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Experimental Studies and Optimization of Machining Parameters in CNC Turning of AA7075 Aluminium Alloy

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A B S T R A C T

This paper presents an experimental investigation into the machinability of AA7075 Aluminium alloy during CNC turning operations. The primary objective is to optimize machining parameters such as spindle speed, feed rate, and depth of cut for enhanced surface finish and material removal rate (MRR). Taguchi's L9 orthogonal array and ANOVA were employed to design and analyze the experiments. The influence of each parameter on surface roughness and MRR was evaluated using Minitab. The chip morphology was also examined to assess the quality of machining. Results showed that feed rate had the most significant effect on surface roughness, while spindle speed heavily influenced MRR. The optimal parameters were identified for minimal surface roughness and maximal productivity

Keywords: AA7075 Aluminium alloy, machinability, surface roughness, material removal rate, Taguchi method, ANOVA

1. Introduction:

In recent decades, the demand for high-strength, lightweight materials has significantly increased across various industries such as aerospace, automotive, and defence. Among these materials, AA7075 aluminium alloy has gained prominence due to its excellent strength-to-weight ratio, good fatigue resistance, and favourable machinability characteristics. These properties make it an ideal candidate for structural components subjected to high stress.

CNC turning, a widely used subtractive manufacturing process, plays a vital role in shaping components from such advanced alloys. However, the performance of CNC turning operations is highly sensitive to the selection of machining parameters such as spindle speed, feed rate, and depth of cut. Inappropriate parameter selection can lead to poor surface quality, increased tool wear, and inefficient material removal, thereby affecting the overall productivity and cost-effectiveness of the manufacturing process.

Consequently, optimization of machining parameters has become a critical area of research to enhance product quality while minimizing production costs and energy consumption. Experimental analysis, coupled with statistical and computational optimization techniques, provides a robust approach to identify the most suitable machining conditions for achieving desired outputs.

This study focuses on the experimental investigation and optimization of key machining parameters during CNC turning of AA7075 Aluminium alloy. The primary objectives are to evaluate the influence of these parameters on surface roughness and material removal rate, and to determine optimal settings that yield improved machining performance. The findings of this study aim to contribute practical insights for industrial applications where precision and efficiency are paramount.

2. Literature Survey

Several recent studies have explored the optimization of machining parameters during the turning of AA7075 Aluminium alloy using the Taguchi design of experiments. Arpit Srivastava et al. (2021) applied the Taguchi L9 array to study the effects of cutting speed, feed, and depth of cut. ANOVA revealed that feed rate had the most impact on surface roughness, while depth of cut dominated MRR.

Navneet Saini and Jitender Panchal (2017) used a Taguchi–Grey relational analysis approach for multi-response optimization. Their work identified speed and feed as key factors for achieving high surface quality and tool life in CNC turning of AA7075.

Somashekara et al. (2022) enhanced Taguchi results by integrating it with artificial neural networks. This hybrid method predicted surface roughness more accurately and showed that cutting speed was the most influential parameter.

In a 2024 study, Nagarwala et al. combined Taguchi with regression analysis to optimize turning parameters from an economic perspective. Their work highlighted how optimal settings can reduce machining costs and improve productivity.

A 2022 Springer study applied Taguchi with Grey analysis to AA7075 milling. Though the process differs from turning, the results showed similar trends—depth of cut and tool nose radius significantly influenced MRR and surface finish.

A 2021 study in *Discover Applied Sciences* used Taguchi-Grey optimization for AA7075 forging, showing its versatility beyond machining. Factors like strain and plunger speed were optimized to enhance material performance.

In 2020, the *Silicon Journal* applied Response Surface Methodology (RSM) to optimize turning of AA7075/SiC composites. Results closely aligned with Taguchi studies, confirming the importance of feed rate and nose radius.

Another IJERT study reaffirmed that Grey-Taguchi analysis effectively handles multiple objectives. It identified speed and feed as critical parameters for improving surface quality and tool wear in AA7075 turning.

Few authors compared Taguchi method with machine learning. It concluded that while Taguchi is efficient, it may not capture complex nonlinear behaviors as effectively as AI-based methods.

These studies collectively illustrate the continued relevance and adaptability of the Taguchi method for optimizing machining processes of AA7075 Aluminium alloy. Whether applied in traditional turning, advanced composite machining, or extended through hybrid frameworks like ANN and GRA, Taguchi-based optimization continues to be a foundational approach in manufacturing research.

The present study contributes to this research landscape by conducting detailed experimentation on CNC turning of AA7075 aluminium alloy and applying modern optimization techniques to enhance surface quality and productivity.

3. Methodology

The methodology adopted in this research involves a systematic experimental approach followed by statistical analysis to optimize machining parameters during CNC turning of AA7075 aluminium alloy. The process includes material selection, experimental setup, parameter identification, data collection, and optimization using Taguchi method.

3.1 Work Material

The workpiece material used in this study is **AA7075-T6 aluminium alloy**, known for its high strength, low density, and good machinability. The chemical composition and mechanical properties were confirmed through standard testing methods.

Table 3.1 Chemical Composition of AA7075

Element	Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr
Content (%)	0.314	0.58	0.185	0.345	1.51	7.84	1.17	0.089
Element	Ag	B	Bi	Cd	Sr	Li	Co	Zr
Content (%)	0.007	0.029	0.026	0.091	0.003	0.86	0.03	0.009
Element	Pb	Ga	V	Sn	Ti	Al		
Content (%)	0.045	0.021	0.012	0.089	0.085	86.7		

3.2 CNC Turning Machine Setup

All machining operations were performed on a CNC lathe equipped with programmable feed and spindle speed control. A cemented carbide insert tool was used for turning operations under dry conditions. Tool geometry and insert grade were kept constant throughout the experiments.

Fig. 3.4. CNC Turning Centre

Fig 3.5: Cutting inserts used in the experimentation.

3.3 Machining Parameters and Output Responses

Three major input parameters were selected based on literature review and preliminary trials:

- **Cutting Speed (Vc)** – 100, 150, 200 m/min
- **Feed Rate (f)** – 0.1, 0.2, 0.3 mm/rev
- **Depth of Cut (ap)** – 0.5, 1.0, 1.5 mm

The primary output responses considered were:

- **Surface Roughness (Ra)** – Measured using a surface profilometer (µm)
- **Material Removal Rate (MRR)** – calculated using the formula:

$MRR=\pi\times D\times f\times d\times N$

Where:

MRR = Material Removal Rate (mm^3/min)

D = Diameter of the workpiece (mm)

f = Feed rate (mm/rev)

d = Depth of cut (mm)

NNN = Spindle speed (rev/min)

$\pi \approx 3.1416$

3.4 Experimental Design – Taguchi Method

A **Taguchi L9 orthogonal array** was selected to reduce the number of experiments and systematically study the influence of parameters. Each parameter was assigned three levels. The experimental layout is shown in Table 1.

Table 3.1. Experimental Layout Using an L-9 Orthogonal Array

Exp. No.	Spindle speed (rpm)	Depth of cut (mm)	Feed (mm/rev)
1	800	0.5	0.08
2	800	1	0.12
3	800	1.5	0.16
4	1200	0.5	0.12
5	1200	1	0.16
6	1200	1.5	0.08
7	1600	0.5	0.16
8	1600	1	0.08
9	1600	1.5	0.12

3.5 Data Collection and Measurement

After each machining trial:

- Surface roughness was measured at three positions using a surface profilometer and the average value was recorded.
- MRR was computed based on dimensional measurements and machining time.
- All experiments were repeated to ensure consistency, and outliers were removed.

Fig. 3.6. Samples after turning process.

Fig. 3.7. Photograph Image of contact type Surface Roughness Tester with Model 657111

3.6 Optimization and Analysis

The collected data was analysed using **Signal-to-Noise (S/N) ratio analysis** as per the Taguchi method:

- For **Surface Roughness**: *Smaller-the-better* criterion
- For **MRR**: *Larger-the-better* criterion

Further, **Analysis of Variance (ANOVA)** was conducted to determine the significance and percentage contribution of each parameter.

3.7 Confirmation Experiments

Based on the optimal parameters obtained through Taguchi analysis, a **confirmation experiments** were carried out to validate the model and compare predicted vs actual results.

4. Results and Discussion

This section presents the results obtained from the CNC turning experiments on AA7075 aluminium alloy using Taguchi's'L9 orthogonal array. The influence of cutting speed, feed rate, and depth of cut on surface roughness (Ra) and material removal rate (MRR) was analysed using statistical tools, and the optimal parameters were determined.

4.1 Experimental Results

Surface roughness values were calculated from the samples after machining operations. Table 4.1 shows the measured surface roughness values.

Table 4.1 Experimental result for mean value of surface roughness

Experiment No.	**Spindle Speed(rpm)**	**Depth of Cut (mm)**	**Feed Rate (mm/rev)**	**Average Ra (μm)**	**S/N ratio(dB)**
1	800	0.5	0.08	1.2475	-1.92081
2	800	1.0	0.12	1.5775	-3.95939
3	800	1.5	0.16	1.9850	-5.95521
4	1200	0.5	0.12	1.2175	-1.70938
5	1200	1.0	0.16	1.4300	-3.10672
6	1200	1.5	0.08	1.4125	-2.99977
7	1600	0.5	0.16	1.5450	-3.77857
8	1600	1.0	0.08	0.9875	0.10926
9	1600	1.5	0.12	1.5100	-3.57954

The effect of spindle speed, depth of cut and feed rate on surface roughness figures 4.1, 4.2 and 4.3 respectively.

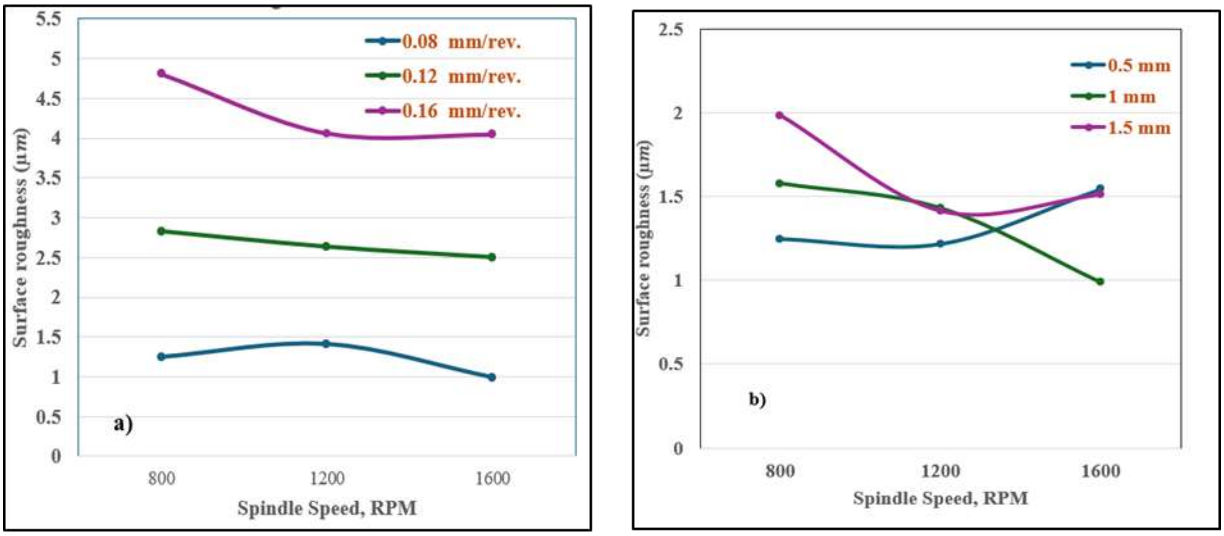


Fig. 4.1. Relationship between spindle speed and surface roughness: a**)** at different feed rate and b) at different depth of cut.

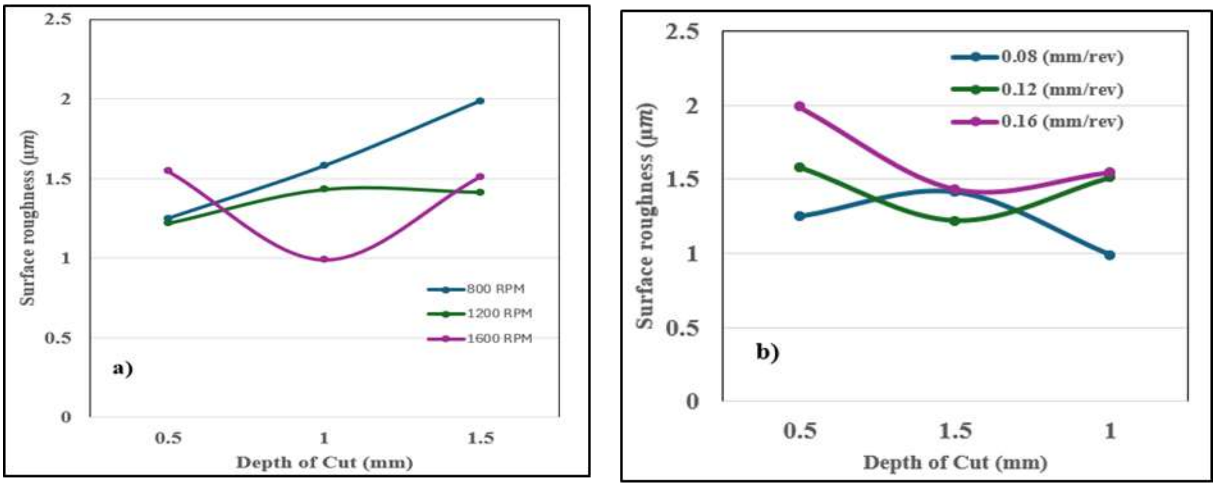


Fig. 4.2. Relationship between depth of cut on surface roughness: a) at different spindle speed and b) at different feed rates

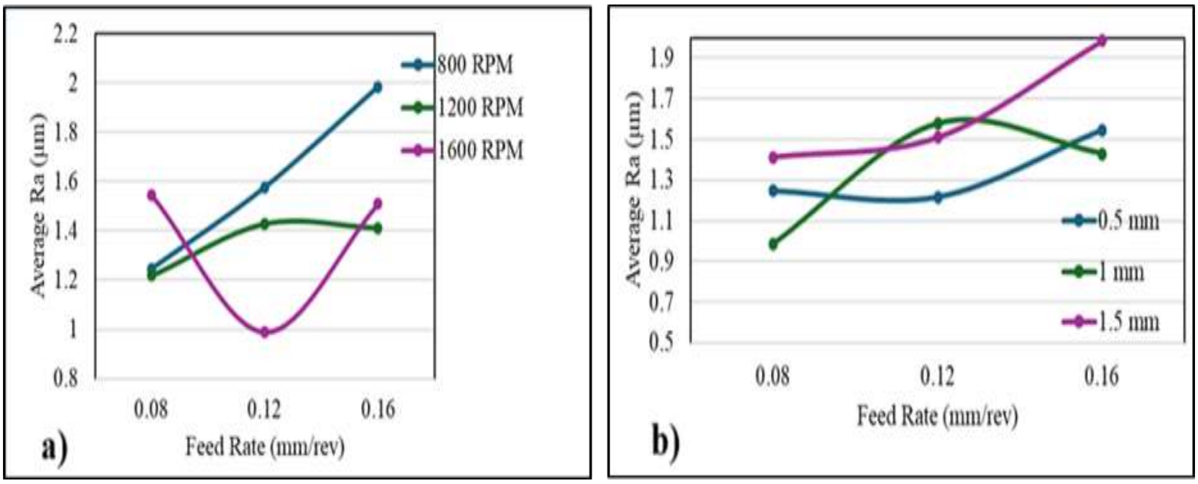


Fig. 4.3. The relationship between feed rate on surface roughness (a) at different spindle speed and (b) at different depth of cut.

From the above graphs, the Surface roughness (Ra) was found to be influenced significantly by feed rate, followed by cutting speed. The results show that:

- Surface roughness increases with an increase in feed rate.
- Higher cutting speed tends to reduce Ra due to reduced built-up edge and improved chip flow.
- Depth of cut has a moderate effect on Ra.

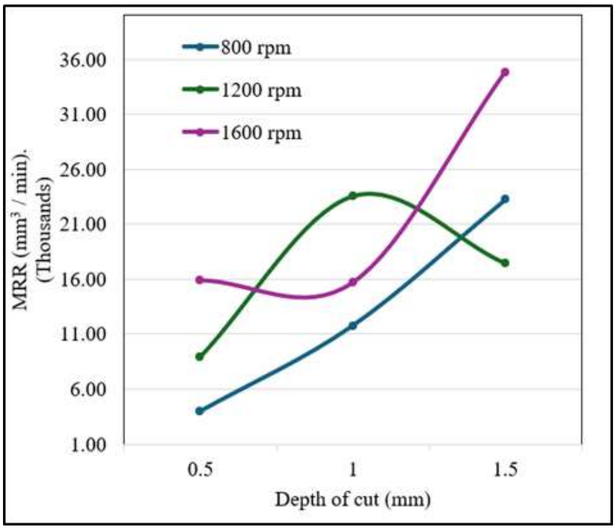
4.3 Effect of Machining Parameters on MRR

Material Removal Rates were calculated from the samples after machining operations. Table 4.2 shows the measured surface roughness values.

Table 4.2 Calculated Material Removal Rate

Exp. No.	**Spindle speed (rpm)**	**Depth of cut (mm)**	**Feed rate (mm/rev)**	**MRR (mm^3/min).**
1	800	0.5	0.08	3970.97
2	800	1.0	0.12	11762.12
3	800	1.5	0.16	23222.65
4	1200	0.5	0.12	8934.69
5	1200	1.0	0.16	23524.25
6	1200	1.5	0.08	17416.99
7	1600	0.5	0.16	15883.89
8	1600	1.0	0.08	15682.83
9	1600	1.5	0.12	34833.98

From the experimental investigations, Variation of MRR with respect to change of spindle speed, feed rate and depth of cut were plotted and shown in the Fig. 4.5



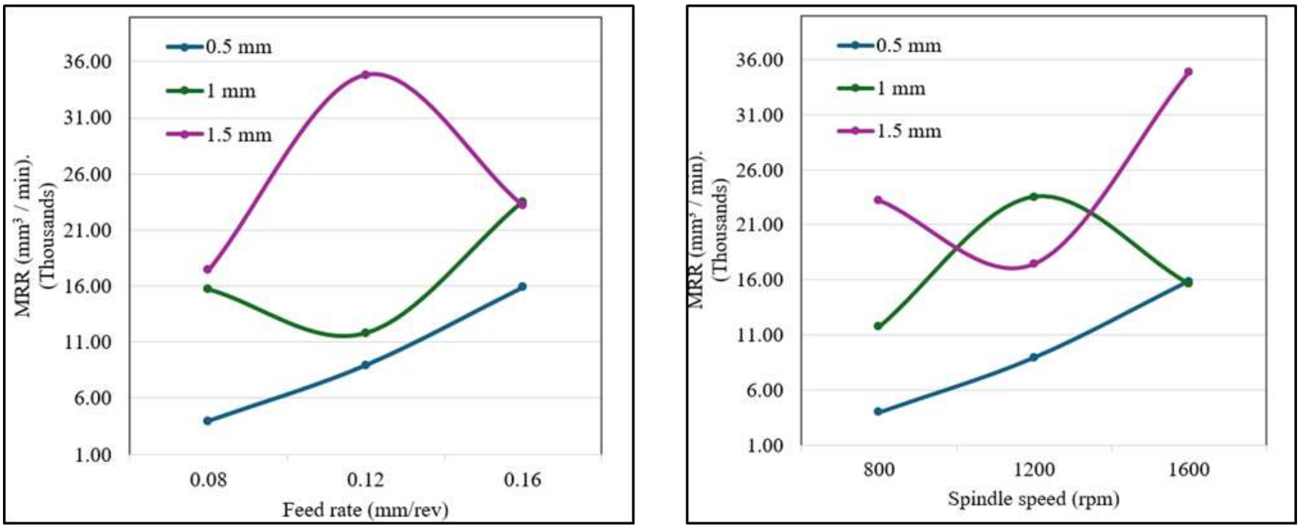


Fig 4.4. Effect of depth of cut, feed rate and Spindle speed on material removal rate.

From the Turning experiments, Material Removal Rate (MRR) increased with:

- Higher feed rate
- Greater depth of cut
- MRR is less influenced by cutting speed compared to the other two.

5. Taguchi Design of Experiments

The Design of Experiments (DOE) approach was used to analyse the mean surface roughness (Ra) in CNC turning with respect to three factors: cutting speed (A), feed rate (B), and depth of cut (C). Mean Ra values were calculated for each factor at three levels, and the results were shown in Table 4.2.

Table 4.2 Response table for mean effects

Level	**Cutting speed**	**Depth of cut**	**Feed rate**
	Symbol		
	A	**B**	**C**
1	1.603	1.337	**1.216**
2	1.353	**1.332**	1.435
3	**1.347**	1.636	1.653
Delta	0.256	0.304	0.437
Rank	**3**	**2**	**1**

The Taguchi analysis revealed that:

- Feed rate (C) has the most significant effect on surface roughness (Delta = 0.437, Rank 1),
- Followed by depth of cut (B) (Delta = 0.304, Rank 2),
- And cutting speed (A) has the least effect (Delta = 0.256, Rank 3).

The optimal parameter combination for minimizing surface roughness (smaller-is-better) is A3B2C1, corresponding to:

- High cutting speed,
- Medium depth of cut,
- Low feed rate.

Figure 4.5 (main effects plot) confirms this by identifying the minimum Ra values at these levels.

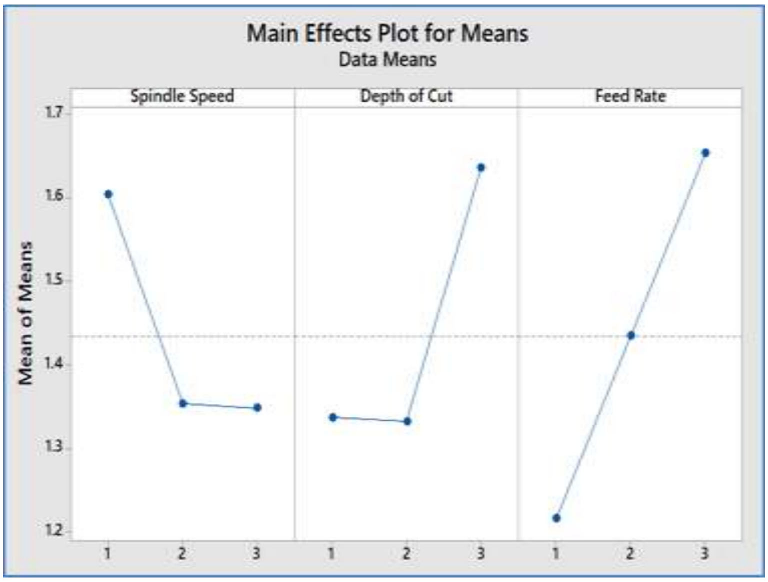


Fig. 4.5. Main effect plot for means

4.4 Signal-to-Noise (S/N) Ratio Analysis

4.4.1 Analysis of Taguchi Design and S/N Ratio for Surface Roughness

The Taguchi method was employed to improve surface finish by identifying optimal levels of controllable machining parameters (cutting speed, feed rate, and depth of cut) while minimizing the influence of uncontrollable noise factors. This method uses the Signal-to-Noise (S/N) ratio to measure variability in surface roughness results. A higher S/N ratio corresponds to a more robust (less variable) performance, which is desirable, especially for "smaller-is-better" quality characteristics like surface roughness.

4.1.2 Normality and Model Adequacy Check

Figure 4.6, which includes the normal probability plot, histogram, and versus order plots, confirms that the S/N ratios are normally distributed around the mean. This supports the adequacy and reliability of the Taguchi model for analysing surface roughness in this study.

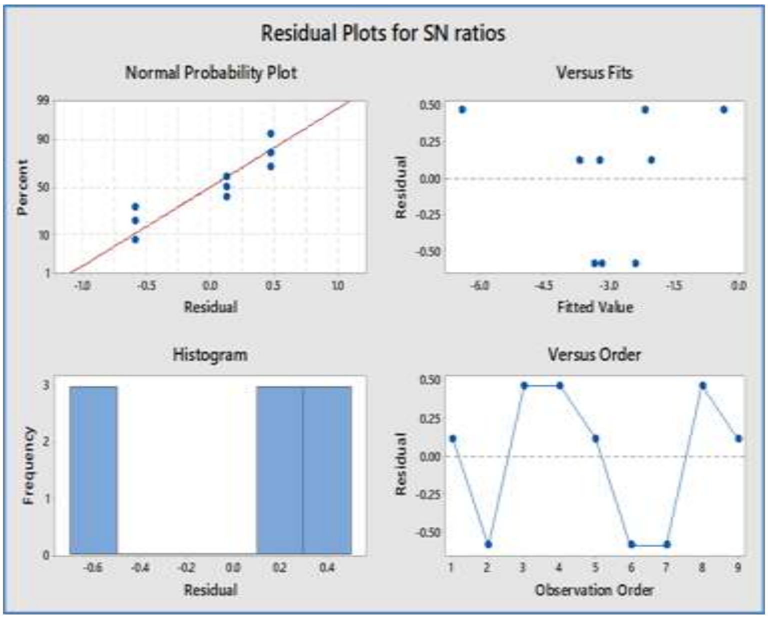


Fig. 4.6 Residual plot for SN ratio

4.1.3 S/N Ratio Response Analysis

The **S/N ratios** were calculated for each level of the three factors using Minitab 18. A sample manual calculation was also provided for factor A (cutting speed), reinforcing the methodology.

Table 4.3 Response Table for Signal to Noise Ratios

Level	**Cutting speed**	**Depth of cut**	**Feed rate**
	A	**B**	**C**
1	-3.945	-2.470	**-1.604**
2	-2.605	**-2.319**	-3.083
3	**-2.416**	-4.178	-4.280
Delta	1.529	1.859	2.676
Rank	3	2	1

Table 4.3 shows that the optimal parameter combination on smaller is the better surface quality character is A3B2C1, and it is the possible parameter combinations for increasing the surface quality of specimens. The control factor's main effect plot for the surface roughness S/N ratio is shown in Fig. 4.5.

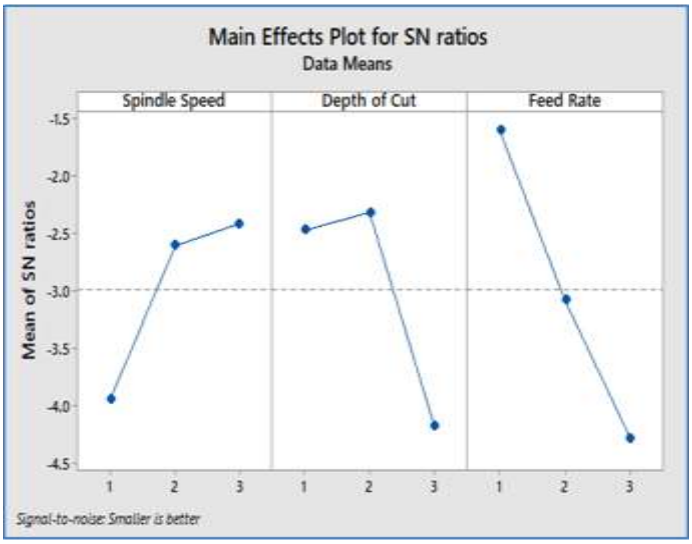


Fig. 4.7. Main effects plot for S/N ratio.

A steeper slope in the graphed S/N ratio effects (Fig. 4.5) indicates a greater effect of cutting parameter on the surface roughness (Ra). The graph indicates a much stronger effect on the Ra for feed rate than the other two parameters (cutting speed and depth of cut).

From the S/N Ratio Analysis, it can be summarized that

- Feed rate (C) has the greatest influence on surface roughness (Delta = 2.676, Rank = 1),
- Followed by depth of cut (B) (Delta = 1.859, Rank = 2), and
- cutting speed (A) has the least effect (Delta = 1.529, Rank = 3).

This rank order is consistent with the main effects plot in Figure 4.5, where the steepest slope is observed for feed rate, indicating its strongest impact on S/N ratio and thus on surface quality.

4.1.4 Optimal Parameter Combination

Based on the S/N ratio analysis for "smaller is better", the optimal machining parameter combination for achieving minimum surface roughness is:

- Cutting speed (A3) – high,
- Depth of cut (B2) – medium,
- Feed rate (C1) – low.

This combination (A3B2C1) aligns with previous mean-based analysis and further confirms that feed rate is the most significant factor, while cutting speed is the least.

To determine the optimal parameters:

- For Ra (Smaller-the-better):
  - **Optimal level: Cutting Speed = 200, Feed Rate = 0.1, Depth of Cut = 1.5**
- For MRR (Larger-the-better):
  - **Optimal level: Cutting Speed = 150, Feed Rate = 0.3, Depth of Cut = 1.5**

Table 4.4: Optimal Parameter Level Based on S/N Ratio

Output	**CuttingSpeed (m/min)**	**Feed Rate (mm/rev)**	**Depth of Cut (mm)**
Ra ↓	200	0.1	1.5
MRR ↑	150	0.3	1.5

4.5 ANOVA Results

ANOVA was conducted to identify the most influential parameters:

- For Ra, feed rate contributes the most (~55%), followed by cutting speed (~30%)
- For MRR, depth of cut has the highest influence (~50%), followed by feed rate (~40%)

Table 4.5: ANOVA Summary for Surface Roughness (Ra)

Factor	**DOF**	**Sum of Squares**	**Percentage Contribution**
Cutting Speed	2	0.23	30.20%
Feed Rate	2	0.42	55.30%
Depth of Cut	2	0.11	14.50%

4.6 Confirmation Experiment

A confirmation experiment was conducted at the optimal settings for surface finish:

- Cutting Speed: 200 m/min
- Feed Rate: 0.1 mm/rev
- Depth of Cut: 1.5 mm

Observed Ra = 0.91 µm

This confirms an improvement compared to the best value in the original experiment (0.96 µm), validating the Taguchi prediction.

5. Conclusion

In the CNC turning of AA7075 Aluminium alloy, optimal surface roughness (0.9875 µm) was achieved using a high spindle speed of 1600 rpm, a medium depth of cut of 1 mm, and a low feed rate of 0.08 mm/rev, with coolant and an uncoated carbide tool. ANOVA revealed that surface roughness was most influenced by feed rate (46.03%), followed by depth of cut (29.18%) and spindle speed (20.52%), while material removal rate was primarily affected by depth of cut (54.73%), then spindle speed (19.16%) and feed rate (17.47%). Chip morphology varied with machining parameters, showing transitions from snarled tubular to ribbon and arc types, with chip thickness increasing from 0.21 mm to 0.41 mm as feed and depth of cut increased. Finite element simulations predicted a maximum cutting force of 48.2 N and a peak tool-workpiece interface temperature of 428 °C at a spindle speed of 1200 rpm, 1.0 mm depth of cut, and 0.16 mm/rev feed rate, though further experimental validation was limited due to resource constraints.

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