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Optimization of Different Process Parameters of Aluminium Alloy 6351 in CNC Milling Using Taguchi Method

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ABSTRACT— The present paper outlines an experimental study to optimize the effects of cutting parameters on Surface Roughness of Aluminium Alloy 6351 by employing Taguchi techniques. This paper deals with optimization of the selected milling parameters, i.e. Cutting Speed, Feed rate, Depth of cut and Coolant flow. Taguchi orthogonal array is designed with three levels of milling parameters and different experiments are done using L_9 (3^4) orthogonal array, containing four columns which represents four factors, and nine rows which represents nine experiments to be conducted and value of each parameter was obtained. The nine experiments are performed and surface roughness is calculated. The Signal to Noise Ratio (S/N) ratio of predicted value and verification test values are valid when compared with the optimum values. It is found that S/N ratio value of verification test is within the limits of the predicted value and the objective of the work is full filled.

Keywords— Taguchi Techniques, Milling Process, Surface Roughness, Cutting Speed, Feed rate, Depth of cut, Coolant Flow, Signal to Noise Ratio (S/N), Aluminium Alloy 6351.

1. INTRODUCTION

Milling is the process of removing extra material from the work piece with a rotating multi-point cutting tool, called milling cutter. The machine tool employed for milling is called milling machine. Milling machines are basically classified as vertical or horizontal. These machines are also classified as knee-type, ram-type, manufacturing or bed type, and planer-type. Most milling machines have self-contained electric drive motors, coolant systems, variable spindle speeds, and power-operated and table feeds. The three primary factors in any basic milling operation are speed, feed and depth of cut. Other factors such as kind of material and type of tool materials have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

CNC (Computer Numerical Control) is the general term used for a system which controls the functions of a machine tool using coded instructions processed by a computer. The application of CNC to a manual machine allows its operation to become fully automated. Combining this with the use of a part program enhances the ability of the machine to perform repeat tasks with high degrees of accuracy. Preparatory functions, called G codes, are used to determine the geometry of tool movements and operating state of the machine controller; functions such as linear cutting movements, drilling operations and specifying the units of measurement. They are normally programmed at the start of a block. Miscellaneous functions, called M codes, are used by the CNC to command on/off signals to the machine functions. The functions allocated to lower M code numbers are constant in most CNC controls, although the higher M code number functions can vary from one make of controller to the next.

Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has received serious attention for many years and it is a key process to assess the quality of a particular product. Surface roughness has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life, etc. It also affects other functional attributes of parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity, etc.

The objective of the present work is to find out the set of optimum conditions for the selected control factors in order to reduce surface roughness using Taguchi's Robust Design Methodology in Milling of 6351 Aluminium Alloy. The experiments are conducted using L_9 (3^4) orthogonal array.

2. LITERATURE SURVEY

Literature review bridges the gap between two stages of a project execution i.e. problem definition and evolution of design configuration (Solution). Extensive literature review is carried out to explore the elements of the present project requirement [1-11]. A thorough study of literature [1-3] suggests that the machining of Aluminium Alloy 6351 is very difficult compared to other Al alloy materials. Aluminium Alloy 6351 plates have been used as a work piece material for the present experiments because Aluminium Alloy 6351 is a high quality alloy commonly found to be used in Aero Space Industry, Automobile industry etc. Very few works have been carried out in the optimization of process parameters in milling process of Aluminium 6351 Alloy with different controlled parameters such as cutting speed, feed rate and depth of cut etc.

3. EXPERIMENTAL SETUP AND DESIGN

The detailed experimental setup is being discussed below, the experimental setup and the parameters are maintained under such conditions so that the machining undergoes smoothly. The work material selected is 6351 Aluminium Alloy.

3.1 Specification of Vertical CNC Milling Machine

The milling operations are carried out on a CNC milling machine make MTAB is shown in Figure No.1. The machining tests are conducted under the different conditions of Cutting speed, Feed rate, Depth of cut and coolant flow. The experiments are conducted at Nalla Narasimha Reddy Educational Society's Group of Institutions, Narapally, Ghatkesar and the machine tool used is MTAB make CNC vertical milling machine. The specifications of CNC machine are shown in Table No. 1.

Table No.1: Specification of MTAB Make CNC Machine

Clamping surface	420X180mm
Repeatability	+0.005mm
Positional accuracy	0.010mm
Coolant tank capacity	40 liters
Power rating	415v
Spindle motor speed	4000rpm
X,Y and Z axis drive	6000rpm
Electrical motor	14p 3phase
Pump	4lpm
Pressure	70 bar
Drawing no	Mech.MFB-1024

Figure No.1: CNC Milling Machine

3.2 Workpiece Material

The workpiece material used is Aluminium Alloy belongs to wrought Aluminium of 90mmX90mmX12mm in the form of plates. The Aluminium association (Aluminium Alloy) defined a number of Aluminium Alloy standards with a numbering scheme for easy reference and are mentioned them in the form of grades. In the present experiment the material used is Aluminium Alloy-6351-T6, which is an Aluminium alloy of wrought Aluminium. The machined work pieces are shown in Figure No. 2.

Aluminium alloy-6351- is an Alloy consisting of 97.8% aluminium (Al), 1.0% silicon (Si), 0.6% manganese (Mn) & 0.6% magnesium (Mg). Aluminium Aalloy-6351 is commonly found to be used in aero space industry, automobile industry etc.

Figure No.2: Aluminium alloy-6351work pieces used for machining

3.3 Cutting Tool

The cutting tool used is uncoated carbide inserts with a tool diameter of 16mm and four teeth shown in Figure No. 3. It consists of very high hardness and good toughness and it is principally intended for roughing of super alloys and Aluminium Alloys. The specification of tool holder used for machining is BT30-ER16, side lock adapter system.

Figure No. 3: Uncoated Carbide Insert

3.4 Surface Roughness Tester

Surface roughness measurement is measured using a portable stylus type Profilometer. The profilometer is portable self controlled instrument for the measurement of surface texture (R_a). The parameter evaluations are microprocessor based. The measurement results are displayed on an LCD screen and can be output to an optional printer or another computer for further evaluation. The instrument is powered by non-rechargeable alkaline battery (9V). It is equipped with a diamond stylus having a tip radius five micro meters.

For measurement of surface roughness, a stylus type surface roughness profilometer has been used during the experiment. The profilometer has been set to a cut off length of 0.8mm, filter 2CR, traverse speed 1mm/sec and 4mm traverse length. Roughness measurements, in the traverse direction, on the work pieces have been repeated 4times and average of 4 measurements of surface roughness parameter values has been recorded. The measured profile has been digitized. Surface roughness measurement with the help of stylus is shown in the Figure No. 4.

Figure No. 4: Profilometer Measuring Surface Roughness

3.5 Design of Experiments

In this work, Taguchi robust design methodology is used to obtain the optimum conditions for surface roughness in milling of Aluminium alloy-6351. The experiments are conducted using L_9 (3^4) orthogonal array.

3.6.1 Selection of control factors and levels

A total of four process parameters with three levels are chosen as the control factors such that the levels are sufficiently far apart so that they cover wide range. The process parameter and their ranges are finalized using literature, books and machine operator's experience. The four control factors selected are spindle speed (A), feed rate (B), depth of cut(C) and coolant flow (D). Aluminium alloy-6351workpieces are used in experimentation. The machining is performed individually depending upon the lubricant conditions. The control levels and their alternative levels are listed in Table No. 2.

Table No. 2: Control Factors and Levels

Factors /Levels	Speed (A) (rpm)	Feed (B) (mm/min)	Depth Of Cut (C) (mm)	Coolant Flow (D) (lt/min)
1	1194	600	0.5	0
2	2487	1100	1.0	2.5
3	3084	1540	1.5	4.8

3.6.2 Selection of orthogonal array

Selection of particular orthogonal array from the standard O.A depends on the number of factors, levels of each factor and the total degrees of freedom.

i) Number of control factors = 4
ii) Number of levels for each control factors = 3
iii) Total degrees of freedom of factors = 4x(3-1)=8
iv) Number of experiments to be conducted =9

Based on these values and the required minimum number of experiments to be conducted 9, the nearest Orthogonal Array fulfilling this condition is L_9 (3^4). The standard L_9 (3^4) Orthogonal Array is shown in Table No. 3. The Factor assignment for L_9 (3^4) has been done which is tabulated in Table No.4.

Table No. 3: Standard L_9 (3^4) O.A.

Experiment Number	Column			
	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table No. 4: Experimental Design

Experiment Number	Column			
	Speed (A) (rpm)	Feed (B) (mm/min)	Depth of Cut (C) (mm)	Coolant Flow (D)
1	1194	600	0.5	0
2	1194	1100	1.0	2.5
3	1194	1540	1.5	4.8
4	2487	600	1.0	4.8
5	2487	1100	1.5	0
6	2487	1540	0.5	2.5
7	3084	600	1.5	2.5
8	3084	1100	0.5	4.8
9	3084	1540	1.0	0

3.6.3. Plan of experiments

The scope and objective of the present work have already been mentioned in the forgoing cases. Accordingly, the present study has been done through the following plan of experiment:

1. Checking and preparing the CNC milling ready for performing the machining operation.
2. Cutting Aluminium Alloy-6351Steel alloy plates by power saw and performing initial end milling operation in CNC milling to get desired dimension of the work pieces.
3. Selection of appropriate tool depending upon the cutting parameters i.e. speed, feed, depth of cut and material.
4. Cutting parameters speed, feed, and depth of cut are selected going through the study of different literature and also in the view of machine standard specifications.
5. Performing face milling operation on Aluminium Alloy specimens in various milling environments involving lubricant conditions and various combinations of process control parameters like: speed, feed, depth of cut. The coolant flow is done depending upon the experiment design
6. Measuring surface roughness and surface profile with the help of a portable stylus-type profilometer for the machined work piece.

4. RESULTS AND DISCUSSION

Aluminium Alloy-6351, alloy pieces of 90mmX90mmX12mm are prepared for conducting the experiment. Using different levels of the process parameters the specimens have been machined accordingly, depending upon Cutting speed, feed rate, depth of cut and coolant flow conditions. Then surface roughness is measured precisely with the help of a portable stylus-type profilometer. The results of the experiments have been shown in Table No. 5.

Table No. 5: Experimental data related to surface roughness (Ra)

Exp No.	Surface Roughness(Ra)			S/N Ratio
	Trail1	Trail2	Mean	
1	5.99	6.23	6.112	-15.7274
2	4.34	4.76	4.5545	-13.1891
3	1.044	0.87	0.957	0.366382
4	3.352	3.385	3.3685	-10.5572
5	4.456	4.474	4.465	-13.0066
6	1.42	1.45	1.435	-3.13846
7	3.567	3.777	3.672	-11.3002
8	2.435	2.449	2.4425	-7.75677
9	3.7	3.9	3.8	-11.5972

The ANOVA calculation is performed for the results obtained i.e. Surface roughness values from Table No.5. The calculations are done manually and compared with the Minitab Statistical Software version 16 and it is verified. The model was checked at 95% confidence level for the adequacy. From the ANOVA it is observed that all the factors selected (Cutting speed, Feed rate, Depth of cut and Coolant flow conditions) are significant shown in Table No.6. Optimization of surface roughness is carried out using Taguchi method (S/N Ratio). Confirmatory tests have also been conducted to validate optimal results.

Table No. 6: Basic Analysis Of Variance

FACTOR	S.S	D.O.F (D_f)	M.S.S (M_{SS})	F-RATIO (DATA)	F-RATIO (TABLE)	RESULT
SPEED	1.96274	2	0.98137	44.74948	4.26	Significant
FEED	17.55753	2	8.778765	400.3028	4.26	Significant
DEPTH OF CUT	2.37412	2	1.18706	54.12874	4.26	Significant
COOLANT FLOW	19.66284	2	9.831421	448.3028	4.26	Significant
ERROR	0.175443	9				
S_t	41.557234					
MEAN	210.802	1				
ST	252.5347	18				

Table No. 7: Analysis Of Variance

FACTOR	S.S	D.O.F (D_f)	M.S.S (M_{SS})	F-RATIO (DATA)	SS^1	ρ %
SPEED	1.96274	2	0.98137	44.74948	1.91888	4.61%
FEED	17.55753	2	8.778765	400.3028	17.51367	42.14%
DEPTH OF CUT	2.37412	2	1.18706	54.12874	2.33026	5.60%
COOLANT FLOW	19.66284	2	9.831421	448.3028	19.61898	47.20%
ERROR	0.175443	9				0.45%
S_t	41.557234					
MEAN	210.802	1				
ST	252.5347	18				100%

4.1 Effect of Cutting Parameters on Surface Roughness

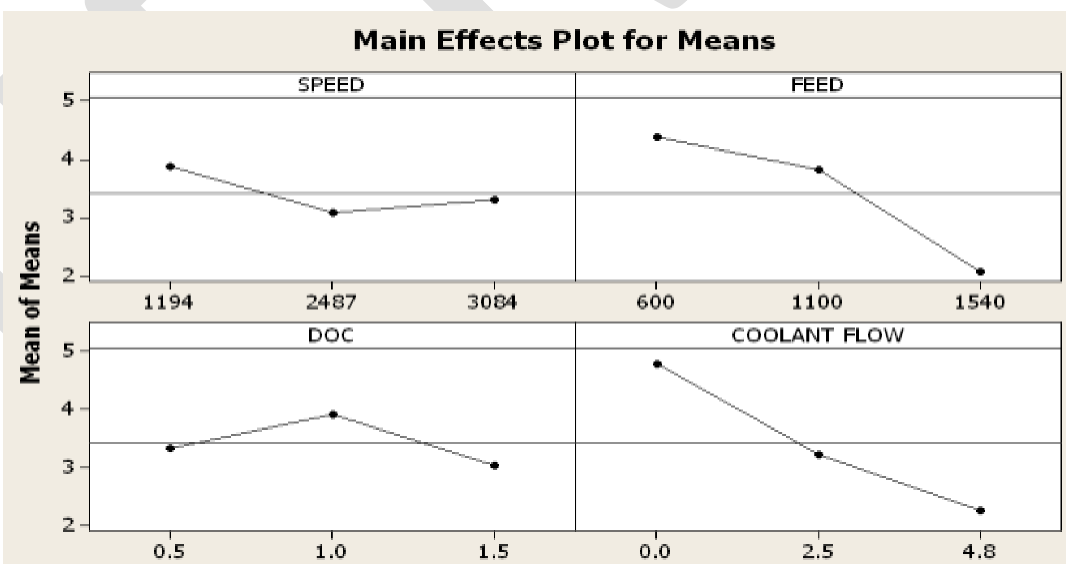

Figure No. 5: Surface roughness v/s All the Process Parameters (Cutting speed, Feed, Depth of cut and Coolant flow)

Figure No. 5 shows the effect of Cutting speed, Feed, Depth of cut and Coolant flow on surface roughness.

It is observed that, the surface roughness is high at low speed and certainly decreasing from low cutting speed to moderate speed conditions, but again from moderate to high cutting speeds, the surface roughness slightly increases. It is observed that, the surface roughness is high at low Feed Rate conditions and decreases from low feeds to moderate Feed rate conditions, and again from moderate to high feed rate, the surface roughness decreases. It is observed that, the surface roughness is low at small depth of cut and certainly increasing from small depth of cut to moderate depth of cut conditions, but again from moderate to high depth of cut, the surface roughness decreases.

It is observed that, the surface roughness is low at high coolant flow conditions and increases from high coolant flow to moderate coolant flow conditions, and again from moderate to low coolant flow i.e. Dry condition, the surface roughness increases. This can be explained by the reason that, surface roughness increases due to temperature, stress and wear at tool tip increases.

4.2 Optimization of Cutting Parameters

Taguchi's robust design methodology has been successfully implemented to identify the optimum settings for control parameters in order to reduce the surface roughness of the selected work piece material for their improved performance, after analysis of data from the robust design experiments the optimum setting are found and is tabulated in Table No. 6. These optimum settings combination is validated by conducting confirmation test and the conformation test results are shown in Table No. 7. It is concluded that the results shown in Table No. 8 are within the acceptable limits of the predicted value and can be implemented in the real time application.

Table No. 6: Optimum Parameters for Surface Roughness

Factors	Optimum values
Cutting Speed(rpm)	2487
Feed Rate(mm/min)	1540
Depth of Cut(mm)	1.5
Coolant Flow(lt/min)	4.8

Table No. 7: Conformation Test Results

Surface Roughness(Ra) Values			S/N Ratio
1	2	Average	
0.89	0.76	0.825	1.670

Table No. 8: Comparison of S/N Ratios

$\eta_{predicted}$	0.9738
$\eta_{conformation}$	1.670

5. CONCLUSION

The objective of the present work is to find out the set of optimum values in order to reduce surface roughness, using Taguchi's robust design methodology considering the control factors for the aluminum alloy 6351 work piece material.
Based on the results of the present experimental investigations the following conclusions can be drawn:

- Analysis of Variance suggests that Coolant flow is the most significant factor for the surface roughness followed by Feed rate. Whereas, Depth of Cut and Cutting Speed appears to have very little effect over roughness value. An increment of Feed rate and Coolant Flow will result in better surface quality in terms of roughness.
- In the present experimentation the optimum speed obtained using Tauguchi technique is 2487rpm. Similarly the results obtained for feed and depth of cut are 1540mm/min and 1.5mm respectively. Hence it can be concluded that the parameters obtained are valid and within the range of Aluminium Alloy machining standards.
- The corresponding Optimum coolant flow is 4.8 lts/min.
- The S/N ratio of predicted value and verification test values are valid when compared with the optimum values. It is found that S/N ratio value of verification test is within the limits of the predicted value and the objective of the work is full filled.

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