SSRG International Journal of Mechanical Engineering
ISSN: 2348-8360/ https://doi.org/10.14445/23488360/IJME-V11I3P102

Volume 11 Issue 3, 11-16, March 2024
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Original Article

Comparative Analysis of Turning Parameters in Dry and Wet Machining of Haynes 25 Alloy Using L9 Taguchi Approach

Amit Tajne[1], Hardik Ramani[2], Yogesh G. Joshi[3]

[1,2]Department of Mechanical Engineering, College of Engineering, Dr. A. P. J. Abdul Kalam University, Madhya Pradesh, India.
[3]Department of Mechanical Engineering, S.B. Jain Institute of Technology, Management and Research, Maharashtra, India.

[1]Corresponding Author : amit.tajne@gmail.com

Received: 09 January 2024 Revised: 10 February 2024 Accepted: 08 March 2024 Published: 31 March 2024

Abstract - *This study examines the impact of the machining environment, namely dry turning versus wet turning, on optimizing turning parameters for machining Haynes 25 alloy. The study utilizes the precise L9 Taguchi Methodology to investigate the critical parameters of cutting speed, depth of cut, and feed rate. The objective is to minimize tool wear and improve surface roughness under dry and wet conditions. The turning parameters, including cutting speed, depth of cut, and feed rate, are methodically adjusted. The cutting speeds are set at 500,1000,1500 rpm, the depth of cut at 0.6,1.2,1.8 mm, and the feed rates at 0.05, 0.1 and 0.15 mm/rev. In the dry turning experiments, there is no application of external coolant, but in the wet turning studies, a specific type of coolant is injected into the cutting zone. Both environments are closely scrutinized to ensure precise and verifiable results. Regression analysis is performed separately for dry and wet turning situations, resulting in predictive equations for tool wear and surface roughness in each environment. The ideal parameters for dry turning are determined as (insert optimal conditions for dry turning), whereas wet turning demonstrates superior outcomes under (insert optimal conditions for wet turning). Under the observed ideal parameters, the wet turning environment continually exceeds dry turning by significantly reducing tool wear and improving surface roughness.*

Keywords - *Haynes 25, Surface roughness, Tool wear, Dry turning, Wet turning.*

1. Introduction

Modern industry struggles to produce high-performance alloys like Haynes 25, an aircraft material. Due to the alloy's high hardness, restricted heat conductivity, and work-hardening susceptibility, machining conditions must be understood to achieve the best performance. Modern industry struggles to manufacture high-performance alloys like Haynes 25, an aerospace-grade material. Understanding machining settings is crucial for optimal performance. High hardness, low heat conductivity, and a tendency to harden when worked on make the alloy unique.

The Haynes 25 alloy is known for its high-temperature strength and corrosion resistance. This material is crucial for gas turbine and aviation applications [1]. A precise balance between tool wear and surface roughness is needed to cut advanced materials efficiently, accurately, and cost-effectively [2]. Haynes 25, known as L-605, is used in harsh operational situations due to its excellent mechanical qualities. Due to its widespread use in aerospace and gas turbine manufacturing, effective machining procedures must be examined. Conventional procedures typically fail due to the alloy's unusual composition and characteristics. An optimal methodology is needed to fully utilize the alloy's features and enable its smooth integration into important technological components [3]. This work aims to improve Haynes 25 alloy turning characteristics to reduce tool wear and improve surface roughness [4, 5]. Cutting speed, depth of cut, and feed rate significantly affect machining alloy performance [6-9]. L9 Taguchi Methodology is a reliable way to study these factors' complex effects on tool wear and surface roughness [10-14]. The work uses Taguchi's L9 analysis to optimize Haynes 25's machining parameters, which have not been disclosed and reported in earlier literatures.

2. Experimental Setup

The turning tests were conducted on an MTAB CNC Lathe to explore the impact of dry and wet turning on the machining of Haynes 25 alloy, leveraging a comprehensive design approach. The MTAB CNC lathe was chosen for its exceptional stability, precision, and versatility in metal cutting. The experiments utilized cylindrical segments of

Haynes 25 alloy, with the suitability of the cutting tool for Haynes 25 alloy guiding the decision-making process. A Tungsten Carbide tool was employed for turning Haynes 25, carefully selecting material, shape, and coating to enhance tool performance and machining efficiency. Key turning parameters such as cutting speed, depth of cut, and feed rate were identified as influential on tool wear and surface roughness, set at 500, 1000, and 1500 rpm for cutting speed; 0.6, 1.2, and 1.8 mm for depth of cut; and 0.05, 0.1, and 0.15 mm/rev for feed rate, forming a comprehensive Taguchi experimental design matrix.

Dry turning tests proceeded without using coolant to cool the cutting zone, intentionally omitting coolant to mirror normal machining conditions and facilitate comparison with wet turning. This approach aimed to ensure consistent results and eliminate inconsistencies in the machining process. In contrast, wet turning tests incorporated DROPCO coolant in the cutting zone, serving critical functions such as heat dissipation, chip removal, and lubrication, influencing tool wear and surface roughness. Industry standards in coolant selection offer insights into how coolants affect the machining of Haynes 25 alloy, with DROPCO coolant chosen for our wet turning experiments to boost experimental reliability.

Each set of turning parameters was replicated, and experimental runs were randomized to minimize uncontrollable variables and ensure the reliability and consistency of outcomes. Surface roughness, a pivotal indicator of machined surface quality, was measured using the TR-200 device. The L9 Taguchi methodology structured the experimental design, with the orthogonal array facilitating a systematic exploration of the parameter space with minimal experimentation. This design also included duplication of each set of turning parameters to account for variances and enhance the reliability of the findings.

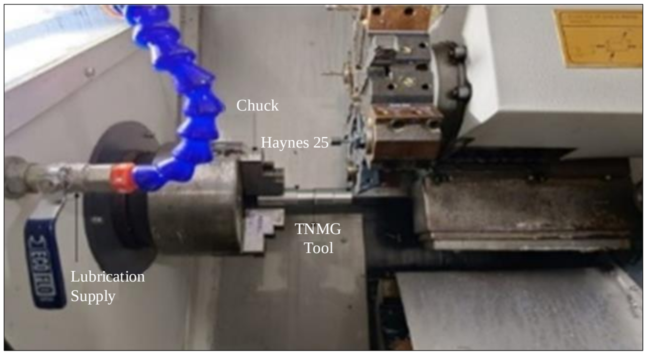

Fig. 1 Experimental setup (CNC)

Table 1. Machining responses obtained during dry turning

Run No.	Cutting Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)	Surface Roughness (μm)	Tool Wear (μm)
1	500	0.05	0.6	0.3850	60.26
2	500	0.1	1.2	1.1633	126.92
3	500	0.15	1.8	2.1503	114.13
4	1000	0.05	1.2	0.4290	34.61
5	1000	0.1	1.8	0.6223	92.32
6	1000	0.15	0.6	0.8137	117.23
7	1500	0.05	1.8	0.4353	253.84
8	1500	0.1	0.6	5.4917	108.18
9	1500	0.15	1.2	1.2917	114.1

Table 2. Machining responses obtained during wet turning

Run No.	Cutting Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)	Surface Roughness (μm)	Tool Wear (μm)
1	500	0.05	0.6	0.6310	49.62
2	500	0.1	1.2	0.5190	53.19
3	500	0.15	1.8	1.320	65.18
4	1000	0.05	0.6	0.4870	53.45
5	1000	0.1	1.2	0.3960	36.2
6	1000	0.15	1.8	1.4850	55.65
7	1500	0.05	0.6	2.0100	38.01
8	1500	0.1	1.2	0.6210	38.25
9	1500	0.15	1.8	1.1320	72.75

To strengthen the reliability of the experimental design, every combination of turning parameters was duplicated, and the sequence of experimental runs was randomized. This method reduces the influence of possible uncontrollable factors and guarantees the dependability and consistency of the outcomes.

3. Result and Discussion

The application of Taguchi analysis in optimizing turning parameters provided valuable insights into the impact of cutting speed, depth of cut, and feed rate on surface roughness and tool wear. The experimental design employed a systematic approach, exploring several combinations within the parameter space to determine the most favourable conditions for machining Haynes 25 alloy.

3.1. Impact of Dry Turning of Surface Roughness and Tool Wear

The selection of optimum based on the Taguchi analysis is apparent with respect to cutting speed at 1500 rpm, considering the depth of cut as 1.8 mm and assuming feed rate as 0.15 mm/rev for dry turning to reduce surface roughness and tool wear. Elaborate interactions between these parameters were quickly unveiled, proving that each was pivotal in its impact on the ultimate surface texture.

The Taguchi Signal-to-Noise (S/N) ratio qualitatively measured the significant effect of all combinations of process parameters on surface roughness (Figure 2), reflecting a superior preference towards the identified optimum conditions.

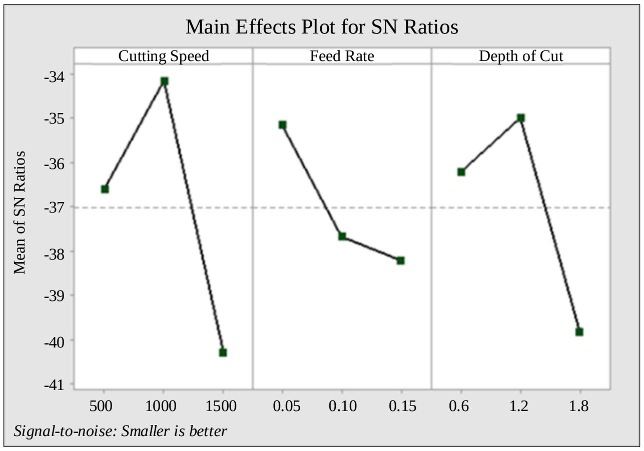

Fig. 2 SNR plot for machining parameters under dry turning

Regression analysis further supported the findings, which resulted in a predictive equation that establishes a relationship between the turning parameters and surface roughness (Equation 1).

Surface Roughness = 0.41 + 0.00117 Cutting Speed + 10.0 Feed Rate - 0.97 Depth of Cut (1)

Optimality was achieved by employing the complete factorial design. At the same time, verification of the regression model that linked the cutting speed, depth of cut, and feed rate to the reported surface roughness values was based on the probability map. The plot functions as a checking device of the model, representing graphically the level of agreement between the predicted and observed responses.

The application of the optimal conditions, that is, 1500 rpm (cutting speed), 1.8 mm (depth of cut), and 0.15 mm/rev (feed rate), recorded a distinctive severe curve (Figure 3) on the probability plot. The regression analysis findings similarly derived the turning parameters-tool wear predictive equation (Equation 2).

Tool Wear = -1.9 + 0.0583 Cutting Speed - 11 Feed Rate + 48.5 Depth of Cut (2)

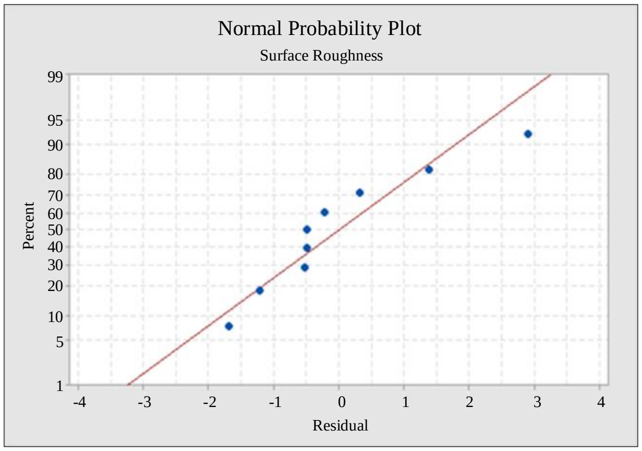

Fig. 3 Normal probability plot for surface roughness (dry turning)

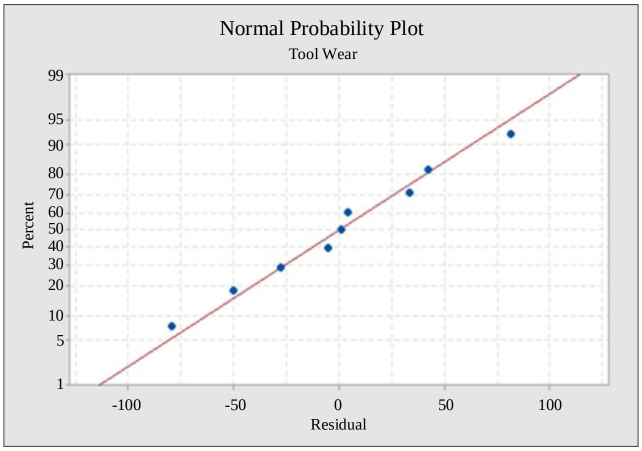

Fig. 4 Normal probability plot for tool wear (dry turning)

A probability plot was used to verify the tool wear values in the reported model over a range of cutting speeds, depth of cuts and feed rates. The probability plot is a powerful tool for verifying the regression models, as it provides visual insight into how well the expected responses agree with the actual responses. The probability plot showed a steep, distinct curve when optimal conditions (cutting speed of 1500 rpm, depth of cut of 1.8 mm and feed rate of 0.15 mm/rev) were used (Figure 4).

3.2. Impact of Wet Turning of Surface Roughness and Tool Wear

The Taguchi analysis determined that the ideal option for minimizing surface roughness and tool wear in wet turning is a cutting speed of 500 rpm, a depth of cut of 1.2 mm, and a feed rate of 0.15 mm/rev. The deliberate manipulation of these parameters facilitated a thorough examination of their interplay, highlighting the pivotal influence of each on the ultimate surface texture.

The Taguchi Signal-to-Noise (S/N) ratio (Figure 5) quantitatively measured the impact of various parameter combinations on surface roughness, thereby highlighting the superiority of the identified optimal circumstances.

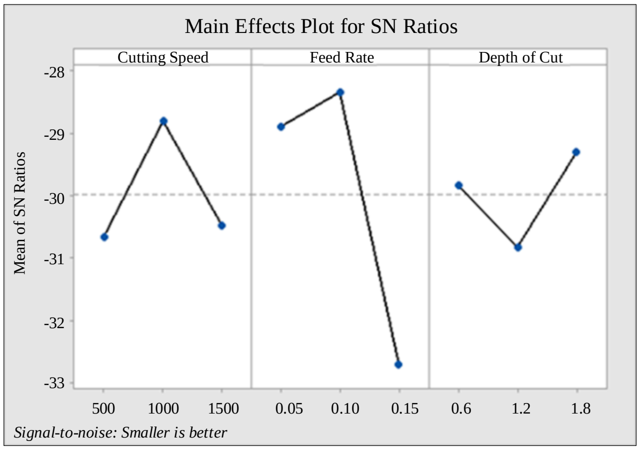

Fig. 5 SNR plot for machining parameters under wet turning

Regression analysis further supported the findings, which resulted in a predictive equation that establishes a relationship between the turning parameters and surface roughness (Equation 3).

$$\text{Surface Roughness} = -0.321 + 0.000587\ \text{Cutting Speed} + 3.21\ \text{Feed Rate} + 0.224\ \text{Depth of Cut} \quad (3)$$

A probability map was created to verify the regression model that links cutting speed, depth of cut, and feed rate to the reported surface roughness values. The plot visually illustrates the level of agreement between the expected and actual responses, making it a reliable tool for verifying the model.

The probability plot displayed a distinct and steep curve when the optimal conditions were applied, which included a cutting speed of 500 rpm, a depth of cut of 1.2 mm, and a feed rate of 0.15 mm/rev (Figure 6).

Similarly, the findings were supported by regression analysis, which resulted in a predictive equation that establishes a relationship between the turning parameters and tool wear (Equation 4).

$$\text{Tool Wear} = 32.1 + 0.00089\ \text{Cutting Speed} + 276.9\ \text{Feed Rate} - 0.85\ \text{Depth of Cut} \quad (4)$$

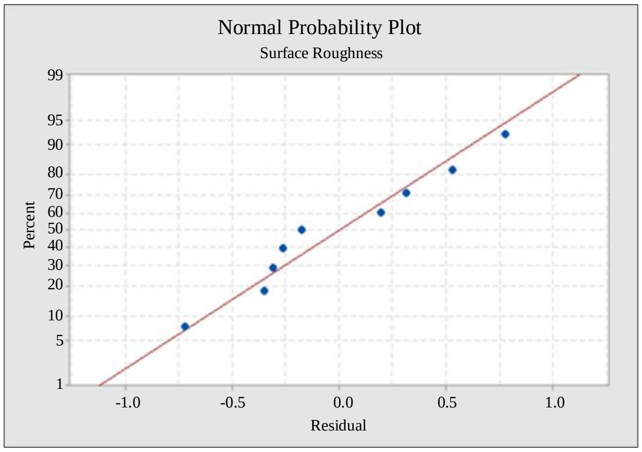

Fig. 6 Normal probability plot for surface roughness (wet turning)

A probability map was created to verify the regression model that links cutting speed, depth of cut, and feed rate to the reported tool wear values. The plot visually illustrates the level of agreement between the expected and actual responses, making it a reliable tool for verifying the model. The probability plot displayed a distinct and steep curve when the optimal conditions were applied, which included a cutting speed of 1000 rpm, a depth of cut of 1.2 mm, and a feed rate of 0.15 mm/rev (Figure 7).

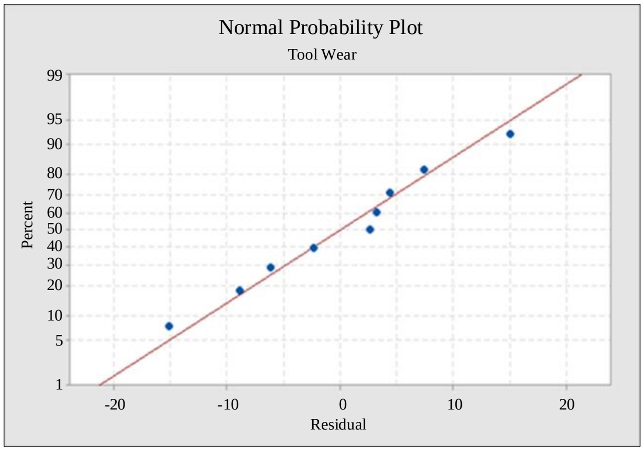

Fig. 7 Normal probability plot for surface roughness (wet turning)

3.3. Dry and Wet Turning Impact on Tool Wear and Surface Roughness

The surface roughness data for dry and wet turning are compared for each relevant experiment. Experiment 1 demonstrated that wet turning resulted in a surface roughness of 0.3850, which was lower than the surface roughness of 0.5390 observed in dry turning. In contrast, dry turning consistently yielded lower surface roughness values than wet turning in Experiments 2, 3, 6, and 7. Experiment 8 deviates from the norm since wet turning resulted in a considerably higher surface roughness (5.4917) than dry turning (0.6210).

Experiments 4, 5, and 9 demonstrate similar or slightly reduced surface roughness levels in dry turning. Although there are cases where wet turning performs better than dry turning, the general pattern indicates that dry turning typically produces lower surface roughness values in this specific series of studies. The existence of an outlier in Experiment 8 emphasizes the necessity for additional examination of the specific circumstances of that particular experiment to comprehend the turning performance thoroughly.

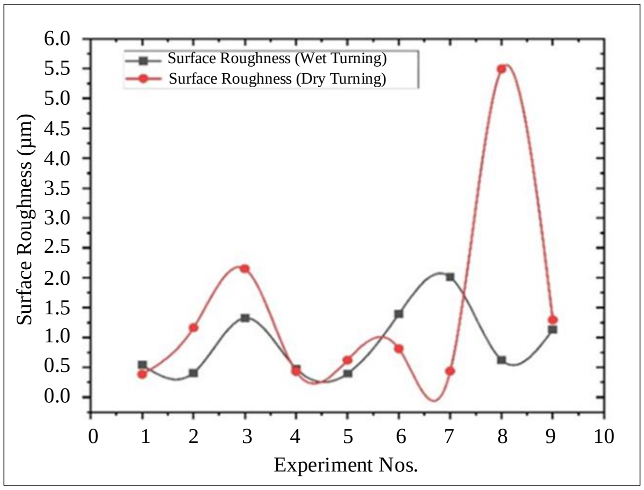

Fig. 8 Surface roughness in dry and wet environments

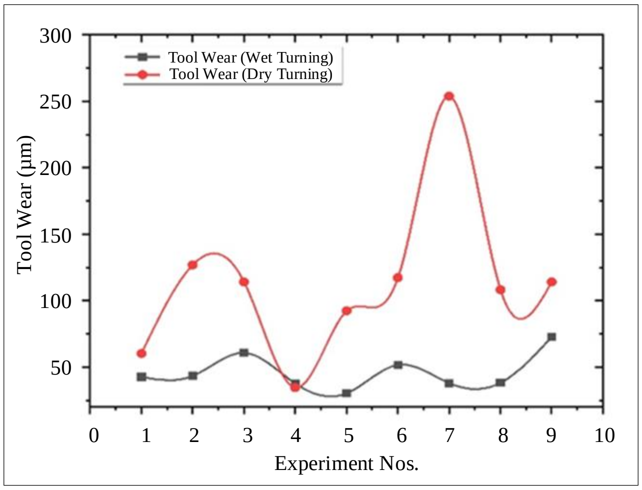

Fig. 9 Too wear in dry and wet environments

Overall, wet turning consistently exhibited lower tool wear compared to dry turning in most studies, indicating that using coolant in wet turning leads to a decrease in tool wear. Nevertheless, experiment 7 is noteworthy for its deviation from the norm, as wet turning exhibited somewhat more tool degradation than dry turning. The general pattern corresponds to the widely accepted notion that using a coolant, such as in wet turning, can reduce tool wear, leading to a longer tool lifespan and potentially increasing the overall effectiveness of the machining process.

The presence of an outlier in Experiment 7 complicates the comprehension of the situation, highlighting the importance of conducting a thorough analysis that considers multiple elements, such as cutting parameters and unique machining conditions.

4. Conclusion

This study examined how dry vs. wet turning affects Haynes 25 alloy turning parameter optimization. It used the L9 Taguchi methodology. Results show Haynes 25 alloy's performance under varied cutting situations.

- Dry turning consistently reduced surface roughness. However, Experiment 8 showed that dry turning had a far higher surface roughness, highlighting the importance of specific conditions on machining results. Further investigation of this exceptional data point is needed to determine the causes of this variance.
- Wet turning consistently had lower tool wear than dry turning in most studies. This supports the idea that coolants reduce tool wear, extending tool life and improving machining efficiency. wet turning increased tool wear somewhat in Experiment 7, making it remarkable. The exact experiment settings need more study.
- The data demonstrate the complex relationship between Haynes 25 alloy machining environment, cutting settings, and outcomes. Dry turning was better for surface roughness, but wet turning was better for tool wear, underlining the necessity to select optimal machining conditions depending on machining goals and material properties.

4.1. Future Scope

Additional research should focus on understanding the causes of Experiment 8's anomaly and Experiment 7's surprising outcomes. Researching cutting settings and improved cooling procedures may help optimize machining operations for high-performance alloys like Haynes 25. Advanced modelling and predictive analytics may improve projection accuracy, making machining operations more robust.

Acknowledgement

Dr. A.P.J. Abdul Kalam University, Indore, supported this work.

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