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A Review on CNC Milling Parameter Optimization Using Taguchi and Response Surface Methodology (RSM)

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Abstract. CNC milling technology is essential to today's industrial sector because it makes it possible to produce components precisely and efficiently. In this study, CNC milling machining parameters are optimized using the Taguchi technique and Response Surface Methodology (RSM). We also analyze several other characteristics such as Spindle Speed (SS), Feed Rate (FR), and Depth of Cut (DoC). To determine important factors and ideal configurations, this study blends statistical analysis, such as ANOVA, with experimental methods. According to the study's findings, the two most important variables affecting surface roughness (Ra) and Material Removal Rate (MRR) are FR and DoC. The optimization approach can help improve product quality while cutting down on production time. This in turn promotes the manufacturing process's efficiency.

Keywords: CNC milling; optimize machining parameters; Taguchi method; response surface methodology (RSM)

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1. Introduction

In the manufacturing sector, milling machines are the main tool used to cut, shape, and create different product components. The two primary types of milling machines that have emerged as a result of technical advancements are CNC (Computer Numerical Control) milling and manual milling. CNC milling has become a vital component of the contemporary manufacturing sector due to its exceptional productivity and ability to produce high-quality goods, meeting the demands of ever-more complicated and effective manufacturing (1,2). CNC milling performance is heavily influenced by CAM (Computer-Aided Manufacturing) software, cutting tools, machine technology, and human resource competencies.

CNC milling technology was first created by researchers at the Massachusetts Institute of Technology (MIT) in the late 1940s and early 1950s. In order to control machine functioning, they constructed an NC (Numerical Control) machine that used perforated tape (3). Automation in machining is made possible by this breakthrough. This technique developed into CNC with computer integration in the 1960s, enabling more intricate, adaptable, and precise programming. Furthermore, a universal programming language for CNC machine operation was introduced: G-code (4). CNC milling is becoming more and more relevant in meeting the demands of contemporary industry as a result of these advancements.

Even so, there are still a number of issues with CNC milling, particularly when it comes to ensuring constant product quality. Among the primary challenges are poor product quality and cutting tool wear, which affects manufacturing costs and efficiency. Numerous investigations have been carried out to get around this problem and improve the machining parameters. The relationship between vibration, cutting force, tool wear, and cutting parameters is crucial for machining optimization (5). Coolant pressure, coolant flow rate, and cutting direction are a few of the factors that significantly affect the quality of the finished product (6). Additionally, by lowering the tool wear level, the parameters of layered cutting tools can enhance the quality of the machining output (7).

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However, vibration affects cutting performance. The primary causes of vibration are misaligned and unbalanced objects (8). A thorough review of the literature is necessary to compile the results of previous research on the variations in parameters affecting the machining process. The CNC milling process can be optimized with the use of this study's improved recommendations and references. This study advances CNC milling technology by offering comprehensive insights into the connection between product quality and productivity and machining parameters. Additionally, this research provides useful solutions to problems in everyday production operations.

2. Methodology

This technique uses Response Surface Methodology (RSM) and Taguchi methodology to optimize machining settings in the CNC milling process. The Taguchi method allows the best parameter combination to be found with the fewest number of experiments by using orthogonal matrices to construct tests. SS, FR, and DoC are ideal parameters; MRR, Ra, and machining time are important replies. Central Composite Design (CCD) is one of the experimental designs used by RSM to forecast the relationship between machining parameters and results. This methodology facilitates the analysis of parameter interactions and the use of desirability functions for multi-objective optimization. The modeling results were tested using Analysis of Variance (ANOVA) to ensure that the parameters were significant. Validating the optimized parameters in practice by contrasting the experimental values with the anticipated outcomes demonstrates the research's usefulness. Figure 1's flowchart illustrates the research's steps.

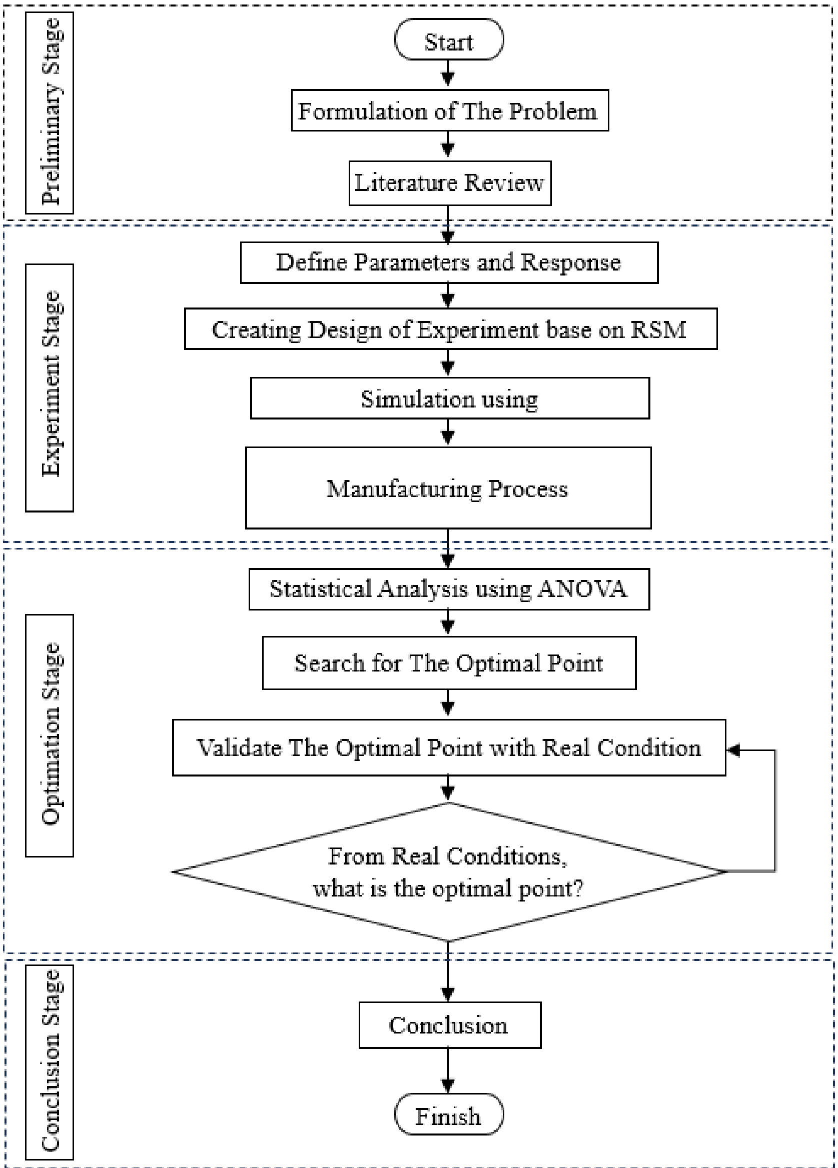

Figure 1. Flowchart for parameter optimization

This method provides an auxiliary set of techniques. Taguchi works well for straightforward experimental designs, whereas RSM is better for intricate modeling. By using these two techniques, the CNC milling process in industrial applications should become more productive, efficient, and high-quality.

3. Taguchi Method and Response Surface Methodology (RSM)

Two optimization methods that are commonly used in CNC milling processes to optimize machining settings are Response Surface Methodology (RSM) and the Taguchi Method.

3.1 Taguchi Method

In order to enhance quality in a variety of industries, such as manufacturing, engineering, biotechnology, marketing, and advertising, Genichi Taguchi created the Taguchi Method, a statistical technique. Using this approach, experiments are created to determine the ideal set of parameters. Taguchi's approach allows for fewer experiments without sacrificing the validity of the results because factors and levels are grouped in an orthogonal matrix. In the Taguchi method, characteristics that have a substantial impact on the end product's quality are identified using analysis of variance (ANOVA) and the signal-to-noise (S/N) ratio methodology to assess process stability and reliability. This method allows the Taguchi method to optimize process parameters both qualitatively and statistically, which makes it a useful tool for raising the quality and efficiency of production. In order to find the best milling parameter combination for achieving lower surface roughness values, researchers used this procedure. Three sets of control parameters were employed in their investigation (Table 1). The Taguchi L9 orthogonal array design was selected for statistical analysis, as displayed in Table 2.

Table 1. Various cutting parameter levels

Trial (T)	CS [m/min]	Radial DoC [mm]	FR [mm/tooth]
T-one	112	0.112	0.075
T-two	180	0.250	0.150
T-three	250	0.312	0.250

Table 2. The orthogonal array of Taguchi L9

Experiment	CS	Radial DoC	FR
Ex-i	T-one	T-one	T-one
Ex-ii	T-one	T-two	T-two
Ex-iii	T-one	T-three	T-three
Ex-iv	T-two	T-two	T-one
Ex-v	T-two	T-three	T-two
Ex-vi	T-two	T-one	T-three
Ex-vii	T-three	T-three	T-one
Ex-viii	T-three	T-one	T-two
Ex-ix	T-three	T-two	T-three

Figure 2 displays the signal to noise (S/N) ratio analysis. The most significant metric, as demonstrated in Figure 2, is the Radial DoC, which accounts for 64% of the average surface roughness according to the ANOVA analysis (9). The most important factor for 060A4 steel material is feed rate (14), and the same is true for SCM400 steel (15). Additionally, the largest contributor to surface roughness is the quantity of inserts [16]. The most important variables affecting the surface roughness of M200 TS (10) material, according to another study, are spindle speed and feed rate. Cutting speed is the most important element affecting MRR for EN24 steel material, whereas feed rate has the biggest impact on Ra (11). The two factors that have the biggest effects on machining time are feed rate and cutting speed (12,13). Table 3 displays all of the authors' optimization outcomes using the Taguchi Method. Table Three. Enhancement Several writers' findings using the Taguchi Method.

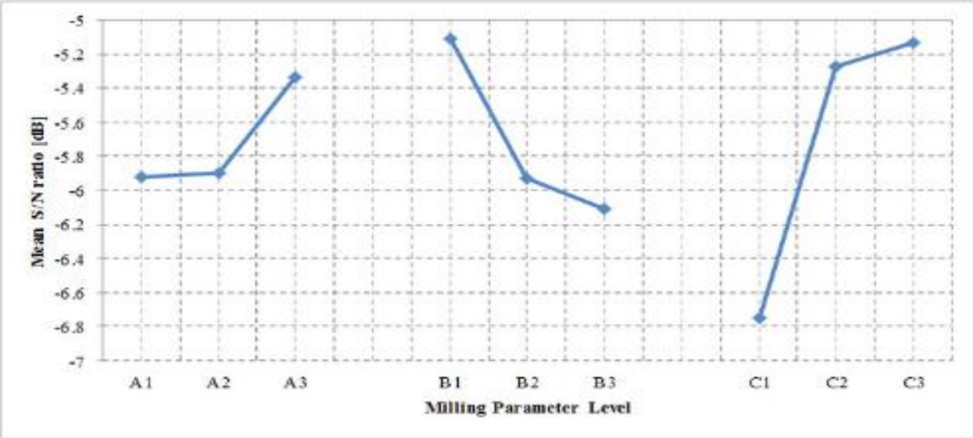

Figure 2. Workpiece on the milling machine table

Table 3. Optimization Results using the Taguchi Method from several authors

No.	Optimized parameters	Key results	Author
1	DoC, CS, FR	Lowest Ra: 0.117 µm	J. Ribeiro, et al (9)
2	DoC, CS, cutting feed (CF)	Optimized Ra	I. Tlhabadira, et al. (10)
3	DoC, CS, FR	MRR maximized; surface roughness minimized	K. Satyanarayana et al. (11)
4	DoC, CS, FR, Machining tolerance	Machining time Cutter ball nose Ø32 mm: 265.730 minutes. Cutter ball nose Ø30.0 mm: 265.51 minutes	E. M. Widodo, et al. (12)
5	DoC, FR, SS	Machining time reduced to 34.25 minutes	M. Mulyadi, et. (13)
6	SS, FR, cutting depth (CD)	Minimum surface roughness; maximum MRR	H. L. H. Anh, et al. (14)
7	DoC, CS, FR, Coolant flow	Minimum Ra and maximum MRR achieved	D. D. Trung et al. (15)
8	DoC, CS, FR, number of inserts	Ra, Rz, and Rq minimized; 71.89% impact from number of inserts	H. Kirli Akin, Y. Fedai (16)

3.2 Response Surface Methodology (RSM)

A statistical optimization technique that simulates the link between input and output variables is called Response Surface Methodology (RSM). This approach yields the best machining parameters, which is why it is frequently used for multi-objective optimization. RSM models and examines the connection between the intended response and process factors. This technique investigates the impact of parameter interactions using intricate experimental designs such as Central Composite Design (CCD). When describing the link between process parameters and measurable results, quadratic models are frequently employed. To ascertain if the examined parameters were significant, an analysis of variance (ANOVA) was performed. Because of this methodology, RSM is a dependable instrument for process optimization and boosting production effectiveness. Low-carbon steel (UNS T51620) CNC milling study to optimize machining parameters. The study's-controlled variables include SS, FR, DoC, and coolant flow rate. These parameters are adjusted experimentally (Table 5) and by three levels (Table 4). Ra and MRR are uncontrolled reactions.

Table 4. The levels of machining parameters

Experiment	SS (rpm) (P)	DoC mm (Q)	FR mm/min (R)	Coolant flow rate l/min (S)
Level 1	1200	0.2	1000	4
Level 2	1850	0.4	1500	6
Level 3	2500	0.6	2000	8

Table 5. Responses and experimental runs

P (rpm)	Q (mm)	R (mm/min)	S (l/min)	Ra (microns)	MRR (mm^3/min)
1850	0.2	1000	6	4.217	0.2361
1850	0.6	2000	6	2.650	1.2931
1200	0.4	1000	6	4.797	0.7826
2500	0.4	2000	6	2.070	0.7466
1850	0.4	1500	4	2.746	0.6249
1850	0.2	1500	6	4.550	0.8636
1850	0.4	1500	6	3.434	0.7646
1850	0.4	1500	6	4.646	0.1954
1850	0.4	1500	6	3.434	0.7646
1200	0.2	1500	6	5.334	0.3351
2500	0.4	1500	8	1.642	0.7873
1850	0.2	1500	8	3.542	0.3578
2500	0.6	1500	6	1.534	1.1941
1200	0.4	1500	6	4.122	0.9043
1200	0.6	1000	6	2.897	1.1211
1850	0.4	1500	6	4.109	0.6429
1850	0.4	2000	8	2.758	0.8863
1200	0.4	1000	6	3.005	0.8053
1200	0.6	1500	6	4.014	1.3111
1200	0.4	1500	4	5.226	0.7419
2500	0.2	1500	6	2.854	0.2181
1850	0.6	1500	8	2.222	1.3338
1850	0.2	2000	6	3.970	0.3171
1850	0.4	1500	6	3.434	0.7646
1850	0.6	1500	4	3.326	1.1714
2500	0.4	2000	4	3.862	0.7239
2500	0.4	1000	6	2.317	0.6656

The effect of parameter interaction can be seen in Figures 3 to Figure 6.

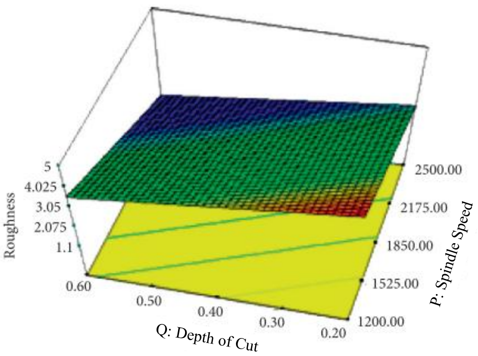

Figure 3. Graph of P and Q's interactions on Ra

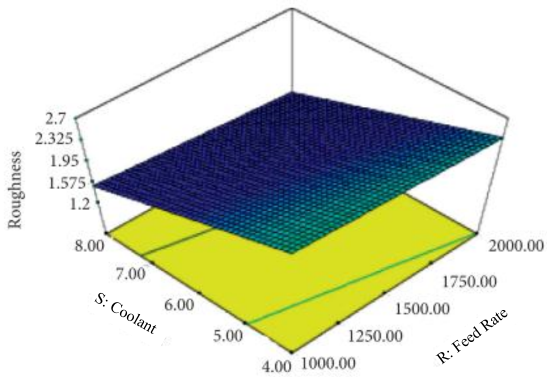

Figure 4. Graph of R and S's interactions on Ra

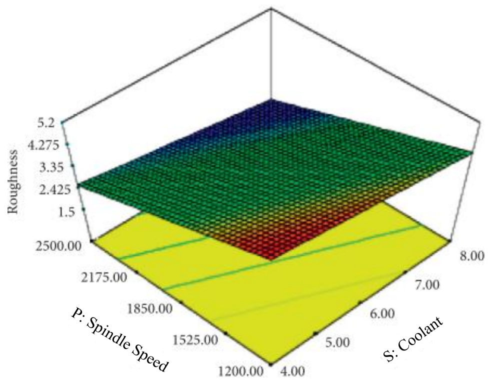

Figure 5. Graph of S and P's interactions on Ra

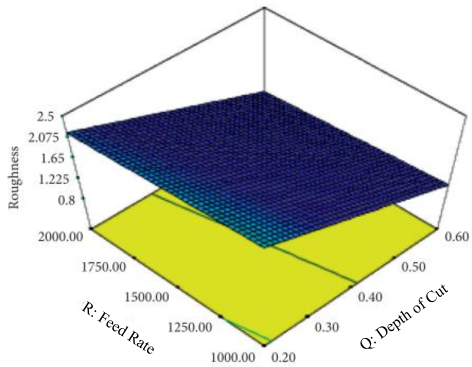

Figure 6. Graph of Q and R's interactions on Ra

The ANOVA analysis found that FR is the parameter that most affects the MRR of low carbon steel UNS T51620. In contrast, the factor that has the biggest impact on Ra is spindle speed. P20 steel (20), aluminum alloy 7075 (18), aluminum AL6063 (22), and AA6351 alloy steel (21) also showed comparable outcomes. The most important factor for machining time is step over (19), which is followed by depth of cut and cutting speed (23). Table 6 displays the full optimization findings utilizing Response Surface Methodology from multiple authors.

Table 6. Optimization Results using Response Surface Methodology (RSM) from several authors

No	Optimized parameters	Key results	Author
1	DoC, SS, FR, Coolant flow rate	Minimum Ra 0.159 µm, MRR 1.294 mm^3/min	R. Suresh Kumar et al. (17)
2	DoC, SS, FR	Ra: 0.159 µm, MRR 32.019 g/min	C. C. Tran, et al. (18)
3	SS, FR, Step over, Toolpath strategy	Machining time 424.46 min	W. D. Lestari et al. (19)
4	CS, FR, Nose radius, Axial DoC, Radial DoC	Ra: 0.615 µm, MRR 298.5 cm^3/min	M. Vishnu Vardhan, et.al. (20)
5	DoC, CS, FR, Tool nose radius	Ra minimized and machining time optimized	G. Karthik Pandiyan, T. Prabaharan (21)
6	DoC, CS, FR.	The minimum Ra achieved was 0.91 µm, with the following optimized parameters: DoC 1.2 mm, CS 1440 rpm, FR 0.2 mm/rev.	Sathish et al. (22)
7	DoC, CS	Optimal machining time 2.57922 minutes	M. Aziz, R. Saraswati (23)

3. Conclusion

According to this study, FR and DoC have the biggest effects on machining results, specifically Ra and MRR. RSM is better at evaluating more complex parameter interactions, although Taguchi's approach is helpful for developing a limited number of tests. The optimal machining settings are generated for a range of applications, such as CNC milling aluminum alloys, low-carbon steels, and other materials, when these two methods are combined. The industrial sector can improve production quality and efficiency by optimizing CNC milling machining parameters, according to this study's helpful recommendations.

References

1. H. Henci. (2019). "An overview of proses CNC machining." J. Mech. Sci. Eng. [Online]. 6(2). pp. 19–23. Available: 10.36706/jmse.v6i2.32
2. A. R. Hidayat. (2023). "Analisa waktu optimasi perawatan mesin CNC milling dengan pendekatan value stream mapping serta perbaikan dengan failur mode and effect analysis pada mesin CNC milling." J. Rekayasa Mesin [Online]. 18(3). p. 345. doi: 10.32497/jrm.v18i3.4099.

3. W. Pease. (1952). “An automatic machine tool.” Sci. Am. [Online]. 187(3). pp. 101–112. doi: 10.1038/scientificamerican0952-101.
4. G. T. Smith. (1993). “CNC machining technology.” CNC Mach. Technol. [Online]. vol. I. doi: 10.1007/978-1-4471-2053-7.
5. X. Chuangwen, D. Jianming, C. Yuzhen, L. Huaiyuan, S. Zhicheng, and X. Jing. (2018). “The relationships between cutting parameters, tool wear, cutting force and vibration.” Adv. Mech. Eng. [Online]. 10(1). pp. 1–14. doi: 10.1177/1687814017750434.
6. T. C. Nguyen, D. H. Tien, B. N. Nguyen, and Q. C. Hsu. (2023). “Multi-response optimization of milling process of hardened S50C steel using SVM-GA based method.” Metals (Basel). [Online]. 13(5). doi: 10.3390/met13050925.
7. F. R. S. Freitas, R. C. B. Casais, F. J. G. Silva, N. P. V. Sebbe, R. P. Martinho, V. F. C. Sousa, R. C. M. Sales-Contini, and F. D. Fernandes. (October 2024). Wear Behavior of TiAlN/DLC Coating on Tools in Milling Copper–Beryllium Alloy AMPCOLOY® 83. Coatings [Online]. 14(1354). pp. 1–20. Available: 10.3390/coatings14111354.
8. S. Subekti, H. Pranoto, M. N. Hidayat, and B. D. Efendy. (2021). “Measurement of vibration on the alternator due to the influence of rotation speed.” Int. J. Adv. Technol. Mech. Mechatronics Mater. [Online]. 2(1). pp. 55–60. doi: 10.37869/ijatec.v2i1.44.
9. J. Ribeiro, H. Lopes, L. Queijo, and D. Figueiredo. (2017). “Optimization of cutting parameters to minimize the surface roughness in the end milling process using the Taguchi method.” Period. Polytech. Mech. Eng. [Online]. 61(1). pp. 30–35. doi: 10.3311/PPme.9114.
10. I. Tlhabadira, I. A. Daniyan, L. Masu, and L. R. VanStaden. (2019). “Process design and optimization of surface roughness during M200 TS milling process using the Taguchi method.” Procedia CIRP. [Online]. 84. pp. 868–873. doi: 10.1016/j.procir.2019.03.200.
11. K. Satyanarayana et al. (2023). “Optimization of machining parameters of CNC milling operation for material removal rate and surface roughness on EN-24 steel using Taguchi method.” E3S Web Conf. [Online]. 391. doi: 10.1051/e3sconf/202339101011.
12. E. M. Widodo, T. A. Purnomo, and N. Ariyanto. (2020). “Machinery parameter optimization of CNC milling programming towards process time.” J. Phys. Conf. Ser. [Online]. 1517(1). doi: 10.1088/1742-6596/1517/1/012044.
13. M. Mulyadi, W. Alfiansyah, A. Akbar, R. Firdaus, and N. F. G. Andita. (2019). “Optimizing machining time for CAD / CAM milling programming using the Taguchi method.” J. Phys. Conf. Ser. [Online]. 1402(4). doi: 10.1088/1742-6596/1402/4/044043.
14. H. L. H. Anh, T. K. Tuan, N. H. Quang, N. H. Luan, T. M. Truong, and N. T. Q. Dung. (2021). “Optimization of milling process by Taguchi-PSI method.” E3S Web Conf. [Online]. 309. pp. 1–5. doi: 10.1051/e3sconf/202130901019.
15. D. D. Trung et al. (2021). “Combination of Taguchi method and MOORA method for multi-objective optimization of SCM400 steel milling process.” E3S Web Conf. [Online]. 309. doi: 10.1051/e3sconf/202130901092.
16. H. Kirli Akin and Y. Fedai. (2018). “Optimization of machining parameters in face milling using multi-objective Taguchi technique.” Teh. Glas. [Online]. 12(2). pp. 104–108. doi: 10.31803/tg-20180201125123.
17. R. Suresh Kumar et al. (2021). “Optimization of CNC end milling process parameters of low-carbon mold steel using response surface methodology and grey relational analysis.” Adv. Mater. Sci. Eng. [Online]. 2021. doi: 10.1155/2021/4005728.
18. C. C. Tran, V. T. Luu, V. T. Nguyen, V. T. Tran, V. T. Tran, and H. D. Vu. (2023). “Multi-objective optimization of CNC milling parameters of 7075 aluminium alloy using response surface methodology.” Jordan J. Mech. Ind. Eng. [Online]. 17(3). pp. 393–402. doi: 10.59038/jjmie/170308.
19. W. D. Lestari et al. (2024). “Optimization of the cutting process on machining time of ankle foot as transtibial prosthesis components using response surface methodology.” Results Eng. [Online]. 21. p. 101736. doi: 10.1016/j.rineng.2023.101736.
20. M. Vishnu Vardhan, G. Sankaraiah, M. Yohan, and H. Jeevan Rao. (2017). “Optimization of parameters in CNC milling of P20 steel using response surface methodology and Taguchi method.” Mater. Today Proc. [Online]. 4(8). pp. 9163–9169. doi: 10.1016/j.matpr.2017.07.273.

21. G. Karthik Pandiyan and T. Prabaharan. (2020). "Optimization of machining parameters on AA6351 alloy steel using response surface methodology (RSM)." Mater. Today Proc. [Online]. 33. pp. 2686–2689. doi: 10.1016/j.matpr.2020.01.369.
22. Sathish T, Siva Subramanian T.B, Tamizharasan N, Varun Karthik E, and Radhakrishnan B. (March 2017). Optimisation of Surface Roughness in CNC Milling Process Using RSM. SSRG International Journal of Mechanical Engineering [Online]. Special Issue. pp. 5–12. Available: www.internationaljournalssrg.org
23. M. Aziz and R. Saraswati. (2022). "Optimalisasi parameter mesin CNC milling 3 axis terhadap waktu produksi dengan menggunakan response surface methodology." Formosa J. Appl. Sci. [Online]. 1(4). pp. 293–304. doi: 10.55927/fjas.v1i4.1089.