Journal of Mines, Metals and Fuels, *73(9): 2903-2909; 2025. DOI: 10.18311/jmmf/2025/49746*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Machining Performance Improvement in Turning of EN24 Steel using Design of Experiments

V. R. Srinivasan[1]*, A. Balthilak[2], S. Rohith[3], P. Raja[4], D. Yogaraj[5], M. R. Kamesh[1], H. Govindaraju[1], G. S. Girishkumar[1], Nitish Kumar[6] and B. A. Praveena[7]

[1]Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bangalore - 560111, Karnataka, India; vrs.mechanical@gmail.com

[2]Department of Mechanical Engineering, Nehru Institute of Technology, Coimbatore - 641105, Tamil Nadu, India

[3]Department of Mechanical Engineering, ATME College of Engineering, Mysuru - 570028, Karnataka, India

[4]Department of Mechanical Engineering, Prathyusha Engineering College, Chennai - 602025, Tamil Nadu, India

[5]Department of Mechanical Engineering, Vel Tech Rangarajan Dr Sagunthala R & D Institute of Science and Technology, Chennai - 600062, Tamil Nadu, India

[6]Department of Mechanical and Industrial Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal - 576104, Karnataka, India

[7]Department of Mechanical Engineering, Nitte Meenakshi Institute of Technology (NMIT), Nitte (Deemed to be University), Yelahanka, Bangalore - 560064, Karnataka, India

Abstract

This study investigates optimization of machining bounds of SPINNER 25 CNC lathe machine, to accomplish greater rate of material elimination and to decrease surface texture value on EN24 steel. For the study, rotational speed, tool feed and cut depth are the machining factors taken into account. To evaluate the impact of parameters influencing surface texture and rate of material elimination, ANOVA analysis is being used. Surface texture and rate of material elimination are the output parameters. L_9 orthogonal table based on Taguchi's technique is adapted to carry out machining experiments. The best values of machining bounds are found for machining and surface texture of 0.567 µm and rate of material elimination 2511 mm^3/min.

Major Findings: *The major finding from this work is that, tool feed has significant impact on material elimination rate and rotational speed has the least impact. The cut depth has the slightest bearing on surface texture and tool feed provide required texture.*

Keywords: *ANOVA Analysis, Rate of Material Elimination, Surface Texture, Taguchi Technique, Turning-Process Optimization*

1.0 Introduction

One important aspect of quality is the surface texture of the machined specimen[1]. Researchers have utilized mathematical algorithms like fuzzy logics, genetic algorithm, grey relational analysis, artificial neural networking and the taguchi technique to forecast the surface texture of milling processes[2-5]. The research makes it clear that the taguchi method is a better approach because other approaches are expensive and tedious due to the need for full factorial tests. This work optimizes the turning process using the taguchi approach using Minitab software

**Author for correspondence*

application. Based on statistical analysis of tests that economically fulfill the process or product for a specified optimal design of experiments, the taguchi technique was developed[6,7]. The fact that several parameters, including noises are taken into account simultaneously for the benefit of this approach. The taguchi approach becomes a potent tool for machining parameter optimization when paired with additional statistical tools such as ANOVA and mean effect plots[8,9]. Numerous academicians have studied the turning process improvement in relation to the Taguchi method[10]. Researches have been done for machining EN31 steel, a work piece material used in automotive applications such as spindle beading rolls, axle punches, and bearings[11,12]. Examining the surface texture of material is crucial for these kinds of uses. The primary goals of this work are to determine the best cutting settings for surface texture (R_a) and rate of material elimination in the turning process in order to use the Taguchi method to increase material elimination rate and reduce surface texture. The impact of machining bounds on surface texture and rate of material elimination are examined by applying taguchi's orthogonal array, signal to noise ratio and ANOVA[13]. The main goal is to determine the ideal cutting parameter combination which will result into reduced surface texture values and a higher rate of material elimination[14,15]. Minitab software is the software application utilized for this work to tackle the statistical challenge. The major finding from this work is that, tool feed has significant impact on material elimination rate and rotational speed has the least impact[16]. The cut depth has the slightest bearing on surface texture and tool feed provide required texture[17].

2.0 Experimental Design

Design of experiment is adapted to perform machining trials. The kinds of experiment design used for the current investigation is orthogonal table based on Taguchi's concept. From the literature review, the machining bounds and their ranges are taken. Based on range of machining bounds available, the levels of machining bounds are being considered as shown in Table 1. Taguchi's standard orthogonal arrays are displayed in Table 2.

Table 1. Machining bound and range

Machining bounds	1st Level	2nd Level	3rd Level
Rotational speed (rpm)	400	500	600
Tool feed (mm/rev)	0.1	0.2	0.3
Cut depth (mm)	0.2	0.3	0.4

Table 2. Taguchi's standard orthogonal arrays

Orthogonal array	Number of Runs	Maximum number of Factors	Maximum of Columns at these levels			
			2 - levels	3 - levels	4 - levels	5 - levels
L_4	4	3	3	-	-	-
L_8	8	7	7	-	-	-
L_9	9	4	-	4	-	-
L_{12}	12	11	11	-	-	-
L_{16}	16	15	15	-	-	-
L'_{16}	16	5	-	-	5	-
L_{18}	18	8	1	7	-	-
L_{25}	25	6	-	-	-	6
L_{27}	27	13	-	13	-	-
L_{32}	32	31	31	-	-	-
L'_{32}	32	10	1	-	9	-
L_{36}	36	23	11	12	-	-
L'_{36}	36	16	3	13	-	-
L_{50}	50	12	1	-	-	11
L_{54}	54	26	1	25	-	-
L_{64}	64	63	63	-	-	-
L'_{64}	64	21	-	-	21	-
L_{81}	81	40	-	40	-	-

Table 3. Standard L_9 orthogonal array

Run	Factor A	Factor B	Factor 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

Table 4. L_9 Orthogonal table based on Taguchi's concept

Machining Run	Rotational speed (rpm)	Tool feed (mm/rev)	Cut depth (mm)
1	400	0.1	0.2
2	400	0.2	0.3
3	400	0.3	0.4
4	500	0.1	0.3
5	500	0.2	0.4
6	500	0.3	0.2
7	600	0.1	0.4
8	600	0.2	0.2
9	600	0.3	0.3

Standard L_9 orthogonal array is presented in Table 3. Machining experiments are being carried out based on L_9 orthogonal table based on Taguchi's concept. The parameter combinations for each run are allocated using MINITAB software, which is indicated in Table 4.

3.0 Experimental Setup

The experimental machining runs are carried out with SPINNER 25 CNC lathe machine, shown in Figure 1.

The workpiece considered is made up of raw material EN24 steel, which is a high carbon, high chromium steel constituting alloying components less than 5%. It is procured as cylindrical shape of 60mm length and 15mm diameter. Power transmission parts, concentrating cylinders and other segments of vehicles having high strength, hardness and workability can be made from EN24 steel. The chemical composition of the selected raw material, as confirmed by the composition test, is displayed in Table 5.

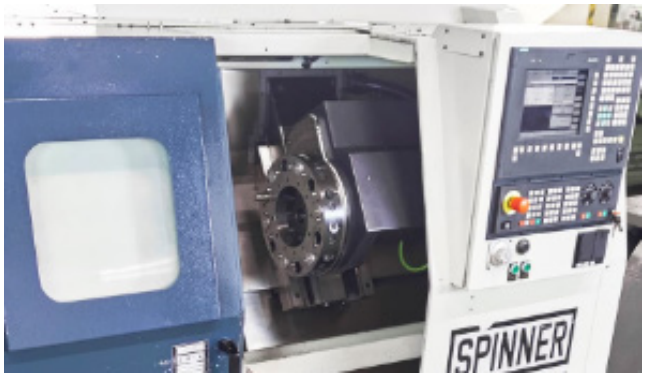


Figure 1. SPINNER 25 CNC lathe machine.

Table 5. Chemical composition of EN24 Steel

Element	Percentage of composition
Carbon (c)	0.36-0.5
Manganese (Mn)	0.45-0.7
Phosphorus (P)	0.035 max
Sulphur (S)	0.035 max
Silicon (Si)	0.1-0.4
Chromium (Cr)	1-1.4
Nickel (Ni)	1-1.5
Molybdenum (Mo)	0.2–0.3
Ferrous (Fe)	Remaining

As per L_9 Orthogonal table based on Taguchi's concept, overall, nine trials are carried out consisting 3 set of trials for each selected machining bounds of tool feed, rotational speed and cut depth. After machining, the surface texture is evaluated using a contact type surface texture tester (SURFTEST SJ-210). Based on the weight difference of the specimen before and after machining, the rate of material elimination is calculated.

4.0 Result Analysis

4.1 Surface Texture

The surface texture parameter considered in this investigation is arithmetic mean roughness (R_a). Measurement of surface texture is done at three places/points on the machined surface and the magnitude of R_a is arrived by considering the average value of three measurements. Surface texture obtained for the

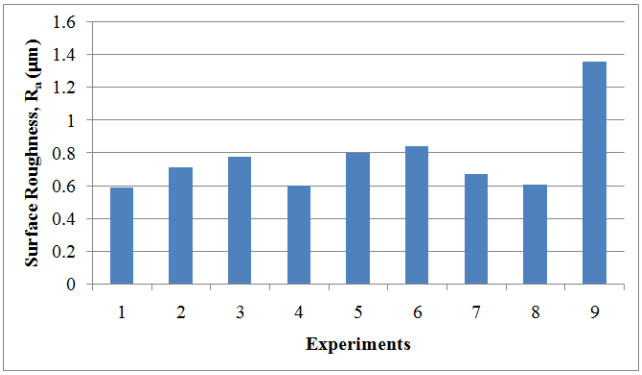


Figure 2. Surface texture obtained for the experiments.

Table 6. Surface texture values from the experiments

Machining Run	Rotational Speed (rpm)	Tool feed (mm/rev)	Cut depth (mm)	Surface texture (µm)
1	400	0.1	0.2	0.591
2	400	0.2	0.3	0.711
3	400	0.3	0.4	0.784
4	500	0.1	0.3	0.6
5	500	0.2	0.4	0.8
6	500	0.3	0.2	0.823
7	600	0.1	0.4	0.641
8	600	0.2	0.2	0.603
9	600	0.3	0.3	1.386

corresponding experiments are shown in Figure 2 and Table 6.

Surface texture values obtained and S/N ratio (signal to noise ratio) related to the corresponding sets of machining bounds are listed in the Table 7.

From the data obtained by the response table for surface texture mentioned in Table 8, it is found that tool feed is in rank 1, rotational speed is in rank 2, and cut depth is in rank 3. It shows that the cut depth has the least impact on surface texture, rotational speed has a moderate impact and tool feed has a substantial impact.

Figure 3 indicates the impact of rotational speed, tool feed and cut depth for S/N ratio of surface texture. It is observed that, the signal to noise ratio is lesser for the third level of rotational speed (600rpm), tool feed (0.3mm/rev) and the second level of cut depth (0.3mm). The objective of analysis is to determine the machining parameter which affects the response significantly.

Table 7. S/N ratio of surface texture

Machining Run	Rotational Speed (rpm)	Tool feed (mm/rev)	Cut depth (mm)	S/N Ratio
1	400	0.1	0.2	4.596
2	400	0.2	0.3	2.986
3	400	0.3	0.4	2.257
4	500	0.1	0.3	3.278
5	500	0.2	0.4	4.479
6	500	0.3	0.2	1.744
7	600	0.1	0.4	3.503
8	600	0.2	0.2	0.351
9	600	0.3	0.3	3.352

Table 8. Response table of surface texture

Level	Rotational speed (rpm)	Tool feed (mm/rev)	Cut depth (mm)
1	3.2813	4.6447	3.4978
2	3.1161	3.1029	2.0623
3	1.7408	0.3906	2.5782
Delta	1.5402	4.2538	1.4357
Rank	2	1	3

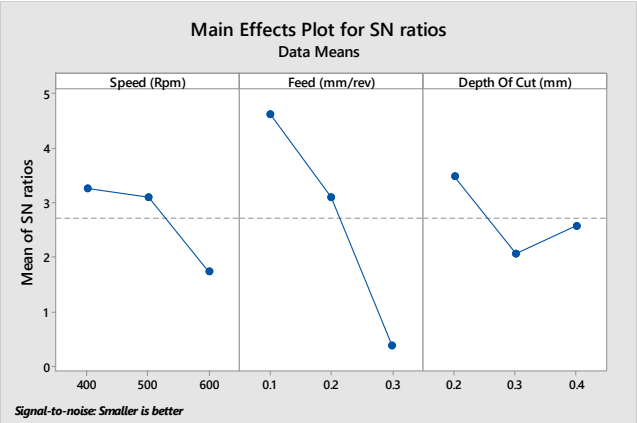


Figure 3. Impact of cut depth, rotational speed and tool feed on the S/N ratio of surface texture.

Table 9 displays the outputs of ANOVA results for surface texture. Table 10 indicates surface texture value obtained, results from the optimized combination of parameters.

Verification machining run is carried out with the set of optimized parameters. Optimized set of parameters

Table 9. ANOVA outputs for surface texture

Origin	Degree of freedom	Adjusted SS	Adjusted MS	F Value	P Value
Regression	3	0.296623	0.098875	2.62	0.164
speed	1	0.052081	0.052081	1.38	0.294
Tool feed	1	0.237607	0.237605	6.27	0.054
Cut depth	1	0.006934	0.006934	0.19	0.687
Error	5	0.189656	0.037932	-	-
Total	8	0.486279	-	-	-

Table 10. Surface texture value obtained with optimized set of parameters

Rotational speed (rpm)	Tool feed (mm/rev)	Cut depth (mm)	Surface texture (µm)
600	0.3	0.4	0.567

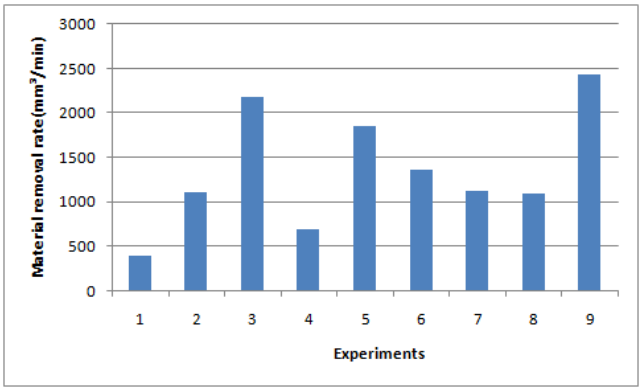


Figure 4. Rate of material elimination obtained for the experiments.

resulted smoother surface texture, comparing to the experimental machining runs.

4.2 The Rate of Material Elimination

The rate of material elimination is the amount of material elimination per unit time period. It plays a vital role in machining productivity. The rate of material elimination is determined by comparing the weight of the specimen before/after machining. The rate of material elimination obtained during the nine trials, as per the designed experiment sets are shown in Figure 4 and Table 11. Table 12 presents the signal to noise ratio of rate of material elimination.

Table 11. Rate of material elimination obtained from the experiments

Machining Run	Rotational speed (rpm)	Tool feed (mm/rev)	Cut depth (mm)	Rate of Material elimination (mm^3/min)
1	400	0.1	0.2	485
2	400	0.2	0.3	1103
3	400	0.3	0.4	2106
4	500	0.1	0.3	678
5	500	0.2	0.4	1837
6	500	0.3	0.2	1391
7	600	0.1	0.4	1109
8	600	0.2	0.2	1101
9	600	0.3	0.3	2487

Table 12. Signal to Noise Ratio of Material Elimination Rate

Machining Run	Rotational speed (rpm)	Tool feed (mm/rev)	Cut depth (mm)	S/N Ratio
1	400	0.1	0.2	57.77
2	400	0.2	0.3	59.86
3	400	0.3	0.4	66.76
4	500	0.1	0.3	56.83
5	500	0.2	0.4	64.36
6	500	0.3	0.2	62.66
7	600	0.1	0.4	60.95
8	600	0.2	0.2	60.73
9	600	0.3	0.3	65.73

Table 13. Response table for rate of material elimination

Level	Rotational speed (rpm)	Tool feed (mm/rev)	Cut depth (mm)
1	59.67	57.52	57.63
2	60.61	63.31	60.11
3	64.15	66.12	63.23
Delta	3.11	9.1	5.94
Rank	3	1	2

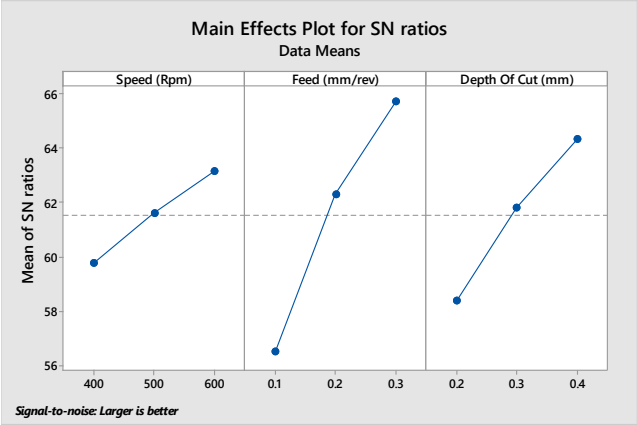


Figure 5. Key effect diagram for the rate of material elimination signal to noise ratio.

Table 14. ANOVA results rate of material elimination

Source	DF	AdjfSS	AdjfMS	F-Value	P-Value
Regression	3	3423781	1241277	24.41	0.003
Rotational Speed	1	159230	160242	3.33	0.124
Tool feed	1	2378771	2487524	51.65	0.002
Cut depth	1	896980	876985	19.02	0.008
Error	5	214562	47891	-	-
Total	8	3458271	-	-	-

Figure 5 shows the main effects plot for signalltolnoise (S/N) ratio of material elimination rate. It indicates

That signalttotnoise ratio is greater for third level of rotational speed (600 rpm), third level of tool feed (0.3 mm/rev), and third levelfoffcut depth (0.4 mm). Response table can be obtained from session part of MINITAB software where all calculation is tabulated. From the data obtained by response table, which is delineated in Table 13, it is observed that tool feed is having the rank 1 and rotational speed is having the rank 3. That means, by conducting Taguchi analysis, conclusion can be drawn from Figure 5 that, tool feed has significant influence effect on material elimination rate and rotational speed has the least effect on material removal rate. Table 14 illustrate the Analysis of Variance (ANOVA) results material elimination rate. Table 15 indicates the material elimination rate value obtained, results from the optimized combination of parameters.

Verification machining run is carried out with the selected set of optimized parameters[18]. Optimized set of parameters resulted higher rate of material elimination,

Table 15. Rate of material elimination value obtained with optimized set of parameters

Rotational Speed (rpm)	Tool feed (mm/rev)	Cut depth (mm)	Material elimination (mm^3/min)
600	0.3	0.4	2511

comparing to the experimental machining runs. In future, this procedure can be implemented to evaluate the machining bounds of composite materials for different potential applications[19-21].

4.0 Conclusion

In the course of finding significant factors and their levels, taguchi analysis is performed to accomplish the required output. In this experiment, taguchi's L_9 orthogonal array is used. Machining experiments are carried out with input factors as tool feed, rotational speed and cut depth to achieve smooth surface texture and higher material removal rate as output. From the insights of response table of the signal to noise ratio, it is found that, tool feed plays a crucial role to get smooth surface texture. Rotational speed contributes to a higher degree for the smooth surface texture. Cut depth contributes to a least degree for the smooth surface texture. Information from the table of response corresponding to the S/N ratio, reveals that tool feed contributes to a higher degree for the rate of material elimination, whereas the rotational speed and cut depth has lesser contribution on the rate of material elimination. The optimum combination of machining bounds is verified by conducting verification machining and smooth surface texture of 0.567µm and higher rate of material elimination 2511mm^3/min are achieved.

5.0 Acknowledgement

The authors would like to thank Dr. R. Keshavamurthy, Head of the Department, Mechanical Engineering Department, Dayananda Sagar College of Engineering, Bangalore, Karnataka, India, for the constant appreciation and support during this investigation.

6.0 References

1. Zębala W, Kowalczyk R. Estimating the effect of cutting data on surface roughness and cutting force during

WC-Co turning with PCD tool using Taguchi design and ANOVA analysis. Int J Adv Manuf Technol. 2015; 77:2241-56. https://doi.org/10.1007/s00170-014-6382-6
2. Sangwan KS, Saxena S, Kant G. Optimization of machining parameters to minimize surface roughness using integrated ANN-GA approach. Procedia CIRP. 2015; 29:305-10.
3. Tseng TL, Konada U, Kwon Y. A novel approach to predict surface roughness in machining operations using fuzzy set theory. J Comput Des Eng. 2016; 3(1):1-3. https://doi.org/10.1016/j.jcde.2015.04.002
4. Senthilkumar G, Murugan R, Gnanakumar G, Nithyanandan N. Fuzzy logic modelling of machining characteristics for CNC milling of EN24 using Ti-N coated tool. Materials Today: Proceedings. 2023; 82: 137-44. https://doi.org/10.1016/j.matpr.2022.12.111
5. Abbas M, Kumar S, Mittal A. Optimization of cutting parameters to improve surface roughness of Al 1070 in turning operation using taguchi method. IJESRT. 2016; 5(7):1324-9.
6. Karpat Y, Özel T. Multi-objective optimization for turning processes using neural network modeling and dynamic-neighborhood particle swarm optimization. Int J Adv Manuf Technol. 2007; 35:234-47. https://doi.org/10.1007/s00170-006-0719-8
7. Gopalsamy BM, Mondal B, Ghosh S. Optimisation of machining parameters for hard machining: grey relational theory approach and ANOVA. Int J Adv Manuf Technol. 2009; 45:1068-86. https://doi.org/10.1007/s00170-009-2054-3
8. Khamel S, Ouelaa N, Bouacha K. Analysis and prediction of tool wear, surface roughness and cutting forces in hard turning with CBN tool. JMST. 2012; 26:3605-16. https://doi.org/10.1007/s12206-012-0853-1
9. Tosun N. Determination of optimum parameters for multi-performance characteristics in drilling by using grey relational analysis. Int J Adv Manuf Technol. 2006; 28:450-5. https://doi.org/10.1007/s00170-004-2386-y
10. Ramesh S, Karunamoorthy L, Palanikumar K. Measurement and analysis of surface roughness in turning of aerospace titanium alloy (gr5). Measurement. 2012; 45(5):1266-76. https://doi.org/10.1016/j.measurement.2012.01.010
11. Gupta M, Kumar S. Investigation of surface roughness and MRR for turning of UD-GFRP using PCA and Taguchi method. Engineering Science and Technology, an International Journal. 2015; 18(1):70-81. https://doi.org/10.1016/j.jestch.2014.09.006
12. Das MK, Kumar K, Barman TK, Sahoo P. Optimization of MRR and surface roughness in PAC of EN 31 steel using weighted principal component analysis. Procedia technology. 2014; 14:211-8. https://doi.org/10.1016/j.protcy.2014.08.028
13. Srinivasan VR, Girishkumar GS, Kamesh MR, Vasu VK, Raja P, Sagar TM, Prathap P, Pavan S, Manjunath H, Ruvel D, Hugar M. Optimization of process parameters of wire electric discharge machining process for machining AISI A2 tool steel. J. Mines Met Fuels. 2024; 22:119-2. https://doi.org/10.18311/jmmf/2024/38682
14. Nalbant M, Gökkaya H, Sur G. Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. Materials and Design. 2007; 28(4):1379-85. https://doi.org/10.1016/j.matdes.2006.01.008
15. Pontes FJ, De Paiva AP, Balestrassi PP, Ferreira JR, Da Silva MB. Optimization of radial basis function neural network employed for prediction of surface roughness in hard turning process using Taguchi's orthogonal arrays. Expert Systems with Applications. 2012; 39(9):7776-87. https://doi.org/10.1016/j.eswa.2012.01.058
16. Sahoo AK, Pradhan S, Rout AK. Development and machinability assessment in turning Al/SiCp-metal matrix composite with multilayer coated carbide insert using Taguchi and statistical techniques. Archives of Civil and Mechanical Engineering. 2013; 13(1):27-35. https://doi.org/10.1016/j.acme.2012.11.005
17. Kumar R, Kumar A, Kant L, Prasad A, Bhoi S, Meena CS, Singh VP, Ghosh A. Experimental and RSM-based process-parameters optimisation for turning operation of EN36B steel. Materials. 2022; 16(1):339. https://doi.org/10.3390/ma16010339 PMid:36614680 PMCid:PMC9822334.
18. Abhang LB, Hameedullah M. Parametric investigation of turning process on EN-31 steel. Procedia Materials Science. 2014; 6:1516-23. https://doi.org/10.1016/j.mspro.2014.07.132
19. Kumar N, Chellam GK, Ningegowda BM, Mishra DK. Exploration of failure and delamination damage analysis of adhesive-bonded composite joints. Composites: Mechanics, Computations, Applications: An International Journal. 2025; 16(2):1-25 https://doi.org/10.1615/CompMechComputApplIntJ.2024052918
20. Lotfi A, Li H, Dao DV, Prusty G. Natural fiber-reinforced composites: A review on material, manufacturing, and machinability. J Thermoplast Compos Mater. 2021; 34(2):238-84.https://doi.org/10.1177/0892705719844546
21. Boban AP, Kumar N, Mishra DK. A review on pineapple and banana natural fiber composite. International Conference on Futuristic Advancements in Materials, Manufacturing and Thermal Sciences. 2024; 1:25-38 https://doi.org/10.1007/978-981-97-7114-1_3