Multi-Response Optimization Of Process Parameters Using Taguchi Method in Vertical Milling For EN31 Steel

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Abstract

The purpose of this experimental research is to get multi-response optimization of process parameters using Taguchi method in vertical milling for EN31 steel intending to minimize the surface roughness and tool wear rate while maximizing material removal rate to improve the productivity of the process with coated carbide insert. Taguchi L9 and Annova have been applied for the experimental design and analysis. This experiment shows that feed is the most important for the tool wear rate. Depth of cut is a factor responsible for the material removal rate and feed is the most notable factor for surface roughness. Spindle speed has little effect on tool wear rate, surface roughness and material removal rate. Mathematical models for three response parameters i.e. tool wear rate, surface roughness, and material removal rate were obtained by the regression analysis method.

Keywords:CNC Milling Taguchi, Anova, Optimisation

1. Introduction

EN31 Steel is the common material used where lightweight and corrosion resistance is required. EN31 Steel is commonly used in the aerospace and automobile industry for the manufacturing of shafts, wheels, bumpers, cylinder blocks, piping brake components, wings, etc. The vertical milling machine has many input process parameters such as spindle speed, feed, depth of cut, etc. These parameters affect the output responses such as surface roughness, material removal rate and tool wear rate. Optimization of input process parameters leads to higher productivity at a lower cost. However, various techniques such as Taguchi design, Response Surface Methodology, Grey Relational Analysis, etc. are available in the literature for the design of experiments and optimization.

Deepak, D. and Beeduet et al. [1] discussed the different parameters by which material removal rate and surface roughness can be optimised for the turning process.Tungsten carbide(TC) tool and SE-40 coolant have been used in CNC Turning machine for this purpose & hence evolutionary optimization techniques like Grey Relational Analysis (GRA) and Taguchi's L9 array base optimization techniques were performed for optimising the parameters. **M. Kaladhar et al.**

[2] suggested the optimization of surface roughness (Ra) for the turning process of austenitic stainless-steel AISI202. Coated cemented carbide inserts have been used in CNC Turning machine for this purpose & hence evolutionary analyse technique analysis of variance (ANOVA) technique was taken into consideration for result parameters and their effects on roughness. It has been calculated that nose radius and feed were the vital parameters for the roughness. **Campatelli et al. [3]** attempted to minimize power consumption in the milling process of Carbon steel. CNC Milling machine was used for this purpose. Response Surface Methodology (RSM) was used to obtain a model fit for the fine-tuning of the process parameter. It was observed that if process parameters will be optimized then cutting energy can be maximized at local level.**Vasudevan et al. [4]** suggested regarding the optimizing the parameters of turning process of GFRP/Epoxy composites in reference to material removal rate (MRR) and surface roughness (Ra). CNC Turning machine was used for this purpose & Grey Relational Analysis (GRA) Fuzzy Interface System (FIS) and Taguchi's orthogonal L27 optimization techniques were performed for optimising the parameters. **Vivek V. Kulkarni et al. [5]** predicted the optimum surface roughness (Ra) and cutting force (Fz) under MQL in the turning of AISI4340 with Nano fluid. Conventional turning machine was used for this purpose. Response Surface Methodology (RSM) optimization technique was used for obtaining the optimum parameter. It has been calculated that depth of cut and feed along with speed are the most significant parameter for the right quality. **V. Jaiganesh et al. [6]** suggested the optimization parameters for the material removal rate (MRR), chip thickness ratio (CTR) and surface roughness (SR) for turning process of mild steel. Carbide tipped general purpose tool have been used in CNC Turning machine for this purpose & Taguchi technique was used for optimising the parameters. Analysis of variance (ANOVA) was used for analyse of the optimum parameter. It was observed that MRR and CTR are directly proportional to each other. **Jagannadha et al. [7]** investigated the impact of machining parameter spindle speed, feed and depth of cut on material removal rate (MRR) and surface roughness (SR) for turning process of aluminium alloy 6063 and A380. CNC Vertical Milling machine was used for this purpose . Taguchi technique was used for conducting the experiment. Analysis of variance (ANOVA) was used for analyse of the optimum parameters. **Yubin Lee et al. [8]** suggested to optimization of parameter MRR and SR for milling process for different material. CNC Milling machine was used for this purpose & Nelder-Mead Simplex Method was used for optimized parameter. It is observed that when the Nelder-Mead simplex method was employed the profit was higher than the maximum profit obtained. **M. Azudd W. Abdullah et al. [9]** studied the surface roughness and burr formation for the End Milling cutter of Al 6061. CNC milling machine used carbide cutting tool for this purpose. The test was repeated 5 times to get the desired results. It is studied that in small slot milling operations the input parameters will impact the roughness very much and also burrs formation. **JijuAnatony et al. [10]** suggested the optimization of multi responses in industrial experiment on case study. Taguchi's Quality Loss function and Principal Component Analysis (PCA) method were used for optimization of the different response systems. It has been studied that the minimum number of uncorrelated function can be achieved by Taguchi's quality loss function and PCA.**. Dr.P. Sudhakar Rao et al.[11]** experimentation highlights the effect of process parameters on the machining responses in terms of WR during the EDM of Al/B4C/Gr metal matrix composite . On increasing the TON time, WR initially decreased upto 400 µsec and after that started to increase. WR is firstly increased on increasing pulse current upto 4 ampere after that started to decrease. On increasing the percentage of reinforcement WR decreases. **Dr. P. Sudhakar Rao et al.[12]** discussed machining of Ti-6246 was carried out on EDM using graphite electrode using EDM oil dielectric. The process variables selected were current, pulse on-time and pulse off-time. Design of experiment was based on Box-Behnken Design of RSM technique. Optimization was conducted through the desirability approach. Machinability of Ti-6246 work material was evaluated with regards to surface roughness, as better surface quality is requirement for every machined component.The optimized response parameter achieved was surface roughness of 0.99 mm. Confirmation test were conducted at optimized variables and the value of surface roughness of 1.01 mm was obtained. Values obtained by multi-response.**Dr P. Sudhakar Rao et al. [13]** discussed about the ECH process in which concluded that they have achieved a very good improvement in average surface roughness Ra about 79.45% at top portion of the cylindrical work piece,85.94% at middle portion of the cylindrical work piece and 79.07% at bottom portion of the cylindrical work piece respectively at 8 minutes of finishing time. **Dr P.S Rao et al. [14]** discussed the analysis and optimization of the experimental results were carried out using response surface methodology. The feed rate was considered as the most influencing parameter for SR and MRR. Speed was considered as the most influencing factor for tool wear and the wt% of reinforcement was considered as least influencing factor for MRR. **Dr .P Sudhakar Rao et al. [15]** suggested that face milling of Incoloy 800 was accomplished with Titanium coated cryogenic treated tungsten carbide inserts to optimize the input process variables viz. Vc , f and d for optimum Tw and Ra . The three-level BBD was employed for developing mathematical models for calculating the optimized values of Ra and Tw. **Dr. P. Sudhakar Rao et al. [16]** discussed that machining is greatly influenced by MRR, TWR and SR. therefore, pulse on time, voltage, current and dielectric medium will be taken as input parameters for optimization purpose. Pulse on time may be most effective parameter for obtaining maximum MRR. Type of dielectric fluid may influence tool wear rate and heat removal. Current may affect the penetration power. Taguchi methodology may be adopted for process optimization. **Dr. P. Sudhakar Rao et al. [17]** discussed the materials used for wire drawing are stainless steel, high carbon steel, copper etc.Experiments have been conducted on various parameters like speed, temperature, friction, stress, force, area of reduction, die angle etc. Different methodologies have been used to improve surface finish of wire and optimization of process parameters. By optimization of process parameters, a better quality wire can be produced . **Dr. P. Sudhakar Rao et al. [18]** discussed the best suited method for synthesis of aluminium matrix composites is stir casting as it is simple and cost-effective.The most used apparatus for wear testing is the Pin-on-disc wear testing machine.The input parameters for wear testing are applied load, sliding distance and sliding speed. **Dr. P.Sudhakar Rao et al. [19]** suggested that Stir casting method is best for adding reinforcement in order to avoid porosity, agglomerations and does not damage the reinforcement. The method of stir casting was successfully used to manufacture the Al 6061composite with proper allocation of particle in the Al matrix composite. The mechanical properties of composite material like compressive strength, hardness, tensile strength enhances because of adding various reinforcement like B4C, SiC, Al2O3, Bamboo leaf and Rice Husk Ash etc. The properties of composite increases by using more than one reinforcement. That type of composite are called as hybrid composite.

The literature review found that numerous researchers have used Taguchi design either in isolation or in combination with the ANOVA method for multi-response optimization of process parameters for minimization of surface roughness and tool wear rate while maximizing material removal rate in the machining of different materials/steel. In this work, an effort was made to get multi -response optimization of process parameters in Vertical Milling Machine for the machining of EN31 Steel to minimize the surface roughness and tool wear rate while maximizing material removal rate to improve the productivity of the process.

2. Material & Experimentation

It is important to select the output parameters of interest for specific practical application. Output parameters are process-dependent variables. In this paper surface roughness, tool wear rate and material removal rate (MRR) have been chosen as output variables. These variables are conflicting in nature as maximization of MRR is sought for and the optimum value of Surface roughness and tool wear rate are also aimed.

Surface roughness: Surface roughness defines how much a surface on the component varies from an ideal flat plane or reference plane constructed by the least-squares method. Coordinate measuring machines are best equipped to measure Surface roughness.

Material Removal Rate (MRR): Material removal rate is defined as the rate of material removal per unit time. It is measured by taking the weight of the Workpiece before and after machining and using the following equation.

D: Depth of cut, mm.
W: Width of cut, mm.
F: Feed rate, mm/min
MRR = (D x W x F / 1000) cc/min

Tool Wear Rate (TWR): Tool wear rate is defined as rate of tool material removal per unit time.TWR is calculated by measuring the weight of the tool before and after machining

The input variables are independent of the process and they are assumed to have an influence on the output variables. The following input variables are selected for this research work are as follows:

Cutting Speed (V): Cutting speed is defined as the linear speed in m/min of the given tooth of a cutter will be moving while the cutting operation takes place.

Where 'D' is in 'meter' and 'N' is in 'r.p.m'.

Feed Rate (F): Feed rate is the relative velocity at which the cutter advances during specific movement of the work piece. The range of feed rate is taken from 50 mm/min to 150 mm/min.

Depth of Cut (d): It is cutting depth along Z-direction. The depth of cut used for this research work is measured in mm and the range taken in this research work is from 0.5 mm to 1.5 mm.

The material, equipment and instruments used in the present work are discussed in this section appended below.

2.1 *EN31 Testing & Confirmation*

EN31 Steel material is selected to perform the machining process. 4 pieces of the length of 100 mm and breadth of 100 mm were taken for the machining purpose. A Spectroscopy test was carried out on (Foundary-Master Xline) to confirm the composition of the material. The elemental composition obtained from the test is shown in Table 1.

Table 1. Chemical Composition of EN31

Elements	**Fe**	**C**	**Si**	**P**	**Mn**	**S**	**Mo**	**Cr**	**Ni**	**Al**
Percentage (By Wts.)	86.4.	0.608	0.563	0.0449	0.849	0.0309	0.149	1.14	0.318	0.0338

2.2 Experimental Setup

The machining operation on EN31 was carried out on a Vertical Milling Machine available in Mechanical Deptt Lab NITTTR Chandigarh and shown in Figure. 1

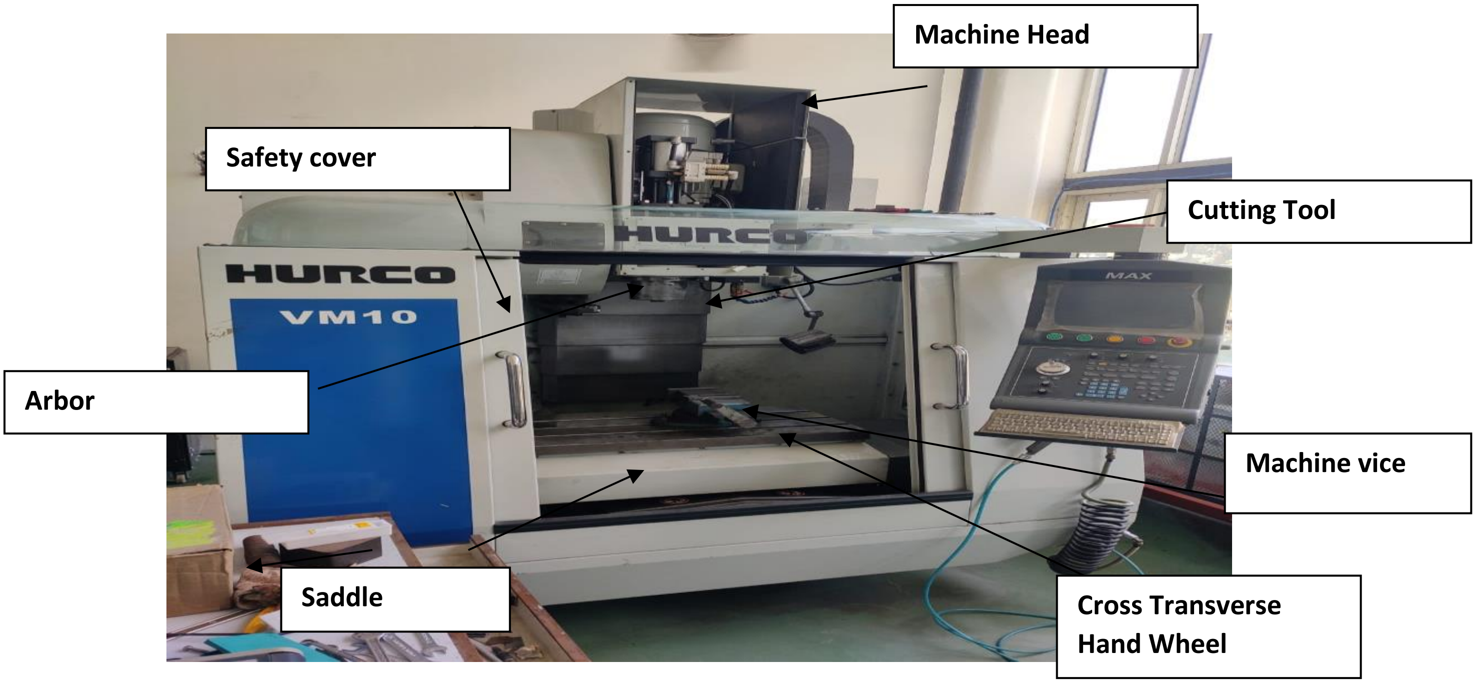


Figure 1.Vertical Milling Machine

The factors and levels selected for the machining of steel alloy are shown in Table 2.

Table 2. Process Parameters & their Levels

Symbol	Input Parameter	Unit	Levels		
			1 (-1)	2 (0)	3 (+1)
S	Spindle Speed	Rpm	600	800	1000
F	Feed Rate	mm/min	50	100	150
D	Depth of Cut	mm	0.5	1.0	1.5

Milling operations were carried out as per L9 orthogonal using Taguchi design.

Measurements

The surface roughness(Ra) of each workpiece is checked by the surfaces roughness tester shown in figure 2 (MITUTOYO make), which is available at NITTTR Chandigarh. Surface roughness is measured in 3 trials and their average value is taken for the result.

Figure 2. Surface Roughness Tester

Material removal rate and tool wear rate of each workpiece were obtained by dividing the difference of initial weight and weight after machining by machining time.

3. Results

The outcomes achieved after machining of EN31 workpieces were analyzed and optimized using different techniques as discussed in this section.

3.1 Taguchi Optimization

The results obtained after machining of EN31 by using input process parameters combinations as per the L9 Taguchi design are given in Table 3.

Table 3. Responses & S/N Ratios

Speed (rpm)	Feed (mm/min)	DOC (mm)	SR (µm)	MRR (gm/min)	TWR (gm/min)	SNRA1	SNRA2	SNRA3
600	50	0.5	5.4	2.42	.0103	**-14.648**	7.67631	**19.7433**
600	100	1	7.19	6.63	.0127	-17.135	16.4303	17.9239
600	150	1.5	7.21	8.21	.0151	-17.159	18.2869	16.4205
800	50	1	6.2	5.26	.0138	-15.848	14.4197	17.2024
800	100	1.5	8.46	7.98	.0161	-18.547	18.0401	15.8635
800	150	0.5	6.45	3.19	.0182	-16.191	10.0758	14.7986
1000	50	1.5	6.79	8.43	.0145	-16.637	**18.5166**	16.7726
1000	100	0.5	7.43	3.42	.0176	-17.42	10.6805	15.0897
1000	150	1	8.23	6.52	.0197	-18.308	16.285	14.1107

In the Taguchi method, the level at which the value of the S / N ratio is higher, the stability will be higher. This will select factor levels with the highest SNR for respective factors. Whatever the requirement is Smaller-the-Better or Larger-the-Better, a higher SNR will result in the smallest deviation. Thus, the parameter with a higher SNR will produce an optimum value and a negligible noise/variance. The observed/experimental value for surface roughness (Ra) is 5.4 µ-m and the corresponding SNR value is -14.648. For material removal rate (MRR) is 8.43 gm/min and the corresponding SNR value is 18.5166. For Tool Wear Rate (TWR) is .0103 and the corresponding SNR value is 19.7433

A more in-depth analysis is done by using ANOVA which outlines the contribution of each parameter/factor

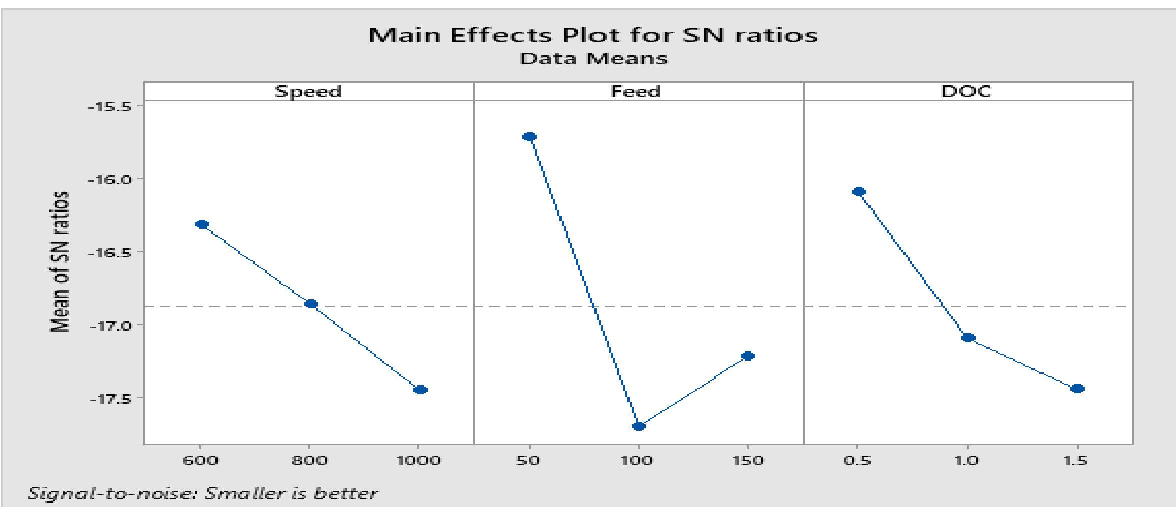
3.1.1 Analysis of S/N Ratio

The contribution of the responses may be found in Table 4.

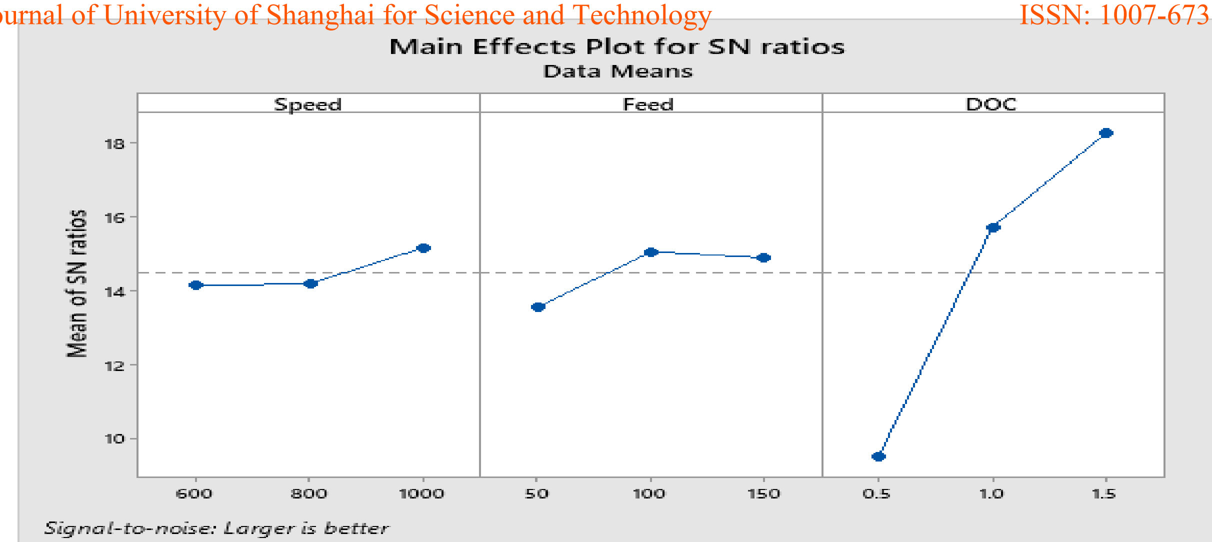
Table 4. Response Table for Signal to Noise Ratios

	Surface Roughness(SR) (Smaller is better)			Material Removal Rate (MRR) (Larger is better)			Tool Wear Rate (TWR) (Smaller is better)		
LEVEL	**Speed**	**Feed**	**DOC**	**Speed**	**Feed**	**DOC**	**Speed**	**Feed**	**DOC**
1	-16.31	-15.71	-16.09	14.131	13.538	9.478	18.03	17.91	16.54
2	-16.86	-17.70	-17.10	14.179	15.050	15.712	15.95	16.29	16.41
3	-17.46	-17.22	-17.45	15.161	14.883	18.281	15.32	15.11	16.35
Delta	1.14	1.99	1.36	1.030	1.513	8.804	2.70	2.80	0.19
Rank	3	1	2	3	2	1	2	1	3

For surface roughness, feed is the highest dominant factor followed by DOC than speed. For tool wear rate also, feed is the highest dominant factor. Whereas DOC affects material removal rate the most. Figure 3 shows factorial effect plots for SNR of Ra , MRR and TWR. Thus it is clear from factorial plots that **'Ra'**is minimized at parameters; S=600, F = 50, DOC=0.5. The **'MRR'** is maximized at S=1000, F=100, DOC=1.5. The **'TWR'** is minimized at parameters; S=600, F = 50, DOC=0.5



(a)



(b)

(c)

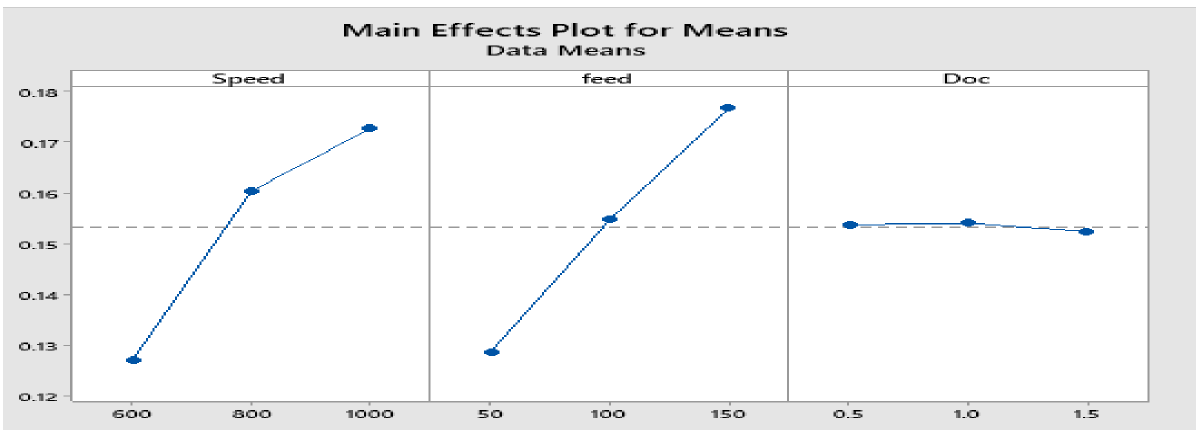


Figure. 3: Mean Effect Plots for (a) Surface Roughness (b) Material Removal Rate (c) Tool Wear Rate

3.1.2 ANOVA

The primary objective of ANOVA is to examine the effect of individual aspects and their interaction. The experimental study was conducted at 95% assurance zone and 5% significance zone. In table 4. The value of R Square explains the range where the input parameters intercept the change in the output response and the predicted variable. Like, for a better model, the R square would have to be larger of great value. The error in all responses is less than 5%, so the performance is acceptable up to a higher level.

Table 5. ANOVA for Surface Roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed	2	1.1705	0.5852	2.35	0.299
Feed	2	3.9625	1.9812	7.95	0.112

DOC	2	1.8104	0.9052	3.63	0.216
Error	2	0.4985	0.2492		
Total	8	7.4418			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.499233	95.30%	73.21%	0.00%

Regression Equation

SR = 7.040 - 0.440 Speed_600 - 0.003 Speed_800 + 0.443 Speed_1000 - 0.910 Feed_50 + 0.653 Feed_100 + 0.257 Feed_150 - 0.613 DOC_0.5 + 0.167 DOC_1.0 + 0.447 DOC_1.5

Table 6. ANOVA for Tool Wear Rate

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed	2	0.003349	0.001674	162.03	0.006
Feed	2	0.003464	0.001732	167.61	0.006
DOC	2	0.000005	0.000002	0.23	0.816
Error	2	0.000021	0.000010		
Total	8	0.006838			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0032146	99.70%	98.79%	93.88%

Regression Equation

TWR = 0.15333 - 0.02633 Speed_600 + 0.00700 Speed_800 + 0.01933 Speed_1000 – 0.02467 feed_50+ 0.00133 feed_100 + 0.02333 feed_150 + 0.00033 Doc_0.5 + 0.00067 Doc_1.0- 0.00100 Doc_1.5

Table 7. ANOVA for Material Removal Rate

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed	2	0.6316	0.3158	1.57	0.389
Feed	2	0.7750	0.3875	1.93	0.342
DOC	2	41.0663	20.5331	102.12	0.010
Error	2	0.4022	0.2011		
Total	8	42.8750			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.448417	99.06%	96.25%	81.01%

Regression Equation

MRR = 5.784 - 0.031 Speed_600 - 0.308 Speed_800 + 0.339 Speed_1000 - 0.414 Feed_50 + 0.226 Feed_100 + 0.189 Feed_150 - 2.774 DOC_0.5 + 0.352 DOC_1.0 + 2.422 DOC_1.5

4.DISCUSSION

This experimental study focus on Taguchi and ANOVA methodology and get multi-response optimization of process parameters in vertical milling for EN 31 steel intending to minimize the surface roughness and tool wear rate while maximizing material removal rate to improve the productivity of the process with coated carbide insert. The results obtained based on the L9 orthogonal array for Taguchi and ANOVA approaches are summarized and compared in this section.

Taguchi Design

Taguchi design along with ANOVA optimizes output responses individually. The optimized response parameters and the corresponding cutting parameters are shown in Table

Table 7: Optimized Parameters Obtained by Taguchi Method

Cutting Parameters						**Response Parameters**		
Speed (RPM)		**Feed (mm/min)**		**Depth of Cut (mm)**		**SR (µm)**	**MRR (gm/min)**	**TWR (gm/min)**
VALUE	**RANK**	**VALUE**	**RANK**	**VALUE**	**RANK**			
600	3	50	1	0.5	2	5.4	-----	-----
600	2	50	1	0.5	3	--	-----	.0103
800	3	50	2	1.5	1	-----	8.43	-----

The same set of cutting parameters were obtained for minimized surface roughness and tool wear rate by Taguchi design, whereas a different set of parameters were achieved for maximizing Material Removal Rate. Analysis showed that feed rate is the most important factor for Surface Roughness. However, the second most important factors for surface roughness were speed and DOC respectively. For DOC is the highest significant parameter for Material Removal Rate followed by speed and feed. Feed is the most responsible factor for Tool Wear Rate followed by Speed to obtain the optimal value of Tool Wear Rate. Depth of Cut was the least responsible factor to obtain the optimal value of Tool Wear Rate.

5.Conclusions

The experimental investigation of EN31 Steel machining with a Vertical Milling Machine was carried out with the Taguchi & ANOVA techniques. The study considered three output variables, such as surface roughness, MRR and TWR . Linear regression models have been developed for predicting these variables. Surface roughness value decreases with increase in cutting speed and increases with an increase in depth of cut. Material removal rate (MRR) value increases drastically with an increase in feed and depth of cut. Tool wear rate (TWR) value increases drastically with an increase in feed and depth of cut. For the validation of results, four additional sets of experiments have been performed and the results are in agreement with predictive models within ±15% and hence the predictive models are validated and can be used for selecting input variables for required values of output variables. Conclusions are as follows. When machining EN31Steel, the most important factor for surface roughness is the feed followed by the speed of the spindle and the least important is DOC. When machining EN31 Steel, the most important factor for material removal rate is the DOC followed by the speed of the spindle and the least important is feed. Feed is the most responsible factor for Tool Wear Rate followed by Speed to obtain the optimal value of Tool Wear Rate. Depth of Cut was the least responsible factor to obtain the optimal value of Tool Wear Rate. From Taguchi method optimum factor levels for surface roughness as speed = 600 rpm, feed = 50 mm/min and DOC = 0.5 mm. For material removal rate the optimum factor levels as speed = 800 rpm, feed = 50 mm/min and DOC = 1.5 mm. For Tool Wear Rate optimum factor levels are as speed = 600 rpm, feed = 50 mm/min and DOC = 0.5 mm

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