of cut, coolant, tool geometry, etc. which affected on required quality parameters. So, selections of such process parameters are important for any quality parameters.

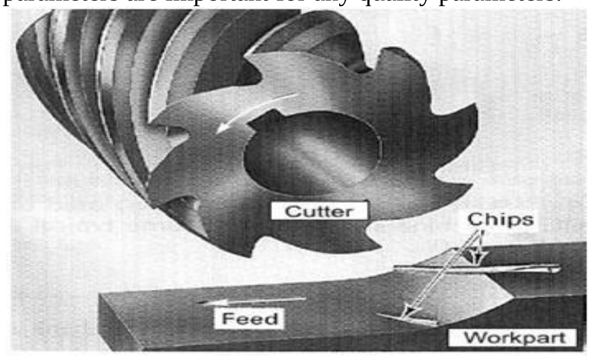

Fig. 1: Basic Milling Operation

2. CNC MILLING PROCESS PARAMETERS

The process parameters which will influence the experiment of optimizing while machining of the Inconel 718 super alloy are listed below:

1) Cutting speed (rpm):

The cutting speed is the cutting speed of cutter of milling machine, measured in revolution per minute (rev/min). The preferred speed is determined based on the material being cut. Excessive cutting speed will cause premature tool wear, breakages, and can cause tool chatter, all of which can lead to potentially dangerous conditions. Using the correct cutting speed for the material and tools will greatly affect tool life and the quality of the surface finish.

$$N = \frac{1000\,V}{\pi D} \text{ (rpm)}$$

2) Feed Rate (mm/min):

It is the velocity at which the cutter is fed, that is, advanced against the work piece. It is expressed in units of distance per time for milling (typically in a millimeters per minute); with considerations of how many teeth (or flutes) the cutter has then determining what that means for each tooth.

3) Depth of cut (mm):

It refers to the amount of material being taken per pass. This is how deep the tool is under the surface of the material being cut. This will be the height of the chip produced. Typically, the depth of cut will be less than or equal to the diameter of the cutting tool.

3. MACHINING CHARACTERISTICS

The most important machining characteristics considered in the present work are:

1) Surface Roughness (R_a): Surface finish is an essential requirement in determining the surface quality of a product. The average surface roughness is the integral absolute value of the height of the roughness profile over the evaluation length (L) and was represented by the equation given below.

Where 'L' is the length taken for the formula,

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

Observation and 'Y' is the ordinate of the profile curve.

Taylor- Hobson Surface roughness tester is uses to measure surface roughness of work piece in microns (μm).

2) Material removal rate (MRR): Material removal rate is the volume of material removed per unit time from the work piece surface. We can calculate material removal rate as the volume of material removed divided by the time taken to cut. The volume removed is the initial volume of the work piece minus the final volume. The cutting time is the time needed for the tool to move through the length of the work piece. This parameter strongly influences the finishing grade of the work piece.

$$MRR = \frac{(\text{Length of workpiece} * \text{Width of workpiece} * \text{Depth of cut})}{\text{Cutting time}}$$

Where, Material removal rate (MRR) in mm3/sec, Length and Width of workpiece in mm, Depth of cut in mm (Varies as per reading), Cutting time in seconds. (Cutting time measured by using a Stop Watch)

4. RESEARCH ON CNC MILLING AND OPTIMIZATION TECHNIQUES

CNC milling is one of the most commonly used in industry and machine shops today for machining parts to precise sizes and shapes. Among different types of milling processes, end milling is one of the most vital and common metal cutting operations used for machining parts because of its capability to remove materials at faster rate with a reasonably good surface quality. Critical process parameters that affect the quality of processed part have been discussed. There has been extensive research on this topic focusing on experimental results and process optimization. Most of the researches on CNC process parameters have been directed toward optimizing of a process parameters either to reduce surface roughness (SR) or to increase material removal rate (MRR) during CNC face milling process. Many researchers have suggested using appropriate statistical designs and optimization techniques to study the effects of process parameters on CNC Milling processed parts. In the following sections, research on each performance parameters is reviewed in detail.

Many researchers applied Taguchi method for optimization of process parameters in different machining operations successfully. In most of the research, milling operation mainly done on aluminum, mild steel, titanium alloy. My research based on the optimization of process parameters on Inconel 718 super alloy which is widely used in aerospace and many other industries due to property of retaining hot hardness, corrosion, wear, creep, fatigue resistance, machining performance and toughness. . It is analyzed from the literature review that till optimization of Inconel 718 is done by using a single milling cutting tool and single machining parameter. But, still no comparative study and optimization is done for single cutting tool with multiple machining parameters simultaneously. Therefore, in my research work, I have taken three process parameters such as cutting speed, feed rate and depth of cut for optimization of Inconel 718 on CNC face milling in order to increase material removal rate (MRR) and reduce surface roughness (SR). There are various optimization methods have been widely used to study the process parameters of CNC Milling process. Applications of the Taguchi method and ANOVA procedures are found to be most dominant among those optimization techniques.

Taguchi method is an effective tool for optimizing CNC Milling process parameters. Taguchi method provides simple, reliable and effective approach in practical applications to improve the product quality at low cost. It is noted that the Taguchi method can reduce the number of experiments significantly. However, Taguchi method can only determine the best combination of levels of process variables and the interaction effects. Critical process parameters are identified using the ANOVA procedure. Taguchi helps to determine optimal sequence and ANOVA technique helps to determine which parameters are most significant and their percentage contribution.

5. EXPERIMENTAL DETAILS

5.1 *Experimental set-up*

The experimental study was carried out in wet cutting conditions on a Hass-US five-axis, high-speed CNC milling machine equipped with a maximum spindle speed of 4000 rpm, and a 7.5 hp (5.6 kW) drive motor. CNC part programs for tool paths were created. CNC milling devices are the most widely used type of CNC machine. Typically, they are grouped by the number of axes on which they operate, which are labeled with various letters. X and Y designate horizontal movement of the work-piece (forward-and-back and side-to-side on a flat plane). Z represents vertical, or up-and-down, movement, while W represents diagonal movement across a vertical plane.

Most machines offer from 3 to 5 axes, providing performance along at least the X, Y and Z axes. Advanced machines, such as 5-axis milling centers, require CAM programming for optimal performance due to the incredibly complex geometries involved in the machining process. The cutting fluid used in the machining is synthetic oil + water. The coolant used at mixture of 1:20 ratio i.e. is one liter of synthetic oil is mixed with 2 litres of water. The coolant used BIOCOOL-100 (Bio stable semi synthetic cutting fluid) which is water soluble.

- CNC Milling Programming:

- N010 G54 G00 G90 X0 Y-46 S700 M03;
- N020 G00 Z-0.2 F50 M08;
- N030 G01 X200;
- N040 M30;

Where, G54= zero offset (X Y part zero), G00= rapid traverse,G90= absolute mode programming, M03=spindle rotation CW, M08= coolant pump ON, G01= linear interpolation, M30= end of main program, S700= spindle speed (700) rpm, F50= feed rate (50) mm/min, Z0.2= depth of cut (0.2) mm.

Fig. 2 (a): CNC Milling Machine (VMC) Set-up

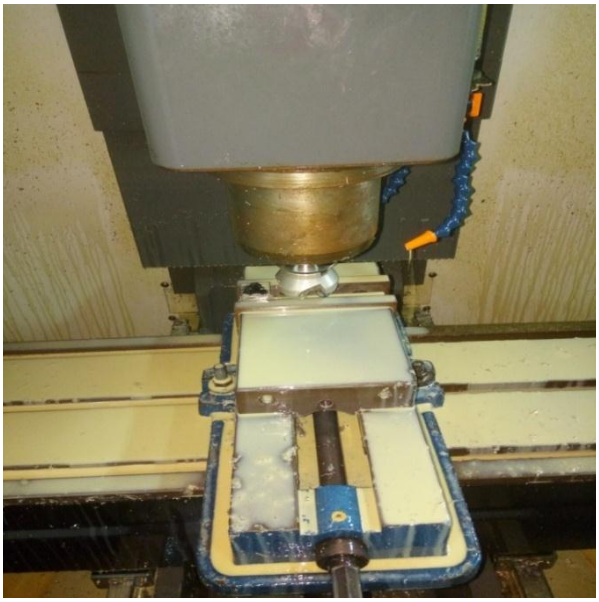

Fig. 2 (b): Actual Face Milling Operation

5.2 *Workpicece material: Inconel 718 super alloy*

Inconel 718 is one of the most commonly used nickel based super alloys in aerospace industry. Also, Inconel 718 super alloy is classified into a “difficult to cut materials” due to its physical properties such as lower thermal conductivity, high affinity for tool materials, and high tendency to work hardening. Inconel 718 super alloy is a high-performance alloy that exhibits several key characteristics, such as excellent mechanical strength, good surface stability, resistance to thermal creep deformation and resistance to corrosion or oxidation. Super alloys are the alloys which consists a comparatively higher mechanical and thermal strength in comparison with individual metals. These properties of super alloys make them eligible for the purpose, where in high strength to weight ratio of a material is to be expected. The total 9 blocks of Inconel 718 super alloy taken having size of 30mm*28mm*20mm (length*width*thickness) for performing the experiment on CNC Milling machine. For Ex.:- Aerospace industry, Jet and Rocket engines, Gas turbines, Nuclear and Steam power plants, Submarines, Petrochemical equipments and Other high temperature applications etc.

Table 1: Mechanical Properties of Inconel 718 alloy

Work piece material	Tensile strengh (MPa)	Yield strength (MPa)	Melting Temp. (ºC)	Elongation (%)	Hardness (HRC)
Inconel 718	1400	1040-1160	1350	14-16	40-45

Table 2: Chemical composition of Inconel 718 alloy (wt%)

Elements	Fe	Ni	Cr	Nb	Mo	Ti	Al
Percentage	2.8	68.1	21.1	5.07	3.6	1.15	0.65

5.3 *Cutting tool: Carbide face mill cutter*

Cutting tools must be made of a material harder than the material which is to be cut, and the tool must be able to withstand the heat generated in metal-cutting process. To conduct the experiment, the carbide cutting tool (with 4 Inserts) of 40 mm diameter is used for face milling operation. The cutting edges of face mills are always located along its sides. As such it must always cut in a horizontal direction at a given depth coming from outside stock. Multiple teeth distribute the chip load, and since teeth are normally disposable carbide inserts, this combination allows for very large and efficient face milling.

Fig. 3: Carbide Face Mill Cutter

5.4 *Surface roughness tester: Taylor- Hobson SR tester*

For measurement of surface roughness, Taylor Hobson's Surtonic 3 stylus probe type surface roughness tester is used as shown in figure. It measures the surface irregularities due to roughness, and is made unresponsive to the more widely-spaced irregularities caused by waviness or curvature. The Display-traverse unit contains a drive moor which traverses the pick-up across the surface to be measured, as well as the electronic circuits for computing and displaying the Ra value.

Fig. 4: Actual SR measurement using Taylor- Hobson SR tester

6. DESIGN OF EXPERIMENT

In the recent years, Taguchi's techniques have been immensely used to optimize both process design and product design, based on comprehensive experimental investigation. The primary advantage of the design of experiments using Taguchi's technique includes simplification of experimental plan, feasibility of study of interaction effects among the different parameters. In recent years, the Taguchi method has become a powerful tool for improving productivity during research and development, so that high quality products can be produced quickly and at low cost. Taguchi's parameter design is an important tool for robust design. Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments.

The methodology of Taguchi for three factors at three levels is used for the implementation of the plan of experiments. The degrees of freedom required for the study is six and Taguchi's L9 orthogonal array is used to define the 9 trial conditions. To perform the experimental design, three levels of the machining parameters were selected as shown in table below. 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 table. Only the main effects are of interest and factor interactions are not studied. The process parameters and levels are listed in Table.

Table 3: Parameters and their levels

Parameters	Level 1	Level 2	Level 3
Cutting speed (rpm)	700	1400	2100
Feed rate (mm/min)	50	100	150
Depth of cut (mm)	0.2	0.4	0.6

Table 4: Experimental layout using an L9 orthogonal array and corresponding results

Ex No	Process parameter			Average response values	
	c (rpm)	f (mm/ min)	doc (mm)	MRR (mm3/ sec)	SR (mic rons)
1	700	50	0.2	1.5849	0.21
2	700	100	0.4	7.1489	0.25
3	700	150	0.6	14.8235	0.29
4	1400	50	0.4	3.4639	0.20
5	1400	100	0.6	12.0000	0.27
6	1400	150	0.2	5.0909	0.27
7	2100	50	0.6	4.6667	0.21
8	2100	100	0.2	3.5000	0.23
9	2100	150	0.4	10.8387	0.27

As we know that Orthogonal Array is to be used for Taguchi method as the experimental analysis basis. The experimental factors and their corresponding levels are identified. Then the experimental result are further used and confirmed by the analysis of variance (ANOVA), in order to check each factor effect versus the machining parameters: Surface Roughness (SR) and Material Removal Rate (MRR). The experimental procedure is as given below:

Identification of CNC Milling process parameters that influence the machining parameters, determination of levels for the factors. Based on the factors and their levels, the degree of freedom is calculated and suitable orthogonal array and degree of freedom is to be selected. The experimental results will be obtained and the signal to noise ratio (S/N ratio), the ANOVA and the corresponding contribution are need to compute. The Taguchi method is the method which converts the parameter design into the S/N ratio, which is known as Quality Characteristic evaluation index, with S/N ratio, least variation and the optimal quality design can be attained. The S/N ratio is the mathematical formula used to calculate the design robustness. For MRR, as larger the S/N ratio, more robust the performance. For SR, as smaller the S/N ratio, more robust the performance. The Signal-to-Noise ratio gives a sense of how close the design is to optimum performance of a product or process. The S/N Ratio is an index for the robustness of quality and it shows the magnitude of interaction between "control factors" and "noise factors". Control and noise factors must be assigned to different groups for the study of robustness, which is significantly different from the traditional DOE approach where there are no distinctions between control and noise factors.

7. RESULT AND DISCUSSIONS

7.1 *Taguchi method*

Dr. Taguchi has developed a method based on "orthogonal array" experiment, which gives much reduced variance for the experiment with optimum settings of control parameters to obtain the best results. "Orthogonal arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's signal-to-noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. 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 (For Making The System Response As Small As Possible):

$S/N = -10\log [1/n] (\Sigma\ y^2)$

2) Nominal The Best (For Reducing Variability Around A Target):

$S/N = -10\log [1/n] (\hat{y}/ S_y^2)$

3) Larger The Better (For Making The System Response As Large As Possible):

$S/N = -10\log [1/n] (1/y^2)$

Where, $\hat{y}$ = average of observed data, S_y = variance of y, n = no. of observations, y = observed data

These SN ratios are derived from the quadratic loss function and are expressed in a decibel scale. Once all of the SN ratios have been computed for each run of an experiment, Taguchi advocates a graphical approach to analyze the data. In the graphical approach, the SN ratios are plotted for each factor against each of its levels. Finally, confirmation tests should be run at the "optimal" product settings to verify that predicted performance is actually realized.

7.1.1 *Taguchi analysis: MRR Vs cutting speed, feed rate, doc*

<u>Larger Is Better</u>

Table 5: Response Table for Signal to Noise Ratios

Level	Cutting speed	Feed rate	Depth of cut
1	14.835	9.391	9.672
2	15.504	16.517	16.192
3	14.987	19.418	19.461
Delta	0.669	10.028	9.789
Rank	3	1	2

7.1.2 *Taguchi analysis: surface roughness vs cutting speed, feed rate, doc*

<u>Smaller Is Better</u>

Table 6: Response Table for Signal to Noise Ratios

Level	Cutting speed	Feed rate	Depth of cut
1	12.12	13.70	12.56
2	12.24	12.06	12.46
3	11.20	11.17	11.89
Delta	0.92	2.53	0.67
Rank	2	1	3

7.2 *Effect of cutting parameters on response*:

- S/N Ratio & Mean Plot for MRR

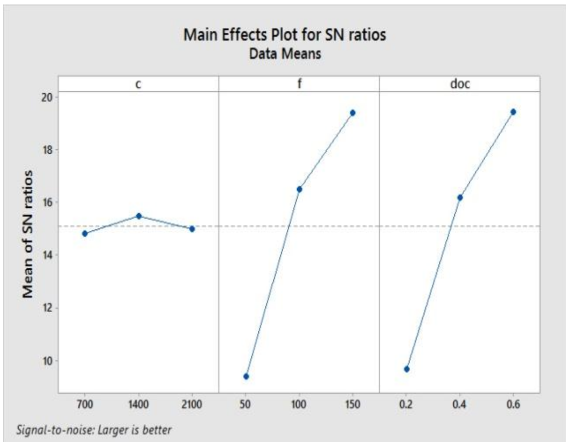

Figure 5 (a): Main Effect Plot for SN Ratio

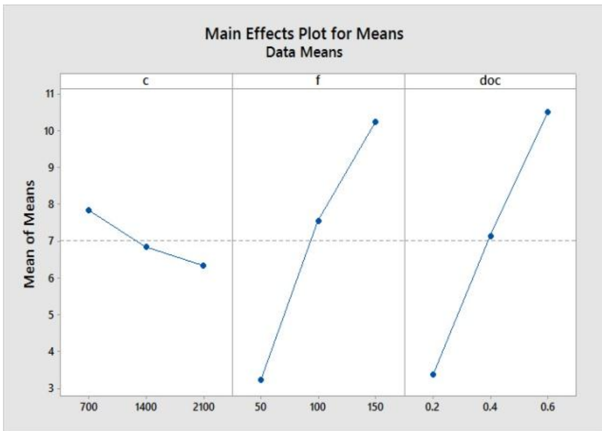

Figure 5 (b): Main Effect Plot for Data Mean

Utilizing the main effect plot of factor means, the effect of varying process parameters on MRR and SR were analysed in the following sections

The above graphs shows that the effects of various process parameters on MRR. From the above Main Effect Plot for SN Ratio Graph (Figure 5a), it clearly shows that I require maximum material removal rate. So, I select larger-is better S/N ratio and optimum parameters from it at maximum S/N ratio and hence, optimum process parameters obtains for maximum material removal rate (MRR) is cutting speed at 1400 rpm, feed rate at 150 mm/min and depth of cut at 0.6 mm.

The above data means graph (Figure 5b) shows that the first most dominating factor to MRR is depth of cut, the second dominating factor is feed rate and the third dominating factor is cutting speed. Also, as the feed rate and depth of cut are increases, then MRR will also be increases. But, as increasing with cutting speed, MRR will be decreases. So, from analysis the feed rate and depth of cut are the main factors that have highest influence on surface roughness (SR).

- S/N Ratio & Mean Plot for Surface Roughness

The below graphs shows that the effects of various process parameters on SR. From the above Main Effect Plot for SN Ratio Graph (Figure 6a), it clearly shows that I require minimum surface roughness. So, I select smaller-is better S/N ratio and optimum parameters from it at maximum S/N ratio and hence, optimum process parameters obtains for minimum surface roughness (SR) is cutting speed at 2100 rpm, feed rate at 50 mm/min and depth of cut at 0.2 mm.

The below data means graph (Figure 6b) shows that the first most dominating factor to SR is feed rate, the second dominating factor is cutting speed and the third dominating factor is depth of cut. Also, as the feed rate is increases, then SR will also be increases. But, as increasing with cutting speed, SR will be decreases. So, from analysis the cutting speed and feed rate are the main factors that have highest influence on surface roughness (SR).

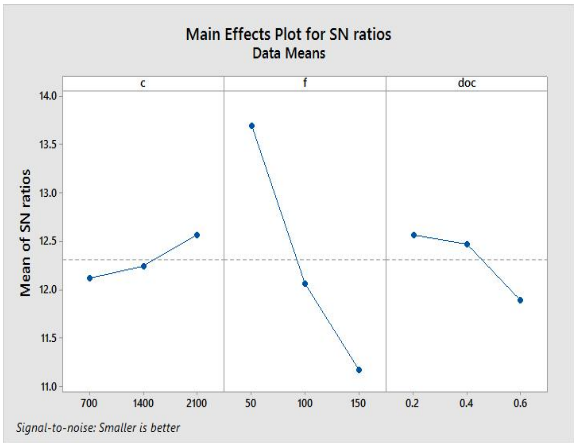

Figure 6 (a): Main Effect Plot for SN Ratio

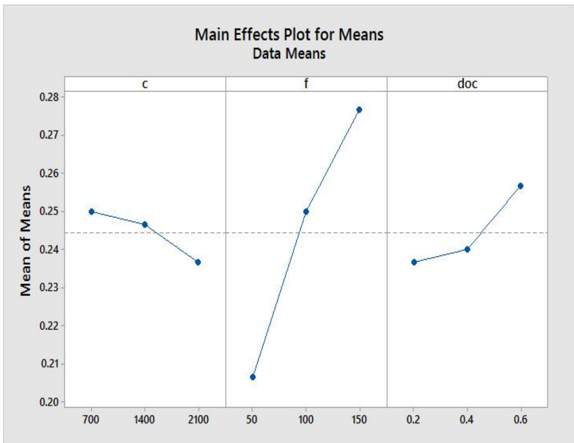

Figure 6 (b): Main Effect Plot for Data Mean

7.3 *Analysis of variance (ANOVA)*

The purpose of the statistical analysis of variance is to investigate which design parameter significantly effects the material removal rate and surface roughness. Based on the ANOVA, the relative importance of machining parameter with respect to material removal rate and surface roughness were investigated to determine to obtain combination of machining parameter. Below tables shows the result of the ANOVA analysis of material removal rate and surface roughness. The purpose of the ANOVA is to determine the process parameters which significantly affect the performance characteristic.

7.4 *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 17.0 statistical software is used. An imperial equation is derived between material removal rate and cutting parameter, similarly also between surface roughness and cutting parameter are given in equation form.
The obtain equation is as follows:

i) MRR = -5.59 - 0.001084 c + 0.0701 f + 17.76 doc

ii) SR= 0.1678 - 0.000010 c + 0.000700 f +0.0500 doc

7.5 *Comparison between mathematical and experimental results*

The result obtained by controlling different process parameters such as cutting speed, feed and doc was obtained by Experimental and Mathematical results are very close to each other. The maximum percentage of error between these two models is less than 5%. As the experimental values are closure to the mean value the equation predicted by regression analysis is closure to the experimental value. The difference between those two values may be due to Experimental or Industrial error. The error occur because of human error, machine error, continuous use cutting tool for long time period during machining, improper tool inserts, many other uncontrollable factors etc.

Table 7: Experimental and Mathematical Results of MRR

Experimental result	Mathematical result	Error Value	Error Percentage
13.5733	14.0634	0.4901	3.61 %

Table 8:Experimental and Mathematical Results of SR

Experimental result	Mathematical result	Error Value	Error Percentage
0.1911	0.1918	0.0007	0.36 %

8. CONCLUSION

In this work, the Design of Experiment (DOE) is used for conducting the experiments by Taguchi method. Taguchi method gives the optimize process parameter combination, while the mathematical model to predict their responses.
Taguchi combined with ANOVA are good methodologies to analyze the result data. Taguchi helps to determine optimal sequence and ANOVA technique helps to determine which parameters are most significant and their percentage contribution.
The results obtain by Taguchi method is summarizing as follows:

1. Milling process having many numbers of factors affecting the process, but for current study the main factors considered are: Cutting speed, Feed rate and Depth of cut.

2. The set of optimum values of selected process parameters obtained for higher material removal rate (MRR) =13.5723 mm3/s are: cutting speed =1400 rpm, feed rate =150 mm/min and depth of cut =0.6 mm.

3. The set of optimum values of selected process parameters obtained for lower surface roughness (SR) =0.1911 microns are: cutting speed =2100 rpm, feed rate =50 mm/min and depth of cut =0.2 mm.

4. Based on the Taguchi design of experiments analysis, the depth of cut (46.13%) and feed rate are the main factors that have highest influence on material removal rate (MRR).

5. Similarly, Based on the Taguchi design of experiments analysis, the feed rate (85.24%) and cutting speed are the main factors that have highest influence on surface roughness (SR).

6. The optimum level of control factors as above are the levels at which the effect of noise factors on the response parameter is less. Taguchi method has proved its success in prediction the optimum milling process parameters to reach the best properties.

REFERENCES

[1] Lohithaksha M. Maiyar, Dr. R. Ramanujam, K. Venkatesan and Dr. J. Jerald, Optimization of machining parameters for end milling of Inconel 718 super alloy using Taguchi based grey relational analysis, International Conference on design and manufacturing, 64, 1276 – 1282, ELSEVIER ScienceDirect (2013)

[2] A. Shokrani,, V. Dhokia, S.T Newman, R. Imani-Asrai "An Initial Study of the Effect of Using Liquid Nitrogen Coolant on the Surface Roughness of Inconel 718 Nickel-Based Alloy in CNC Milling " 45th CIRP Conference on Manufacturing Systems, ELSEVIER ScienceDirect (2012)

[3] Ampara Aramcharoen, Shaw Kah Chuan "An experimental investigation on cryogenic milling of Inconel 718 and its sustainability assessment" 6th CIRP International Conference on High Performance Cutting, HPC, ELSEVIER ScienceDirect (2014)

[4] Bulent Kaya, Cuneyt Oysu, Huseyin M. Ertunc "Force-torque based on-line tool wear estimation system for CNC millingof Inconel 718 using neural networks" Advances in Engineering Software 42, 76–84, ELSEVIER ScienceDirect (2011)

[5] R.M. Arunachalam, M.A. Mannan, A.C. Spowage, "Surface integrity when machining age hardened Inconel 718 with coated carbide cutting tools " International Journal of Machine Tools & Manufacture 44, 1481–1491, ELSEVIER ScienceDirect (2004)

[6] Mandeep Chahal, "Investigations of Machining Parameters on Surface Roughness in CNC Milling using Taguchi Technique" Vol.4, No.7, 2013 - National Conference on Emerging Trends in Electrical, Instrumentation & Communication Engineering, ISSN 2222-1727

[7] Piyush pandey, Prabhatkumar sinha, Vijay kumar, Manastiwari "Process Parametric Optimization of CNC Vertical Milling Machine Using Taguchi Technique in Varying Condition" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320- 334X, Volume 6, Issue 5 (May. - Jun. 2013), PP 34-42

[8] Aruna, M., Dhanalaxmi, V., & Mohan, S., "Design Optimization of Cutting Parameters when Turning Inconel 718 with Cermet Inserts". International Journal of Mechanical and Aerospace Engineering 6 (2010)

[9] Avinash A. Thakre, "Optimization of Milling Parameters for Minimizing Surface Roughness Using Taguchi's Approach", International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 6, June 2013, pp. 226-230.

[10] Mihir Thakorbhai Patel, "Optimization of Milling Process Parameters - A Review" International Journal of Advanced Research in Engineering and Applied Sciences Vol. 4 | No. 9 | September 2015

[11] A. Devillez, G. Le Coz, S. Dominiak, D. Dudzinski, "Dry machining of Inconel 718, workpiece surface integrity" Journal of Materials Processing Technology 211, 1590– 1598, ELSEVIER ScienceDirect (2011)

[12] Tomáš Vopát, Jozef Peterka, Vladimír Šimna, Marcel Kuruc, "The Influence of Different Types of Copy Milling on the Surface Roughness and Tool Life of End Mills" Procedia Engineering 100, 868 – 876, ELSEVIER ScienceDirect (2015)

[13] Chandra Nath, Zachary Brooks, Thomas R. Kurfess, "Machinability study and process optimization in face milling of some super alloys with indexable copy face mill inserts" Journal of Manufacturing Processes 20,88–97, ELSEVIER ScienceDirect (2015)

[14] Emel Kuram, Babur Ozcelik, "Multi-objective optimization using Taguchi based grey relational analysis for micro-milling of Al 7075 material with ball nose end mill" Measurement 46,1849–1864, ELSEVIER ScienceDirect (2013)

[15] A.B. Shelar, A.M. Shaikh, "Optimization of CNC Milling Process by using Different Coatings - A Review" IARJSET, Vol. 4, Special Issue 1, January 2017.