# Investigating the Effect of Cutting Speed, Feed Rate, and Radial Depth of Cut on Tool Wear during Turning of Al-1060 Alloy by High-Speed Steel Cutting Tools

Nandhagopal S[1], Nashreen J[2], Siyas Mahmood S,Neshikamai J A, J Pradeep Kumar

{nandhagopal2701@gmail.com[1], nashreennas24@gmail.com[2], siyasmahmood5@gmail.com[3]}

Department of Production Engineering, PSG College of Technology, Coimbatore, India[1,2,3]

**Abstract.** Aluminum alloys are known for good machinability and high strength to weight ratio, so they have been used in structural and automotive applications. In this paper, the effect of three factors such as cutting speed (m/min), feed rate (mm/min) and radial depth of cut (mm) on the output response tool wear for the machining of Al 1060 alloy was investigated by using Taguchi L27 orthogonal array design and statistical tools. The optimal combination of parameters was identified based on the tool wear rate. The optimal parameters achieved are a cutting speed of 150 m/min, feed rate of 50 mm/min, and a radial depth of cut of 0.5 mm. These results will be used to enhance the utilization of high-speed steel cutting tools by minimizing tool wear.

**Keywords:** Machinability, Tool wear, Taguchi DoE, ANOVA, SQC.

## 1 Introduction

Okokpujie, Ohunakin, Bolu and Okokpujie have done the study titled "Experimental dataset for prediction of tool wear during turning of Al-1060 alloy by high-speed steel cutting tools” [1]. Our Experimental dataset was taken and referenced from their study.

As industries evolve over these periods, resources need to be used as minimally as possible. The production industries are experiencing unprecedented global rivalry, pressuring manufacturers to make components at the lowest possible cost without sacrificing the quality of the final product. The focus of this investigation lies in understanding the intricate relationship between cutting parameters specifically feed rate, cutting speed, and radial depth of cut on tool wear during the turning of Al-1060 alloy. This alloy is known for its corrosion resistance, ductility, and weldability properties. It was used for manufacturing bushes, reflector plates, etc... In the crust of the Earth, aluminum ranks as the second most abundant element. It usually exists in combination with oxygen, silicon, fluorine, and other elements rather than in its metallic state due to its reactive nature. The most popular light metal material in use today is aluminum alloy, and researchers are currently focusing a lot of their attention on this material's corrosion resistance property. Machining operations, particularly turning, are fundamental to the production of intricate components and optimizing these processes is

ICAMDMS 2024, February 23-24, Coimbatore, India

DOI 10.4108/eai.23-2-2024.2346996

crucial for enhancing overall productivity and product quality. Turning operations on aluminum alloys involves material removal to achieve desired shapes and dimensions. Tool wear, a common concern in machining operations, can significantly impact the quality and cost-effectiveness of the manufacturing process. The Taguchi method requires very little work and is applied quickly. Numerous industries are using Taguchi's technique to enhance process quality in the manufacturing industry.

Hrairi, Daoud and Zakaria conducted incremental sheet forming using Taguchi based grey optimization, to identify the combination of control factors. The study found that step depth influences 68.5%, tool diameter influences 9.7%, and no. sheets influences 6.1% for the responses wall angle, surface roughness, and the spring back to achieve high-quality products [2]. Kumar and Gulati optimized process parameters for AA6063-O aluminum alloy with helical tool path using incremental forming with Taguchi design and ANOVA. The ideal parameters that provide favorable conditions are found as 0.8mm of thickness, 0.2mm of incremental depth, 7.52mm of diameter of the tool, 1000 rpm of spindle speed, 1000mm/min of feed rate, 50° of wall angle, with the hemispherical shaped tool for forming force [3]. Umamaheswarrao, Raju, Suman and Sankar used Central Composite Rotatable Design (CCD) and TOPSIS optimization procedures to optimize the output factors cutting force and surface roughness for the parameters of AISI 52100 steel with PCBN cutting tools in a lathe. Cutting speed, depth of cut, feed, negative rake angle, and nose radius are the determining elements. The analysis revealed that the most significant element, with an optimal value of 45°, is the negative rake angle including the cutting speed of 200 m/min, feed of 0.1 mm/rev, cut depth of 0.8 mm, and nose radius of 1.2 mm [4]. Sathish, Arul, Subbiah, Ravichandran, and Mohanavel in their study, end milling operation of Inconel 617 they used L27 orthogonal array for optimizing the factors for the outcomes such as machined surface roughness and MRR. The optimal value obtained was 0.208 µm and 8.2 mm3/s [5]. Murugesan et al., in their experiment, used Taguchi orthogonal array design and ANOVA to examine the influence of tool radius, feed rate, incremental depth, and spindle speed on AA3003-H18 Al alloy sheet. They found that the minimal 0.323µm surface roughness can be achieved at 3.0mm tool radius, 3000rpm spindle speed, 0.10mm incremental depth, and 2000mm/min feed rate. They also discovered that 0.80 and 0.64µm surface roughness are achieved by using engine oil lubricants and the engine oil and grease lubricant blend [6]. Panneerselvam, Kandavel, and Kishore to compare high-speed steel with newly synthesized powder metallurgy tools for turning of AISI 1020 steel. They have used L9 orthogonal array matrix in conducting experiments and concluded that the newly synthesized tool has good performance over the High-speed Steel, and they have also found the effects and impacting factors using the ANOVA and SN ratio [7]. Singh and Kumar have conducted the experiment for selecting the optimal control variables for tool wear on TiC coated carbide tool using Taguchi method and obtained the values for machining En24 steel for crater and flank wear [8]. From the literature review, it was identified that cutting speed was one of the critical parameters in tool wear. However, the interaction of cutting parameters especially cutting speed on tool wear of Al 1060 alloy in consideration with HSS tool was not studied effectively. In this article, statistical analysis of control parameters such as cutting speed, feed rate and radial depth of cut was performed to study the detailed relationship on tool wear of HSS as an output factor for turning of Al 1060 alloy.

## 2 Experimental Methods and Materials

High speed steel cutting tools are known for their ability to withstand the challenges posed by machining the workpiece with their unique characteristics such as high Hardness, abrasive resistance etc., High-speed steel (HSS) is characterized by a composition comprising carbon (C) in the range of 0.7% to 1.4%, tungsten (W) between 12% and 18%, chromium (Cr) around 3% to 5%, vanadium (V) ranging from 1% to 5%, and molybdenum (Mo) typically between 1% and 10%.

The implementation of Statistical Quality Control tools, using Minitab software, with Taguchi design adds a robust analytical dimension to this investigation. Dr. Genichi Taguchi created the Taguchi design methodology, which accounts for the innate variability of materials and manufacturing processes during the design phase itself.

The Data sets used in this study were taken from the study titled "Experimental dataset for prediction of tool wear during turning of Al-1061 alloy by high-speed steel cutting tools" Okokpujie, Ohunakin, Bolu and Okokpujie [1].

This paper deals with selecting the optimal response for the machining parameters such as cutting speed, feed rate and radial depth of cut for the orthogonal turning of Al-1060 round bar with cross section of Ø38mm and 380mm length on TC CNC lathe (Fanuc). As from the above stated reference paper, the tool wear data sets were obtained based on L27 orthogonal Taguchi design matrix using JSM-6700F SEM for every experimental run and utilized here.

The data for the chosen input parameters were gathered from the aforementioned peer-reviewed article. Statistical analysis was carried out using Minitab, a data analysis software. Investigation was performed on charts such as the correlogram, surface plot, main effect plot, and interaction plot. Studies using correlograms revealed considerable correlations exist between the independent input parameters and the output parameter. Surface plot was utilized to visualize the effect on tool wear at different levels of input parameters, main effect plots provided insight into the relative contributions of each component, while interaction plots suggested potential synergistic effects between factors. ANOVA was performed to state the significance of input parameters see Figure 1.

Table 1. The experimental data obtained from the L27 Taguchi design of experiments and their resposnes [1].

| Cutting speed (m/min) | Feed rate (mm/min) | Radial depth of cut (mm) | Tool Wear (TWmax) |
|---|---|---|---|
| 150 | 50 | 0.5 | 0.272 |
| 150 | 50 | 1 | 0.293 |
| 150 | 50 | 1.5 | 0.226 |
| 150 | 100 | 0.5 | 0.299 |
| 150 | 100 | 1 | 0.237 |
| 150 | 100 | 1.5 | 0.286 |
| 150 | 150 | 0.5 | 0.34 |

| | | | |
|---|---|---|---|
| 150 | 150 | 1 | 0.296 |
| 150 | 150 | 1.5 | 0.26 |
| 200 | 50 | 0.5 | 0.221 |
| 200 | 50 | 1 | 0.36 |
| 200 | 50 | 1.5 | 0.409 |
| 200 | 100 | 0.5 | 0.312 |
| 200 | 100 | 1 | 0.415 |
| 200 | 100 | 1.5 | 0.379 |
| 200 | 150 | 0.5 | 0.363 |
| 200 | 150 | 1 | 0.386 |
| 200 | 150 | 1.5 | 0.424 |
| 250 | 50 | 0.5 | 0.324 |
| 250 | 50 | 1 | 0.343 |
| 250 | 50 | 1.5 | 0.316 |
| 250 | 100 | 0.5 | 0.33 |
| 250 | 100 | 1 | 0.213 |
| 250 | 100 | 1.5 | 0.359 |
| 250 | 150 | 0.5 | 0.321 |
| 250 | 150 | 1 | 0.445 |
| 250 | 150 | 1.5 | 0.311 |

The experiment was done with three parameters with three levels. As listed in Table 1. cutting speed with the variation of 150, 200 and 250 (m/min), feed rate with the variation of 50, 100 and 150 (mm/min) and radial depth of cut with the variation of 0.5, 1, 1.5 (mm) and their corresponding output responses were detailed.

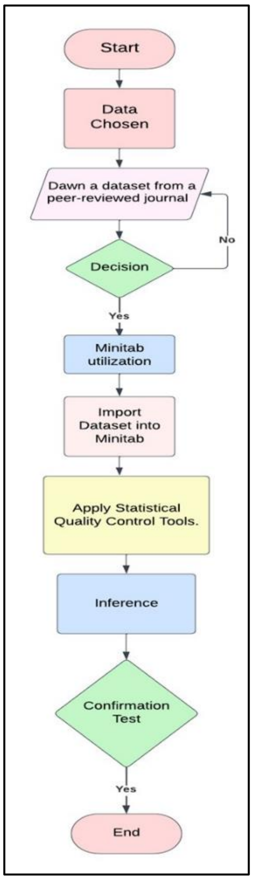



**Fig. 1.**Workflow chart.

## 3 Results and Discussion

The individual and the combined effect of influencing factors on tool wear and its significance is discussed by using Analysis of Variance with the P Test.

Table 2. Analysis ofVariance.

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Cutting speed (m/min) | 2 | 22.494 | 22.494 | 11.2468 | 4.94 | 0.04 |
| Feed rate (mm/min) | 2 | 7.068 | 7.068 | 3.5339 | 1.55 | 0.27 |
| Radial depth of cut (mm) | 2 | 1.339 | 1.339 | 0.6696 | 0.29 | 0.753 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Cutting speed (m/min)* Feed rate (mm/min) | 4 | 3.585 | 3.585 | 0.8963 | 0.39 | 0.808 |
| Cutting speed (m/min)* Radial depth of cut (mm) | 4 | 15.7 | 15.7 | 3.925 | 1.72 | 0.238 |
| Feed rate (mm/min) * Radial depth of cut (mm) | 4 | 10.552 | 10.552 | 2.6379 | 1.16 | 0.397 |
| Residual Error | 8 | 18.227 | 18.227 | 2.2784 | | |
| Total | 26 | 78.965 | | | | |

From Table 2, analysis of variance, we can infer that the P value of cutting Speed is less than 0.05. It depicts the influence of cutting speed is strongly significant. In the case of other parameters, it could be seen that they have lesser significancy as compared with cutting speed. Here, the ANOVA table displays statistical significance at a 95% confidence level.

### 2.1 Inference

The impact of process variables on the output response such that tool wear for the turning of Al-1060 bar is discussed below. This study worked on the impact caused and the interaction control variables and output response help to develop this process and to improve the required product.

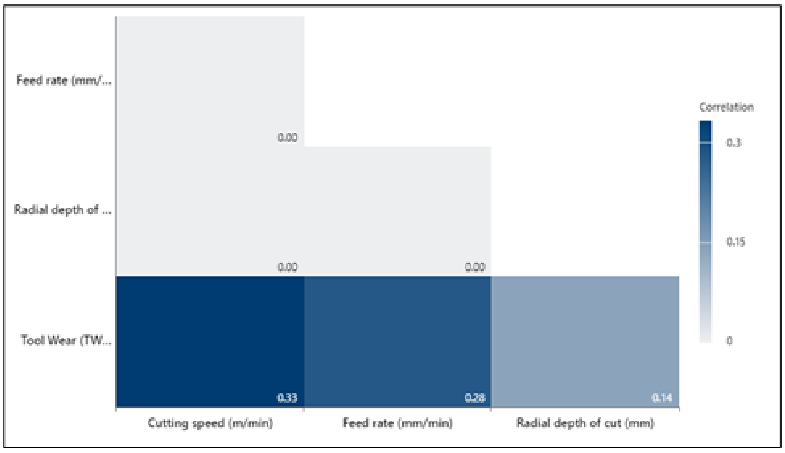
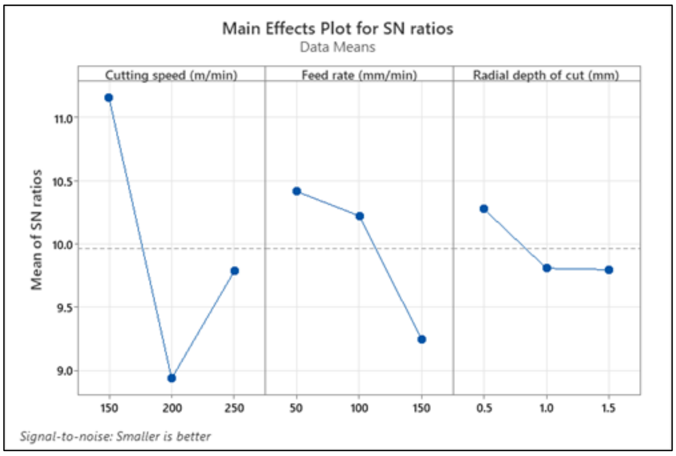


**Fig. 2.**shows correlation between each factor and output response.

Correlogram shows the relationship between the three machining factors and tool wear. From Figure 2. It shows that the input parameters are independently affecting the tool wear. It is clearly notable that there is a stronger correlation of 0.33 between tool wear and cutting speed. As continued, there is a feed rate that has a correlation of 0.28 followed by 0.14 for radial depth of cut which has a much lower impact on the tool wear for high-speed steel. The above correlation values transparently show the order and quantity of influencing characteristics of the input parameter. This data abruptly shows the resemblance towards the




results obtained from the ANOVA.

**Fig. 3.**Main effect plot for SN ratios.

From Figure 3, it could be concluded that the individual effect of cutting speed at 150 m/min influence more and then decreases at level 2 and then increases at 250 m/min. The effect of feed rate is more at 50 mm/min and then decrease at each level followed by the radial depth of the cut at 0.5mm influences the most and then it is almost constant from 1 to 1.5 mm.

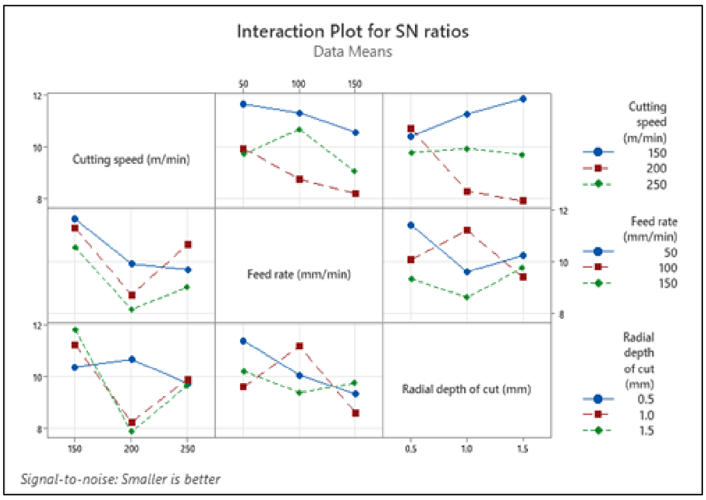



**Fig. 4.** Shows the interaction between process parameters

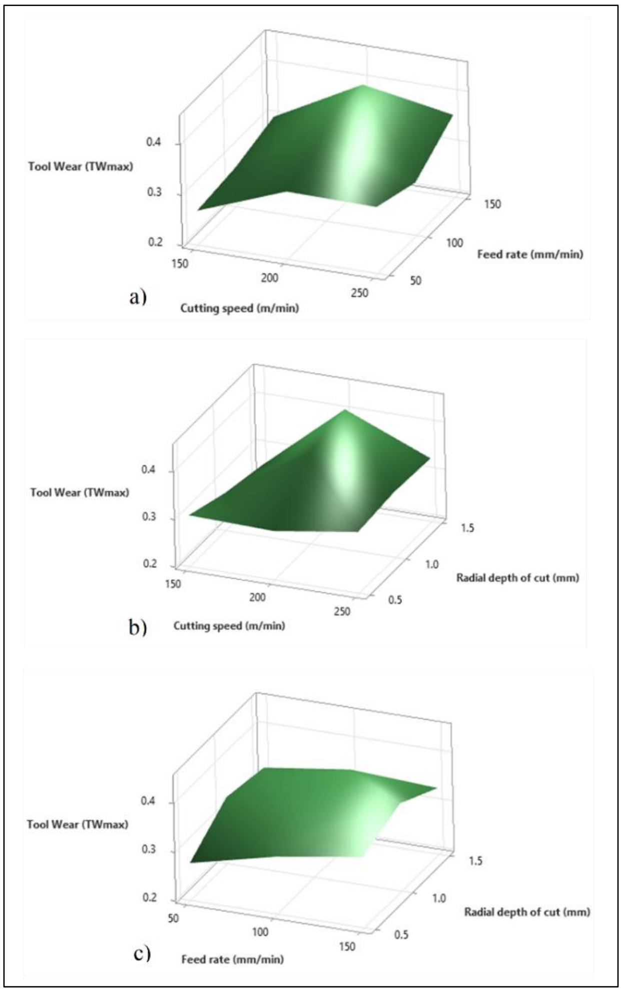



**Fig. 5.** Surface plot describes the effect of factors on tool wear rate.

Figure 5**.** depicts the tool wear characteristics at different machining parameters. In Figure 5 a, it could be inferred that the maximum tool wear is at level 1 and level 3 of cutting speed and radial depth of cut. From Figure 5 b, tool wear increases drastically and decreases for cutting speed with respect to radial depth of cut and tool wear increase and get constant with respect to cutting speed. From Figure 5 c. radial depth of cut and feed rate affects tool wear in the same manner. In continuation with the surface plot, the interaction plot also demonstrates the combined effect of machining parameters on the tool wear as shown in Figure 4.

Table 3. Depitcs the ranking of individual factors.

| Levels | Cutting speed (m/min) | Feed rate (mm/min) | Radial depth of cut (mm) |
|---|---|---|---|
| 1 | 11.155 | 10.414 | 10.276 |
| 2 | 8.94 | 10.223 | 9.809 |
| 3 | 9.789 | 9.246 | 9.798 |
| Delta | 2.216 | 1.168 | 0.478 |
| Rank | 1 | 2 | 3 |

Table 3. depicts the ranking of the input parameters based on SN ratio (Smaller is better) shows that the dominant influencing factor is cutting speed subsequently feed rate and radial depth of cut.

### 2.2Confirmation Test

**Prediction**

| S/N Ratio | Mean |
|---|---|
| 11.5368 | 0.268370 |

**Settings**

| Cutting speed (m/min) | Feed rate (mm/min) | Radial depth of cut (mm) |
|---|---|---|
| 150 | 50 | 0.5 |

**Fig.6.** Predicted values for the optimal test run obtained from the analysis.

Table 4. shows the actual values of the experimental data for the corresponding test run.

| Cutting speed (m/min) | Feed rate (mm/min) | Radial depth of cut (mm) | Tool Wear (TWmax) | S/N ratio | MEAN1 |
|---|---|---|---|---|---|
| 150 | 50 | 0.5 | 0.272 | 11.3086 | 0.272 |

The Minitab generated (predicted optimal) values of SN ratios and Mean of the optimal machining parameters such as cutting speed of 150 m/min, feed rate of 50 mm/min and radial depth of cut of 0.5 mm (shown in Figure 6) are compared with the actual values of the experiment (shown in Table 4) in which both values are approximately the same. From which we can infer that the prior parameter design from the experimental run is predicted properly for optimum combination.

## 3 Conclusion

This study is to find the optimal combination of process variables such as cutting speed, feed rate, and radial depth of cut for the minimum tool wear. This research was carried out to produce minimum tool wear of HSS tool for the turning of Al-1060 alloy by using L27 Taguchi orthogonal array. It is clearly depicting that the interaction of process parameters on output response with optimized results are useful for developing different kinds of products efficiently and to choose the best value of control variables.

From ANOVA, it could be inferred that the cutting tool is the dominant parameter which significantly affects tool wear. In contrast, the influence of feed rate and radial depth of cut are not significant as compared with the cutting speed.

The optimal process parameters are cutting speed of 150 m/min, feed rate of 50 mm/min, and radial depth of cut of 0.5 mm.

The above stated optimal level occurs in Test run 1 with a minimum tool wear of 0.272.

This work is useful in selecting optimum parameters in machining and understanding the effects of control parameters on tool wear.

## References


[1] Okokpujie, I. P., O. S. Ohunakin, C. A. Bolu, and K. O. Okokpujie. "Experimental data-set for prediction of tool wear during turning of Al-1061 alloy by high speed steel cutting tools." Data in brief 18 (2018): 1196-1203.

[2] Hrairi, Meftah, Jamal I. Daoud, and Faiz Zakaria. "Optimization of incremental sheet metal forming process using grey relational analysis." Int. J. Recent Technol. Eng 7 (2019).

[3] Kumar, Ajay, and Vishal Gulati. "Experimental investigations and optimization of forming force in incremental sheet forming." Sādhanā 43 (2018): 1-15.

[4] Umamaheswarrao, Ponugoti, D. Ranga Raju, Koka Naga Sai Suman, and Bhuvanagiri Ravi Sankar. "Optimizing cutting parameters in hard turning of AISI 52100 steel using topsis approach." Journal of Mechanical and Energy Engineering 3, no. 3 (2019): 227-232.

[5] Sathish, T., K. Arul, Ram Subbiah, M. Ravichandran, and V. Mohanavel. "Optimization on end milling operating parameters for super alloy of Inconel 617 by Taguchi's L27 orthogonal array." In Journal of Physics: Conference Series, vol. 2027, no. 1, p. 012013. IOP Publishing, 2021.

[6] Murugesan, Mohanraj, Jae-Hyeong Yu, Kyu-Seok Jung, Sung-Min Cho, Krishna Singh Bhandari, and Chang-Whan Lee. "Optimization of forming parameters in incremental sheet forming of AA3003-H18 sheets using Taguchi method." Materials 15, no. 4 (2022): 1458.

[7] Panneerselvam, T., T. K. Kandavel, and P. Kishore. "Experimental investigation on cutting tool performance of newly synthesized P/M alloy steel under turning operation." Arabian Journal for Science and Engineering 44, no. 6 (2019): 5801-5809.

[8] Singh, Hari, and Pradeep Kumar. "Tool wear optimization in turning operation by Taguchi method." (2004).