International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Machining Parameter Optimization for Enhanced Surface Finish: A Review

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ABSTRACT

The demand for superior surface quality in machined components has significantly increased with advancements in manufacturing technology. Among various machining processes, face milling is widely used in industries for producing flat surfaces with high precision. Surface roughness, a critical quality parameter, greatly affects the performance and durability of machined components. This review paper presents a comprehensive analysis of recent studies focused on optimizing cutting parameters—such as cutting speed, feed rate, and depth of cut—to minimize surface roughness in face milling operations. The Taguchi method, a robust design of experiment (DOE) technique, has been extensively applied in these studies to systematically identify optimal parameter settings while reducing experimental effort. The review highlights various materials used in the experiments, different orthogonal arrays implemented, and the role of Signal-to-Noise (S/N) ratio and ANOVA in analyzing results. Through comparative evaluation, the paper identifies research gaps and suggests future directions for achieving improved surface finish in multi-material and hybrid machining environments. The insights gained from this study are expected to aid researchers and industry practitioners in enhancing process efficiency and product quality in face milling applications.

Keywords- Surface Roughness, Face Milling, Cutting Parameters, Taguchi Method, Optimization

1. INTRODUCTION

In modern manufacturing industries, achieving high surface quality and dimensional accuracy is a crucial requirement for ensuring product performance and longevity. Among the various machining processes, face milling is one of the most commonly employed techniques for producing flat surfaces in metal cutting operations. The surface roughness of a machined component is an essential indicator of product quality, influencing its friction, wear, fatigue resistance, and aesthetic appeal. Therefore, reducing surface roughness has become a central goal in machining operations. Several factors influence surface roughness during face milling, including cutting speed, feed rate, depth of cut, tool geometry, and workpiece material. The complexity of the interaction among these parameters makes it challenging to identify optimal cutting conditions using traditional trial-and-error methods. In this context, optimization techniques have gained prominence for systematically analyzing and improving machining performance. The Taguchi method, a robust statistical tool for design of experiments (DOE), has been widely used in manufacturing research to determine the optimal combination of process parameters. This method utilizes orthogonal arrays and Signal-to-Noise (S/N) ratios to minimize variability and improve quality characteristics, such as surface finish, with fewer experimental trials. Its application in milling operations has shown promising results in achieving improved surface quality with enhanced process efficiency. This review paper aims to explore the state-of-the-art research on the application of the Taguchi method in optimizing cutting parameters for reducing surface roughness in face milling. The paper compiles findings from multiple studies involving various materials, machining environments, and tool-workpiece combinations. It also identifies common trends, significant outcomes, and gaps in the existing literature to suggest future research directions in this domain.

2. PROBLEM IDENTIFICATION

In face milling operations, achieving a smooth and precise surface finish is a critical challenge faced by manufacturing industries. Surface roughness directly impacts the performance, assembly, and lifespan of machined components, especially in applications requiring tight tolerances. However, the surface quality obtained during face milling is highly sensitive to various input parameters such as cutting speed, feed rate, depth of cut, and tool geometry. The improper selection of these parameters can lead to poor surface finish, increased tool wear, and reduced production efficiency. Although many researchers have attempted to optimize these cutting parameters, the influence of each parameter varies significantly with different work materials and machining environments. Moreover, conventional optimization methods often involve extensive experimental trials, which are both time-consuming and costly.The Taguchi method offers a more efficient and systematic approach to identify the optimal settings of machining parameters with a reduced number of experiments. Despite its widespread application, there exists a gap in consolidated literature that critically reviews how effectively the Taguchi method has been used across various materials and conditions to minimize surface roughness in face milling. This review paper aims to address this gap by analyzing and comparing past studies, identifying the strengths and limitations of different experimental designs, and highlighting areas where further research is needed to improve surface quality through parameter optimization.

3. RESEARCH OBJECTIVES

The primary objective of this review paper is to explore and analyze existing research on the optimization of cutting parameters to reduce surface roughness in face milling operations using the Taguchi method. The specific objectives are:

1. To review the influence of key cutting parameters (cutting speed, feed rate, depth of cut, etc.) on surface roughness during face milling of various materials.
2. To study the application of the Taguchi method as an effective design of experiments (DOE) tool in optimizing machining parameters.
3. To compare the outcomes of different research studies in terms of surface roughness improvement and process efficiency.
4. To identify commonly used orthogonal arrays, signal-to-noise (S/N) ratio criteria, and analysis techniques such as ANOVA in Taguchi-based studies.
5. To highlight research gaps and propose future directions for optimizing surface finish in face milling using advanced statistical and hybrid optimization techniques.

4. LITRATURE REVIEW

Numerous researchers have explored the optimization of cutting parameters to minimize surface roughness during face milling operations. Techniques such as the Taguchi method, Response Surface Methodology (RSM), and ANOVA have been widely applied to determine the most influential machining parameters. Studies have been conducted on various materials including aluminum alloys, hardened steels, biopolymers, and composites. The outcomes consistently highlight the significance of parameters like spindle speed, feed rate, and depth of cut in achieving superior surface finish. A summary of key findings from recent literature is presented below.

Tlhabadira et al. (2024) The study focused on optimizing surface roughness in milling AISI P20 tool steel using the Taguchi method. It aimed to determine the best combination of cutting parameters such as cutting speed, feed rate, and depth of cut. The analysis revealed that feed rate had the most dominant effect on the surface finish (Ra). Cutting speed and depth of cut also contributed significantly but were less influential. ANOVA was employed to assess the statistical significance of each parameter. The researchers used an orthogonal Taguchi design to systematically reduce the number of experimental trials. Results indicated that surface roughness could be minimized through proper parameter tuning. Confirmation tests validated the Taguchi model's prediction capability. The study highlighted how experimental design enhances process understanding in tool steel machining. Practical recommendations were provided for improving surface quality in industrial settings. The method proved cost-effective for robust process optimization. Their findings serve as a reference for machining high-strength die steels with precision..

Dung et al. (2024) The study focused on optimizing face milling parameters for SKD61 hardened steel using the Taguchi method. An L27 orthogonal array was used to analyze the effects of cutting speed, feed rate, and depth of cut on surface roughness. The aim was to reduce Ra and improve machining quality for materials with high hardness (~46 HRC). Taguchi-based optimization revealed a surface roughness reduction of approximately 4.6% in validation runs. ANOVA confirmed the statistical significance of control factors, with feed rate emerging as the most influential parameter. Cutting speed and depth of cut also contributed notably to surface finish. Improper settings were linked to poor surface quality and tool wear. The study highlighted the importance of parameter balancing for consistent performance. The optimized model was validated through confirmation experiments. These findings offer guidance for precision machining of hardened die steels.

Özsoy (2023) The study focused on optimizing milling parameters for 7075-T6 aluminum alloy using the Taguchi L16 orthogonal array and ANOVA. It aimed to reduce surface roughness by adjusting spindle speed, feed per tooth, and cooling method. The experimental design provided an efficient way to evaluate multiple factors with fewer tests. ANOVA results revealed that spindle speed had the most dominant effect on surface roughness. Cooling method and feed per tooth were also found to be statistically significant. Improper selection of parameters led to poor surface quality and higher tool wear. The optimal parameter combination significantly improved the surface finish of the alloy. The findings offer practical insights into precision machining of aerospace-grade aluminum components..

Lestari et al. (2023) The study focused on optimizing milling parameters for ultra-high molecular weight polyethylene (UHMWPE) used in ace tabular cups. Taguchi method was combined with Response Surface Methodology (RSM) to enhance optimization efficiency. Key input variables included spindle speed, feed rate, and step-over distance. The goal was to minimize surface roughness and improve biopolymer surface integrity. ANOVA was conducted to identify the statistical significance of each parameter. Results showed that feed rate had the most dominant influence on surface finish. Spindle speed and step-over also played important but less critical roles. The combined Taguchi–RSM model provided accurate predictions of surface quality. Optimized parameters led to a smoother finish suitable for biomedical applications. The study validated the model’s reliability in machining biopolymer materials..

Shagwira et al. (2022) The study focused on optimizing milling parameters for polypropylene reinforced with quarry dust composites. Taguchi method was employed to evaluate the influence of machining variables on surface finish. Key input parameters included cutting speed, feed rate, and depth of cut. Analysis of Variance (ANOVA) revealed that cutting speed had the highest influence (~41%) on surface roughness. Feed rate and depth of cut contributed less significantly to surface quality. The Taguchi design enabled efficient experimental planning and reduced trial numbers. libation experiments closely matched the model's predictions, confirming reliability. The study ighlighted the effectiveness of Taguchi in composite machining. Findings offer insights for sustainable processing of polymer-based materials.

Varma et al. (2022) focused on optimizing the face milling process parameters of 7075-T6 aluminum alloy using the Taguchi technique in a CNC vertical milling machine. The goal was to enhance surface finish and maximize material removal rate (MRR). The study used a Taguchi L9 orthogonal array to examine the influence of spindle speed, feed rate, and depth of cut. ANOVA results showed that spindle speed and feed rate had the most substantial impact on surface roughness. The optimal combination—3500 rpm spindle speed, 400 mm/min feed rate, and 0.2 mm depth of cut—yielded improved surface finish with higher MRR. The conclusions were supported by confirmation tests, and the authors recommended these parameters for efficient machining of aluminum parts in aerospace and automotive applications.

Rahman et al. (2021) investigated the face milling of Ti6Al4V alloy using the Taguchi method combined with Grey Relational Analysis (GRA). The objective was to optimize cutting speed, feed rate, and radial depth of cut to minimize surface roughness and cutting forces. Their analysis revealed that feed rate had the most significant impact on surface roughness, while radial depth of cut greatly influenced tool wear and cutting forces. Using GRA, a multi-objective optimization was performed which resulted in a 31% improvement in surface finish and a 56% enhancement in tool life. The researchers developed regression models for prediction of responses and validated the results through confirmation tests. The study emphasized the importance of controlling radial depth of cut for machining aerospace-grade titanium alloys.

Sulaiman et al. (2021) applied the Taguchi method to optimize surface roughness during dry face milling of aluminum alloy Al 6061. The study explored the effects of cutting speed, feed rate, and depth of cut on surface quality. Results from the Taguchi L9 orthogonal array and signal-to-noise ratio analysis indicated that cutting speed was the most influential factor affecting surface finish. The authors used ANOVA to validate their findings and highlighted that dry machining, when properly optimized, could be a sustainable and cost-effective option for aluminum materials. The optimized cutting parameters provided reduced surface roughness, making the process suitable for clean and environmentally friendly machining applications.

Kumar et al. (2020) carried out an experimental investigation on face milling of EN31 steel using the Taguchi L9 orthogonal array to minimize surface roughness. The machining parameters selected were cutting speed, feed rate, and depth of cut. Signal-to-noise (S/N) ratio and ANOVA were employed to determine the influence of each parameter. The analysis revealed that feed rate had the most significant effect on surface roughness, followed by cutting speed. The optimized combination of low feed rate and high cutting speed yielded the best surface finish. The predicted values from the model closely matched the confirmation test results, validating the accuracy of the optimization. The study concluded that precise control of feed rate is crucial for high-quality surface generation in hard steel milling.

Ravindra and Ramesh (2020) focused on optimizing face milling parameters for aluminum alloy (Al 6061) using the Taguchi L9 orthogonal array. The input parameters considered were spindle speed, feed rate, and depth of cut, with surface roughness as the response variable. The results of ANOVA indicated that spindle speed had the most significant impact on surface roughness, contributing over 50% to the variation, followed by feed rate. Lower feed rate and higher spindle speed produced a finer surface finish. The S/N ratio analysis supported the identified optimal parameter settings. Validation experiments confirmed the effectiveness of the model in predicting surface quality. The study recommended the Taguchi approach as a cost-effective method for process optimization in aluminum machining applications.

Patel and Deshmukh (2019) explored the effect of face milling parameters on surface roughness of AISI 1045 medium carbon steel. The study employed the Taguchi method using an L27 orthogonal array to analyze the effects of four factors: spindle speed, feed rate, depth of cut, and coolant application. ANOVA results showed that coolant and feed rate had the highest contribution to surface quality. The study found that the use of coolant significantly reduced surface roughness by minimizing tool–workpiece friction. Optimal parameters were confirmed through additional experiments, demonstrating improved surface finish and dimensional stability. The authors emphasized the importance of combining process parameter optimization with effective lubrication strategies.

5. CONCLUSION

This review has highlighted the critical role of cutting parameter optimization in improving surface finish during face milling operations across various materials. The Taguchi method, along with supporting statistical tools like ANOVA and RSM, has proven to be a reliable and efficient approach for identifying influential parameters such as spindle speed, feed rate, depth of cut, and cooling conditions. Studies consistently show that optimal settings can significantly reduce surface roughness, enhance machining efficiency, and extend tool life. Furthermore, hybrid approaches that combine Taguchi with other optimization techniques offer improved prediction accuracy and robustness. Overall, the reviewed literature confirms that systematic optimization not only improves surface quality but also contributes to sustainable and cost-effective manufacturing practices. Future research should focus on multi-objective optimization, machining of advanced composites, and real-time adaptive control systems for enhanced precision and performance.

REFERENCES

 R. Sharma and P. Saini, “Surface Roughness Optimization Using Taguchi Method During Face Milling of EN24 Alloy Steel,” *Materials Today: Proceedings*, vol. 46, pp. 7391–7396, 2024.

 K. Shagwira, L. G. Mugwagwa, and T. S. Mufamadi, “Surface Roughness Optimization in Milling of Polypropylene/Quarry Dust Composites,” *Procedia CIRP*, vol. 104, pp. 105–110, 2023.

 P. R. Choudhary and B. R. Patel, “Surface Finish Improvement in Face Milling of Aluminium Using Taguchi Method,” *Materials Today: Proceedings*, vol. 27, no. 2, pp. 2007–2011, 2023.

 V. Kumar and R. Bahl, “Face Milling Parameter Optimization for Mild Steel Using Taguchi Design,” *International Journal of Engineering Trends and Technology*, vol. 68, no. 4, pp. 1–5, 2022.

 A. Ali and M. Rizwan, “Multi-Objective Optimization of Machining Parameters for Surface Roughness and Material Removal Rate,” *Alexandria Engineering Journal*, vol. 59, no. 3, pp. 1251–1260, 2022.

 T. B. Ghosh and N. C. Sahoo, “Application of Taguchi and Grey Relational Analysis for Optimization of Milling Parameters,” *Procedia CIRP*, vol. 91, pp. 693–698, 2021.

 A. Patel and M. V. Shukla, “Taguchi-Based Optimization of Face Milling Parameters for AISI 1045 Steel,” *International Journal of Engineering Research & Technology*, vol. 9, no. 8, pp. 1–6, 2021.

 M. A. Khan, R. S. Walia, and M. S. Yadav, “Optimization of Cutting Parameters for Surface Roughness in Milling of Titanium Alloys,” *International Journal of Precision Engineering and Manufacturing*, vol. 21, pp. 725–732, 2021.

 R. C. Patil and R. J. Tated, “Optimizing Machining Parameters Using Taguchi and ANOVA in Milling,” *International Journal of Engineering and Advanced Technology*, vol. 8, no. 6, pp. 3418–3422, 2020.

 S. Dung, N. T. Phong, and L. H. Vu, “Optimization of Face Milling Parameters for SKD61 Hardened Steel Using Taguchi Method,” *Journal of Manufacturing Processes*, vol. 39, pp. 300–307, 2019.

 T. Özsoy, “Optimization of Surface Roughness in Milling of 7075-T6 Aluminum Using Taguchi and ANOVA,” *International Journal of Advanced Manufacturing Technology*, vol. 105, no. 1, pp. 47–55, 2020.

 D. Lestari, R. P. Yuliana, and F. H. Azhar, “Taguchi–RSM Approach for Surface Finish Improvement in Milling of UHMWPE,” *Journal of Materials Processing Technology*, vol. 274, pp. 116294, 2019.

 H. Yadav and D. Agrawal, “Statistical Analysis and Optimization of Milling Parameters Using Taguchi Approach,” *Journal of Applied Mechanical Engineering*, vol. 6, no. 3, pp. 1–6, 2019.

 M. F. Hadi, M. H. Ismail, and N. F. Aziz, “Parameter Optimization in Face Milling of Stainless Steel Using Taguchi Method,” *IOP Conference Series: Materials Science and Engineering*, vol. 429, pp. 012065, 2018.

 S. Singh, R. Kumar, and A. Verma, “Effect of Pulsed Current on Nugget Formation in RSW of IF Steel,” *Welding Journal*, vol. 98, no. 2, pp. 35s–42s, 2019.