Effect of Biobased and Synthetic Coolants on Surface Roughness of ST 42 Steel in CNC End Milling Process

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**Abstract.** This study investigates the influence of spindle speed variation and coolant type on the surface roughness of ST 42 steel during CNC end milling. Two coolants were utilized: a biobased oil and a synthetic cutting fluid. Surface roughness measurements were conducted using a digital surface roughness tester at spindle speeds of 400, 500, and 600 rpm. The results demonstrate that both the coolant type and spindle speed significantly affect surface quality. The biobased coolant generally produced smoother surfaces, with the lowest Ra value of 0.879 µm recorded at 500 rpm. Conversely, the highest surface roughness occurred at 400 rpm using the synthetic coolant, reaching an Ra of 2.617 µm. These findings suggest that biobased coolants may offer an environmentally friendly and effective alternative for enhancing surface finish in CNC machining of mild steel.

# INTRODUCTION

Machining processes are an integral part of industrial manufacturing, serving as the core of many production activities. The role of machinery in assisting human work is indispensable. Precision in geometry and product variation demand that human resources continuously adapt and improve. In workshop settings, numerous machines have been developed to ease human labor, such as lathes, scrapers, milling machines, drills, grinders, and others [1].

The milling process involves several parameters that serve as performance indicators, including spindle speed, cutting speed, depth of cut, feed rate, cutting angle, chip load, material type, and cutting tool selection—all of which significantly influence surface quality. In machining experiments, independent variables such as spindle speed, depth of cut, and workpiece material are often varied, while dependent variables typically include surface roughness. Machining is widely employed in manufacturing metal components, estimated to account for 60% to 80% of all machining operations used in the production of complete machine parts. Milling, in particular, involves material removal using a rotating multi-point cutting tool. The tool's multiple cutting edges rotate around its axis to enhance cutting efficiency. The machined surface may be flat, angled, curved, or a combination of profiles, depending on the clamping system used [2].

Coolants serve critical functions in machining by dissipating heat, extending tool life, and minimizing thermal deformation of the workpiece. Recent research has shown that biobased coolants and synthetic cutting fluids offer promising, environmentally friendly alternatives to conventional mineral-oil-based coolants. ST 42 steel, commonly used in engineering applications, requires a low surface roughness—especially for components subjected to high friction. Selecting an appropriate coolant can mitigate friction effects between the tool and workpiece, thereby improving the surface finish. Understanding the influence of coolant type on ST 42 steel during end milling is therefore essential, as it may guide industries in choosing efficient, cost-effective, and eco-friendly cooling media that improve product quality [3].

Coolant application during machining helps prolong tool life, reduce workpiece deformation due to heat, enhance surface quality, and remove chips from the cutting zone. The use of coolant significantly affects the surface roughness, which is a key criterion for determining whether a machined product meets consumer standards. Surface irregularities can result in dimensional deviations, notch formation, stress concentration, and eventual cracking or failure under high loads. These rough surfaces also accelerate corrosion due to increased surface area and grooves [4].

Previous research compared the surface roughness of ST 42 steel using two different coolants—a mixture of limewater and waste cooking oil (1:4) and a synthetic cutting fluid—during end milling at various spindle speeds (955, 995, 1035 rpm) and depths of cut (0.1, 0.3, 0.5 mm). The best result with the limewater-oil mixture was obtained at 1035 rpm and 0.1 mm depth, achieving 0.02 µm surface roughness, whereas the synthetic fluid yielded 0.01 µm under the same conditions. The highest roughness (3.31 µm) was found at 955 rpm and 0.5 mm depth using the limewater-oil mixture [5].

Another study examined how different coolants affected the surface roughness of ST 37 steel during turning. Coolants tested included water, synthetic cutting oil, and radiator coolant, with 30 specimens tested. Surface roughness was measured three times per specimen. The results showed that the synthetic oil produced the highest roughness (2.031 µm), followed by radiator coolant (2.402 µm), and water (3.113 µm) [6].

Environmentally friendly coolants are gaining attention for their biodegradability and lower ecological impact. One study explored coconut oil as a biodegradable coolant during face milling. Using a conventional milling machine, tests were conducted at spindle speeds of 360 and 490 rpm and feed rates of 60 and 70 mm/min. The surface produced at 360 rpm with 70 mm/min feed was smoother than with a lower feed. A similar trend was observed at 490 rpm [7].

In another study, the influence of coolant type and spindle speed on the surface roughness of S45C steel in CNC turning was investigated. The research revealed that coolant type and spindle speed significantly affected surface finish. The lowest surface roughness (2.771 µm) was achieved using a conventional coolant at 1950 rpm, while the highest (3.313 µm) occurred with compressed air cooling at 1400 rpm [8].

Surface roughness is also influenced by cutting temperature, which affects both the tool and workpiece. An experiment on AISI 1045 steel investigated the relationship between coolant type and cutting conditions in CNC milling. Regression models were developed for various coolant mixtures: oil-to-water ratios of 1:60, 1:40, and 1:20. Results showed that cutter speed had a significant effect on roughness, while feed rate had minimal impact [9].

he main objective of this study is to analyze how different coolant types influence the surface roughness of ST 42 steel during end milling. It aims to assess the effectiveness of biobased and synthetic coolants in reducing surface roughness and to determine optimal machining parameters, such as spindle speed and depth of cut, that yield the best surface finish. The study also seeks to examine the possible effects of coolant on the microstructure and mechanical properties of ST 42 steel [10].

The microstructure of steel is largely determined by its carbon content. Low-carbon steels are primarily composed of ferrite and a small amount of pearlite, while high-carbon steels are dominated by pearlite with minimal cementite. Medium-carbon steels contain a mixture of ferrite and pearlite depending on their carbon level [11].

ST 42 steel contains less than 0.3% carbon and is widely used for structural frames, automotive components, and other engineering applications requiring a balance of strength and ductility. It is easy to machine, weld, and cut, making it ideal for various manufacturing processes. Additionally, ST 42 is affordable and offers reliable performance under moderate loads [12].

A milling machine is a type of machine tool that performs cutting operations using a rotating multi-point cutter. Manual milling machines are referred to as conventional milling machines, while computer-controlled ones are called CNC milling machines [13].

Milling theory involves the cutting process and tool movement. There are three types of milling directions: up milling (tool rotation opposite to table feed), down milling (tool rotation same as feed direction), and neutral milling, where the workpiece width exceeds or is smaller than the cutter diameter [14].

Coolants are fluids used to cool and lubricate the cutting zone. Their main functions include lowering cutting temperature, reducing friction, increasing tool life, and removing chips from the cutting area [15].

Surface roughness refers to irregularities and deviations in surface texture, typically measured as a pattern of peaks and valleys. Factors influencing roughness include cutting parameters, tool geometry, coolant use, material defects, and chip flow conditions [16].

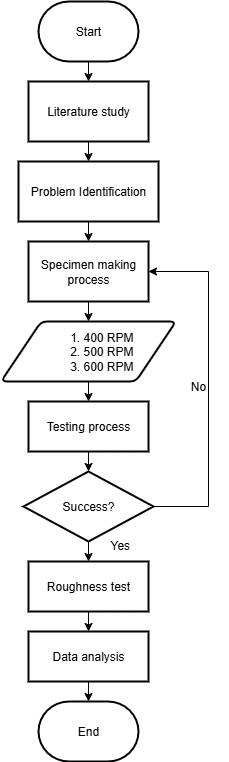
Cutting tools are essential in precision manufacturing. Selecting the appropriate tool type for a specific material is critical. Common tools include shell end mills for roughing, slotting cutters for T-shaped grooves, and gear cutters for producing gear teeth [17]. Feed rate refers to the speed at which the cutting tool advances through the workpiece, usually expressed in mm/min or mm/rev, depending on the machine and process [18]. The spindle is the main rotating shaft in a machine that holds and drives the cutting tool or workpiece. In milling machines, the spindle drives the cutting tool, delivering the torque and speed necessary for material removal [19]. Modern CNC milling machines are equipped with adjustable coolant flow systems. Flow rate is typically measured in liters per minute (L/min) and plays a critical role in maintaining coolant effectiveness during machining operations [20].

Based on the above context, this study addresses the following research questions: (1) How do biobased and synthetic coolants influence the surface roughness of ST 42 steel in end milling? (2) Is there a significant difference in surface finish between the two types of coolants? (3) To what extent can these coolants improve the quality of the machined surface?

The specific objectives of this study are: (1) To evaluate the effect of two different coolants on surface roughness during CNC milling of ST 42 steel; (2) To conduct a comparative analysis on the effectiveness of biobased versus synthetic coolants; and (3) To identify the coolant that yields the best surface finish under varying spindle speeds.

This study is limited to ST 42 steel specimens. The coolants tested include a biobased oil and a synthetic cutting fluid. Surface roughness measurements were performed using a digital surface roughness tester, with process parameters set at spindle speeds of 400, 500, and 600 rpm.

# Methodology

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**Figure 1.** Research methodology flowchart.

This experimental research investigates the effect of spindle speed variation and coolant type on the surface roughness of CNC-milled ST 42 steel. The study used two types of coolants: a biobased formulation named Bromus and commercially available cooking oil. The cutting tool used was a 6 mm diameter High-Speed Steel (HSS) end mill with a cutting depth of 1 mm. The process was carried out using a CNC milling machine.

Workpieces were cut into rectangular specimens measuring 60 mm × 60 mm × 10 mm. Three spindle speeds—400, 500, and 600 rpm—were applied. Each variation of spindle speed and coolant type was tested with four repetitions, yielding a total of 24 data points. Surface roughness was evaluated in terms of Ra, Rq, and Rz parameters using a Surface Roughness Tester.

Before the cutting process, the toolpath was programmed using CAD/CAM software, and the cutting fluid was applied in a flood condition to ensure sufficient lubrication and cooling during milling. After the machining process, each sample was cleaned to remove residues and then measured for surface roughness. The methodology follows the flow outlined in Fig. 1, which presents a step-by-step diagram of the experimental workflow.

All measurement results were documented, tabulated, and analyzed to identify trends and determine which combination of spindle speed and coolant type produces the smoothest surface.

# Results and Discussion

After applying the experimental procedures described earlier, surface roughness measurements were obtained using a Surface Roughness Tester on CNC milling operations. Each specimen was tested four times, and the results were categorized based on the use of two coolant types: a biobased coolant (Bromus) and cooking oil. Surface roughness values were assessed using Ra, Rq, and Rz parameters.

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| --- | --- | --- | --- | --- | --- | --- |
| **TABLE 1.** Average Ra Surface Roughness Values (µm). | | | | | | |
| **Spindle Speed (rpm)** | **Coolant** | **Trial 1** | **Trial 2** | **Trial 3** | **Trial 4** | **Average** |
| 400 | Bromus | 4.060 | 3.337 | 1.167 | 1.906 | 2.617 |
|  | Cooking Oil | 1.190 | 0.581 | 1.844 | 0.682 | 1.074 |
| 500 | Bromus | 1.319 | 0.943 | 0.661 | 0.595 | 0.879 |
|  | Cooking Oil | 2.041 | 1.405 | 0.702 | 0.958 | 1.276 |
| 600 | Bromus | 1.490 | 1.521 | 1.359 | 1.263 | 1.263 |
|  | Cooking Oil | 0.695 | 1.122 | 1.310 | 1.032 | 1.032 |

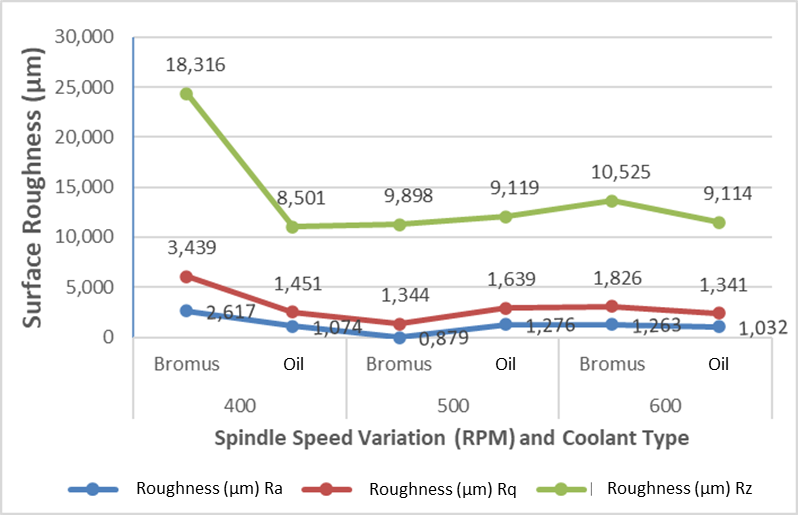
Table 2 presents the Rq roughness data. The highest values were found at 400 rpm, reaching 3.439 µm for Bromus and 1.451 µm for cooking oil. The lowest Rq value (1.344 µm) was achieved using Bromus at 500 rpm, while cooking oil showed its lowest Rq (1.341 µm) at 600 rpm.

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| --- | --- | --- | --- | --- | --- | --- |
| **TABLE 2.** Average Rq Surface Roughness Values (µm). | | | | | | |
| **Spindle Speed (rpm)** | **Coolant** | **Trial 1** | **Trial 2** | **Trial 3** | **Trial 4** | **Average** |
| 400 | Bromus | 4.948 | 4.208 | 1.551 | 3.050 | 3.439 |
|  | Cooking Oil | 1.600 | 0.764 | 2.552 | 0.890 | 1.451 |
| 500 | Bromus | 2.080 | 1.480 | 0.963 | 0.855 | 1.344 |
|  | Cooking Oil | 2.518 | 1.822 | 0.974 | 1.244 | 1.639 |
| 600 | Bromus | 1.782 | 1.925 | 1.865 | 1.732 | 1.826 |
|  | Cooking Oil | 0.910 | 1.410 | 1.623 | 1.424 | 1.341 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **TABLE 3.** Average Rz Surface Roughness Values (µm). | | | | | | |
| **Spindle Speed (rpm)** | **Coolant** | **Trial 1** | **Trial 2** | **Trial 3** | **Trial 4** | **Average** |
| 400 | Bromus | 19.628 | 21.618 | 9.005 | 23.013 | 18.316 |
|  | Cooking Oil | 10.225 | 4.671 | 12.884 | 6.227 | 8.501 |
| 500 | Bromus | 15.252 | 10.218 | 7.695 | 6.427 | 9.898 |
|  | Cooking Oil | 12.892 | 10.133 | 6.573 | 6.879 | 9.119 |
| 600 | Bromus | 9.293 | 11.342 | 10.033 | 11.435 | 10.525 |
|  | Cooking Oil | 5.623 | 9.514 | 9.340 | 11.982 | 9.114 |

Table 3 summarizes the Rz roughness values. At 400 rpm, the highest Rz was 18.316 µm with Bromus and 8.501 µm with cooking oil. Interestingly, cooking oil recorded its lowest Rz value (8.501 µm) at 400 rpm, while Bromus achieved its lowest (9.898 µm) at 500 rpm. At 600 rpm, both coolants produced moderate Rz values.

Figure 2 illustrates the relationship between spindle speed and average roughness values (Ra, Rq, and Rz) for each coolant type.

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**Figure 2.** Surface roughness trend (Ra, Rq, Rz) vs. spindle speed for Bromus and cooking oil.

From the Fig. 2, it is evident that the highest average roughness occurred at 400 rpm with Bromus. All three parameters reached their peak values at this speed: Ra = 2.617 µm, Rq = 3.439 µm, and Rz = 18.316 µm. The lowest Ra value (0.879 µm) was observed at 500 rpm using Bromus, while the lowest Rq (1.341 µm) and Rz (8.501 µm) were obtained using cooking oil at 600 rpm and 400 rpm, respectively.

These results indicate that both spindle speed and coolant type significantly influence surface finish in CNC milling of ST 42 steel. Bromus exhibited better performance at higher spindle speeds (500–600 rpm), whereas cooking oil produced more consistent results across the speed range.

# CONCLUSION

The design and development of the granular organic fertilizer sieving machine, with a target capacity of 15 kg/hour, have been successfully completed using the Pahl and Beitz systematic design methodology. Through a structured design process consisting of planning, conceptualization, embodiment, and detailed design stages, the machine was tailored to meet specific functional, structural, and economic requirements.

The final prototype demonstrated effective performance in separating granular fertilizer based on particle size, with a single-layer horizontal oscillating sieve driven by a belt and pulley system powered by a 3 HP gasoline engine. The power transmission system and structural frame were carefully calculated and evaluated to ensure mechanical integrity and operational stability. The machine successfully fulfilled the design targets, including throughput capacity, structural rigidity, ease of operation, and cost-efficiency. Furthermore, the use of locally available materials and components minimized production costs while maintaining product quality and durability.

It is recommended that future research focus on the following: (1) integrating multi-layer sieving mechanisms to enhance particle classification accuracy; (2) exploring alternative power sources such as solar-powered DC motors for improved energy sustainability; and (3) implementing vibration dampening systems to reduce operational noise and improve user comfort. Additionally, long-term field testing is necessary to assess machine reliability under varied working conditions and environmental factors.

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