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Study Effects of the Milling Parameters on the Surface Roughness of Low Carbon Steel AISI 1015

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ABSTRACT

The machining process is a technique that uses a cutting tool to remove small chips of material from a work piece. Milling operation encompasses various tasks and tools, from small individual parts to large-size components. It is one of the most commonly used techniques for producing custom parts with exact tolerances. The surface roughness of machined parts significantly impacts the finished item's quality and performance. This paper studies predicting the values of surface roughness of low-carbon steel AISI 1015 in milling operations. Three different machining parameters, each has three levels, are selected to investigate the resultant surface roughness of the AISI 1015 low-carbon steel samples, including different spindle speeds, feed rates, and depths of cut. The results revealed that the feed rate of 100 mm/min at a spindle speed of 930 rpm and a depth of 1.5 mm produced, which has the lowest surface roughness (Ra) value of 1.170 µm, while the feed rate of 300 mm/min at a spindle speed of 1100 rpm produced the greatest surface roughness value of 2.605 µm.

1. Introduction

A milling operation achieves the current industry's most popular method for machining metals. At least one stage of manufacturing several pieces must involve milling operations. CNC milling operation is one of the most often utilized processes due to its adaptability and flexibility, which enables the production of goods in a shorter amount of time at a high level of quality and an affordable price [1]. The milling process involves feeding the workpiece against a spinning cutter with several cut edges on a flat, curved, or uneven surface. The basic components of milling machines are a reciprocating adjustable worktable that feeds sand and mounts the workpieces and a motor-driven spindle that mounts and rotates the mill cutters. In essence, they can be categorised as horizontal or vertical. Most milling machines have self-contained coolant systems, electric drive motors, power-operated table feeds, and variable spindle speeds [2]. To reduce production costs and get the needed level of product quality, determining the best machining conditions is viewed as an effective engineering effort in terms of time-saving and accuracy. Surface roughness is one of the most important performance indicators in the milling process. The machining hour rate and the cost of production are assumed to be directly influenced by the smaller Ra, which is required for an efficient milling operation [3, 4]. For different reasons, the surface finish has been the focus of in-depth research. To simulate Ra, various researchers have

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also used a variety of techniques, such as static techniques.
Additionally, various procedures or methodologies have been used to optimize process parameters. Numerous recent scientific investigations have used the Analysis of Variance (ANOVA) approach because of its powerful prediction capabilities [1, 5]. Rajdran, et al, 2008 [6] employed a mathematical regression model to calculate tool wear that considers milling's link to output value and input value features including feed, depth, and cutting speed. In an experiment based on the design experiment technique, an HSS cutter was used to test the universal milling machine for AISI 1020 steel. Azln and Safiian, 2009 [7] developed a mathematical model for anticipating values to comprehend milling machining. Surface finish was one of the key characteristics used to gauge milling performance and the caliber of machining surfaces.
Regression models are developed using the Statistical Package of Social Science software to find the value of coefficients. The developing model deals with the real experimental value of the surface roughness performance measure using end mill machining operation. Khair, et al, 2021[8] focused on reducing surface roughness for the cutting-off or parting operation during the turning process by optimizing the machining parameters cutting speed (v), feed rates (f), and depth of cut (d). The findings showed that a better surface finish could be achieved at a minimum cutting speed of 140 m/min; a minimum feed rate of 0.01 mm/rev, and a minimum depth of cut of 1 mm.
Moreover, the feed rate and cutting speed significantly impacted the surface roughness of AISI D3 steel, demonstrating their dependability in achieving the desired level of surface roughness. Lubaid, et al, 2021 [9] examined how the carbide tool's dimensional inaccuracy and surface roughness affected each milling process parameter. Taguchi's L9 orthogonal array was used to maximize the performance characteristics of pocket-milling, and the GRA approach was then used to identify the ideal set of parameters. The experiment shows that X3Y1Z1, or a spindle speed of 3000 rpm, a feed rate of 200 mm/min, and a depth of cut of 0.1 mm, is the ideal set of settings for pocket-milling pure copper.
According to the ANOVA results, the feed rate of 77.20% has the greatest impact on the dimensional accuracy and surface roughness of the workpiece, while the spindle speed of 13.72%, and the depth of cut at 0.38%, were found to be the second and third orders, respectively. Lujain H. Kashkool, 2022 [10] utilized a TiN-coated carbide insert to examine how turning machining operations affected the surface roughness of AISI 1045 steel. The results showed that the lowest Ra value is obtained at a feed rate of 50 mm/min at a spindle speed of 355 rpm, while the maximum Ra value is produced at a feed rate of 160 mm/min at a spindle speed of 710 rpm. In general, higher spindle speeds led to higher Ra, while lower spindle speeds led to lower Ra.
The Analysis of Variance (ANOVA) method is used in this study to estimate how the milling parameters of spindle speed (rpm), feed rate (mm/min), and depth of cut (mm) will affect the intended output surface roughness (Ra).

2. Experimental Work

2.1 Materials

Low-carbon steel AISI 1015 is selected to machine the specimens. The chemical work mentioned in Table (1) consults with the central organization for quality assurance and standardization. Figure (1) depicts a sample that has been cut using an end mill or a horizontal milling machine (CNC ACCUWAY UM-85) by using the machining parameters listed in Table (2).

Table 1. Chemical composition for Low Carbon steel AISI 1015.

Material	Si%	Cu%	Mn%	S%	C%
Weight	0.301	0.232	0.392	0.024	0.138
Material	Cr%	Ni%	Co%	P%	Fe%
Weight	0.221	0.089	0.006	0.014	Bal.
Material	Al	Zr	Nb	V	Mo
Weight	0.001	0.001	0.001	0.0005	0.030
Material	W	Ta	Sn	Ti	Zn
Weight	0.005	0.014	0.011	0.001	0.002

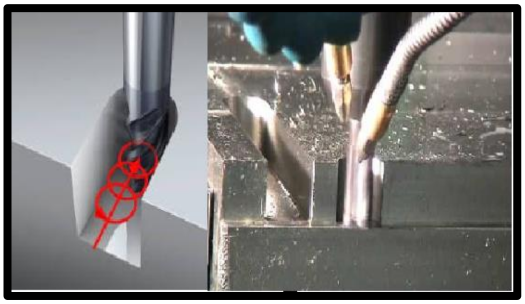

Figure 1. Specimens after machining

2.2 Selection of Parameters

The parameters that affect surface roughness include the feed rate (mm/min), spindle speed (rpm), and depth of cut (mm). Three levels of each cutting parameter are taken into consideration. The experimentation levels and parameter values are listed in Table (2).

Table 2. Levels and Process Parameters

Sr. No.	Process Parameter	Levels		
		1	2	3
1	Spindle Speed N (rpm)	930	1100	1450
2	Feed Rate f (mm/min)	100	200	300
3	Depth of cut d (mm)	1.5	2	2.5

2.3 Calculations of the Surface Roughness

The surface roughness (Ra) calculations are repeated four more times after milling at various locations, and the average result is then selected. Ra average values can represent the roughness of a machined surface. A pocket surf surface roughness tester is used to determine the value of Ra in the subsequent test.

3. Design of Experiments

3.1 The Taguchi Approach and the Experimental Design Method

Taguchi is an effective, straightforward, and systematic method for identifying the ideal machining conditions in the production process, which is produced through the design of experiments utilizing the Taguchi method [11].

In this study, the relationship between the machining parameters of feed rate, depth of cut, and spindle speed was investigated (N). To evaluate all the parameters with the fewest number of experiment trials possible, Taguchi developed the unique idea of an orthogonal array (OA), which sped up the experimental process.

In this study, the L9 orthogonal array is used, and experiments are produced with the aid of the MINITAB 18 statistical tool. The Taguchi method uses the signal-to-noise (S/N) ratio to quantify performance characteristics that deviate from the required levels. According to Taguchi's (smaller the better) strategy, which is represented in Eq. (1) and tries to reduce surface roughness [12], the (S/N) ratio is determined. The Taguchi orthogonal L9 array and experimental results are shown in Table 3.

$$S/N = -10\log_{10}(\sum Y^2/n) \qquad (1)$$

Where,
n: the number of measurements
y: the given factor level combination.

Table 3. Levels of the cutting parameters and the values of the surface roughness

No.	Spindle Speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	Surface Roughness (µm)	Predicted
1	930	100	1.5	1.170	1.28889
2	930	200	2.0	1.760	1.62389
3	930	300	2.5	1.620	1.63722
4	1100	100	2.0	1.840	1.85722
5	1100	200	2.5	1.600	1.71889
6	1100	300	1.5	2.605	2.46889
7	1450	100	2.5	1.550	1.41389
8	1450	200	1.5	1.995	2.01222
9	1450	300	2.0	2.380	2.49889

3.2 Analysis of Variance

The statistical significance of the milling parameters is examined using analysis of variance (ANOVA) to examine the interactions and contributions of the various components. Table 4 displays the ANOVA findings for (Ra). The statistical significance of the milling parameters is examined using ANOVA to examine the interactions and contributions of the various components. Table 4 displays the (ANOVA) findings for Ra.

The Degree of Freedom (DOF) corresponding to each factor, Mean Square (MS), Sum of Squares (SS), F-ratio, and percentage contribution are often included in the ANOVA Table (4). The feed rate is projected to be the most significant cutting parameter in the current work, contributing (45.826%). During the milling operation, the spindle speed and cut depth contribute 29.753% and 18.026% to the surface roughness.

Table (4) shows the overall significance of the Ra values. The value for Ra is calculated below, as shown in equation (2) to represent the relationship between the machining parameters (spindle speed, feed rate, and depth of cut) and the response, represented by the surface roughness.

$$Ra\ (\mu m) = 1.8356 - 0.319\ N\_930 + 0.179\ N\_1100 + 0.139\ N\_1450 - 0.316\ f\_100 - 0.051\ f\_200 + 0.366\ f\_300 + 0.088\ d\_1.5 + 0.158\ d\_2.0 - 0.246\ d\_2.5 \quad (2)$$

Table 4. Analysis of variance (ANOVA) for the workpiece.

Source of variance	DF	Adj SS	Adj MS	F-Value	P-Value	(%) Contribution
N	2	0.460	0.230	4.65	0.177	29.753
f	2	0.709	0.354	7.17	0.122	45.826
d	2	0.279	0.139	2.82	0.262	18.026
Error	2	0.099	0.0494	-	-	-
Total	8	1.546				

4. Results and Discussion

The correlation between the predicted and measured value of surface roughness is shown in Figure 2. There is a greater degree of agreement between the two bar charts. A portable surface roughness tester is used to assess surface roughness for all tests, demonstrating how well the Taguchi technique predicts the variables. The machining parameters are examined using ANOVA, which also identifies the conditions that substantially impact the quality characteristic. This analysis is utilized to determine the parameters' contribution to controlling the milling processes' output. The values of "P%" in Table (4) illustrate the effectiveness of all the correlations between the predicted and measured surface roughness values shown in Figure 2. There is a greater degree of agreement between the two bar charts. A portable surface roughness tester is used to assess surface roughness for all tests, demonstrating how well the Taguchi technique predicts the variables. The machining parameters are examined using ANOVA, which also identifies the conditions that have a substantial impact on the quality characteristic. This analysis is utilized to find out the contribution of parameters in controlling the output of the milling processes. The values of "P%" in Table (4) illustrate the effectiveness of all conditions related to the response characteristics within the limiting range. The feed rate is one of the key criteria for achieving the least surface roughness. According to Table 4, the spindle speed is the second important parameter for minimizing surface roughness.

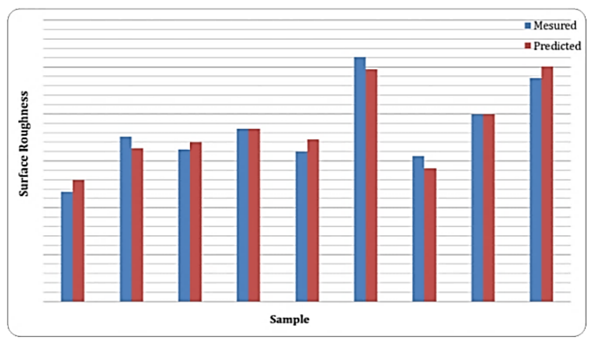

Figure 2. shows the comparison between the predicted and measured surface roughness for the experimental value

The relationship between the means of surface roughness and the mean signal-to-noise ratio is plotted in Figures 3 and 4. It is clear from these figures that the feed rate has a significant impact on surface roughness. Surface roughness will be at its minimum value when the feed rate is equal to 100 mm/min. On the other hand, at a feed rate of 300 mm/min, the surface roughness will reach its maximum value.

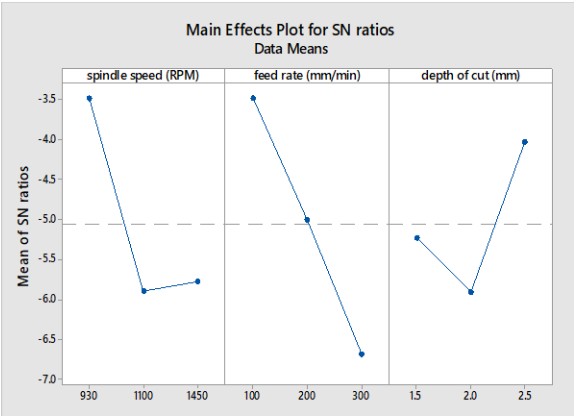

Figure 3. Main Effect Plot of Surface Roughness

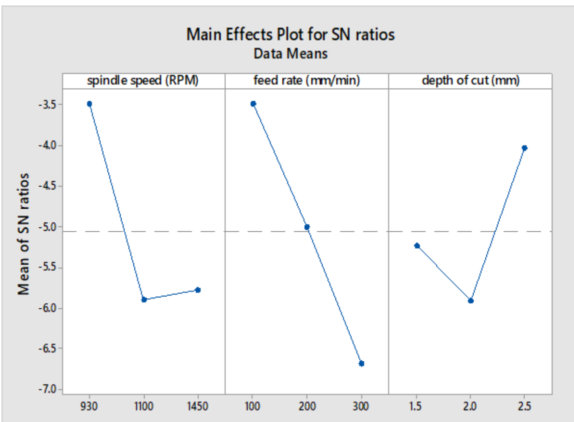

Figure 4. Signal-to-Noise Ratio Main Effect Plot

The surface plots of surface roughness vs (spindle speed and feed rate), (spindle speed and depth of cut), and (feed rate and depth of cut) are illustrated in Figures 5, 6, and 7 respectively. From Figure 5, the greater (Ra) can be obtained when the spindle speed is 1100 r.p.m and the feed rate is 300 mm/min. From Figure 8, the greater (Ra) can be obtained when the spindle speed is 1100 r.p.m and the depth of cut is 1.5 mm. From Figure 7, the greater (Ra) can be calculated when the feed rate is 300 mm/min, and the depth of cut is 1.5 mm. This indicates that increasing roughness results from increased feed rate and decreased depth of cut, and vice versa.

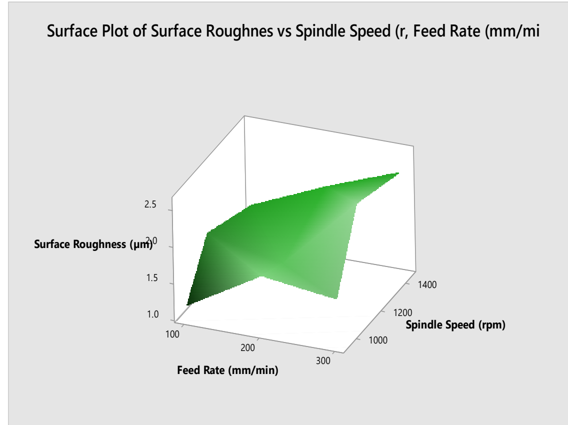

Figure 5. Surface plot of Ra vs spindle speed, feed rate

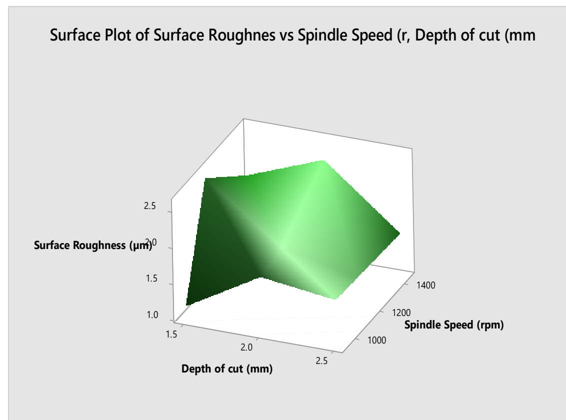

Figure 6. Surface plot of Ra vs spindle speed, depth of cut

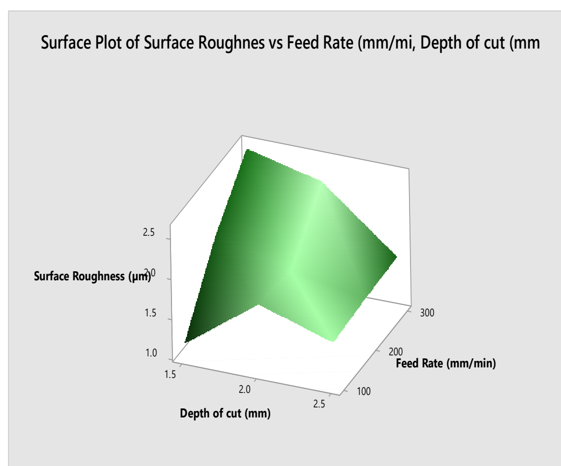

Figure 7. Surface plot of Ra vs feed rate, depth of cut

5. Conclusion

Several concluding remarks are drawn from this research as follows: The quality of the finished item, which may impact its tolerance and performance, is significantly influenced by the surface roughness of machined parts. This research examines the estimation of low-carbon steel AISI 1015 surface roughness values during milling operations.

Nine variable samples are chosen to evaluate the final surface roughness of the AISI 1015 low-carbon steel samples. Three machining parameters, such as various spindle speeds, feed rates, and depths of cut, are used in the experiment design.

Based on the results, the feed rate of 100 mm/min at 930 rpm spindle speed and a depth of 1.5 mm provided the lowest surface roughness (Ra) value of 1.170 m, while the feed rate of 300 mm/min at 1100 rpm spindle speed produced the highest surface roughness value of 2.605.

Comparative results show that the predicted values generated by the Taguchi method and the experimental results are in good agreement. It could be demonstrated that higher surface roughness will result from higher spindle speeds.

Further research work can be achieved using AI, such as artificial neural networks, to predict the best value of Ra.

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