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**Research Article**

# Investigate the Influence of Process Factors on the Surface Roughness of Stainless Steel

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Abstract: In this article, the effects of critical turning parameters—namely rotational speed, feed speed, and cutting depth—on surface roughness were comprehensively examined during longitudinal turning operations without the use of coolant. The investigation was conducted using a carbide cutting tool (Ken100-P30-2300K) on nine cylindrical specimens of Stainless Steel 316. The cutting depth was held constant at 0.5 mm, given its negligible influence on surface roughness. Rotational speeds were varied at 100, 500, and 1500 RPM, while feed speeds were adjusted to 0.15, 0.3, and 0.6 mm/rev, utilizing a conventional lathe machine. The analysis revealed a direct proportionality between feed speed and surface roughness, where an increase in feed speed corresponded to a rise in surface roughness. Conversely, an inverse relationship was established between rotational speed and surface roughness, indicating that higher rotational speeds generally resulted in reduced roughness. Notably, an anomalous increase in surface roughness was observed at a rotational speed of 500 RPM when the feed speed was maintained at 0.3 mm/rev. Beyond this point, the inverse trend resumed consistently across other feed speed settings. The optimal cutting conditions for minimizing surface roughness in Stainless Steel 316 were identified at a rotational speed of 1500 RPM and a feed speed of 0.15 mm/rev. These findings provide valuable insights for optimizing machining parameters to achieve superior surface finish in turning operations.

**Keywords:** Turning process, surface roughness, Rotational speed, Feed speed, Cutting depth, Chemical composition.

## 1. Introduction

The lathe machine represents a fundamental instrument in industrial manufacturing, playing a pivotal role in the design and production of precision-engineered components [1]. Over the years, the development of lathe technology has been marked by significant advancements aimed at enhancing machining accuracy, efficiency, and adaptability to complex geometries [2]. One of the most critical considerations in machining is the surface finish of the workpiece, as surface roughness directly affects the overall quality, functionality, and efficiency of the manufacturing process.

Surface roughness is a key determinant of surface integrity and precision, with far-reaching implications for performance, particularly in components subjected to dynamic or fluctuating loads. A smoother surface minimizes friction between interacting mechanical parts, thereby enhancing wear resistance, improving fatigue life, and promoting efficient energy transfer. Additionally, precise surface finishes mitigate vibrations during machining operations, reducing defects and improving dimensional accuracy [3].

Numerous factors influence surface roughness, among which rotational speed, cutting depth, and feed speed are the most critical. The relationship between these parameters and surface roughness is well-established. Rotational speed exhibits an inverse relationship with surface roughness, whereby higher speeds generally result in smoother surfaces. Conversely, feed speed displays a direct relationship, where increased feed rates typically contribute to greater surface roughness. Cutting depth, while still a factor, has a relatively minor effect compared to the other parameters [4]. Advanced methods for evaluating surface roughness include tactile (contact-based) devices and optical measurement systems, the latter offering superior precision and non-intrusive measurement capabilities

In this article, a conventional lathe machine (model XL580VSx3000), manufactured in 2013 and capable of operating within a speed range of 1 to 2000 RPM, was employed to systematically assess the effects of key machining parameters—rotational speed, cutting depth, and feed speed—on surface roughness. The workpieces were composed of Stainless Steel 316, a corrosion-resistant alloy widely utilized in various industrial applications and readily available in the local market. This material was selected due to its high durability, machinability, and widespread use in precision components. The primary objective of this research is to experimentally evaluate the surface roughness of machined workpieces by maintaining constant parameters for workpiece material, cutting depth, and cutting tool type, while varying the feed speed and rotational speed. Specifically, the study aims to establish the relationship between feed speed and surface roughness at a fixed rotational speed, as well as the relationship between rotational speed and surface roughness at a constant feed speed. The experimental data and corresponding analysis will facilitate the identification of optimal operating conditions for machining Stainless Steel 316, ultimately contributing to enhanced surface quality and process efficiency in industrial applications.

## 2. Methodology

The surface finish of the machined metal Stainless Steel 316 reflects the product's quality. Several factors influence surface finish during machining, including Cutting depth, feed speed, Rotational speed, and other operational conditions such as the type and age of the lathe machine, the cutting tool, and other factors affecting the quality of the machined surface. Figure 1 presents illustration of the lathe machine.

**Figure 1.** Illustration of the lathe machine.

## 3. Cutting Tool

Different kinds of cutting tools are needed for various cutting operations under various circumstances. Depending on the type of machining, the substance of the workpiece, and the amount and quality of production, different materials are used to make cutting tools. Hard materials that can tolerate high temperatures, strong cutting pressures, and wear resistance are usually used to make these tools. They satisfy the demands of contemporary applications, preserve dimensional precision, increase process effectiveness, save expenses, improve surface polish, and lessen vibrations [5]. A carbide tool (Ken100-P30-2300K) made in Pakistan was utilized in this investigation [6]. Figure 2 illustrates cutting tool used in the investigation.

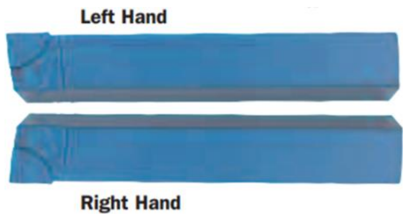


**Figure 2.** Cutting tool used in the invitigation.

**Table 1.** Specifications of the cutting tools.

| Tool No. | Cut | Shank | | Weight | Order Code | | |
|---|---|---|---|---|---|---|---|
| | | Height | Width | Each | P40 | P30 | K20 |
| 100 | RH | 3/8" | 3/8" | 70g | - | -2010k | - |
| 101 | LH | 3/8" | 3/8" | 70g | - | -2040k | - |
| 102 | RH | 1/2" | 1/2" | 120g | -2055k | -2060k | -2080k |
| 103 | LH | 1/2" | 1/2" | 120g | - | -2100k | -2210k |
| 106 | RH | 5/8" | 5/8" | 260g | - | -2180k | - |
| 110 | RH | 3/4" | 3/4" | 440g | - | -2280k | -2290k |
| 111 | LH | 3/4" | 3/4" | 440g | - | -2300k | - |

## 4. Surface Roughness Measurement

Various methodologies have been developed to assess surface roughness, with the most common techniques involving tactile (contact-based) devices and optical measurement systems. Tactile devices, often relying on a stylus that physically traces the surface, provide reliable and cost-effective measurements. However, optical devices, which utilize non-contact methods such as laser interferometry or confocal microscopy, generally deliver higher accuracy and precision due to their ability to detect fine surface features without mechanical interference [7-10]. In this work, a SURTRONIC 3+ surface roughness measuring device, manufactured by Taylor-Hobson, was employed to accurately quantify the roughness of the machined surfaces. The device, widely recognized for its portability and precision, operates based on contact-based profiling, making it well-suited for industrial applications requiring on-site measurements. Figure 3 demonstrates surface roughness measurement device (SURTRONIC 3+).


**Figure 3.** Surface roughness measurement device (SURTRONIC 3+).

## 5. Workpiece Material

The material selected for this investigation was Stainless Steel 316, a high-performance, corrosion-resistant alloy known for its superior mechanical properties, including high tensile strength, excellent machinability, and resistance to pitting and crevice corrosion. Its chemical composition, primarily containing chromium, nickel, and molybdenum, makes it ideal for applications involving harsh or corrosive environments [9,10]. Due to its widespread industrial use in sectors such as marine, chemical, and aerospace engineering, Stainless Steel 316 was chosen as a representative material for this study. The material was readily sourced from the local market, ensuring consistency and availability. Figure 4 illustrates the raw cylindrical steel samples used for machining.

**Figure 4.** Samples of raw Stainless Steel 316.

- Chemical Properties of Stainless Steel

*a)* Iron (Fe), chromium (Cr), and other elements like nickel (Ni), manganese (Mn), molybdenum (Mo), and carbon (C) make up the majority of stainless steel. These components give stainless steel its unique qualities, including strength, endurance, and resistance to corrosion [10,12].

*b)* Chemical Properties:

Content of Chromium (Cr): Rust and corrosion are avoided by the passive layer of chromium oxide ($CrO_3$) that is formed on the surface by chromium (10.5% or higher). Toughness, ductility, and resilience to acids and alkalis are all improved by nickel (Ni). frequently found in austenitic stainless steels, such as grades 304 and 316. In chloride-rich settings, as those found in marine applications (e.g., 316 stainless steel), molybdenum (Mo): Increases resistance to pitting corrosion [13,14]. Carbon (C): Found in different concentrations, carbon increases strength and hardness but can decrease corrosion resistance if present in large quantities. Additional Components: Wear resistance and hardness are enhanced by manganese (Mn). Oxidation resistance is improved by silicon (Si). Strength and resilience to corrosion are increased by nitrogen (N).

- Chemical Composition of 316 Stainless Steel

A well-liked austenitic grade, 316 stainless steel is renowned for its exceptional resistance to corrosion, especially in settings high in chloride. The chemical, medical, and marine sectors all make extensive use of it. Organizations like ASTM and UNS have established standards for the composition of 316 stainless steel [11-13]. Table 2 shows chemical composition of 316 Stainless Steel.

**Table 2.** Chemical composition of 316 Stainless Steel.

| Element | Symbol | Composition (% by weight) |
|---|---|---|
| Chromium | Cr | 16.0–18.0 |
| Nickel | Ni | 10.0–14.0 |
| Molybdenum | Mo | 2.0–3.0 |
| Manganese | Mn | ≤ 2.0 |
| Silicon | Si | ≤ 1.0 |
| Carbon | C | ≤ 0.08 |
| Phosphorus | P | ≤ 0.045 |
| Sulfur | S | ≤ 0.030 |
| Nitrogen | N | ≤ 0.10 |
| Iron | Fe | Balance |

*c)* Features of the Composition:

Chromium (Cr): By creating a passive oxide layer, it resists corrosion. Toughness, ductility, and resistance to chemical attack are all enhanced by nickel (Ni). Particularly in chloride and marine conditions, molybdenum (Mo) improves resistance to pitting and crevice corrosion. To prevent carbide precipitation, which can impair corrosion resistance, carbon (C) should be kept to 0.08%. Fe (iron): The primary component, forming the base of the alloy [14,15].

## 6. Rotational Speed (N)

Rotational speed refers to the number of revolutions completed by the workpiece per minute (RPM). It is a critical parameter in machining processes, directly influencing the interaction between the cutting tool and the material. Variations in rotational speed significantly impact surface roughness, tool wear, and overall machining performance, with higher speeds generally contributing to smoother surface finishes. In this direction, feed speed denotes the distance traveled by the cutting tool along the workpiece axis per revolution, expressed in mm/rev [15-17]. In longitudinal turning, this movement occurs parallel to the workpiece's axis, ensuring continuous material removal along its length. Controlling feed speed is crucial for achieving the desired surface finish, as increased feed rates typically lead to higher surface roughness. Figure 5 illustrates the direction of feed speed during longitudinal turning operations.

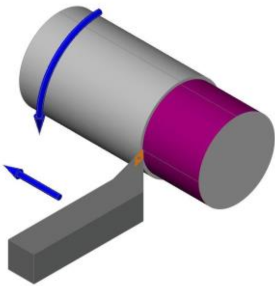

**Figure 5**. Illustration of feed speed direction.

## 7. Results

In this study, data were collected from nine symmetrical cylindrical samples of Stainless Steel316 with a diameter of 25mm. The effects of Rotational speed and feed speed on surface roughness were investigated while keeping the Cutting depth constant at 0.5 mm. The Rotational speed was varied at (100, 500, 1500RPM) and the feed speed was varied at (0.15, 0.3, and 0.6mm/rev). Table 3 indicates Surface roughness results at a feed speed of 0.15mm/rev. Table 4 shows the results obtained when the feed speed is changed to (0.3mm/rev).

**Table 3.** Surface roughness results at a feed speed of 0.15mm/rev.

| **Rotary speed (R.P.M.)** | 100 | 500 | 1500 |
|---|---|---|---|
| **Roughness ratio (μm)** | 2.69 | 2.38 | 2.31 |
| **Feed speed (mm/rev)** | 0.15 | 0.15 | 0.15 |
| **Cutting depth (mm)** | 0.5 | 0.5 | 0.5 |

**Table 4.** Surface roughness results at a feed speed of 0.3mm/rev.

| **Rotary speed (R.P.M.)** | 100 | 500 | 1500 |
|---|---|---|---|
| **Roughness ratio (μm)** | 5.22 | 5.42 | 3.55 |
| **Feed speed (mm/rev)** | 0.3 | 0.3 | 0.3 |
| **Cutting depth (mm)** | 0.5 | 0.5 | 0.5 |

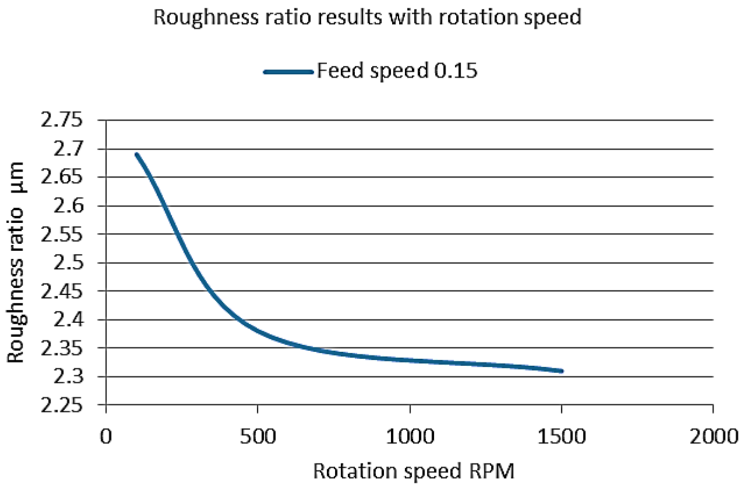


**Figure 6.** Relationship between surface roughness and Rotational speed at a feed speed of 0.15mm/rev.

From Figure 6, it is observed that as the Rotational speed increases, the surface roughness decreases, indicating an inverse relationship, with the Cutting depth and feed speed fixed at 0.5mm and 0.15mm/rev, respectively.

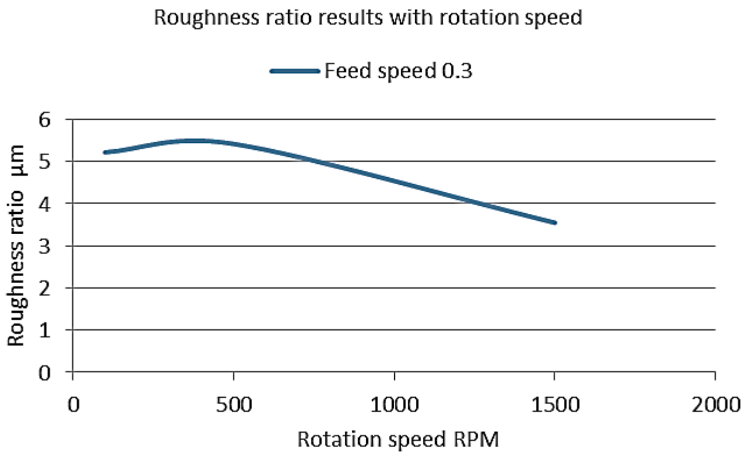


**Figure 7.** Relationship between surface roughness and Rotational speed at a feed speed of 0.3mm/rev.

From Figure 7, a slight increase in surface roughness is observed at 500RPM compared to 100RPM after which the surface roughness decreases with increasing Rotational speed, indicating an inverse relationship up to 1500RPM, with the Cutting depth and feed speed fixed at 0.5mm and 0.3mm/rev, respectively. Table 5 presents surface roughness results at a feed speed of 0.6mm/rev.

**Table 5.** Surface roughness results at a feed speed of 0.6mm/rev.

| **Rotary speed (R.P.M.)** | 100 | 500 | 1500 |
|---|---|---|---|
| **Roughness ratio (µm)** | 17.48 | 14.04 | 10.44 |
| **Feed speed (mm/rev)** | 0.6 | 0.6 | 0.6 |
| **Roughness ratio (mm)** | 0.5 | 0.5 | 0.5 |

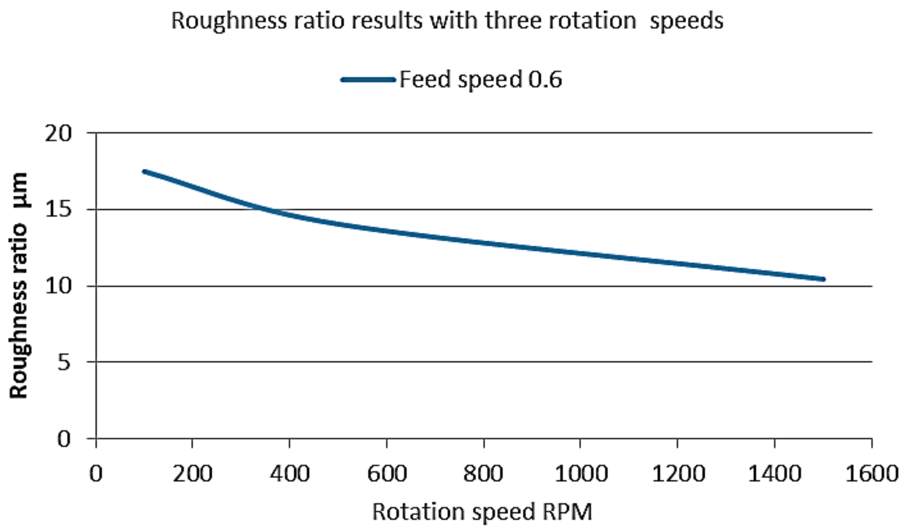


**Figure 8.** Relationship between surface roughness and Rotational speed at a feed speed of 0.6mm/rev.

From Figure 8, it is observed that at a Rotational speed of 100RPM, the surface roughness is 17.48µm. As the Rotational speed increases to 500RPM, the surface roughness decreases to 14.04µm, and at 1500RPM, it further decreases to 10.44µm. This indicates an inverse relationship between Rotational speed and surface roughness, with the Cutting depth and feed speed fixed at 0.5mm and 0.3mm/rev, respectively .Three feed speed were used in this study: (0.15, 0.3, 0.6mm/rev), with the Rotational speed fixed at (100, 500, 1500RPM) as shown in Table 6.

**Table 6.** Surface roughness results at a Rotational speed of 100RPM.

| Feed speed (mm/rev) | 0.15 | 0.3 | 0.6 |
|---|---|---|---|
| Roughness ratio (µm) | 2.69 | 5.22 | 17.48 |
| Rotary speed (R.P.M.) | 100 | 100 | 100 |
| Depth of cut (mm) | 0.5 | 0.5 | 0.5 |

Table 6 shows the results of the surface roughness ratio readings obtained when using different rotational speeds with both the Cutting depth (0.5mm) and the feed speed (feed) (0.15mm/rev) fixed.

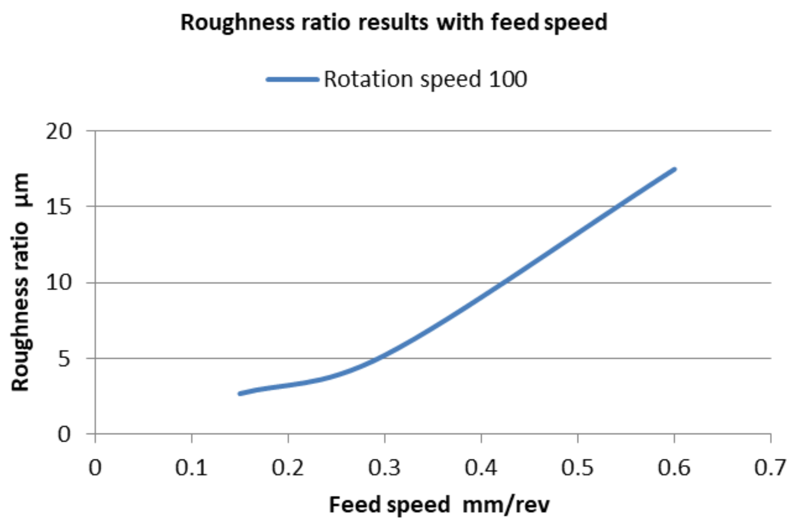


**Figure 9.** Relationship between surface roughness and feed speed at a Rotational speed of 100RPM.

From Figure 9, it is observed that at a feed speed of 0.15mm/rev, the surface roughness is 2.69µm. As the feed speed increases to 0.3mm/rev, the surface roughness increases to 5.22µm, and at 0.6 mm/rev, it further increases to 17.48µm. This indicates a direct relationship between feed speed and surface roughness, with the Cutting depth and Rotational speed fixed at 0. mm and 100RPM, respectively. Table 7 shows the results obtained with the rotational speed fixed at the value (500R.R.M).

**Table 7.** Surface roughness results at a Rotational speed of 500RPM

| Feed speed (mm/rev) | 0.15 | 0.3 | 0.6 |
|---|---|---|---|
| Roughness ratio (µm) | 2.38 | 5.42 | 14.04 |
| Rotary speed (R.P.M.) | 500 | 500 | 500 |
| Depth of cut (mm) | 0.5 | 0.5 | 0.5 |

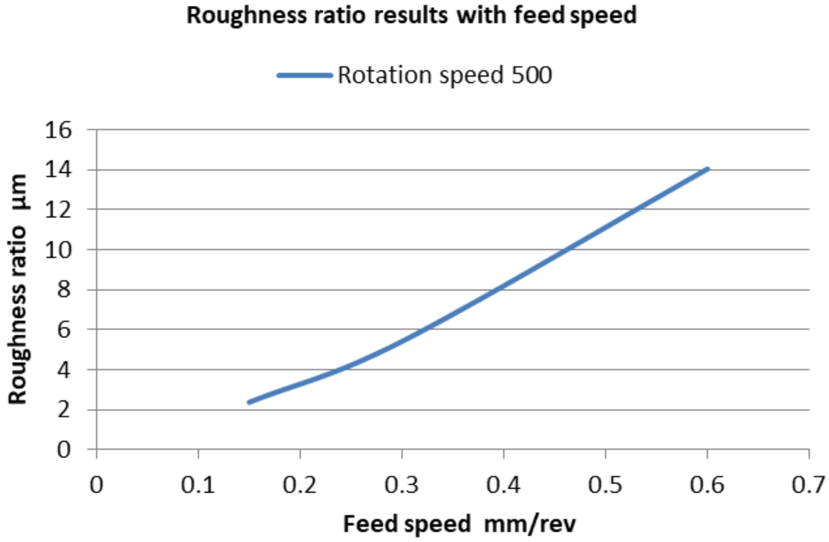


**Figure 10**. Relationship between surface roughness and feed speed at a Rotational speed of 500 RPM.

From Figure 10, it is observed that at a feed speed of 0.15mm/rev, the surface roughness is 2.38µm. As the feed speed increases to 0.3mm/rev, the surface roughness increases to 5.42µm, and at 0.6 mm/rev, it further increases to 14.04µm. This indicates a direct relationship between feed speed and surface roughness, with the Cutting depth and Rotational speed fixed at 0.5mm and 500RPM, respectively . Table 8 shows the results of the roughness ratio with the feed speed when the rotational speed is fixed at (1500 R.P.M.).

**Table 8.** Surface roughness results at a Rotational speed of 1500RPM.

| **Feed speed (mm/rev)** | 0.15 | 0.3 | 0.6 |
|---|---|---|---|
| **Roughness ratio (µm)** | 2.31 | 3.55 | 10.44 |
| **Rotary speed (R.P.M.)** | 1500 | 1500 | 1500 |
| **Depth of cut (mm)** | 0.5 | 0.5 | 0.5 |

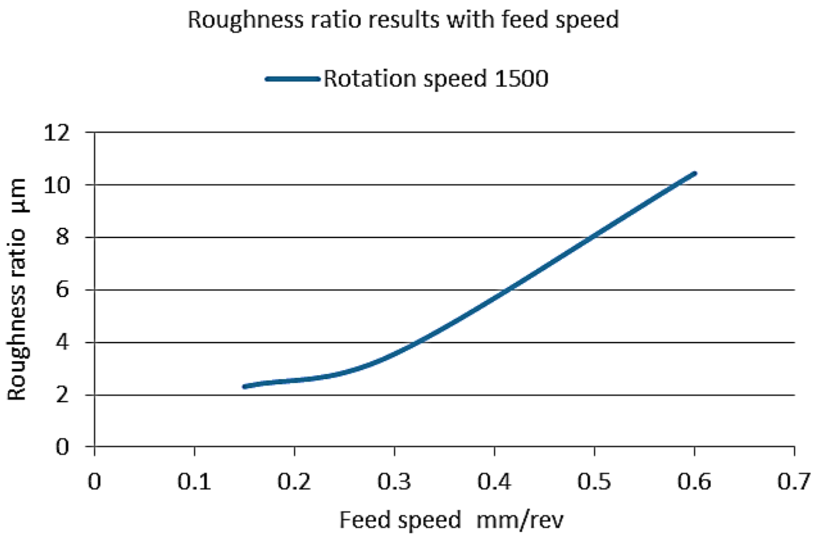


**Figure 11.** Relationship between surface roughness and feed speed at a Rotational speed of 1500RPM.

From Figure 11, it is observed that at a feed speed of 0.15mm/rev, the surface roughness is 2.31µm. As the feed speed increases to 0.3mm/rev, the surface roughness increases slightly, and at 0.6 mm/rev, it further increases to 10.44µm. This indicates a direct relationship between feed speed and surface roughness, with the Cutting depth and Rotational speed fixed at 0.5mm and 1500RPM, respectively .

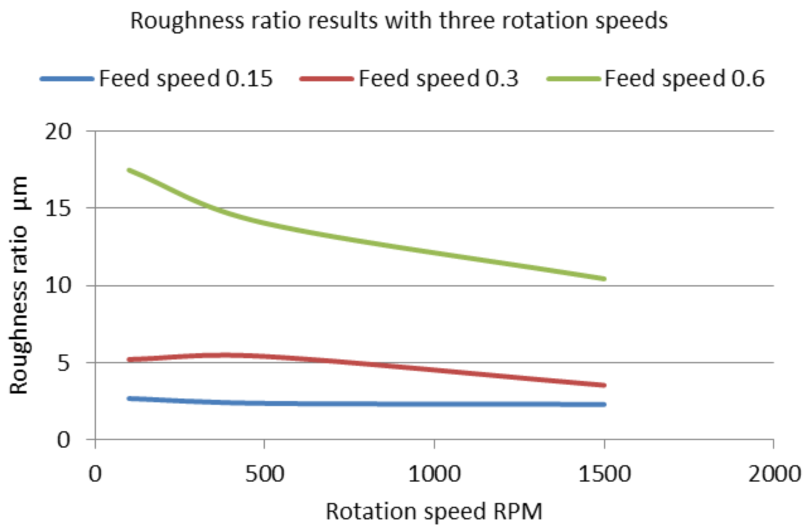


**Figure 12.** Relationship between surface roughness and Rotational speed for feed speed of 0.15, 0.3, and 0.6 mm/rev.

Figure 12 compares the feed speed of 0.15, 0.3, and 0.6 mm/rev to determine the optimal values for Stainless Steel316. It is observed that the highest surface roughness corresponds to a feed speed of 0.6mm/rev, followed by 0.3mm/rev, with the best surface finish achieved at 0.15 mm/rev

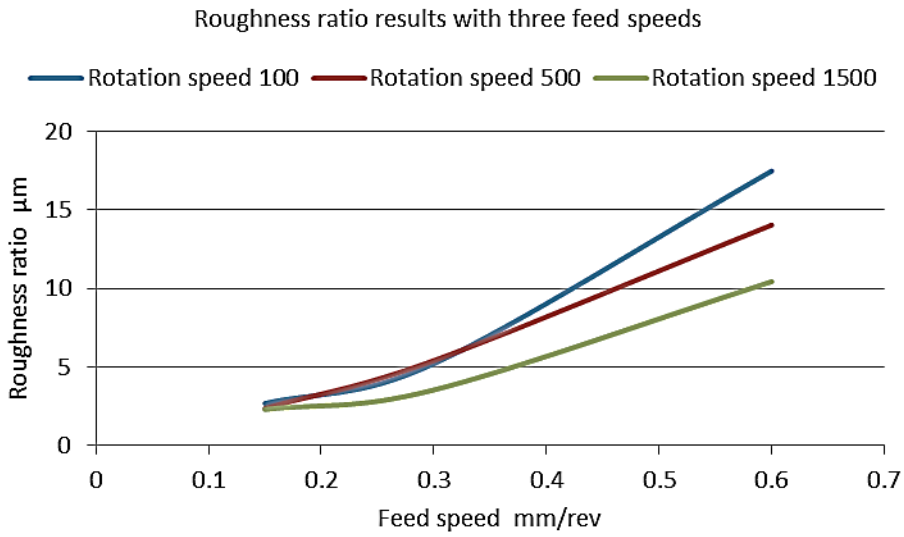


**Figure 13.** Relationship between surface roughness and feed speed for Rotational speeds of 100, 500, and 1500 RPM.

Figure 13 compares the Rotational speeds of 100, 500, and 1500 RPM to determine the optimal values for Stainless Steel 316. The highest surface roughness is observed at 100RPM, followed by 500RPM, with the best surface finish achieved at 1500RPM .From the investigation, it is concluded that the lowest surface roughness for Stainless Steel316 is achieved at a Rotational speed of 1500RPM and a feed speed of 0.15mm/rev, with a constant Cutting depth of 0.5mm

## 8. Conclusion

The investigation highlights the significant impact of rotational speed and feed speed on the surface roughness of Stainless Steel 316 during machining processes. An inverse correlation was observed between rotational speed and surface roughness, where higher rotational speeds (e.g., 1500 RPM) yielded smoother surfaces due to enhanced cutting dynamics and reduced friction at the tool-workpiece interface. Conversely, a direct correlation was identified between feed speed and surface roughness, as higher feed rates (e.g., increasing from 0.15 to 0.6 mm/rev) resulted in greater surface roughness due to the formation of more pronounced machining marks and material deformation. The optimal machining conditions for minimizing surface roughness were achieved with a rotational speed of 1500 RPM, a feed speed of 0.15 mm/rev, and a constant cutting depth of 0.5 mm. These findings underscore the importance of parameter optimization in precision machining, particularly when machining high-performance materials like Stainless Steel 316, where surface quality plays a critical role in functional performance. For superior surface finishes, lower feed speeds and higher rotational speeds are recommended, making them essential considerations in precision engineering applications.

The study also emphasizes the need to refine and extend the scope of machining investigations to further enhance the accuracy of surface finishes and optimize process efficiency. Future research could explore broader ranges of cutting depth, feed speed, and rotational speed to identify the ideal operating conditions for diverse machining scenarios. Expanding the research to include other metals and alloys, such as aluminum and copper, would provide valuable insights into how machining variables influence surface characteristics across various materials. Additionally, adopting advanced computer numerical control (CNC) lathes is recommended to improve precision in controlling cutting conditions, thereby enhancing reproducibility and minimizing variability in surface roughness outcomes. Statistical analysis of the experimental data is advised to establish robust mathematical models and predictive equations, which would help in determining the optimal combination of machining parameters. Future studies could further investigate the integration of process efficiency improvements and cost reduction strategies while ensuring the required surface quality is maintained. These efforts would contribute to sustainable and economically viable machining processes, supporting high-performance applications across various industries.

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