# Optimization of Turning Parameters of AISI 4340 Steel Using Parallel Textured Tool

**Manjari Malviya, Sunil Kumar, Apurva Anand**

*Department of Mechanical Engineering, Babu Banarasi Das University, Lucknow*

*manjarimalviya1997@gmail.com*, *sonkar.sunil@gmail.com*, *apurva2050@yahoo.co.in*

## Abstract

In present work, the influence of machining parameters on surface roughness of AISI 4340 steel using a parallel textured carbide cutting tool is studied. Textures parallel to cutting edge are produced on rake face of tool using a copper electrode having a diameter of 500µm. Spacing between two successive lines is kept at 100µm and depth of lines is kept at 50µm. Machining parameters considered are cutting speed, feed rate, and depth of cut. Surface roughness is selected as a response parameter. Taguchi $L_9$ technique is employed for optimizing the machining parameters to obtain minimum surface roughness. ANOVA is utilized to find contribution of each parameter to surface quality. Results revealed that feed rate was the most influential factor in surface quality with a contribution of 61.71% followed by depth of cut with 24.31% contribution, and cutting speed with 14.06% contribution. Confirmation experiment shows an improvement in surface roughness by 19.21% when it is compared with experiment number one of Taguchi $L_9$ OA.

**Keywords**. ANOVA; Parallel Texture; Surface Roughness; Taguchi

## 1. INTRODUCTION

Nowadays, demand for materials possessing rich surfaces is rapidly increasing in market because of their excellent performance characteristics. Turning is a widely used metal cutting process in which material is removed from a rotating surface using a single-point cutting tool to get desired surface quality. Mechanism of turning process is shown in Figure 1.

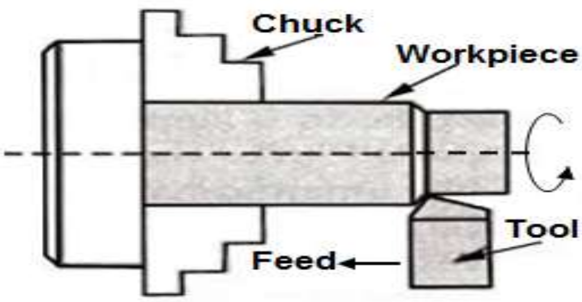



Figure 1. Turning process [1]

Cutting tools used for this purpose are generally made up of High-speed steel, ceramics, carbide, diamonds, cubic boron nitride, etc. Turning of alloy steel such as AISI 4340 steel is a challenging task since high friction and adhesion at tool-chip interface produce extreme temperatures at cutting zone which leads to high tool wear, reduction in tool life, and also deterioration of surface quality. Therefore, it is necessary to modify cutting tool in such a way that it produces a better-turned surface. Surface texturing is relatively a new application that overcomes above-stated drawbacks by introducing different textures such as vertical, parallel, and dot at flank or rake face of cutting tool inserts. Surface texturing on rake face of cutting tool reduces cutting forces, increases load-carrying capacity, and improves wear resistance and surface quality. Rake face textured tools reduced tool chip contact area and thus decreased cutting forces, cutting temperature, and friction coefficient at tool-chip interface [2].

Gap provided between grooves in textured tools helped in heat dissipation from tool surface of titanium alloy when chip slides over tool face, thus reducing cutting temperature at tip of cutting edge [3]. Microscale parallel textures made on rake face of cutting tool helped reduce friction on tool surface and also reduced cutting forces [4]. Turning was performed on annealed 1045 steel and 6061 aluminum workpieces using an isotropic parallel textured tool with a width and depth of 100µm produced on rake face and a significant reduction in feed rate and improvement in surface quality were found [5]. Effect of different textured tools on built-up edge formation and tool wear during turning of carbon steel was studied. It was found that textured tools helped in destabilizing BUE resulting in a better surface quality [6]. Influence of built-up edge formation on surface roughness through microscale orthogonal cutting tests on titanium alloy Ti6Al4V was investigated. It was found that effect of BUE on surface quality varied depending on cutting speed and uncut chip thickness. Better surface values were also obtained at a cutting speed of 62m/min [7]. Influence of rake angle of a carbide milling cutter on surface quality of titanium alloy TB17 was investigated. It was concluded that surface roughness increases by increasing the rake angle [8]. Micro textures on rake face of carbide tool reduced friction coefficient and improved lubrication of tool [9]. There are no certain guidelines made for designing textures and thus, machining parameters can be optimized using trial-and-error method only [10].

Type of surface texturing greatly influences turning parameters and surface roughness of hard materials and alloys. Texturing of tools helped in improving wear resistance by reducing cutting zone temperature and also caused a reduction in machining forces [11]. Authors also found less BUE on tool edge in a cutting tool having surface texture grooves 45º inclined to main cutting edge when compared with other tools [12]. Textured tools improved surface quality, tool wear, and cutting zone temperature as compared to non-textured tools [13]. Therefore, demand for textured tools is rapidly increasing in market as it helps in reducing manufacturing costs, yields higher productivity, and also safeguard health of operators and environment. In present study, surface quality of AISI 4340 steel is evaluated using a parallel textured carbide cutting tool. Taguchi $L_9$ OA is used with machining parameters considered as cutting speed, feed rate, and depth of cut while surface roughness is considered as a response parameter. Optimum results are verified by performing validation experiments.

## 2. LITERATURE REVIEW

Many researchers have found that textured tools significantly help in reducing surface roughness. A comparative analysis between spot and dimple textured tools at different cutting speeds showed that spot-textured cutting tools produced better surface quality as compared to dimple and non-textured tools [14]. Authors found that parallel textured tools produced lesser wear than non-textured tools. It was also revealed that textured tools produced better surface quality and lower cutting temperature when compared with non-textured tool [15]. In another study, surface roughness of steel was compared and analyzed by three different types of textures that were vertical, parallel, and dot with a non-textured tool. It was found that surface quality improved at high cutting speed for all types of texturing [16].

Effect of varying turning parameters like cutting speed, feed rate, and depth of cut in turning of AISI 420 steel was investigated. It was found that feed rate was the most significant factor that influenced surface roughness with a contribution of 80.71% [17]. Influence of turning parameters on surface quality of AISI 4140 steel was studied and it was found that feed rate had a maximum contribution to surface quality while cutting speed and depth of cut had negligible effects. It was also concluded that surface roughness increases by increasing feed rate [18]. It was found that with cutting speed = 350m/min and feed rate = 0.15mm/rev, surface quality improved. It was also revealed that surface quality deteriorates at a higher feed rate [19]. Optimum condition for reducing surface roughness of AISI 1045 steel was found as cutting speed = 116m/min, feed rate = 0.06mm/rev, and depth of cut = 0.25mm. Authors also inferred that surface roughness improves at a lower feed rate [20].

For obtaining high productivity and low manufacturing costs, metal cutting industries need to perform operations at optimum conditions. Taguchi methodology is very useful for optimizing machining parameters and producing high-quality products at a relatively low cost. It is the most effective approach for solving complex problems as it uses an orthogonal array that studies entire parametric space with a small number of experiments. Therefore, researchers utilized this approach in many research papers and optimal results provided by this approach showed a significant improvement in all types of responses. When Taguchi $L_9$ OA was utilized during turning of AISI D3 steel, it was found that feed rate was the most influential factor which affected surface quality [21]. Taguchi $L_9$ OA was used on turning parameters like cutting speed, feed rate, and depth of cut during machining of SS-304 steel using carbide tools. After result analysis, best combination was found at cutting speed = 350m/min, feed rate = 0.12mm/rev, and depth of cut = 0.40mm [22]. Based on Taguchi optimization technique, at cutting speed = 90m/min, feed rate = 0.15mm/rev, and depth of cut = 0.5mm, improvement in surface roughness was found to be 244% when compared with initial setting [23]. Minimum value of surface roughness of 52100 hardened alloy steel was achieved at an optimum condition of cutting speed = 140m/min, feed rate = 0.08mm/rev, and depth of cut = 0.19mm [24].

## 3. EXPERIMENT DETAILS

### *3.1. Materials*

For experiment, AISI 4340 steel having a diameter of 25mm and a length of 78mm is selected as workpiece. Composition of AISI 4340 steel is listed in Table 1.

Table 1. AISI 4340 steel composition

| Component | C | Mn | P | S | Si | Ni | Cr | Mo | Fe |
|---|---|---|---|---|---|---|---|---|---|
| Weight (%) | 0.38-0.43 | 0.6-0.8 | 0.035 | 0.035 | 0.15-0.35 | 1.65-2.00 | 0.7-0.9 | 0.2-0.3 | Bal. |

### 3.2. Machine tool and cutting tool

All experiments are performed on a lathe machine. Its specification is listed below:

Range of spindle speed: 45-800 rpm

Height of centers: 200mm

Diameter of a hole through spindle: 41mm

Required H.P.: 2 HP (1.5 KW)

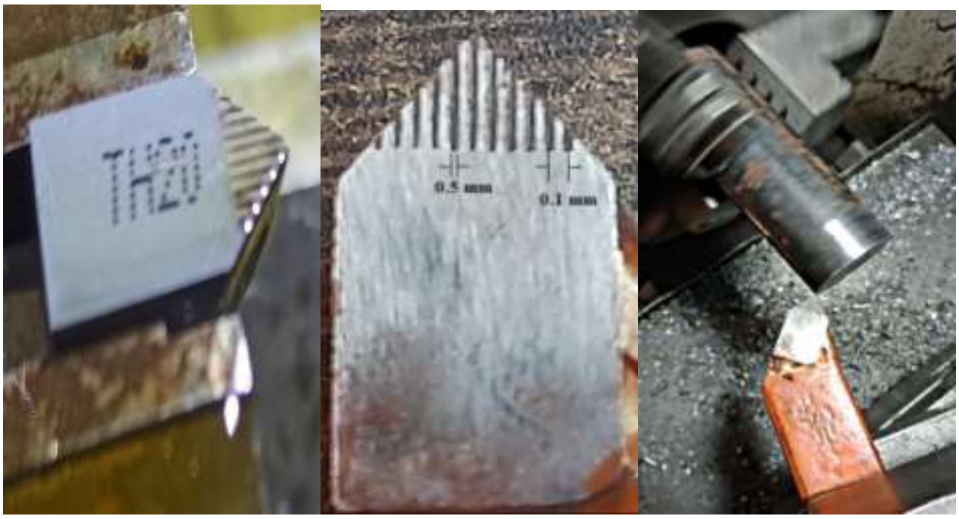
Cutting tool inserts used for experimentation are carbide with ISO designation of E10-TH20. A ZNC 25 EDM machine with a capacity of 250L is used for making parallel textures on rake face of cutting tool as shown in Figure2. A copper electrode with a diameter of 500µm is used for making lines parallel to cutting edge. Distance between two successive lines is kept at 100µm and depth of lines is kept at 50µm. Parallel textures produced by EDM are depicted in Figure3(a) and dimensions of parallel textures are depicted in Figure3(b). These textured inserts are then brazed on a left-hand cutting tool holder having a rake angle of -6º. For measuring surface roughness, a TR200 roughness tester with a cut-off length of 0.8mm is used. To minimize variation in surface roughness, each experiment is performed three times and average surface roughness is considered.

Experimental setup in actual condition is shown in Figure3(c). Range of machining parameters has been decided after pilot experimentation. Factors and their levels are given in Table 2. Experiments are conducted using Taguchi $L_9$ OA which is carried out on MINITAB 19. OA depends on degree of freedom (DF) which can be calculated by equation (3.2) [25].

$$\mathrm{DF} = [(\mathrm{level} - 1)\ \text{for each input} + (\mathrm{level} - 1) \times (\mathrm{level} - 1) + 1] \quad (3.2)$$

Surface roughness values obtained from all nine experiments are then converted into S/N ratios which are further utilized for obtaining optimum level and performing ANOVA analysis. Taguchi $L_9$ OA and surface roughness values are provided in Table 3.


Figure 2. Texturing performed on EDM




(a) (b) (c)

Figure 3: (a) Parallel textures produced by EDM; (b) Dimensions of parallel texture (c) Turning performed on AISI 4340 by parallel textured cutting tool

Table 2. Factors and levels

| Factors | Symbols | 1 | 2 | 3 |
|---|---|---|---|---|
| Cutting speed (m/min) | V | 80 | 100 | 120 |
| Feed rate (mm/rev) | f | .16 | .20 | .24 |
| Depth of cut (mm) | t | .25 | .50 | .75 |

Table 3. Experimental analysis for $L_9$ OA on parallel-texture

| Trial No. | Input Conditions | | | Parallel-textured | S/N ratio |
|---|---|---|---|---|---|
| | V (m/min) | f (mm/rev) | t (mm) | Ra(μm) | |
| 1 | 1 | 1 | 1 | 2.732 | -8.7296 |
| 2 | 1 | 2 | 2 | 1.784 | -5.0278 |
| 3 | 1 | 3 | 3 | 3.997 | -12.0346 |
| 4 | 2 | 1 | 2 | 1.213 | -1.6772 |
| 5 | 2 | 2 | 3 | 2.468 | -7.8469 |
| 6 | 2 | 3 | 1 | 3.784 | -11.5590 |
| 7 | 3 | 1 | 3 | 1.171 | -1.3711 |
| 8 | 3 | 2 | 1 | 2.214 | -6.9035 |
| 9 | 3 | 3 | 2 | 2.512 | -8.0003 |

## 4. RESULT AND DISCUSSION

In this section, results obtained from Taguchi $L_9$ OA have been analyzed in form of ANOVA and S/N ratio. Finally, confirmation experiments are performed and feasibility of experiments is checked.

### *4.1. Taguchi Method*

Taguchi is a method of optimization in which parameters are optimized by using S/N ratio. It is calculated by using equation (4.1) [13] and values obtained are presented in Table 3.

$$\mathbf{S/N = -10 \log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right]} \tag{4.1}$$

Here, yi = observed response, n = number of trials.

### *4.2. ANOVA analysis*

S/N ratio (Table 3) is used for calculating ANOVA which is analyzed in form of degree of freedom (DF), adjusted sum of squares (SS), mean sum of squares (MS), F-ratio, and percentage contribution (PC). ANOVA results are shown in Table 4. Percentage contribution of each factor to response is shown in Figure4. and effect of control factors at each level on S/N ratio is shown graphically in Figure5.

Average S/N ratios at each level is presented in Table 5. It is observed (Table 5) that cutting speed at level-3 (V = 120m/min), feed rate at level-1 (f = 0.16mm/rev) and depth of cut at level-2 (t = 0.50mm) is optimal parameter level.

Table 4. ANOVA analysis

| Parameters | DF | Adj SS | Adj MS | F-ratio | PC (%) |
|---|---|---|---|---|---|
| V | 2 | 15.10 | 7.548 | 1 | 14.06 |

| | | | | | |
|---|---|---|---|---|---|
| f | 2 | 66.25 | 33.127 | 4.387 | 61.71 |
| t | 2 | 26.01 | 13.00 | 1.722 | 24.31 |
| Pooled error# | -- | 15.10# | 7.548 | -- | -- |
| Total | 6 | 107.36 | -- | -- | -- |

Table 5. Average S/N ratio at each level

| Mean | V | f | t |
|---|---|---|---|
| Level 1 | -8.5973 | -3.9259* | -9.0640 |
| Level 2 | -7.0277 | -6.5927 | -4.9017* |
| Level 3 | -5.4249* | -10.5313 | -7.0842 |

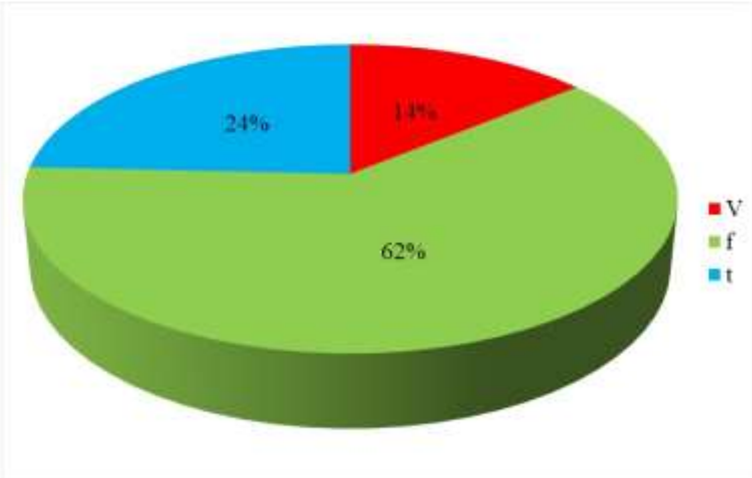



Figure 4. Percentage contribution of each factor

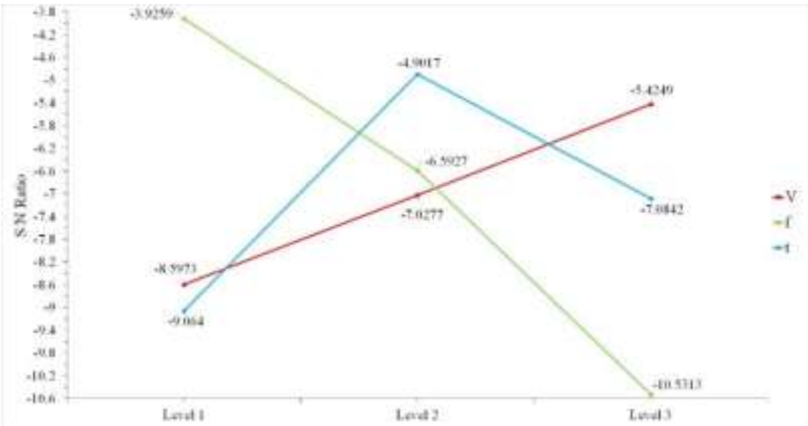



Figure 5. Effect of control factors on S/N ratio

### *4.3. Validation of optimal level*

Optimal level obtained after the analysis is $V_3$-$f_1$-$t_2$ (V = 120m/min, f = 0.16mm/rev, and t = 0.50mm). Experiments are conducted at optimal condition and then compared with initial setting which is listed in Table 6. It is noted (table 6) that percentage improvement in response; Ra = 19.21% from initial setting parameters.

Table 6. Confirmation experiment

| Response | Initial Setting $V_1$-$f_1$-$t_1$ | Optimum results | | |
|---|---|---|---|---|
| | | Predication $V_3$-$f_1$-$t_2$ | Experiment $V_3$-$f_1$-$t_2$ | %Improvement |
| Ra | 2.732 | – | 2.207 | 19.21% |

## 5. CONCLUSION

In present study, performance of textured carbide tool is evaluated in terms of surface quality of AISI 4340 steel. For this TM technique is used and following conclusions are drawn:

1. Percentage contribution of each factor on response is, cutting speed = 14.06%, feed rate = 61.71%, and depth of cut = 24.31%.
2. Optimal level of input parameter using Taguchi $L_9$ technique is, cutting speed = 120m/min, feed rate = 0.16mm/rev, and depth of cut = 0.50mm.
3. ANOVA analysis indicates that feed rate is the most significant parameter that affects surface roughness followed by depth of cut and cutting speed.
4. Improvement in response obtained during confirmation experiment is, Ra = 19.21%.

## ACKNOWLEDGMENTS

The authors express their sincere gratitude to BBD University, Lucknow for providing support in this experimental study.

## REFERENCES

[1] S. Kumar, R.N. Yadav, and R. Kumar, ‘Modelling and optimization of duplex turning of titanium alloy (grade 5) using Taguchi methodology-response surface methodology’, Int. J. Ind. Syst. Eng., 35(4), pp. 463-481, 2020.

[2] D. Jianxin, W. Ze, L. Yunsong, Q. Ting and C. Jie, ‘Performance of carbide tools with textured rake-face filled with solid lubricants in dry cutting processes’, Int. J. Refract. Met. Hard Mater.,30(1), pp. 164-172, 2012.

[3] J. Xie, M.J. Luo, K.K. Wu, L.F. Yang, and D.H. Li, ‘Experimental study on cutting temperature and cutting force in dry turning of titanium alloy using a non-coated micro-grooved tool’, Int. J. Mach. Tools Manuf, 73, pp. 25-36, 2013.

[4] N. Kawasegi, H. Sugimori, H. Morimoto, N. Morita, and I. Hori, ‘Development of cutting tools with microscale and nanoscale textures to improve frictional behavior’, Precis. Eng., 33(3), pp. 248-254, 2009.

[5] P. Koshy, and J. Tovey, ‘Performance of electrical discharge textured cutting tools’, CIRP Ann., 60(1), pp. 153-156, 2011.

[6] J. Kummel, D. Braun, J. Gibmeier, J. Schneider, C. Greiner, V. Schulze, and A. Wanner, ‘Study on micro texturing of uncoated cemented carbide cutting tools for wear improvement and built-up edge stabilization’, J. Mater. Process. Technol., 215, pp. 62-70, 2015.

[7] S.N.B. Oliaei, and Y. Karpat, ‘Investigating the influence of built-up edge on forces and surface roughness in micro-scale orthogonal machining of titanium alloy Ti6Al4V’, J. Mater. Process. Technol., 235, pp. 28-40, 2016.

[8] S.Y. Du, M.H. Chen, Z.S. Zhu, and X.N. Wang, ‘Experimental research on Surface Integrity of Milling New Ultra-High Strength Titanium Alloy TB17’, Modul. Mach. Tool Autom. Manuf. Tech, 4, pp. 125-129, 2017.

[9] T. Sugihara, and T. Enomoto, ‘Performance of cutting tools with dimple textured surfaces: a comparative study of different texture patterns’, Precis. Eng., 49, pp. 52-60, 2017.

[10] V. Sharma, P.M. Pandey, ‘Recent advances in turning with textured cutting tools: a review’, J. Clean. Prod., 137, pp. 701–715, 2016.

[11] Y. Wei, M.R. Kim, D.W. Lee, C. Park, and S.S. Park, ‘Effects of micro-textured sapphire tool regarding cutting forces in turning operations’, Int. J. Precis. Eng. Manuf. - Green Technol., 4(2), pp. 141-147, 2017.

[12] P. Sivaiah and U. Bodicherla, ‘Effect of Surface Texture Tools and Minimum Quantity Lubrication (MQL) on tool Wear and Surface Roughness in CNC Turning of AISI 52100 Steel’, J. Inst. Eng. (India): Series C, 101(1), pp. 85-95, 2019.

[13] P. Sivaiah, M. Revantha Kumar, S. Bala Subramanyam, and K.L.V. Prasad, K.L.V., ‘A comparative study on different textured and untextured tools performance in turning process’, Mater. Manuf. Process., 36(8), pp. 926-935, 2021.

[14] M.S. Sawant, N.K. Jain, I.A. Palani, ‘Influence of dimple and spot-texturing of HSS cutting tool on machining of Ti-6Al-4V’, J. Mater. Process. Technol., 261, pp. 1-11, 2018.

[15] S.K. Rajbongshi and D.K. Sarma, ‘Performance parameters studies in the machining of AISI D2 steel with parallel-textured, groove-textured & non-textured cutting tool at the flank face’, Int. J. Refract. Met. Hard Mater., 83, p. 104970, 2019.

[16] C. Pan, Q. Li, K. Hu, Y. Jiao, Y. Song, ‘Study on surface roughness of Ger15 machined by micro-texture PCBN tools’, Mach. 6(3), p. 42, 2018.

[17] A. Zerti, M.A. Yallese, I. Meddour, S. Belhadi, A. Haddad, and T. Mabrouk, ‘Modeling and multi-objective optimization for minimizing surface roughness, cutting force, power, and maximizing productivity for tempered stainless steel AISI 420 in turning operations’, Int. J. Adv. Manuf. Technol., Vol. 102, Issue 1 (4), pp. 135-157, 2019.

[18] A. Sahinoglu, and M. Rafighi, ‘Investigation of vibration, sound intensity, machine current, and surface roughness values of AISI 4140 during machining on the lathe’, Arab J Sci Eng., 45(2), pp. 765-778, 2020.

[19] P. Chandra, C.R.P. Rao, and R. Kiran, ‘Influence of machining parameter on cutting force and surface roughness while turning alloy steel’, Mater. Today: Proc. 5(5), pp. 11794-11801, 2018.

[20] A.T. Abbas, M.K. Gupta, M.S. Soliman, M. Mia, H. Hegab, M. Luqman and D.Y. Pimenov, ‘Sustainability assessment associated with surface roughness and power consumption characteristics in nanofluid MQL-assisted turning of AISI 1045 steel’, Int. J. Adv. Manuf. Technol., 105(1), pp. 1311-1327, 2019.

[21] J.S. Dureja, R. Singh, and M.S. Bhatti, ‘Optimizing flank wear and surface roughness during hard turning of AISI D3 steel by Taguchi and RSM methods’, Prod. Manuf. Res., 2(1), pp. 767-783, 2014.

[22] N.J. Rathod, M.K. Chopra, P.K. Chaurasiya, U.S. Vidhate, and A. Dasore, ‘Optimization on the Turning Process Parameters of SS 304 Using Taguchi and TOPSIS’. Ann. Data Sci., pp.1-15, 2022.

[23] A. Hascalik, and U. Caydas, ‘Optimization of turning parameters for surface roughness and tool life based on the Taguchi method’, Int. J. Adv. Manuf. Technol., 38(9), pp. 896-903, 2008.

[24] S. Mane, and S. Kumar, ‘Analysis of surface roughness during turning of AISI 52100 hardened alloy steel using minimal cutting fluid application’, Adv. Mater. Process. Technol., pp. 1-12, 2020.

[25] P.J. Rose, ‘Taguchi Technique for Quality Engineering’, Tata McGraw-Hill, New York, 1996.