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Experimental Studies on Optimization of Process Parameters in Machining of EN24 Using Taguchi Method

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Abstract

Due to environmental concerns and tighter laws around pollution and contamination, there is an increase in the need for renewable and biodegradable cutting fluids. Surface finish and material removal rate (MRR) are both important factors in determining the quality of a metal cutting and manufacturing operation. The product's quality is ensured by a superior surface polish. The Taguchi technique was employed in this study to examine how the machining parameters affected the MRR and surface roughness during turning. variable cutting fluids, including cottonseed oil, coconut oil, and mineral oil, as well as variable cutting speeds, feed rates, and depths of cut were employed in the experiments. In this work, the Taguchi approach was employed to determine the ideal process variables for lowering surface roughness and elevating MRR. The L9 orthogonal array, which considers three levels and four elements, was used to arrange the experiments. The outcomes were then optimized using the Taguchi approach.

Keywords

Surface roughness, Material removal rate, Cutting fluids, Turning process, Taguchi

Introduction

Traditional metal cutting fluids (MCFs) are petroleum-based and not biodegradable, which means they can have a negative impact on the environment and pose health risks to workers. Alternative MCFs, such as water-based, vegetable-based, and synthetic fluids, are often biodegradable and less harmful to the environment and human health [1, 2]. Heat is the initial source of energy used in material removal. Turning is a widely used machining method, especially for finishing machined components. The MRR and machining properties including surface roughness, circularity, and dimensional deviations of the result are significantly influenced by the cutting settings utilized [3]. The performance of the lubricant will be improved much by the addition of nanoparticles into the base fluid [4]. Recently, polymer nanocomposites have gained much interest due to their advanced applications [5].

Using tungsten carbide cutting tools and the Taguchi method, Yang and Tarng [6] studied the cutting properties of S45C steel bars. They determined that the optimal parameters to utilize for turning operations include cutting speed, feed rate, and depth of cut based on performance indicators including tool life and surface roughness. Davim [7] looked at how cutting conditions (such as cutting speed and feed) and cutting time affected turning composites made from metal matrix. Using an orthogonal array and analysis of variance (ANOVA), they

looked at the cutting features of surface roughness, power consumed, and flank wear.

However, MCFs have a number of disadvantages, including health risks and environmental contamination. Davim et al. [8] found that cutting fluids increase tool life and produce superior surface quality. However, they also found that MCFs can cause health problems, such as skin irritation and respiratory problems. Additionally, MCFs can contaminate the environment if they are not properly disposed of. Dhar et al. [9] found that recycling cutting fluids is complex and costly. This is because MCFs often contain harmful chemicals, which can be difficult to remove. Zhang et al. [10] found that machining operations can be performed with less MCFs, while still maintaining good tool life and surface quality. This is due to the development of new machining processes like minimal quantity lubrication (MQL) and dry machining.

In response to the growing demands for environmentally friendly production, manufacturers are testing new techniques are necessary for removing cutting fluids. MQL and dry machining are some of these methods. Using MQL, the cutting zone is cooled and lubricated with a very little amount of cutting fluid. While still preserving good tool life and surface quality, this helps to lessen the impact of cutting fluids on the environment.

Numerous experiments have demonstrated that Ti6Al4V may be machined more effectively when castor oil-based cutting fluids are used. Castor oil was shown to consistently reduce tool wear when utilized as a cutting fluid as opposed to dry machining, according to Shyha et al. [11]. When palm oil-based cutting fluid was used instead of dry or flood lubrication, Prakash and Ramana [12] discovered that the machining performance was consistently superior in terms of surface quality and tool life. In comparison to dry and flood lubrication, MQL with vegetable oil reduced tool wear, according to Garcia and Ribeiro [13]. It is significant to note that during dry machining of titanium alloys, diffusion wear is frequently thought to be the most typical wear type. Garcia and Ribeiro [13] discovered that MQL use prevented the occurrence of diffusion wear. This is due to the fact that MQL's enhanced cooling aids in avoiding the development of a diffusion layer on the tool surface. Both MQL and the use of castor oil-based cutting fluids have promise for enhancing Ti6Al4V machining performance. Compared to conventional cutting fluids, these methods provide a number of benefits, including a smaller negative environmental effect and better surface quality [14].

According to the literature, a range of steel grades and high strength alloys are machined, and optimization techniques are used to achieve the greatest possible process parameter balance for the least amount of surface roughness, the least amount of cutting force, and an extended tool life. Less study has been conducted on the machining of both soft and hard materials using different cutting fluids, though. In the ongoing research study, the machining of the widely available material EN28 is examined. Utilizing several cutting fluids, including mineral oil, cottonseed oil, and coconut oil, the surface roughness and MRR are studied. There are variations in cutting depths, feed rates, and speeds. This study uses the Taguchi technique to pinpoint the best process variables for minimizing surface roughness and maximizing MRR. A statistical technique that may be used to enhance experimental designs is the Taguchi approach. It is an effective method that may be used to pinpoint the variables that affect a process the most and establish the ideal concentrations of those variables.

Materials and Method

Materials

High tensile strength, toughness, and resistance to wear are all characteristics of EN24 steel. Components including sturdy axles, screws, motors, nuts and bolts, and shafts are frequently made using it. At lower temperatures, EN24 steel may maintain significant impact strength. Table 1 displays the mechanical properties of EN24 steel. Table 2 displays the characteristics of the cutting fluids utilized in the present research.

Experimentation

In this experimental study, cutting fluids are employed to convert EN24 workpiece material on a precision tool lathe. The precision tool lathe machine (Gedeeweiler precision lathe MLZ-250W) for turning operations is shown in figure 1. Changes are made to machining input parameters including turning speed, feed, depth of cut, and cutting fluids to see how they affect the surface roughness and MRR of the machined workpiece.

Controlling variables and levels

Four process factors totalling three levels are chosen as the control variables such that the levels are sufficiently apart to

Table 1: Workpiece material mechanical properties according to EN24 [15].

Tensile strength (MPa)	850 - 1000
Yield strength (MPa)	680
Elongation (%)	13
Impact strength (J)	54
Hardness (HBN)	248 - 302
Thermal conductivity (W/mk)	41.9
Density (Kg/m^3)	7480
Melting point (°C)	1500

Table 2: Properties of cutting fluids [16-18].

Properties	Cotton seed oil	Coconut oil	Mineral oil
Kinematic viscosity (mm^2/sec)	31.347	27.9	29.55
Viscosity index	39.278	155	116
Saponification value	193.23	250-264	-
Iodine value	110	7-12	-
Pour point (°C)	0	20	-9
Flash point (°C)	312	240	150
Fire point (°C)	360	177	160
Auto ignition	Does not take place	Does not take place	Does not take place
Density (Kg/m^3)	921.50	915.1	850
Flow rate (mm^3/sec)	0.153	0.06	2.70
Specific gravity	0.921	0.915	0.85



Figure 1: Lathe machine used in the present work.

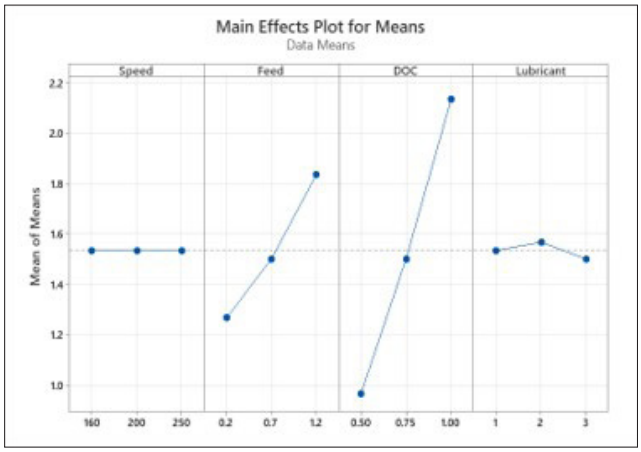


Figure 2: Process parametric effect on MRR.

Table 3: Control factors and levels.

Factors	Level 1	Level 2	Level 3
Speed	160	200	250
Feed	0.2	0.7	1.2
Depth of cut	0.5	0.75	1.0
Cutting fluid	Cotton seed oil	Coconut oil	Mineral oil

cover a broad range. The process parameter's ranges are taken from published sources. The four control factors that were selected are spindle speed, feed rate, depth of cut, and cutting fluid. In experiments, a coated carbide CNMg120408 tool is employed. Table 3 is a list of the control variables and their alternate levels.

Results and Discussion

After machining of the EN24 bar, the MRR and surface roughness was measured. The obtained experimental results for various test conditions as per orthogonal array is tabulated in table 4. The ideal process variables are computed using the Taguchi technique and ANOVA analysis.

Process parameters' impact on MRR

Figure 2 illustrates how process factors affect MRR. With a percentage of 80.8%, depth of cut is seen to have a significant impact on MRR, followed by feed rate with a percentage of 19%, while the other two factors have no discernible effect. When the depth of cut and feed are both 1 mm, the MRR is seen to be high (1.2 mm/rev). The MRR is increasing with increasing speed and depth of cut. Other investigators also noted comparable outcomes. Spindle speed is not at all contributing due to the selected levels in the current study. The material of the workpiece also has an impact on the MRR. Harder materials require higher cutting speeds and feeds to achieve the same MRR as softer materials. The machine tool also has an impact on the MRR. The rigidity of the machine tool can limit the MRR, as can the accuracy of the machine tool. The optimal process parameters for maximizing MRR will vary depending on the workpiece material, the tool material, and the desired surface finish [19, 20]. Table 5 displays the means response table. It is clear from table 5 that depth of cut is placed first, followed by feed. The optimal depth of cut for maximizing MRR will vary depending on the

Table 4: Experimental test conditions and their comments.

Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Lubricant	MRR (cc/min)	Surface roughness (µm)
160	0.2	0.5	Mineral oil	0.7	2.0
160	0.7	0.75	Coconut oil	1.5	2.5
160	1.2	1	Cotton seed oil	2.4	3.0
200	0.2	0.75	Cotton seed oil	1.2	2.6
200	0.7	1	Mineral oil	2.1	2.5
200	1.2	0.5	Coconut oil	1.3	2.7
250	0.2	1	Coconut oil	1.9	2.6
250	0.7	0.5	Cotton seed oil	0.9	2.8
250	1.2	0.75	Mineral oil	1.8	2.9

Table 5: Table of responses for means.

Level	Speed	Feed	Depth of cut	Lubricant
1	1.5333	1.2667	0.9667	1.5333
2	1.5333	1.5000	1.5000	1.5667
3	1.5333	1.8333	2.1333	1.5000
Delta	0.0000	0.5667	1.1667	0.0667
Rank	4	2	1	3

workpiece material, the tool material, and the desired surface finish. For soft materials, a larger depth of cut can be used to achieve a higher MRR. For hard materials, a smaller depth of cut must be used to prevent premature tool wear and deflection of the workpiece. For a smooth surface finish, a smaller depth of cut must be used.

Table 6 displays the model summary and ANOVA for the MRR. The R^2 score of approximately 100% in table 6 indicates that the anticipated model is successfully forecasting the answers. Equation 1 contains the regression equation for forecasting the MRR.

$$MRR = -0.580 + 0.000000\ Speed + 0.5667\ Feed + 2.333\ Depth\ of\ cut - 0.0167\ Lubricant \quad (1)$$

Process parameters' impact on surface roughness

Figure 3 illustrates how process factors affect surface roughness. With a percentage of 49.3%, feed is seen to

Table 6: ANOVA for MRR.

Source	DF	Adj SS	Adj MS	F-value	P-value
Regression	4	2.52500	0.63125	168.33	0.000
Speed	1	0.00000	0.00000	0.00	1.000
Feed	1	0.48167	0.48167	128.44	0.000
Depth of cut	1	2.04167	2.04167	544.44	0.000
Lubricant	1	0.00167	0.00167	0.44	0.541
Error	4	0.01500	0.00375		
Total	8	2.54000			
Model Summary					
S	**R^2**	**R^2 (adj)**	**R^2 (pred)**		
0.0612372	99.41%	98.82%	96.82%		

have a significant impact on surface roughness, followed by lubricant with a percentage of 25.1%, and the final two factors, speed, and depth of cut, with percentages of 16.3% and 9%, respectively. When using mineral oil as a lubricant with a feed of 0.2 mm, the surface roughness is seen to perform better. Low speed, low feed, and shallow depth of cut are excellent for the surface roughness. Identical results were detected by other investigators as well. Depth of cut is contributing less due to the selected levels in the current study. The material of the workpiece has an impact on the surface roughness as well. Depending on the material of the workpiece, the material of the tool, and the intended surface finish, different process parameters will be required to achieve the appropriate surface finish. The surface quality is also influenced by the machine tool [21-24]. The rigidity of the machine tool can limit the surface finish that can be achieved, as can the accuracy of the machine tool.

Table 7 displays the response table for methods for surface finish. It is clear from table 7 that feed is placed first, followed by lubricant. The feed rate is the rate at which the cutting tool enters the workpiece during a turning process. The workpiece's surface finish is significantly influenced by the feed rate. In general, the surface finish degrades as the feed rate rises. This is due to the fact that at greater feed rates, cutting forces and temperatures are higher, increasing the quantity of material that is expelled and the amount of heat produced. This can lead to tearing and other surface defects.

The surface finish is represented by the ANOVA in table 8, and it is evident from table 3 that all characteristics taken into consideration have an impact on the surface finish since the p-value for each answer is less than 0.05. In a turning operation, a variety of process variables influence the surface finish. The surface polish is influenced by the spindle speed, feed rate, depth of cut, tool type, and coolant. During a turning process, the feed rate has a considerable influence on the workpiece's surface polish. The optimal feed rate for achieving the desired surface finish will vary depending on the specific application. The regression equation for predicting the surface roughness is given in equation 2.

Surface Roughness = 1.057 + 0.002978 Speed + 0.4667 Feed + 0.4000 Depth of cut + 0.1667 Lubricant (2)

Table 7: Response chart for surface finishing methods.

Level	Speed	Feed	Depth of cut	Lubricant
1	2.500	2.400	2.500	2.467
2	2.600	2.600	2.667	2.600
3	2.767	2.867	2.700	2.800
Delta	0.267	0.467	0.200	0.333
Rank	3	1	4	2

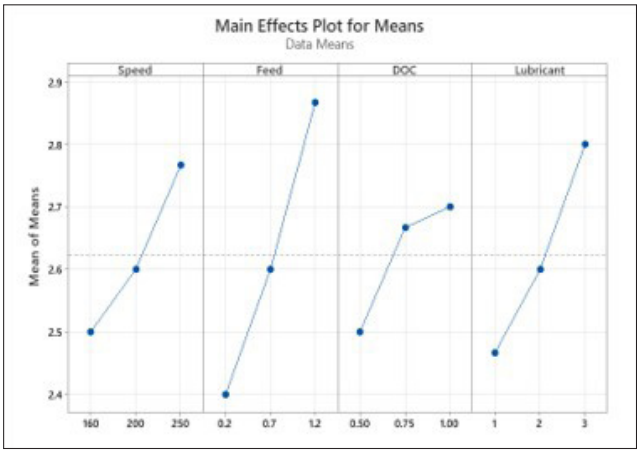


Figure 3: Process parametric effect on surface roughness.

Table 8: ANOVA for surface roughness.

Source	DF	Adj SS	Adj MS	F-value	P-value
Regression	4	0.66154	0.165385	47.20	0.001
Speed	1	0.10821	0.108206	30.88	0.005
Feed	1	0.32667	0.326667	93.22	0.001
Depth of cut	1	0.06000	0.060000	17.12	0.014
Lubricant	1	0.16667	0.166667	47.56	0.002
Error	4	0.01402	0.003504		
Total	8	0.67556			
Model Summary					
S	**R^2**	**R^2 (adj)**	**R^2 (pred)**		
0.0591954	97.93%	95.85%	89.28%		

Table 9: Comparison of the experimental and expected values for both reactions.

Response	MRR	Surface roughness
Speed	200	160
Feed	1.2	0.2
Depth of cut	1	0.5
Lubricant	Coconut oil (2)	Mineral oil (1)
Experimental	2.51	1.94
Predicted	2.39	1.99
Error %	4.7	3.1

Confirmation tests

Trials and tests were carried out using the ideal set of process parameters, and the outcomes were recorded. The findings that were obtained were contrasted with the outcomes that the regression equation anticipated. The results of both the predicted and the obtained is shown in table 9. The error of both results is within the limits.

Conclusion

In the current investigation, EN24 bar was turned while being subjected to various process parameters. For the inquiry, nine trials employing the Taguchi L9 orthogonal array, and three validation tests were finished. The feed rate and depth of cut were discovered to be the most crucial variables impacting the MRR in the study. The MRR was influenced by the feed rate by 19% whereas the depth of cut by 80.8%. The other two factors, cutting speed and lubricant, had no significant impact on the MRR. The study also found that three factors, feed rate, lubricant, considering the relationship between cutting depth and cutting speed, were significantly correlated with surface roughness. These three factors together accounted for 49.3% of the total surface roughness. The results of the ANOVA and regression analyses support the conclusions of the study. The MRR and surface roughness were significantly influenced by the feed rate, the depth of cut, and the lubricant, according to the results of the ANOVA study. The results of the regression analysis demonstrated that the MRR and surface roughness could be predicted using a linear model based on the values of the three components. The study also found that effective lubrication can lead to improved surface quality when soft metals are being machined. This is because lubrication can help to reduce friction and heat, which can lead to a smoother surface finish.

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None.

Conflict of Interest

None.

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