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TAGUCHI BASED OPTIMIZATION FOR SURFACE ROUGHNESS AND CHIP THICKNESS DURING END MILLING PROCESS ON ALUMINIUM 6351-T6 ALLOY

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ABSTRACT

In any machining operations, quality is the important conflicting objective. In order to assure for high productivity, some extent of quality has to be compromised. Similarly productivity will be decreased while the efforts are channelized to enhance quality. In this study, the experiments were carried out on a CNC vertical machining center to perform 10mm slots on Al 6351-T6 alloy work piece by K10 carbide, four flute end milling cutter. Furthermore the cutting speed, the feed rate and depth of cut are regulated in this experiment. Each experiment was conducted three times and the surface roughness and chip thickness was measured by a surface analyser of Surf Test-211 series (Mitutoyo) and Digital Micrometer (Mitutoyo) with least count 0.001 mm respectively. The selection of orthogonal array is concerned with the total degree of freedom of process parameters. Total degree of freedom (DOF) associated with three parameters is equal to 6 (3X2).The degree of freedom for the orthogonal array should be greater than or at least equal to that of the process parameters. There by, a L9 orthogonal array having degree of freedom equal to (9-1= 8) 8 has been considered .But in present case each experiment is conducted three times, therefore total degree of freedom (9X3-1=26) 26 has been considered.

Finally, Analysis of variance (ANOVA) was conducted to compare the predicted values with the experimental values confirm whose effectiveness in the analysis of average of surface roughness and chip thickness.

Keywords: CNC End milling, Al 6351-T6 alloy, Taguchi method, S/N Ratio, ANOVA

1. INTRODUCTION

Milling is the most extensively used machining process which may be employed in at least one stage of fabrication in manufacturing industries. In the present days CNC milling machines are commonly used as they possesses versatility, flexibility and allows manufacture of products in shorter time at reasonable cost and good surface finish. End milling is one of the important milling operations, which is commonly used in manufacturing industries due to its capability of producing complex geometric surfaces with reasonable accuracy and surface finish.

In end milling process, surface finish and material removal rate are two important aspects, which require attention both from industry personnel as well as in Research and Development, because these two factors greatly influence machining performance. CNC machines are most suitable to achieve high quality products in shorter time and to produce products at minimum cost.

2. LITERATURE STUDY

Recently, several attempts have been made to determine the optimal machining parameters for achieving minimum surface roughness from offline adjustment or online adaptive control. These attempts are categorized into six major portions: machine tool, workpiece and tool properties, cutting, thermal and dynamic parameters.

Abhang and Hameedullah (2011), utilized the regression modeling in turning process of En-31 steel using response surface methodology (RSM) with factorial design of experiments. A first-order and second-order surface roughness predicting models were developed by using the experimental data and analysis of the relationship between the cutting conditions and response (surface roughness).

Further, Reddy et al. (2014), carried out studies on application of aluminum alloy 6351 towards aerospace structures and its allied infrastructure. In this context considering Al 6351 which was used for making pressure vessel cylinders is now

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utilized for aircraft structures. In this investigation the tensile strength on circular rod specimen of Al 6351 is determined by applying the loads on universal testing machine with various dimensions.

Krishna, Reddy and Hussain (2014), carried out studies on friction stir welding (FSW) which is a solid state welding and is gaining more applications in various industries due to better quality of the joint as it has no negative effect on parent metal.

Balla and Patil (2012) described use and steps of Taguchi design of experiments and orthogonal array to find a specific range and combinations of turning parameters like cutting speed, feed rate and depth of cut to achieve optimal values of response variables like surface finish, tool wear, material removal rate in turning of Brake drum of FG 260 gray cast iron Material.

Naidu, Vishnu and Raju (2014) also applied taguchi based optimization for surface roughness during end milling of EN 31 steel in their work. Taguchi orthogonal array is designed with three levels of milling parameters and different experiments are done using L9 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.

Avinash (2013), considered in his paper an experimental plan based on Taguchi's technique including L9 orthogonal array with four factors and three levels for each variable and studying the contribution of each factor on surface roughness. The experiments were conducted on 1040 MS material on CNC vertical milling machine using carbide inserts. The analysis of mean and variance technique is employed to study the significance of each machining parameter on the surface roughness.

Korat and Agarwal (2012), conducted an experimental study to optimize the effects of cutting parameters on surface finish and MRR of EN24/AISI4340 work material by employing Taguchi techniques. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation. Maurya, Diwaker (2012) studied on CNC end milling, influence of various machining parameters like, tool feed (mm/min), tool speed (rpm), tool diameter (mm) and depth of cut (mm).

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Benardos and Vosniakos (2002) predicted surface roughness in CNC face milling using neural networks and Taguchi's design of experiments. The surface roughness and dimensional deviation have been predicted by measuring cutting forces and vibrations in turning process by Risbood, Dixit and Sahasrabudhe (2003).

The cutting speed, feed rate and depth of cut were chosen as an input and the workpiece was steel bars. It was observed that the length and the diameter of the steel bar have insignificant effect on the surface roughness compared to the cutting speed, feed rate and depth of cut.

With the reduction of feed rate the chip removal action is improved and high quality surface is obtained. An adaptive neural network-based fuzzy inference system is presented by Hoa et al. (2009) for the prediction of the surface roughness in the end milling process using hybrid Taguchi-genetic learning algorithm. The material of 6061 aluminium alloy has been used as a workpiece.

The spindle speed, feed rate and depth of cut were selected as the machining parameters. Experimental results have shown that the optimal prediction error of the hybrid Taguchi-genetic learning algorithm HTGLA-based on adaptive-network based fuzzy inference system ANFIS approach is 4.06% which outperforms the optimal prediction errors 4.65% and 4.17% obtained, respectively, by using Matlab toolbox.

Based on the literature survey performed, venture into this research was amply motivated by the fact that a little research has been carried out towards optimization of chip thickness, it was observed that major works concentrated on surface roughness. So in this work chip thickness also considered to obtain optimal levels of process parameters during end milling of Aluminum6351-T6 alloy.

3. INTRODUCTION TO TAGUCHI DESIGN METHOD

Taguchi Method was proposed by Dr. G. Taguchi in the year 1950. This method explores the concept of quadratic quality loss function and uses a statistical measure of performance called signal-to-noise (S/N) ratio. In Taguchi method (PHILLIP, 2005), the process parameters are divided into two groups such as control factors and noise factors.

The control factors are the controllable parameters which affect the process significantly whereas noise factors are the variables that affect the process and are either uncontrollable or more expensive to control. Signal represents the effect on

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the average response while the noise is a measure of the influence on the deviation from the average response.

The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise), which indicates the scattering around a target value. This ratio helps to identify the optimum level of process parameters. The combination of parameters with the highest S/N ratio will be the optimum setting of process parameters.

A high S/N ratio is desirable as the signal level is much higher than the random noise level that leads to best performance. The calculation of S/N ratio depends on the quality characteristics of the product or process to be optimized. The equation for calculating S/N ratios for “smaller is better” is given below.

$$S/N = -10 \log \frac{1}{n} \sum_{i=1}^{n} (y_i)^2$$ ---------------- (1) for smaller is better

Where, yi = average of surface roughness and chip thickness in the i th test and n = number of replications.

The orthogonal arrays are used to find parameters which will improve the performance which will improve the performance of a product or process. Another application of OA technique is to find less expensive, alternative product design, material or production method which will provide performance equivalent to that of a corresponding existing alternative. The orthogonal arrays used by Taguchi approach allow the study of simultaneous effects of several factors efficiently and providing better results using smaller number of experimental runs.

The selection of orthogonal array is concerned with the total degree of freedom (DOF) of process parameters. Total degree of freedom (DOF) associated with three parameters is equal to 6 (3X2).The degree of freedom for the orthogonal array should be greater than or at least equal to that of the process parameters. There by, a L9 orthogonal array having degree of freedom equal to (9-1= 8) 8 has been considered .But in present case each experiment is conducted three times, therefore total degree of freedom (9X3-1=26) 26 has been considered finally.

4. EXPERIMENTATION AS PER TAGUCHI DESIGN METHOD:

A plan of experiments based on Taguchi technique has been used to acquire the data. An orthogonal array, signal to noise (S/N) ratio and analysis of variance

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(ANOVA) are employed to investigate the machining characteristics of Al 6351-T6 alloy material using K10 carbide end mill.

Finally, confirmation test have been carried out to compare the predicted values with the experimental values to confirm its effectiveness in the analysis of average surface roughness and chip thickness. Machining parameters and their levels tabulated in Table 1 and Experimental plan as per Taguchi L9 orthogonal array and measured responses are depicted in table 2.

Figure 1: Experimental setup
(CNC Vertical Machining Center, KENT INDIA Co, Ltd, Taiwan)

In this study, the experiments were carried out on a CNC vertical machining center (KENT and ND Co. Ltd, Taiwan make shown in Figure 1) to perform 10mm slots on Al 6351-T6 alloy work piece of size 300mm X 50mm X 25mm by K10 carbide, 4 flute end milling cutter. Furthermore the cutting speed (rpm), the feed rate (mm/min) and depth of cut (mm) are regulated in this experiment. Each experiment was conducted three times and the chips are collected and measured the chip

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thickness (mm) with Digital Micrometer (Least Count 0.001mm, Mitutoyo make shown in Figure 3) which are shown in Figure 2, finally surface roughness is measured at five places on each slot then average of them in μm is considered by a surface analyser of Surf Test-211 series (Mitutoyo) shown in Figure 4.

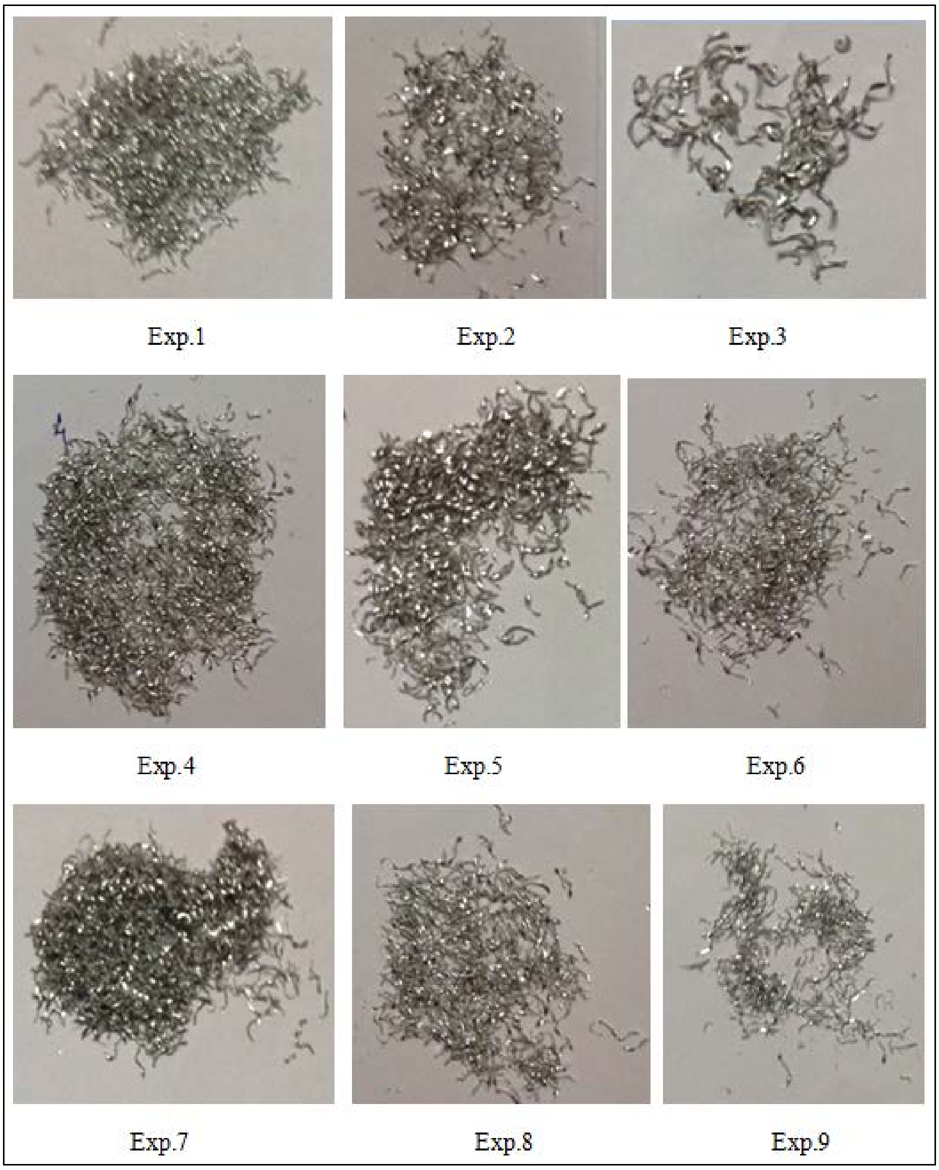

Figure 2: Camera images of collected chips (average) with different machining conditions

Figure 3: Measurement of chip thickness using Mitutoyo 293-340-30 Digital Micrometer

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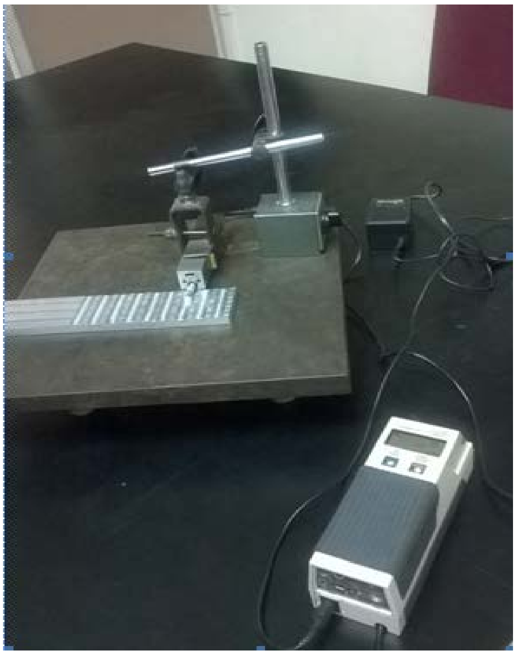

Figure 4: Measurement of surface roughness using Surf Test-211 series (Mitutoyo)

Factors and levels fixed from previous literature and specifications of the equipment and availability of measuring apparatus.

Table1: Machining parameters and their levels

Symbol	Factors	Units	Level 1	Level 2	Level 3
A	Spindle Speed	rpm	600	800	1000
B	Feed Rate	mm/min	50	100	150
C	Depth of Cut	mm	0.3	0.5	0.7

Table 2: Experimental plan as per Taguchi L9 orthogonal array and measured responses

Exp. No.	Machining Parameters			Average Surface Roughness (Ra) µm	Average Chip Thickness (Ct) mm	S/N Ratio
	Spindle Speed (A) rpm	Feed Rate (B) mm/min	Depth of Cut (C) mm			
1	1	1	1	0.166	0.125	16.6574
2	1	2	2	0.216	0.140	14.7980
3	1	3	3	0.233	0.230	12.7088
4	**2**	**1**	**2**	**0.145**	0.180	15.7329
5	2	2	3	0.165	0.190	14.9945
6	2	3	1	0.170	0.210	14.3771
7	**3**	**1**	**3**	0.190	**0.100**	16.3733
8	3	2	1	0.240	0.130	14.2887
9	3	3	2	0.225	0.220	13.0529

*In the table.2 above the S/N ratios calculated from eq.1

5. RESULTS AND DISCUSSIONS:

After performing the experiments, responses are recorded using suitable apparatus and tabulated in Table 2 then using design of experiment software for

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example minitab@17.3, S/N ratios for smaller is the better condition determined by giving input data and calculated the means of s/n ratios corresponding levels of parameters and depicted the values in Table 3 for S/N ratios, from this table, rankwise priority of parameters to influence the process obtained i.e. A3BIC2 (rank wise) to minimize the responses during machining of Al 6531-T6 material identified experimentally.

Table 3: Means of S/N Ratio

Level	Spindle Speed(rpm) A	Feed Rate (mm/min) B	Depth of cut(mm) C
1	14.72	**16.25**	**15.11**
2	**15.03**	14.69	14.53
3	14.57	13.38	14.69
Delta	0.46	2.87	0.58
Rank	3	1	2

From measured responses experimentally, minimum surface roughness obtained at experiment 4 corresponding level of factors areA2B1C2 and minimum chip thickness obtained at experiment 7 corresponding level of factors are A3B1C3.

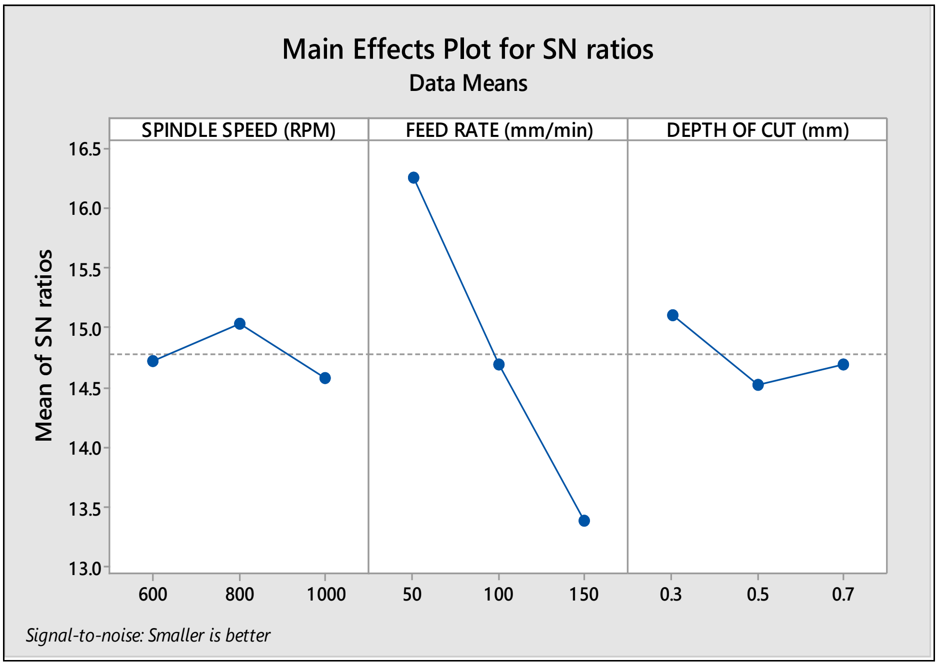

Figure 5: Main effects plot for S/N Ratio

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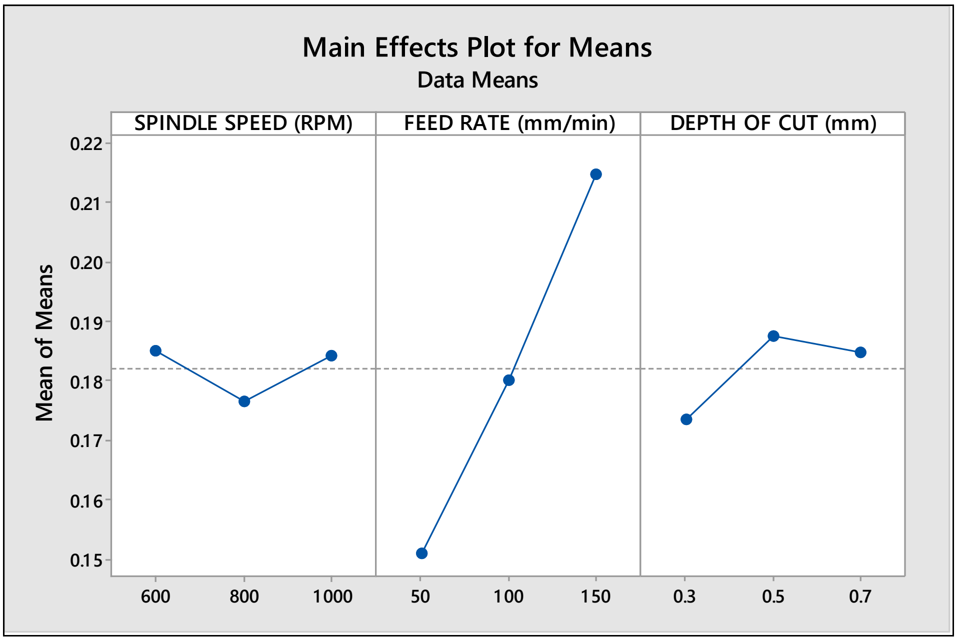

Figure 6: Main effects plot for Data Means

For main effect plots for S/N ratios and data means are drawn (Shown in Fig.5 and Fig.6), from this analyzed that optimum combination of levels of process parameters A2B1C1 obtained by 800 rpm spindle speed, 50 mm/min feed rate and 0.3 mm depth of cut gives good results to get optimum values of responses.

5.1. Analysis of Variance (ANOVA)

ANOVA is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. A test result (calculated from the null hypothesis and the sample) is called statistically significant if it is deemed unlikely to have occurred by chance, assuming the truth of the null hypothesis.

The ANOVA table organized as follows:

The first column is entitled Source of Variation and delineates the between treatment and error or residual variation. The total variation is the sum of the between treatment and error variation. The second column is entitled Sums of Squares (SS) and is computed by summing the squared differences between each treatment (or group) mean and the overall mean. The squared differences are weighted by the sample sizes per group (nj).

The error sum of squares (SSE) and is computed by summing the squared differences between each observation and its group mean (i.e., the squared differences between each observation in group 1 and the group 1 mean, the squared differences between each observation in group 2 and the group 2 mean, and so on).

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The double summation (SS) indicates summation of the squared differences within each treatment and then summation of these totals across treatments to produce a single value. The total sum of squares (SST) and is computed by summing the squared differences between each observation and the overall sample mean.

In an ANOVA, data are organized by comparison or treatment groups. If all of the data were pooled into a single sample, SST would reflect the numerator of the sample variance computed on the pooled or total sample. SST does not figure into the F statistic directly. However, SST = SS + SSE, thus if two sums of squares are known, the third can be computed from the other two. The third column contains degrees of freedom. The between treatment degrees of freedom is df1 = k-1.

The error degrees of freedom is df2 = N - k. The total degrees of freedom is N-1 (and it is also true that (k-1) + (N-k) = N-1). The fourth column contains Mean Squares (MS) which are computed by dividing sums of squares (SS) by degrees of freedom (df), row by row. Specifically, MS=SS/ (k-1) and MSE=SSE/ (N-k). Dividing SST/ (N-1) produces the variance of the total sample. The F statistic is in the rightmost column of the ANOVA table and is computed by taking the ratio of MS/MSE.

For confirmation of above experimental study, ANOVA for raw data of response was obtained by design of experiments software for example Minitab @17.3 and the values are tabulated in Table 4 and 5.

Table 4: ANOVA for Surface Roughness

Symbol	Cutting Parameters	DO F	SS	MS	F	Remarks
A	Spindle Speed (rpm)	2	0.005606	0.002803	8.40*	significant
B	Feed Rate (mm/min)	2	0.003398	0.001699	5.09 *	significant
C	Depth of Cut (mm)	2	0.000028	0.000014	0.04	Insignificant
Error		20	0.000668	0.000334		
Total		26	0.009698			

*Significant, if F exp > F table, from table at 95%confidence level F critical = 3.49

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Table5: ANOVA for Chip Thickness

Symbol	Cutting Parameters	DO F	SS	MS	F	Remarks
A	Spindle Speed (rpm)	2	0.002906	0.001453	1.70	Insignificant
B	Feed Rate (mm/min)	2	0.012006	0.006003	7.04 *	significant
C	Depth of Cut (mm)	2	0.001006	0.000503	0.59	Insignificant
Error		20	0.001706	0.000853		
Total		26	0.017622			

*Significant, if F exp > F table, from table at 95%confidence level F critical = 3.49

From “table 4” ,surface roughness is more influenced by spindle speed and feed rate in an order but depth of cut is less influenced during end milling of Al 6351-T6 alloy material.

From “table 5”, chip thickness is more influenced by feed rate, spindle speed is less influenced and depth of cut not influenced during end milling of Al 6351-T6 alloy material.

From minitab@17 interaction of process parameters on measured responses (both surface roughness and chip thickness separately) are obtained for various levels of machining parameters considered during experimentation.

From interaction plot(Figure 7) for surface roughness, it is observed that interaction of B, C factors with factor A for response Ra shows that feed rate and depth of cut both are of level 3, level 1 and level 2 caused to higher, moderate and lower effects on surface roughness with respect to spindle speed, interaction of A, C factors with factor B for response Ra shows that spindle speed and depth of cut both are of level 2,level 3 and level 1 caused to higher, moderate and lower effects on surface roughness with respect to feed rate and interaction of A,B factors with factor C for response Ra shows that feed rate and depth of cut both are of level 1,level 2 and level 3 caused to higher, moderate and lower effects on surface roughness with respect to depth of cut.

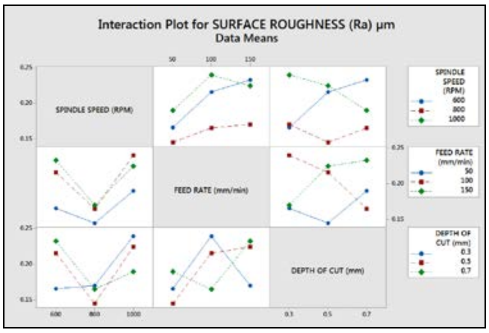

Figure 7: Interaction plot for surface roughness

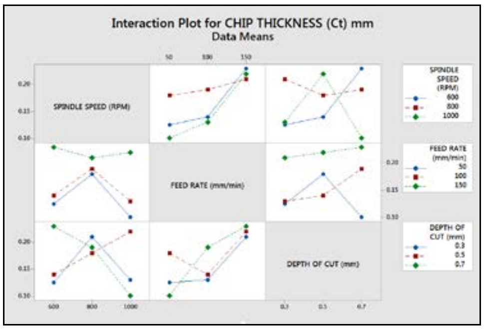

Figure 8: Interaction plot for chip thickness

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From interaction plot for chip thickness roughness, it is observed that interaction of B, C factors with factor A for response Ra shows that feed rate and depth of cut both are of level 2,level 1 and level 3 caused to higher, moderate and lower effects on surface roughness with respect to spindle speed, interaction of A, C factors with factor B for response Ra shows that spindle speed and depth of cut both are of level 3,level 1 and level 2 caused to higher, moderate and lower effects on surface roughness with respect to feed rate and interaction of A,B factors with factor C for response Ra shows that feed rate and depth of cut both are of level 3,level 2 and level 1 caused to higher, moderate and lower effects on surface roughness with respect to depth of cut.

5.2. Confirmation Experiment

Once the optimal level of machining parameters is selected the final step is to predict and verify the improvement of the experiment no.4 by setting the optimal level of the machining parameters 800rpm as spindle speed, 50mm/min as feed rate and 0.5mm depth of cut. The estimated response value using the optimum level of the machining parameters can be calculated as,

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{q} (\bar{\gamma}_j - \gamma_m) \qquad (2)$$

Where ᵞm is the total mean of the response (average surface roughness and chip thickness) value, ᵞj is the mean of the response value at the optimum level and q is the number of machining parameters that significantly affects the multiple performance characteristics. Based on equation (2) the estimated surface roughness and chip thickness values for the optimal machining parameters can be obtained. Table.6 and Table.7 shows the results of the confirmation experiment using the optimal machining parameters.

Table 6: Mean of measured average Surface Roughness and Chip Thickness responses

	Mean Surface Roughness (µm)			Mean Chip Thickness (mm)		
Level	A	B	C	A	B	C
1	0.205	0.167	0.192	0.165	0.135	0.155
2	0.16	0.207	0.195	0.193	0.153	0.180
3	0.218	0.209	0.196	0.150	0.220	0.173

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Table 7: Optimal values of individual machining characteristics

machining characteristics	Optimal combination of parameters	Significant parameters(at 95% confidence level)	Predicted optimum value	Experimental value
Average Surface Roughness(Ra)	A2B1C2	A,B	**0.1326 µm**	0.145 µm
Average Chip thickness (Ct)	A2B1C2	B	**0.135mm**	0.18mm

6. CONCLUSIONS

On comparing the signal to noise ratio, rankwise priority of parameters to influence the process obtained i.e. A3BIC2 (rank wise) to minimize the responses during end milling of aluminium 6351-T6 alloy, the feed rate have to be maintained at higher level, spindle speed maintained at moderate level and depth of cut in lower level yields better surface roughness and minimum chip thickness. Average surface roughness (Ra) is greatly reduced from 0.145 µm to 0.1326 µm and the chip thickness (Ct) is also reduced from 0.18 mm to 0.135 mm.

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