

## Research Article

# Analysis of CSN 12050 Carbon Steel in Dry Turning Process for Product Sustainability Optimization Using Taguchi Technique

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The aim of this research paper is to investigate the machinability of CSN 12050 carbon steel bars using carbide insert tool in order to utilize the optimum cutting parameters by employing Taguchi approach. Experiments have been performed under dry cutting condition using an optimization approach according to Taguchi's  $L_9(3^4)$  orthogonal arrays; signal-to-noise ratio tests are designed. Analysis of variance (ANOVA) was performed to determine the importance of machining parameters on the material removal rate (MRR). The results were analyzed using signal-to-noise ratios (S/N); 3D surface graphs, main effect graphs of mean, and predictive equations are employed to study the performance characteristics. The optimal parameters resulted as  $A_3B_2C_3$  (i.e., cutting speed 275 (m/min), depth of cut 0.35 (mm), and feed rate 0.25 (mm/rev), respectively). In the present study, there is an improvement of 5.22 dB at optimal cutting conditions for each significant MRR response parameters such as cutting speed, depth of cut, and feed rate. With these proposed optimal parameters, it is possible to optimize machinability for product sustainability.

## 1. Introduction

Turning process is the most common method for metal cutting and especially for the finishing machined parts in the manufacturing industries. Optimization techniques application in turning process is an essential for increasing quality of product and to sustain competitiveness in the manufacturing industries. In today's scenario, the furthest significant thing which is considered in manufacturing industries is the value of a product.

The value of a product can be increased by either improving the quality of the products or reducing the cost, environmental, and societal impacts. Surface finish ( $R_a$ ) is the most critical measures for quality, performance, and service life of the mechanical products and it is a good parameter to evaluate the sustainability of the machined products [1–4].

In turning operations, reducing power consumption and maximizing the material removal rate (MRR) could influence

the performance of mechanical components and the production costs in the manufacturing industries [5–8]. In order to improve the machining conditions, effort is required to minimize the value of power consumption and maximize the value of MRR by selecting optimal turning process parameters such as cutting speed ( $V_c$ ), depth of cut ( $C_d$ ), and feed rate ( $f_r$ ) [9–12]. Taguchi's method can be applied for optimization of the process parameters to produce high quality products that can encounter the goal of product sustainability [13–15].

On the bases of literature review, it had found that a substantial amount of work was carried in relation to  $R_a$ , MRR, and power consumption with parametric optimization through modeling, simulation, and design of experiment (DOE) using Taguchi method. Nevertheless, no work was found in analysis of turning process and in competitiveness with performance parameters for product sustainability optimization using Taguchi techniques on CSN 12050 carbon steel. The present research work shows the detailed plan of

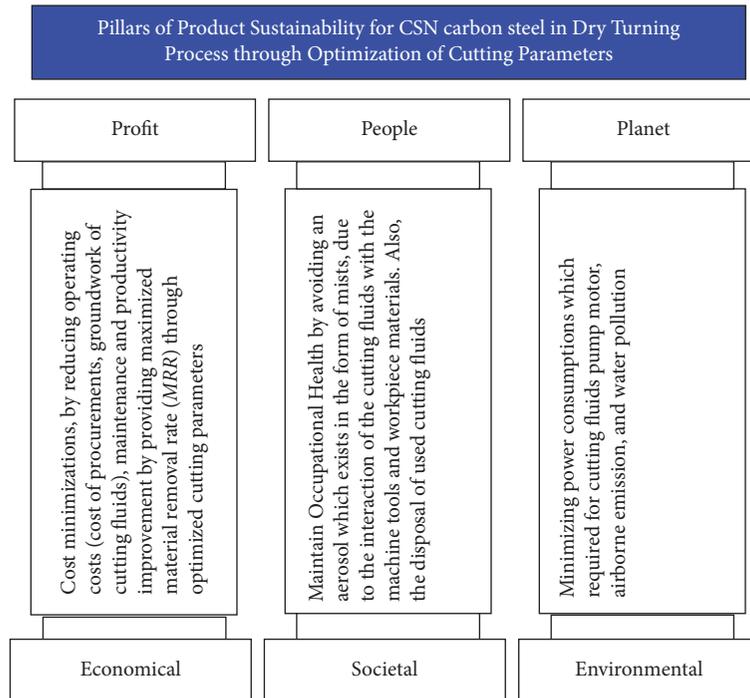


FIGURE 1: Pillars of product sustainability and the corresponding benefits.

experimentation through scientific methodology based on Taguchi design of experiments.

The main objective of the present work is to investigate turning process parameters which will give maximum material removal rate *MRR* using the CNC lathe turning operations on CSN 12050 carbon steel workpiece material. The aim of the research of this paper is to investigate the machinability of CSN 12050 carbon steel in order to utilize the optimum cutting parameters using Taguchi method. The paper is organized as follows: an overview of Taguchi method and experimental aspect, *DOE*, and experimental setup using the parameter design to determine and analyze the optimal cutting parameters in turning operations. Product sustainability has been taken into account by specifying dry cutting condition and identifying the optimal of cutting parameters. Consequently, sustainability can be achieved from economical, societal, and environmental aspects as illustrated in Figure 1. Finally, the paper concludes with a summary of this research work based on the analysis of experimental results.

## 2. Taguchi Method and Experimental Aspects

Taguchi method provides the practical engineer with a useful starting point for quality improvement. The traditional experimental design method is more focused on the statistical aspects whereas the Taguchi's method is primarily focused on the engineering aspects of quality. Taguchi has developed a methodology for the application of design of experiments, including practitioner's handbook [14, 15]. This methodology has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world

of manufacturing [13]. Taguchi introduces his approach, using experimental design [14] for designing and developing products/processes.

Taguchi method is encouraged due to its desirability of the application that can incorporate the statistical methods into the authoritative engineering process. In Taguchi method, the main parameters have influence on process results, which are positioned at different rows in a designed orthogonal arrays (*OAs*). The difference between the functional value and objective value is recognized as the loss function that can be expressed by signal-to-noise (*S/N*) ratio. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (*S/N*) ratio ( $\eta$ ). Usually, there are four categories of the performance characteristics in the analysis of the *S/N* ratio, that is, the higher-the better, the lower-the better, the nominal-the better, and fraction-defective [9, 14]. Hence, the higher-the better performance characteristic is used for this research work. The *S/N* ratio for each level of process parameters is computed based on the *S/N* analysis. Furthermore, a statistical analysis of variance (*ANOVA*) is performed to see which process parameters are statistically significant. With the *S/N* and *ANOVA* analysis, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. In this research paper, the cutting parameter designed by Taguchi method is adopted to obtain factors which influence the optimal machining performance (*response*) in turning process [15].

The quality characteristic used for the analysis of S/N ratio ( $\eta$ ) [9, 15] is expressed as

$$\text{Larger-the better, } \eta = -10 \log \left[ \frac{1}{n} \sum_{i=1}^n \frac{1}{Y_i^2} \right] \quad (1)$$

where  $n$  is number of trial /observations and  $Y_i$  is measured value of quality characteristics for  $i^{th}$ , trial condition. Notice that these S/N ratios are expressed on decibel scale.

The goal of this research was to produce maximized material removal rate (*MRR*) in turning operation. Larger *MRR* values represent better or maximized material removal rate. Therefore, the larger-the better quality characteristic was implemented and introduced in this study. The quality characteristic is continuous and nonnegative (0 to  $\infty$ ). The ideal target value of this type quality characteristic is  $\infty$  (as larger as possible) [15].

The following equations used to calculate the weight of material removed, with the required cycle time to remove material, measured in *gm/min*, or *mm<sup>3</sup>/min* [8, 16], are expressed as

$$W_i = V \times \rho \quad (2)$$

where  $W_i$  weight of material before machining,  $V$  volume of the machined workpiece material, and  $\rho$  is density of workpiece material

$$W_f = (V_1 + V_2) \times \rho \quad (3)$$

where  $W_f$  is weight of material after machining

$$t_c = t_f - t_i \quad (4)$$

where  $t_c$  is cycle times to remove the material,  $t_i$  is starting time, and  $t_f$  is finishing time

$$MRR (gm/min) = \frac{MR_w}{t_c} \quad (5)$$

where  $MR_w$  is weight of material removed

$$MRR (mm^3) = \frac{MRR (gm/min)}{\rho} \quad (6)$$

$$MRR = \frac{W_i - W_f}{\rho s \times t_c} mm^3/min \quad (7)$$

The pillars in Figure 1 show the achievement of profit and economical aspect through cost minimization: procurements cost, operating costs, reduced use of cutting fluids, maintenance cost, and productivity improvement as a result of optimized cutting parameters. The success of people and societal aspects shows how to maintain occupational health by avoiding an aerosol which exists in the form of mists, due to the interaction of the cutting fluids with the machine tools and workpiece materials. Correspondingly, the possibility of our planet and environmental wellbeing by reducing the disposal of used cutting fluids, power consumption required for cutting fluids pump motor, airborne emission, and water pollution. The overall benefits of product sustainability achievements shown in Figure 1 pillars through dry turning conditions for CSN 12050 carbon steel summarized the ultimate goal of this study.

TABLE 1: Selected orthogonal array and levels.

Experiment Number	Process control factors		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

*2.1. Design of Experiments.* “Experimental Design (*ED*) is a strategy of planning, conducting, analyzing, and interpreting experiments so that sound and valid conclusions can be drawn efficiently, effectively, and economically” [14, 15]. Design of Experiment (*DOE*) with Taguchi is divided into three main phases which are planning, conducting, and analysis phase [15]. The planning phase is the most important phase for experiment to provide the expected information. Sometimes the information from the experiment is in positive or negative sense. Positive information is an indication of which factor and which level lead to improving product or process performance. Negative information is an indication of which factor does not lead to improvement.

The aim of this experiment is to analyze the effect of cutting parameters on the turned CSN 12050 carbon steel response of material removal rate (*MRR*).

The experiment is planned using Taguchi’s orthogonal array in design of experiments (*DOEs*) which help in reducing the number of experiments. The experiments are conducted according to a three level  $L_9(3^4)$  orthogonal arrays (*OAs*). In this research to conduct the experiment dry turning process of CSN 12050 carbon steel is performed on CNC lathe.

Orthogonal arrays (*OAs*) were mathematical invention recorded in early 1897 by Jacques Hadamard, a French mathematician. The Hadamard matrices are identical mathematically to the Taguchi matrices; the columns and rows are rearranged [13].

Nomenclatures of arrays can be defined [13, 15] as  $L_a(b^c)$  where  $L$  is Latin square,  $a$  is number of rows,  $b$  is number of levels, and  $c$  is number of columns (factors).

Degrees of freedom (*DOF*) are associated with the *OAs* =  $a - 1$ .

The experimental design considered for the investigation to achieve an optimal material removal rate during the turning process of CSN 12050 carbon steel is based on the  $L_9$ ; orthogonal arrays are shown in Table 1. Orthogonal arrays are a special standard experimental design that requires only a small number of experimental trials to find the main control factor effects on the output or response of the turning process [15]. After conducting a number of trials on the required

TABLE 2: Design matrix of variables to the orthogonal array.

Experiment Number	Cutting Speed $V_c$ , (m/min)	Depth of Cut $C_d$ , (mm)	Feed Rate $f_r$ , (mm/rev)
1	100	0.25	0.10
2	100	0.35	0.20
3	100	0.50	0.25
4	175	0.25	0.20
5	175	0.35	0.25
6	175	0.50	0.10
7	275	0.25	0.25
8	275	0.35	0.10
9	275	0.50	0.20

TABLE 3: Selected levels for the factors.

Control Parameters	Units	Codes as per Minitab	Levels		
			1	2	3
Cutting speed ( $V_c$ )	m/min	A	100	175	275
Depth of cut ( $C_d$ )	mm	B	0.25	0.35	0.50
Feed rate ( $f_r$ )	mm/rev	C	0.10	0.20	0.25

TABLE 4: Experimental setup and machining conditions.

Workpiece materials	CSN 12050 carbon steel
Size (diameter x length)	37 x 100 mm
Cutting tool inserts	Sandvik Coromant carbide insert
Machine tool	CNC center lathe
Cutting condition	Dry machining

cutting parameters the appropriate ranges of design matrix of variables to the OAs are set as given in Table 2.

**2.2. Experimental Setup.** Tables 3 and 4 indicated process parameters used for the current work such the control parameters, the levels used in the experiment, experimental setup, and conditions. Analysis of variance for  $S/N$  ratio was evaluated by using Minitab 17 software. The cutting parameters were identified as cutting speed,  $V_c$  (m/min) depth of cut,  $C_d$  (mm), and feed rate,  $f_r$  (mm/rev).

Figure 2 shows the experimental setup on CNC center lathe of a model TOS-TRENCIN sn40 UPGRADED GSK CNC 980TDb with Power voltage 380V; Control voltage 110 V; Illuminating lamp voltage 24V; Total CAP 2KVA; Frequency 50; Phase 3; Degree of protection IP54; Fusing current 40 A; Swing Over Bed ways: 16" and Distance Between Centers: 60" for the turning operation. A round bar specimen of CSN 12050 carbon steel with a diameter of 37mm and 100 mm length was mounted. The cutting tool used for this experimentation is the Sandvik Coromant carbide insert tool with dimensions of 20 x 20 x 200 mm (w×h×l in mm) shown in Figure 3.

### 3. Results and Discussion

In order to analyze the value of  $MRR$  by combining with the result of experimentation the amount of  $MRR$  obtained by turning using CNC lathe can be computed by substituting (2), (3), (4), and (5) into (7), we can develop the new equation (8) as [9]

$$MRR = \frac{\rho_s (\pi r^2 h)_i - \rho_s (\pi r^2 h)_f}{\rho_s (t_{cf} - t_{ci})} \text{mm}^3/\text{min} \quad (8)$$

where  $\rho_s$  is density of CSN 12050 carbon steel =  $(7.85 \times 10^{-3} \text{ g/mm}^3)$ ;  $h$ , is height of the machined workpiece material;  $r$  is radius of workpiece material;  $t_{cf}$  is final cycle time;  $t_{ci}$  is initial cycle time;  $i$  is initial, and  $f$  is final.

Turning operation on a CNC center lathe using carbide tool has made on CSN 12050 carbon steel of 37 mm diameter and 100 mm length and conducted for 3 repetitions. The influence of cutting speed ( $V_c$ ), depth of cut ( $C_d$ ), and feed rate ( $f_r$ ) on the  $MRR$  is observed as per predesigned  $L_9$ , orthogonal array. The experimental results of  $MRR$  are tabulated in Table 5.

**3.1. Effect of Control Factors on Material Removal Rate.** To achieve high quality and low-cost products, the analysis of process parameters on  $MRR$  are very significant for any material before real time applications. In this concern, the experiments are performed on CSN 12050 carbon steel under variable control factors to predict the optimized material removal rate ( $MRR$ ) during turning process. As per the previous discussion,  $L_9$  orthogonal array is used to proceed the experiments and the experimental results shown in Table 5 and analyzed using Taguchi method.

The  $S/N$  ratio results on  $MRR$  are calculated using the larger-the-better criterion. Hence, the mean  $S/N$  ratio for each

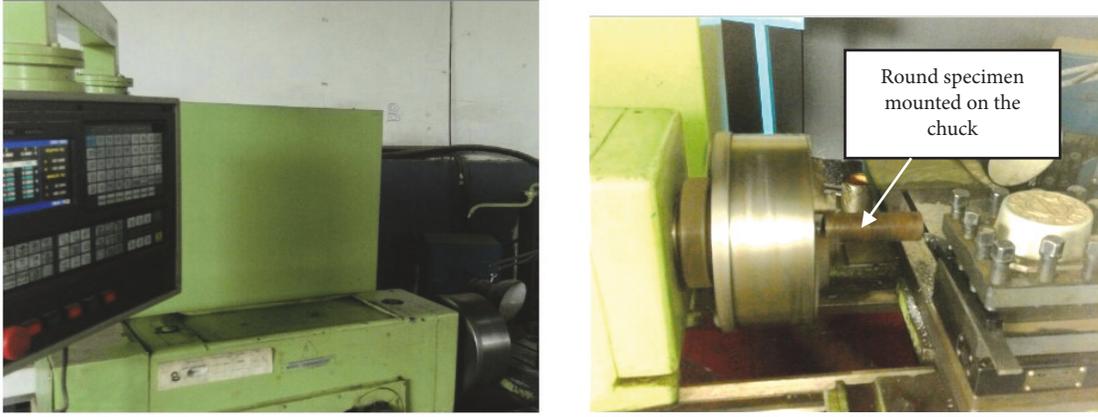


FIGURE 2: Experimental setup on CNC center lathe (TOS-TRENCIN sn40 UPGRADED GSK CNC 980TDb) for the turning operation of specimen of CSN 12050 carbon steel.

TABLE 5: Taguchi  $L_9$  orthogonal array experimental design matrix results of performance parameters of material removal rate with the corresponding control factors.

Trial Number	Cutting Speed $V_c$ , (m/min)	Depth of cut $C_d$ , (mm)	Feed rate $f_r$ , (mm/rev)	Material Removal Rate $MRR$ , (mm <sup>3</sup> /min)	S/N Ratio (dB)
01	100	0.25	0.10	1484.45	63.43
02	100	0.35	0.20	3973.00	71.98
03	100	0.50	0.25	3694.66	71.35
04	175	0.25	0.20	2906.25	69.27
05	175	0.35	0.25	4477.32	73.02
06	175	0.50	0.10	2687.79	68.59
07	275	0.25	0.25	5008.00	73.99
08	275	0.35	0.10	4186.80	72.44
09	275	0.50	0.20	3829.74	71.66
The total mean S/N ratios value					70.64



FIGURE 3: Tool of Sandvik Coromant carbide insert cutter with dimensions of 20 x 20 x 200 mm (w×h×l in mm).

level of the factors cutting speed (m/min), depth of cut (mm), and feed rate is summarized in Table 5. The calculated total mean S/N ratio has been illustrated in Table 6. The response table indicates the average of the selected characteristics for each level of factors and includes rank based on delta statistics, which compare the relative extent of effects. The delta statistic is calculated as the difference of the highest

average and the lowest average for each factor. Thus, the ranks are assigned based on the delta values. The Minitab 17 software assigns rank 1<sup>st</sup> to the highest delta value for  $f_r$  (mm/rev) rank 2<sup>nd</sup> to the second highest for  $V_c$  (m/min) and 3<sup>rd</sup> to the  $C_d$  (mm). The main effects plots for each of the process parameters have been shown in Figure 4.

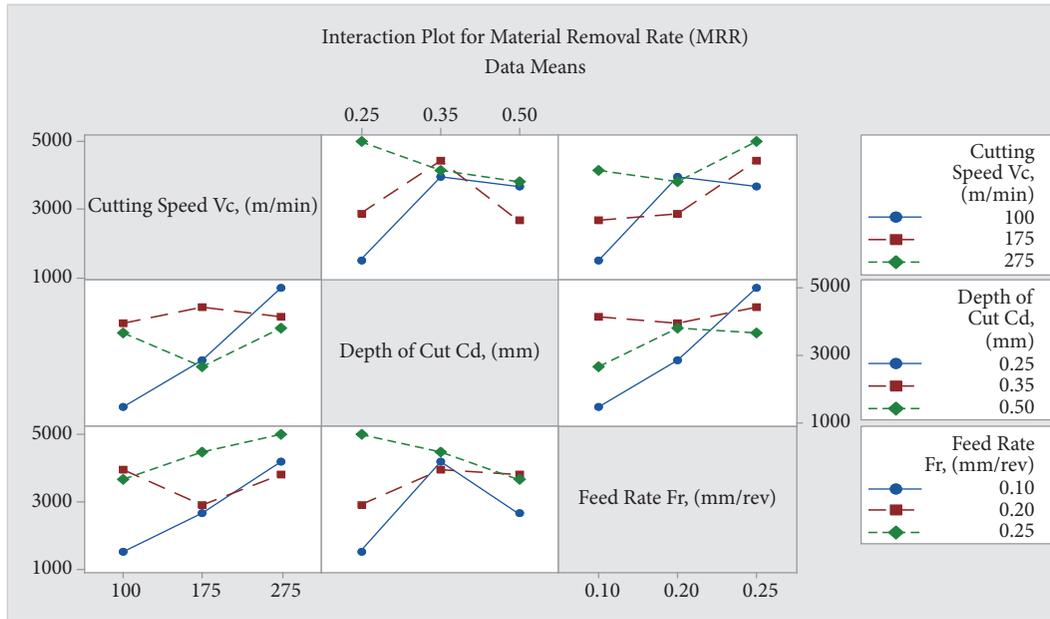
The control parameter  $f_r$  (mm/rev) and  $V_c$  (m/min) are the most significant influence on the optimization of  $MRR$  (mm<sup>3</sup>/min) while the control parameter  $C_d$  (mm) has some shared effect and the combination of S/N ratio is  $A_3B_2C_3$ .

$MRR$  is the higher-the-better type quality characteristics and can be seen from Figure 4, by which the third level ( $A_3$ ) of cutting speed = 275 (m/min), the third level of feed rate ( $C_3$ ) = 0.25 (mm/rev), and the second level of depth of cut ( $B_2$ ) = 0.35 (mm) provide maximum value of  $MRR$  (mm<sup>3</sup>/min). It can be observed from Figure 4 that  $MRR$  is initially increased with increase in  $C_d$  (mm) and then decreased with further increase in  $C_d$  (mm). The  $MRR$  is increased continuously with increase in feed rate and cutting speed.

TABLE 6: Response table of mean signal to noise ratios.

Level	Cutting speed $V_c$ , (m/min) Code – A	Depth of cut $C_d$ , (mm) Code – B	Feed rate $f_r$ , (mm/rev) Code – C
1	68.92	68.90	68.15
2	70.29	72.48	70.97
3	72.70	70.53	72.79
Delta	3.78	3.58	4.64
Rank	2	3	1

The total mean S/N ratios value = 70.637

FIGURE 4: The main effect plot for S/N ratios data means for MRR ( $\text{mm}^3/\text{min}$ ).

The use of both ANOVA technique and S/N ratio approach makes it easy to analyze the results and make it fast to reach the optimum control parameters for better response of MRR and to give flawless conclusion. ANOVA determines the ratio between the regression mean square and mean square error and is termed as F-ratio or variance ratio as shown in Table 7.

Table 7 shows the percentage contribution of each of the parameters. Accordingly, the same trend as the main effect plots can be observed for the given process control parameters such as the parameters (C),  $f_r$  (mm/rev), and (A),  $V_c$  (m/min) had the most significant influence on MRR while the parameter (B),  $C_d$  (mm), was not significant within the specific experimental range.

**3.2. Confirmation Tests.** Confirmation test is required to determine the accuracy of the result obtained from the Minitab software to achieve the optimal level of processes parameters [9, 15]. Once the optimal level of the process parameters is selected, the final step is to predict and verify the improvement of the performance characteristic using the optimal level of the process parameters. The estimated S/N

ratio ( $\hat{\eta}$ ), using the optimal level of the process parameters, can be calculated as given in [9]

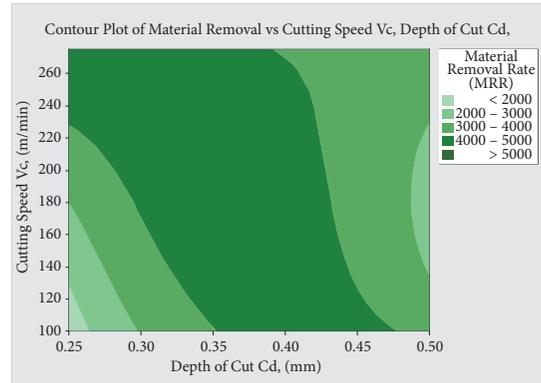
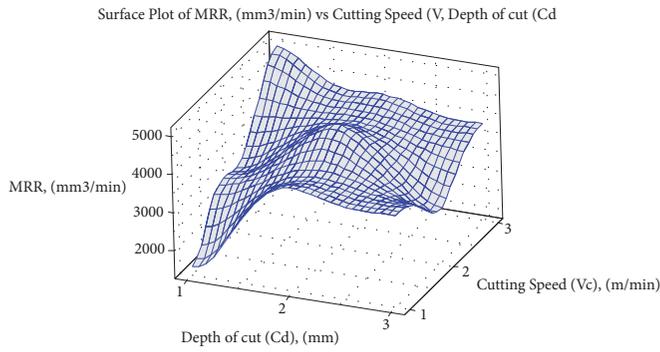
$$\hat{\eta} = \eta_m + \sum_{i=1}^q (\bar{\eta}_i - \eta_m) \quad (9)$$

where  $\eta_m$  is the total mean of the S/N ratio,  $\bar{\eta}_i$  is the mean S/N ratio at the optimal level, and  $q$  is the number of the process parameters that significantly affect the performance characteristic. In Table 7 result of the estimated S/N ratio (73.927) and the actual S/N ratio (74.091) shows an insignificant difference. The parametric analysis had been carried out to study the influences of the input process parameter on MRR in turning process using CNC lathe. The contour and the response surface plots for MRR with respect to selected input turning parameters are presented in Figure 5. From the plots it is clear that MRR ( $\text{mm}^3/\text{min}$ ) increases with an increase of feed rate and cutting speed. This increase becomes more noticeable as the value of feed and cutting speed rises, due to higher rate of material removal.

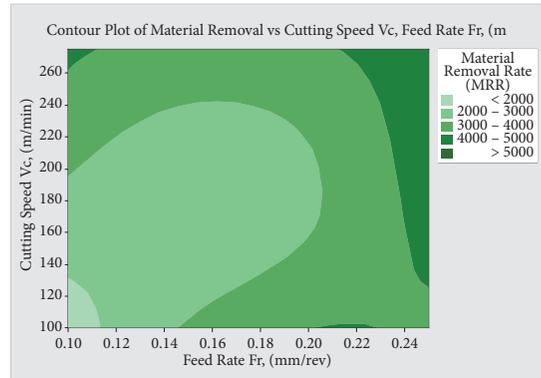
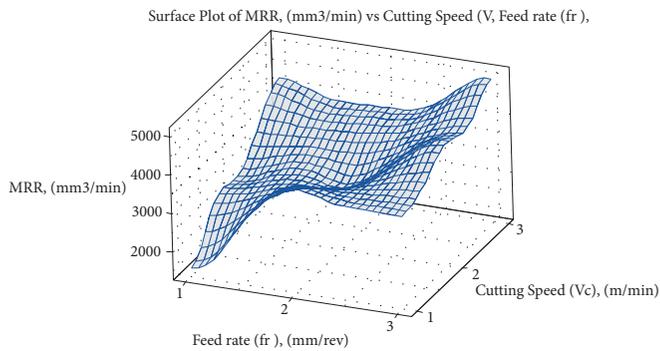
After selecting the optimum level of cutting process parameters, the final step is checked and determines the

TABLE 7: Analysis of variance (ANOVA) results for MRR ( $\text{mm}^3/\text{min}$ ).

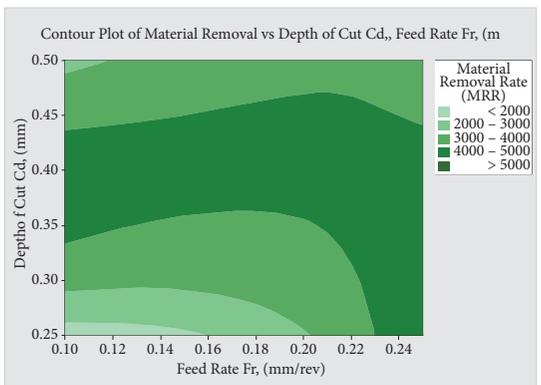
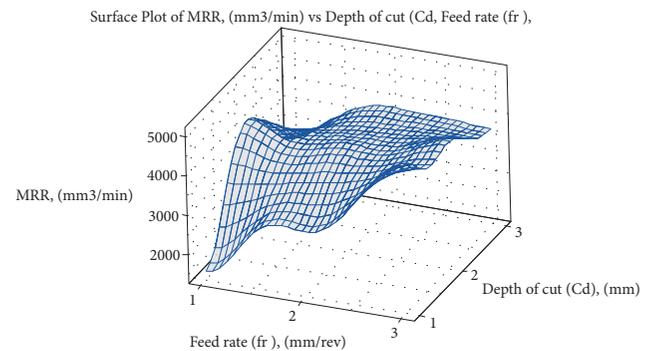
Source	DOF	Adj (SS)	Adj (MS)	F - value	P - Value	Contribution %C
A	2	2729112	1364556	1.29	0.342	18.51 %
B	2	1892157	946079	0.79	0.496	12.83 %
C	2	3874391	1937196	2.23	0.189	26.27 %
Error	6	6251873				
Total	12	14747533				



(a)



(b)



(c)

FIGURE 5: 3D surface and contour plots for turning process control factors versus MRR ( $\text{mm}^3/\text{min}$ ).

TABLE 8: Confirmation test results and comparison of  $S/N$  ratios.

Measurement Indicators		Level	MRR	$S/N$ ratios (dB)
Initial parameters		$A_2B_3C_3$	2773.87	68.862
Optimal parameters	Theoretical	$A_3B_2C_3$		73.927
	Experimental	$A_3B_2C_3$	5065.15	74.091

Improvement of  $S/N$  ratio = 5.23 dB.

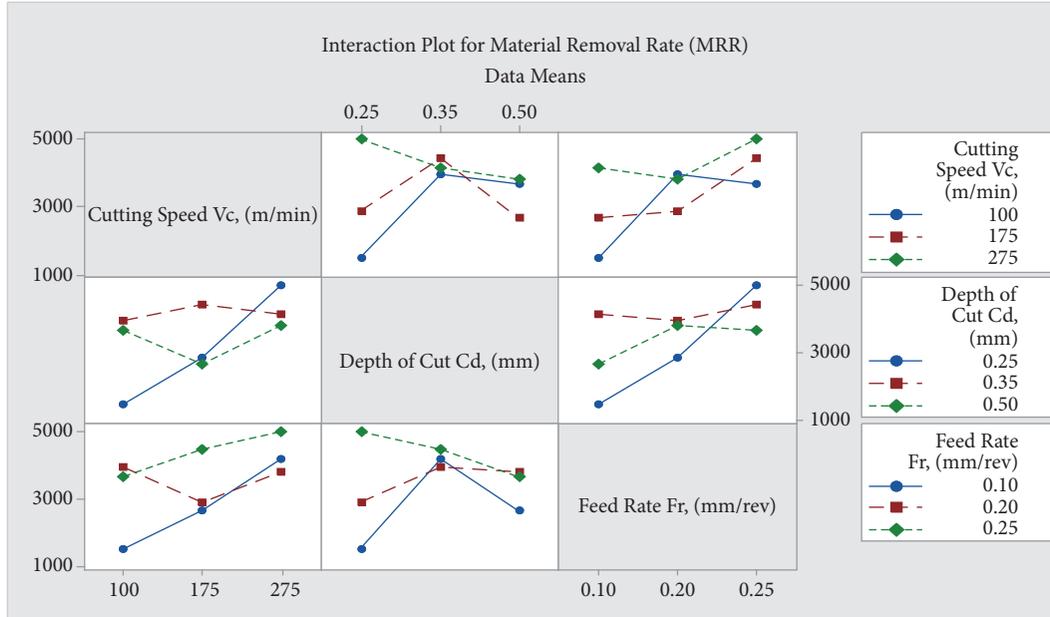


FIGURE 6: Interaction plots for  $MRR$  ( $\text{mm}^3/\text{min}$ ) with the corresponding process control factors.

improvement of  $MRR$  ( $\text{mm}^3/\text{min}$ ). To predict and verify the optimization in performance characteristic by using the optimum level cutting parameters the experimentation was once again performed initially at  $A_2B_3C_2$  and the optimized values  $A_3B_2C_3$ . The parametric combination for maximum  $MRR$  ( $\text{mm}^3/\text{min}$ ) was observed at  $A_3B_2C_3$ , that is, cutting speed 275 (m/min), depth of cut 0.35 (mm), and feed rate 0.25 (mm/rev). Table 8 also confirms the reproducibility of experimental conclusion due to its insignificant variations of the results between the experimental and theoretical values.

The progress of the  $S/N$  ratio from the initial cutting parameters to the optimal cutting parameters is 5.23 (dB). Consequently, the material removal rate in turning operations is significantly improved through the implemented (DOE) approach.

From Figure 6 one can easily understand at a glance, as it is a common interest response of Mean Signal-to-Noise Ratios Larger is better for optimization of material removal rate ( $\text{mm}^3/\text{min}$ ). As we can observe from the plot, the effect of bonding force on the pull strength is different at low and high levels of cutting speed. An interaction between factors occurs when the change in response from the low level to the high level of one factor is not the same. That is, the effect of one factor is dependent upon a second factor. It is observed that the interactions plots are used to compare the relative

strength of the effects across control factors in turning process as given in Figure 6.

The residual plots for material removal rate ( $\text{mm}^3/\text{min}$ ) are shown in Figure 7. These are generally fall on a straight line implying that errors are distributed normally. From the figure, it can be concluded that all values are within the control range, indicating that there is no an unusual structure and also the residual analysis does not indicate any model insufficiency. Hence, these values yield better results in future predictions.

#### 4. Conclusions

In the present work, a study has been carried out to optimize the process control parameters: cutting speed, depth of cut, and feed rate with respect to  $MRR$  in dry turning environment using CNC lathe. The material used for the investigation was CSN 12050 carbon steel. The  $L_9, (3^4)$  orthogonal array has been employed for experimental design and analysis of  $MRR$ . The experimental results based on  $S/N$  ratio approach and ANOVA analysis provides a systematic and efficient methodology for optimization of cutting parameters for maximized  $MRR$  and ease of machinability. The results based on  $S/N$  ratios and ANOVA show that feed rate has most significant factor compared to cutting speed and depth of cut has least significant factor. The optimal combination of

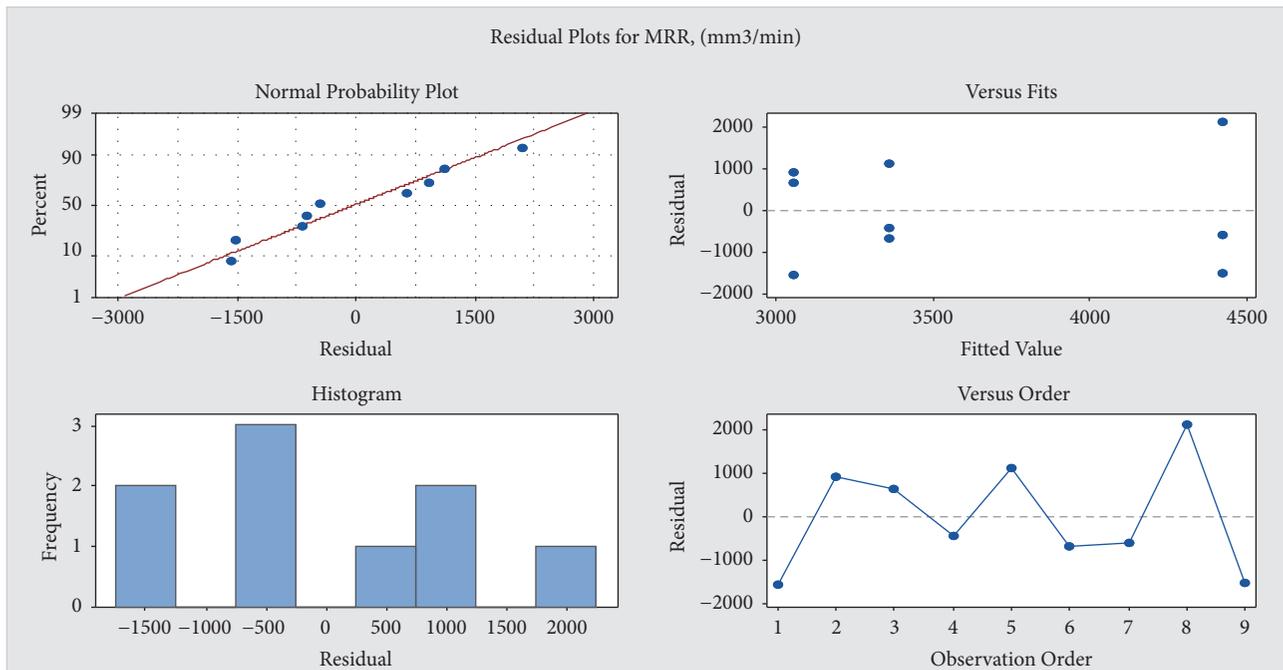


FIGURE 7: Residual plots for  $MRR$  ( $\text{mm}^3/\text{min}$ ) due to the effect of process control factors.

cutting parameters for  $MRR$  is cutting speed 275 (m/min), depth of cut 0.35 (mm), and feed rate 0.25 (mm/rev).

The final experiments for confirmation have been carried out to validate the optimal cutting parameters. The comparison from initial cutting parameters to the optimal cutting parameters about 5.229 (dB) improvement of  $MRR$  is observed. Moreover, it is noticeable that machining at higher cutting speeds leads to shorter cycle times and maximized material removal rate. Hence, the results confirmed the substantial role of dry turning process to realize the ultimate goal of product sustainability optimization for economically, environmentally, and societally sound-full machining.

### Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

### Conflicts of Interest

The authors declare that they have no conflicts of interest.

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