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Enhancing Surface Roughness in the Taguchi Method for Turning Alloy Steel in Wet and Dry Environments

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Abstract

The present investigation focuses on evaluating the performance of turning operations in alloy steel with particular emphasis on the effect of cutting parameters on surface roughness. In the machining of alloy steel, tool life and surface integrity are significantly influenced by parameters such as spindle speed, depth of cut, and feed rate. Among these, feed rate has been observed to exert the most prominent effect on surface roughness. To systematically analyze these influences, the Taguchi method employing an L9 orthogonal array design was selected as the most suitable approach for experimental planning. This method not only reduces the number of experimental trials but also provides an efficient statistical framework to evaluate the contribution of individual parameters. Three levels were chosen for each cutting factor to comprehensively study their interactions and effects. The experiments were performed under both wet and dry turning conditions using a CNC lathe machine, with workpieces of 45 mm diameter and 145 mm length. For each condition, three sets of trials were conducted to ensure repeatability, and the average values were considered as the final outcomes. The signal-to-noise (S/N) ratio analysis was used to determine the robustness of the parameters, while analysis of variance (ANOVA) was employed to quantify the percentage contribution of each factor. Optimization of the experimental data was carried out using Minitab 17 software, which assisted in identifying the optimal combination of parameters for achieving minimum surface roughness. The results revealed that feed rate was the most critical factor influencing surface finish, followed by spindle speed and depth of cut. Furthermore, it was observed that wet turning yielded comparatively better results in terms of surface quality when compared to dry turning, thereby highlighting the importance of lubrication in improving machining performance. The findings of this work provide useful insights for industry practitioners to optimize cutting conditions, enhance tool life, and improve productivity in alloy steel machining. This study demonstrates the efficiency of the Taguchi method in machining optimization and emphasizes its applicability in both academic and industrial research contexts.

Keywords: Turning, orthogonal array, roughness, spindle, Taguchi method, signal-to-noise.

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INTRODUCTION

Manufacturing is the procedure of turning raw materials into completed products in order to satisfy consumer demands. This involves employing diverse manufacturing techniques to modify the physical characteristics of the raw materials, such as their shape and dimensions.

Turning Process

Turning is a fundamental machining process utilized to produce rotational components by removing material from a workpiece. The process requires a workpiece, a suitable setup, and a cutting tool, along with one or more turning machines to execute the operation effectively. The cutting tool, generally a single-point tool fixed to the machine, is positioned before the workpiece is clamped securely. When the workpiece rotates, the tool engages its surface, removing material in the form of small chips to generate the desired geometry and surface finish [1–6].

Ravikumar and Kulkarni examined the challenges in machining hard titanium alloys, which often experience severe tool wear due to their high strength and low thermal conductivity. Their study demonstrated that hard turning, a dry machining process using a single-point cutting tool, effectively addresses such issues for materials with Vickers hardness exceeding 45 HV. By employing the Taguchi L9 orthogonal array, they optimized cutting parameters to improve surface roughness and tool wear characteristics. The analysis of response tables revealed optimal conditions that enhanced the longevity of machined components, with tool wear assessed using a confocal microscope and surface roughness measured via Form Talysurf [7].

Similarly, an experiment was conducted to investigate the effects of cutting parameters and cutting fluid flow on surface roughness and tool wear using the Taguchi orthogonal array. Their results indicated that feed rate exerted the most significant influence on surface roughness (34.3%), while cutting fluid flow rate also had a notable impact (33.1%). Furthermore, cutting speed (43.1%) and depth of cut (35.8%) were identified as the key factors affecting tool wear. To provide higher surface quality and less tool wear, the ideal machining conditions were low feed rate, medium depth of cut, high cutting speed, and a low-flow, high-velocity cutting fluid [8].

This research was extended by applying a Taguchi-based Grey Relational Analysis approach to optimize the turning parameters for Grade 5 titanium alloy. Their findings revealed that cutting speed had a dominant effect on cutting force and tool life, whereas feed rate most strongly influenced surface roughness. Cutting speed was found to be the most important factor when cutting force, tool life, and surface roughness were all taken into account at the same time through L9 orthogonal array experiments [9–12].

METHODOLOGY

In the previous section, the goals of the current work were briefly discussed. As a result, the following experimental strategy was used to conduct the current investigation:

1. Examining and getting the lathe ready to carry out the machining task. Cutting steel bars with a control saw and turning them in a lathe to achieve the required workpiece dimensions (45 mm in diameter and 145 mm in length).
2. Using different combinations of procedure control parameters, such as spindle speed, feed, and depth of cut, to perform straight turning operations on specimens in both dry and wet situations.
3. For both dry and wet turns, the cut length was maintained at 50 mm.

Figure 1: Picture of the work piece before machining.

Table 1. Chemical composition of alloy steel in %.

C	Si	Mn	P	I	Cu	Ni	Al
0.75	6.5	0.5	0.015	1.3	3.0	0.5	87.4

Material Used

Because it was appropriate for the majority of engineering and construction applications, Alloy Steel bars (45 mm in diameter and 145 mm in length) were chosen as the material Figure 1.

Alloy Steel

Alloy Steel is an economical medium-carbon steel that displays suitable strength and toughness properties, making it applicable for components requiring induction or flame hardening. The bar's hardness is gauged at 187 HB. Table 1

Process Variables and their Limits

The software MINITAB 17 was employed to establish the experimental design, following Taguchi's L9 Orthogonal Array (OA). This current study incorporates essential process factors, specifically Spindle speed, feed, and depth of cut

RESULT AND DISCUSSION

Taguchi Main Effect Plots for Surface Roughness

The main effect plot illustrates the variation in surface roughness in relation to spindle speed, feed rate, and cut depth. The variable's change level is shown by the X axis, while the response's change is represented by the Y axis.

Analysis of S/N Ratio for Surface Roughness for Dry and Wet Turning

We can learn about the variations in the process from the signal to the nose of rats. This section displays the values of all the results according to the Taguchi array parameter design layout. To identify the main contributing factors to the variation of force levels, the S/N ratios have been calculated. In this situation, lower-the-better is employed (Figures 3 and 4).

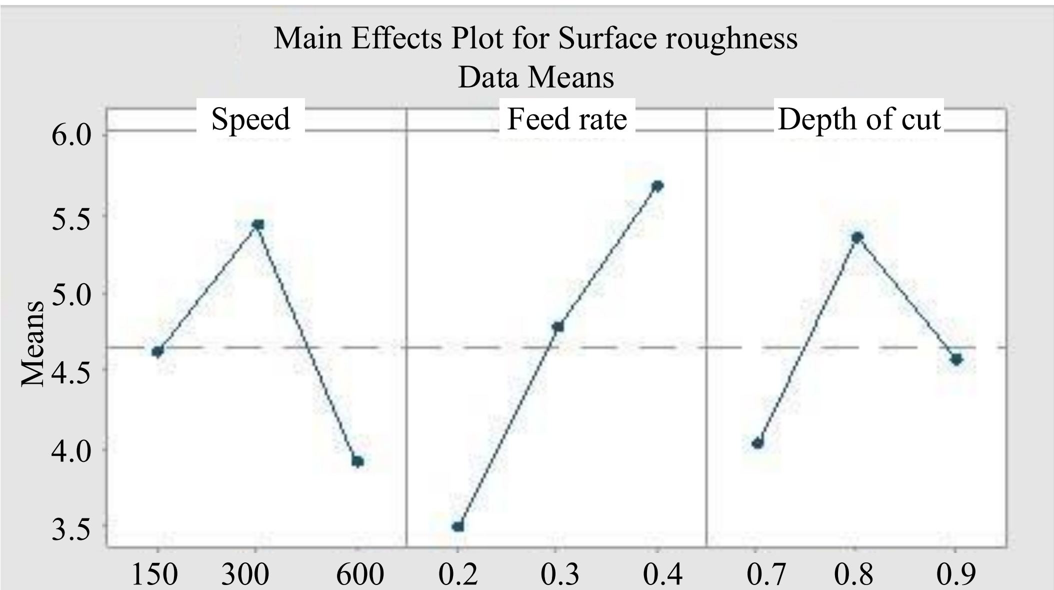

Figure 2. Main effects plot showing the influence of spindle speed, feed rate, and depth of cut on surface roughness during wet turning.

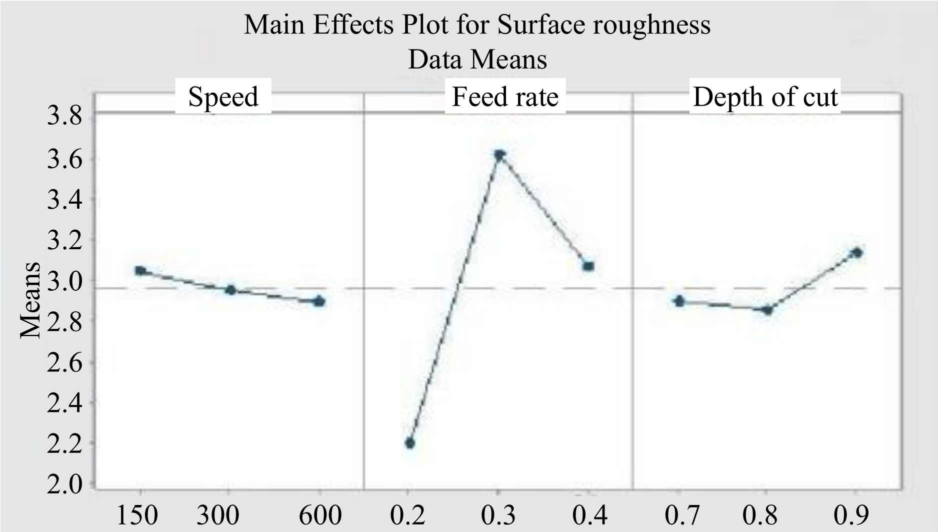

Figure 3. Main effects plot illustrating the variation of surface roughness with machining parameters under wet turning.

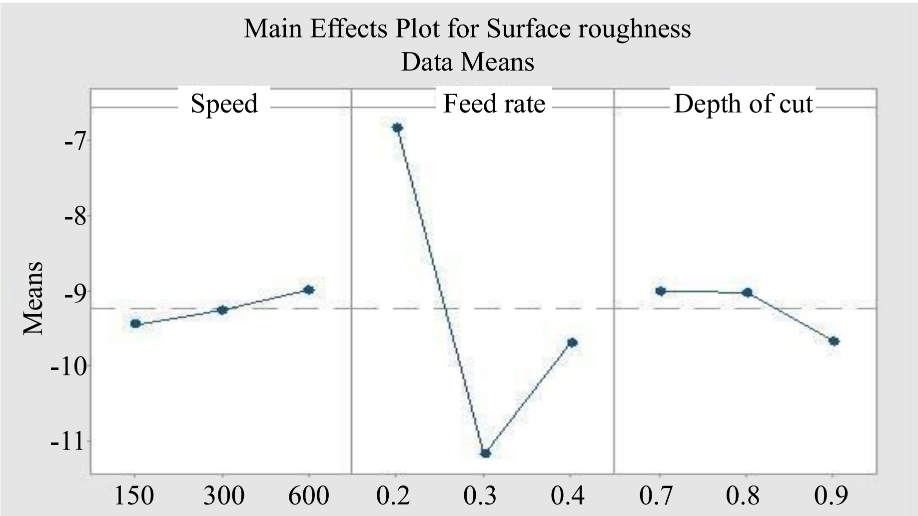

Figure 4. Main effects plot for S/N ratios for surface roughness in wet.turning.

CONCLUSION

The experimental investigation on dry turning of alloy steel clearly indicates that surface roughness is significantly influenced by the cutting parameters, namely feed rate, depth of cut, and spindle speed. Among these, feed rate emerges as the most dominant factor, as higher feed values consistently result in increased surface roughness due to greater tool-workpiece interaction and higher material removal per revolution. The effect of depth of cut is found to be nonlinear, where surface roughness initially increases with increasing depth of cut and subsequently decreases beyond a certain value. The equilibrium between cutting stability and chip production at various depths is responsible for this behavior.

On the other hand, spindle speed shows a reverse trend; as spindle speed increases, surface roughness decreases, suggesting that higher cutting speeds improve the finish by reducing built-up edge formation and ensuring smoother chip flow.

The Taguchi analysis and the signal-to-noise (S/N) ratio graph further validate these observations by identifying the optimal combination of parameters for minimizing surface roughness in dry turning. The best result was obtained at a spindle speed of 150 rpm, a feed rate of 0.2 mm/rev, and a depth of cut of 0.7 mm, which produced a minimum surface roughness value of 2.52 µm. This optimized setting demonstrates the potential of the Taguchi method in effectively predicting the machining conditions required for improved surface quality.

Overall, the study concludes that careful selection of feed rate, depth of cut, and spindle speed is crucial for achieving better surface finish in dry turning of alloy steel. The findings provide useful guidance for industries aiming to optimize machining performance while minimizing surface defects and tool wear under dry cutting conditions.

Conclusion from Surface Roughness in Wet Turning

The analysis of wet turning experiments reveals that surface roughness is predominantly influenced by depth of cut, feed rate, and spindle speed, with depth of cut being the most critical parameter. It is observed that an increase in depth of cut generally leads to higher surface roughness due to greater cutting forces and tool-workpiece interaction. Conversely, a reduction in feed rate improves the surface quality, as lower material removal per revolution results in finer tool marks on the surface. The spindle speed has a positive effect; greater speeds often result in less surface roughness.

This improvement at elevated spindle speeds can be attributed to smoother chip formation, reduced built-up edge, and effective lubrication provided in wet conditions.

The signal-to-noise (S/N) ratio analysis supports these findings and highlights the optimal machining parameters for minimizing surface roughness. The best performance was obtained at spindle speed =600 rpm, feed rate =0.2 mm/rev, and depth of cut =0.9 mm, which resulted in a minimum surface roughness value of 2.11 µm. The reduced surface roughness under wet turning compared to dry turning emphasizes the positive role of coolant in dissipating heat, reducing friction, and enhancing the overall surface finish.

In summary, wet turning provides superior surface quality compared to dry turning, with optimal results achieved through careful selection of cutting parameters, particularly by controlling depth of cut and utilizing higher spindle speeds. The outcomes of this study highlight the effectiveness of wet machining in achieving smoother surfaces in alloy steel, making it a preferred approach for applications where a high-quality surface finish is critical.

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