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Enhancing the Surface Finish on EN19 Using CNC Lathe through Dry Machining, MQL, Liquid Nitrogen Bath (LNB)

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Abstract:- Cutting fluids are used in manufacturing processes to reduce friction, control heat generation, and extend tool life by providing heat absorption, lubrication, and cooling. Achieving higher productivity and quality in manufacturing is a significant challenge, with modern methods like CNC turning playing a critical role in addressing this challenge. The objective is to optimize CNC turning parameters specifically for machining EN19 alloy steel, which is widely utilized in automotive and machine tool industries. The goal is to enhance surface finish without sacrificing productivity. This requires strategic implementation of Dry machining, Minimum Quantity Lubricant (MQL), Flood Cooling, and Liquid Nitrogen Bath (LBN) techniques. Machining parameters such as cutting speed, feed rate, and depth of cut also play a crucial role in improving surface finish. Experimentation involves varying these parameters across different levels while applying all three lubrication conditions to determine their impact on surface finish. The most effective combination of machining parameters and lubrication methods can be identified through systematic testing and analysis to optimize surface finish while maintaining productivity in the CNC turning of EN19 alloy steel.

Keywords:- *CNC Lathe, Surface Finish, Talysurf, Parameters, Surface Roughness.*

I. INTRODUCTION

In contemporary manufacturing, the aim is to produce high-quality products at low cost and in a short period of time. To achieve this, automated and flexible manufacturing systems are utilized, along with computerized numerical control (CNC) machines that provide high precision and minimal processing duration. Turning is the predominant technique for cutting, particularly when it comes to finishing machined components. Additionally, to attain the desired quality of any product through machining, it is essential to select the cutting parameters accurately. Parameters in the turning process, including cutting tool design and materials, depth of cut, feed rates, cutting speeds, and the application of cutting fluids, influence both the rate of material removal and the machining characteristics such as surface finish, roundness, and dimensional variances of the finished product.

Turning involves removing metal from the outer diameter of a rotating cylindrical workpiece. This method is used to decrease the workpiece's diameter, typically to a precise measurement, and to produce a polished finish on the metal. Frequently, the workpiece is turned so that different segments have varying diameters. Turning is a machining procedure that creates cylindrical components. In its fundamental concept, it can be characterized as the machining of an external surface. In contemporary manufacturing, the objective is to produce high-quality products at low cost and rapid turnaround times. Automated and adaptable manufacturing systems are employed alongside CNC machines that can attain impressive accuracy and very short processing durations. Turning remains the most frequently utilized method for cutting and finishing machined components. Furthermore, to generate any desired quality through machining, it is crucial to choose the cutting parameters wisely.

Turning makes up a significant portion of lathe operations. Therefore, it encompasses the machining of straight and conical surfaces, as well as external cylindrical and grooved workpieces. The cutting tool was fixed to the tool post, which is powered by the lead screw, and removes material by moving along the bed.

The Importance of Turning in Contemporary ManufacturingTurning ranks among the most widely used machining techniques in modern manufacturing, especially for cutting and finishing machined pieces. This technique is essential for shaping cylindrical parts, which are vital to numerous industrial sectors. Turning entails removing material from the outer diameter of a rotating cylindrical workpiece to achieve a specific shape, size, and finish. The main objectives of turning are to reduce the workpiece's diameter to a predetermined measurement, guarantee a smooth surface finish, and create components with different diameters throughout their length.

The turning process is adaptable and can produce a diverse array of components, including straight, conical, curved, and grooved workpieces. Its flexibility renders it crucial in industries such as automotive, aerospace, medical device manufacturing, and heavy machinery. By employing specialized tools and advanced CNC systems, manufacturers can achieve consistent outcomes, even with complex geometries.

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➢ *Key Parameters Influencing Turning*

In order to reach the expected quality in turning, it is important to fine-tune several cutting parameters. These parameters encompass.

➢ *Cutting Tool Geometry and Materials:*

The design, inclination, and composition of the cutting tool play a crucial role in the effectiveness and quality of the turning operation. Depending on the hardness and characteristics of the workpiece material, tools made from high-speed steel (HSS), carbide, or ceramic are typically utilized.

- *Depth of Cut:*

The amount of material taken away in one pass is determined by the depth of cut. This aspect has a direct impact on both the material removal rate (MRR) and the forces applied to the cutting tool and the workpiece.

- *Feed Rate:*

The feed rate indicates how far the cutting tool moves along the workpiece for each revolution. An increased feed rate enhances the material removal rate (MRR) but could negatively affect the surface finish.

- *Cutting Speed:*

Cutting speed refers to the linear speed of the surface of the workpiece in relation to the cutting tool. Finding the optimal cutting speed is essential for achieving a balance between tool longevity and productivity.

- *Cutting Fluids:*

The application of cutting fluids, including lubricants and coolants, aids in lowering heat production, reducing tool deterioration, and enhancing surface quality. Additionally, cutting fluids facilitate chip removal, which prevents blockages and guarantees efficient functioning.

➢ *Importance of Parameter Optimization*

The careful choice and adjustment of cutting parameters are crucial for achieving the desired surface quality, dimensional accuracy, and roundness in machined components. Improper parameter settings can lead to problems like tool deterioration, thermal distortion, and inadequate surface finish. Modern CNC machines provide precise control over these parameters, allowing manufacturers to create parts with minimal deviations and excellent quality. In addition to enhancing quality, parameter optimization leads to cost savings. By decreasing tool wear and shortening machining time, manufacturers can reduce production expenses and boost overall efficiency. Furthermore, the capability to adjust parameters for various materials and shapes improves the adaptability of turning processes.

➢ *Machine Specifications*

The FANUC Lokesh TL 160 CNC Lathe Machine is a robust and high-performing machine crafted for precision machining and turning a diverse array of components. Its primary applications lie within industries that demand exceptional accuracy, rapid speeds, and repeatability, including automotive, aerospace, medical, and general machining. Featuring a FANUC CNC control system, the machine guarantees user-friendly operation, rapid setup, and enhanced efficiency. Below is an in-depth overview of the FANUC Lokesh TL 160 CNC Lathe Machine, highlighting its attributes, specifications, and potential uses. This compact yet durable CNC lathe combines precision, power, and versatility, designed to address the rigorous requirements of turning tasks, and is capable of processing various materials, including metals, alloys, and composites. The TL 160 offers advanced technological features that deliver outstanding performance in both low- and high-volume production settings.

➢ *Key Features:*

- *FANUC CNC Control System:*

The TL 160 features the FANUC Series 0i-TD CNC control system, which is well-regarded for its user-friendly interface and simplicity. This FANUC control system guarantees rapid processing times, minimized cycle times, and enhanced overall performance of the machine. It boasts functionalities such as advanced conversational programming, management of tool offsets, and control over multiple axes. The graphical interface is designed to allow operators to easily set up, program, and oversee operations.

- *Spindle Drive:*

The TL 160 is fitted with a high-torque, high-speed spindle drive. The spindle is engineered to provide exceptional rigidity and precision during machining. Capable of reaching spindle speeds of up to 4000 RPM, it offers several spindle motor options, making it apt for both rough and finish machining. Quality bearings support the spindle, ensuring seamless operation, decreased vibrations, and extended tool life.

- *Feed Motors and Servo Drives:*

The TL 160 incorporates robust servo motors for precise control of the X and Z axes. These servo motors facilitate high-speed movements with minimal backlash, guaranteeing consistent accuracy throughout the machining procedure. The FANUC servo drives are recognized for their efficiency and long-lasting performance, delivering smooth and precise feed control.

- *Rigid Construction:*

This machine is designed with a sturdy cast iron structure that provides high precision and stability. Its solid base and bed enhance vibration damping, allowing the machine to maintain tight tolerances even under heavy cutting conditions. This construction enables the machine to endure the rigors of demanding cutting tasks while retaining accuracy.

- *Tooling and Tool Changer:*

The FANUC Lokesh TL 160 CNC Lathe includes an automatic tool changer (ATC) capable of accommodating a diverse range of tools. The ATC can handle automatic tool loading and changes, significantly reducing downtime during machining cycles. The tool holder arrangement supports both

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external and internal turning tools, providing flexible machining options.

- *Chuck and Tailstock:*

The machine is outfitted with a hydraulic chuck that secures the workpiece firmly. This chuck can manage both small and large diameter workpieces, offering versatility for various applications. Furthermore, the tailstock aids in supporting lengthy workpieces during turning operations, thereby enhancing part accuracy and minimizing deflection.

- *High Precision and Accuracy:*

The FANUC Lokesh TL 160 is designed for high precision, ensuring tight tolerance control across diverse operations. Its linear guideways and high-precision ball screws contribute to the machine's capability of producing parts with micron-level accuracy. The integration of linear encoders on the axes minimizes thermal distortion and guarantees reliability during extensive production runs.

- *User-Friendly Interface:*

The FANUC control system provides a user-friendly interface that streamlines programming and operation. Operators are able to create, modify, and execute programs directly via the CNC control panel. The machine accommodates both G-code and conversational programming, making it suitable for both seasoned programmers and operators with lesser experience.

- *Customizable Options:*

The TL 160 can be tailored with a variety of options, including an upgraded spindle motor, additional tool stations, or the integration of a bar feeder for automated loading of bar stock. These customizations allow the machine to meet specific application requirements and production needs, offering increased adaptability across a range of industries**.**

➢ *Machine Specifications*

Table 1 Specifications of FANUC Lokesh TL160 CNC Lathe Machine

Brand	**Lokesh**
Model Name/Number	TL160 Series
Swing Over Bed	390 mm
Standard Chuck Size	165 mm
X-Axis Stroke	300 mm
Z-Axis Stroke	230 mm
Max Boring Bar Día	40 mm
Overall Weight	2500 Kg
Bed Capacity	30 Degree-H
Max Turning Día (Up to)	100 mm
Max Turning Length (With Chuck)	200 mm
Overall Size (LXBXH)	2.2x1.4x1.7 Mtrs
Positional Accuracy	0.01 mm
CNC System	Fanuc/ Siemens/ Mitsubishi (Make)
Tool Shank Size	25x25 mm
Feed Rate (Inf Variable)	0-10000 mm/min
Rapid Transverse X-Axis	30 (36) mtrs/min
Rapid Transverse Z-Axis	30 (36) mtrs/min

Fig 1 FANUC Lokesh TL 160 CNC Lathe Machin

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II. METHODOLOGY

A. *Material Selection*

EN19 is a premium medium-carbon steel recognized for its outstanding strength, toughness, and wear resistance. It is commonly utilized in the production of components that demand high tensile strength and durability against heavy loads and shocks, including shafts, gears, and parts for automobiles. When choosing EN19 for CNC lathe machining, it is essential to comprehend the material's characteristics, benefits, and machining factors to guarantee optimal performance and quality of the finished parts.

➢ *Properties of EN19 Steel:*

EN19, commonly referred to as 4340 steels under the AISI classification, is an alloy steel that includes carbon (0.38–0.43%), chromium (0.90–1.20%), nickel (1.65–2.00%), molybdenum (0.20–0.30%), along with trace amounts of other elements.

- *The Alloying Components Contribute to the Unique Properties of EN19:*

Elevated Tensile Strength: In its raw state, EN19 offers a tensile strength ranging from approximately 850 MPa to 1000 MPa, and can reach up to 1300 MPa after undergoing heat treatment. This quality makes it suitable for components that experience significant stress.

- *Resilience to Impact and Fatigue:*

The material demonstrates remarkable toughness, allowing it to endure impact loading and repeated stress without failure.

- *High Hardness:*

EN19 can be subjected to heat treatment to obtain substantial hardness, which is advantageous for applications where resistance to wear is crucial.

Table 2 Material Composition of EN19

Element	Content (%)
Iron (FE)	96.785 – 97.77
Chromium, Cr	0.90 – 1.50
Manganese, Mn	0.50 – 0.80
Carbon, C	0.35 – 0.45
Silicon, Si	0.15 – 0.30
Molybdenum, Mo	0.20 – 0.40
Sulfur, S	0.040
Phosphorous, P	0.035

B. *CNC Programming for Turning Operation*

```
0305;
N01 G21 G90 G98;
N02 M03 S2500;
N03 M06 T0101;
N04 G00 X33.0 Z2.0;
N05 G00 X32.0;
N06 GO1 Z-100 F100.0;
N07 GO1 X33.0 Z2.0;
N08 G00 X31.0;
N09 G01 Z-100.0;
N10 G01 X33.0 Z2.0;
N11 G00 X30.0;
N12 G01 Z-100.0;
N13 G01 X33.0 Z2.0;
N14 G28 X0.0 Z0.0;
N15 M05 M30;
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C. *Process Approach of Turning Process*

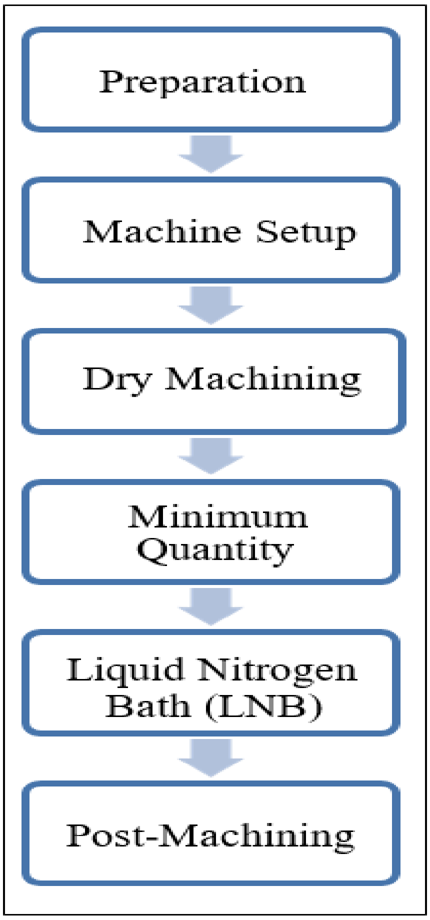

Fig 2 Process Approach of Machining

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D. Turning Operation

CNC (Computer Numerical Control) turning operations conducted on machines like the FANUC Lokesh TL 160 represent the forefront of precision machining technology, merging sophisticated automation with outstanding efficiency to create cylindrical components for a variety of industries. The Lokesh TL 160, utilizing FANUC's dependable and advanced control systems, is a sturdy CNC lathe designed for high-efficiency turning tasks. It incorporates state-of-the-art features to manage different materials, ranging from metals like steel, aluminum, and titanium to plastics and composites, guaranteeing high levels of precision and repeatability. This machine is frequently utilized in fields such as automotive, aerospace, medical, and general engineering, where accuracy and consistency are paramount. The FANUC Lokesh TL 160 features a resilient bed structure that reduces vibrations, a high-speed spindle for optimized rotational accuracy, and a programmable turret that can accommodate multiple tools. Its adaptability allows it to perform a broad spectrum of turning tasks, including facing, straight turning, taper turning, threading, grooving, drilling, and boring, all managed through FANUC's user-friendly interface and robust G-code programming capabilities. The process on the Lokesh TL 160 starts with the secure fastening of the workpiece onto its chuck, attached to the high-speed spindle. This spindle rotates the workpiece at exact speeds dictated by the CNC program, while the cutting tool mounted on the turret is navigated along the designated tool paths. FANUC's sophisticated controls facilitate smooth transitions between tasks, allowing for the seamless machining of intricate shapes in a single setup. For instance, facing operations are carried out to produce a flat surface at the end of the workpiece, establishing the basis for subsequent processes. Following that, turning operations reduce the workpiece diameter according to specified dimensions, shaping cylindrical forms or detailed profiles. For more complicated features, taper turning generates angled surfaces, while threading operations create helical grooves for screw threads. Grooving produces slots or channels, while drilling or boring operations create or enlarge holes with great precision. Knurling tasks can also be done on the Lokesh TL 160 to add texture to the surface for improved grip or aesthetic purposes. The machine's capability to transition between these tasks effectively, using several preloaded tools, decreases cycle time and eliminates the necessity for separate setups. A notable characteristic of the FANUC Lokesh TL 160 is the implementation of FANUC's advanced control technology. The FANUC interface allows operators to easily program the machine, emulate operations, and track performance in real time. This control system accommodates high-speed machining, precise tool positioning, and adaptable control to dynamically optimize cutting parameters. These features are especially crucial in industries where components must adhere to strict quality requirements. For instance, in the automotive industry, the Lokesh TL 160 can manufacture parts such as shafts, pistons, and gear blanks with minimal tolerances, ensuring dependable performance. In aerospace settings, it produces parts like turbine blades and housing components, where accuracy and material integrity are essential. In the medical field, the machine's precision enables the fabrication of orthopedic implants, surgical instruments, and dental parts, meeting the rigorous standards necessary for biocompatibility and patient safety. The electronics sector benefits from the machine's ability to generate small, detailed parts like connectors and housings with excellent surface finishes.

E. Dry Machining

Dry machining represents a contemporary manufacturing technique that executes machining tasks without utilizing cutting fluids or coolants. In CNC lathe turning, this method is increasingly being adopted as industries strive to boost sustainability, minimize expenses, and enhance operational productivity. By depending solely on the interaction of cutting tools with the workpiece, dry machining avoids the environmental, financial, and logistical complications linked to coolant utilization. This technique has become particularly significant in sectors such as automotive, aerospace, and general manufacturing, where a commitment to green manufacturing practices and cost-effectiveness is essential.

One of the most notable advantages of dry machining is its environmental benefit. Cutting fluids, typically made up of oils, emulsifiers, and various chemical additives, present environmental risks due to their complex disposal requirements. They necessitate specialized treatment to prevent water source contamination and compliance with environmental regulations. By eliminating the need for cutting fluids, dry machining not only mitigates ecological damage but also removes the expenses and logistical hurdles related to managing and disposing of these fluids. This makes it an appealing choice for manufacturers aiming to adhere to strict environmental standards while decreasing their carbon footprint.

Cost reductions are another major factor driving the shift to dry machining. Coolants contribute to operational costs through their purchase and upkeep and also require investments in additional equipment such as pumps, filtration systems, and storage tanks. These systems require regular maintenance and consume energy, further increasing production expenses. Dry machining avoids these costs entirely, resulting in reduced overhead expenses. Furthermore, the absence of coolants streamlines shop floor operations and minimizes the risks associated with leaks or contamination in the machining environment, fostering a cleaner and safer workspace.

Improvements to workplace safety presented by dry machining are also significant. Cutting fluids can generate mist and fumes, which may pose health risks to operators if they are exposed over extended periods. Additionally, spills can create slippery areas, heightening the risk of workplace accidents. By forgoing cutting fluids, dry machining promotes a more secure and sanitary working environment. The lack of fluid residues also makes cleaning and maintenance tasks easier, further boosting operational efficiency.

Despite these benefits, implementing dry machining in CNC turning processes does present challenges. A primary concern is the generation of heat. Cutting fluids play an essential role in dissipating heat produced during machining, especially at high speeds or when dealing with tough materials. In the absence of coolant, both the cutting tool and the workpiece may endure elevated thermal stress, which could result in tool wear, thermal distortion, or compromised surface finish. To address this issue, dry machining utilizes advanced cutting tool materials, such as ceramics, cubic boron nitride (CBN), or coated carbides, which provide superior heat resistance and durability in dry cutting applications.

Fig 3 Dry Machining Tested Workpieces

Dry machining proves to be particularly beneficial in situations where cost efficiency and sustainability are of utmost importance. For example, in the automotive sector, items like brake discs and engine components are frequently manufactured using dry machining methods due to their effectiveness with cast iron and hardened materials. Likewise, the aerospace sector is increasingly turning to dry machining for precision components made from advanced alloys, employing high-performance tools and machinery to satisfy stringent quality standards.

F. Minimum Quantity Lubrication (MQL)

Minimum Quantity Lubrication (MQL) represents a modern machining method that creates a link between traditional wet machining and fully dry machining. In CNC lathe turning operations, MQL entails the use of a minimal quantity of lubrication, usually between 10 to 50 milliliters per hour, applied directly to the cutting area. The objective is to maximize lubrication and cooling effects while reducing the environmental, financial, and operational drawbacks linked with conventional cutting fluids. By applying a fine mist of lubricant exactly where it is required, MQL improves machining efficiency and performance while promoting sustainable manufacturing practices.

One of the main benefits of MQL is its considerable decrease in cutting fluid usage compared to traditional techniques. Standard machining operations typically depend on flood coolant systems that utilize large amounts of fluid to lubricate, cool, and remove chips from the cutting zone. These systems incur significant expenses associated with fluid procurement, upkeep, filtration, and disposal, along with environmental issues stemming from coolant waste. In contrast, MQL employs only a small fraction of the fluid, substantially lowering costs and ecological footprint. This positions MQL as an appealing option for sectors striving to adopt green manufacturing practices.

MQL enhances the performance and lifespan of tools by delivering targeted lubrication at the interface between the tool and workpiece. The fine mist of lubricant diminishes friction between the cutting tool and the material, subsequently reducing heat generation. Unlike dry machining, which can result in thermal stress and accelerated tool wear due to the lack of cooling, MQL provides sufficient heat dissipation while maintaining an almost dry environment. This equilibrium aids in extending tool life and improving machining consistency. Moreover, the precise application of lubricant avoids excessive accumulation or contamination, resulting in cleaner operations and superior surface finishes.

Another significant advantage of MQL is its capacity to boost machining efficiency and productivity. The lubrication offered by MQL decreases cutting forces, enabling smoother and more stable turning operations. This is especially beneficial in high-speed CNC lathe turning, as lower friction and heat generation allow for increased cutting speeds and feed rates without compromising tool durability or workpiece quality. Additionally, the fine mist of lubricant promotes effective chip formation and removal, preventing chips from disrupting the cutting process or harming the machined surface.

The effectiveness of MQL is also heavily influenced by machining parameters and tool selection. Tools with coatings such as titanium nitride (TiN) or aluminum titanium nitride (AlTiN) are ideal for MQL applications, as they improve heat resistance and minimize tool wear. Likewise, optimized cutting speeds, feed rates, and cut depths are vital for maximizing MQL's benefits without sacrificing machining quality. Ensuring proper clamping of the workpiece and reducing machine vibrations are crucial for achieving reliable results.

Fig 4 Minimum Quantity Lubrication Tested Workpieces

MQL proves particularly efficient in machining operations involving hard metals, alloys, or abrasive materials, where controlled lubrication greatly affects tool performance and surface quality. It is commonly utilized in sectors like automotive and aerospace, where precision, cost efficiency, and sustainability are critical. For instance, MQL is used in the production of components like engine parts, turbine blades, and shafts, which require high accuracy and durability while following strict environmental regulations.

G. Liquid Nitrogen Bath (LNB)

The use of a Liquid Nitrogen Bath (LNB) during CNC lathe turning operations represents an advanced and innovative approach to machining that addresses some of the critical challenges in modern manufacturing. LNB involves the application of liquid nitrogen, typically at a temperature of -196°C (-321°F), either directly to the cutting zone or as a cooling medium to immerse the workpiece or cutting tool. This ultra-cold medium provides significant cooling, enabling improved machining performance, especially for difficult-to-machine materials such as high-strength alloys, hardened steels, and composites. LNB is an important development in machining technology, particularly in industries that demand high precision, exceptional surface quality, and enhanced tool life while maintaining eco-friendly practices.

The primary advantage of using an LNB in turning operations is its ability to manage heat generation effectively. Machining processes inherently produce heat due to friction and deformation at the tool-workpiece interface. Excessive heat can lead to tool wear, thermal expansion of the workpiece, and compromised surface finish. Conventional cutting fluids may not be sufficient to handle the thermal loads encountered when machining advanced materials or performing high-speed operations.

Liquid nitrogen, with its extremely low temperature, dissipates heat rapidly and prevents thermal damage to both the cutting tool and the workpiece. This allows for more aggressive machining parameters, such as higher cutting speeds and feed rates, without sacrificing quality or tool life.

Another key benefit of LNB-assisted machining is the enhancement of tool performance and longevity. High temperatures during machining accelerate tool wear mechanisms like crater wear, flank wear, and plastic deformation. By cooling the tool effectively, LNB reduces these wear phenomena and extends tool life significantly. This is particularly beneficial when working with expensive cutting tools, such as those made from polycrystalline diamond (PCD), cubic boron nitride (CBN), or advanced ceramic materials. Additionally, the cryogenic properties of liquid nitrogen can improve the hardness and toughness of some cutting tools, further enhancing their resistance to wear. LNB also improves surface finish and dimensional accuracy. The rapid cooling effect minimizes thermal expansion of the workpiece, ensuring that the dimensional tolerances are maintained during machining. Moreover, the reduced friction and controlled heat generation result in a smoother cutting action, which contributes to better surface quality. These advantages are critical in applications such as aerospace, automotive, and medical device manufacturing, where precision and reliability are paramount.

The application of LNB is particularly advantageous in industries where machining advanced materials is common. For example, in aerospace manufacturing, turning operations on titanium and nickel-based superalloys often require effective thermal management due to their low thermal conductivity and high strength. LNB enables these materials to be machined efficiently, improving productivity and reducing costs. Similarly, in the automotive industry, machining hardened steel components benefits from the improved tool life and surface quality afforded by cryogenic cooling. The medical device industry also utilizes LNB to manufacture components with high precision and biocompatibility requirements.

Fig 5 Liquid Nitrogen Bath Tested Workpieces

H. Surface Finish

Surface finish is an essential feature of any machined component, indicating its microscopic irregularities and overall texture. The Talysurf, a contact-based profilometer, employs a stylus to trace the surface of a workpiece. It is built to deliver precise measurements of surface roughness, waviness, and other texture features. The device includes several crucial parts, comprising a diamond-tipped stylus, a traversing unit, a data acquisition system, and analysis software. The stylus serves as the main component that contacts the surface of the workpiece. It is very sharp and robust, ensuring minimal disruption to the surface being measured. The stylus is attached to a traversing unit that moves it linearly over the surface under controlled conditions. As the stylus traverses, it follows the peaks and valleys of the surface, accurately capturing height variations.

The Talysurf operates on the principle of stylus deflection as it moves over surface irregularities. These deflections are transformed into electrical signals through a transducer, which can be an inductive or capacitive sensor. The signals are then digitized and processed to produce a surface profile. This data offers a highly precise representation of the surface topography, facilitating detailed analysis of roughness parameters. Talysurf instruments can measure a broad spectrum of surface finish characteristics, such as Ra (average roughness), Rz (average maximum height), Rt (total height of the profile), and waviness parameters. The accuracy and consistency of Talysurf systems make them essential for quality control and research purposes.

To measure surface finish using a Talysurf, the workpiece and instrument require proper preparation. The workpiece must be clean and free from contaminants like oil, dust, or debris, as these can affect the measurement. Calibration of the Talysurf instrument is necessary before use to guarantee accuracy. This calibration involves verifying the system against a certified reference standard with a known surface profile. Once the Talysurf is checked, the workpiece is securely positioned on the instrument's surface plate or

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fixture to eliminate any movement during measurement. Correct alignment of the workpiece ensures that the stylus accurately traverses the designated area.

After the setup, the operator configures the Talysurf system to specify the measurement parameters. These parameters include traversing length, measurement speed, and resolution. The traversing length defines the area of the surface to be scanned, while the measurement speed ensures that data is collected accurately without harming the stylus or the surface. Resolution, which indicates the smallest measurable deviation, is vital for identifying fine surface features. With parameters established, the Talysurf stylus starts its movement across the surface. As it travels, it registers vertical deviations caused by surface irregularities. These deviations are converted into electrical signals and recorded in real time.

The data gathered by the Talysurf is processed using dedicated software. This software creates a comprehensive surface profile, which visually represents the surface's texture. From this profile, a variety of roughness and waviness parameters can be determined. The most frequently used parameter is Ra (average roughness), which reflects the average deviation of the surface profile from the mean line. It serves as a general indicator of the surface texture and is commonly used in quality control processes. Other parameters, such as Rz (average maximum height), describe the vertical distance between the highest and lowest points over a defined sampling length. These parameters are crucial for applications where specific functional traits, such as sealing, friction, or load-bearing capacity, are essential.

Fig 6 Surface Roughness Measurement Using Talysurf.

I. Test Parameters

In CNC lathe turning processes, the selection of testing parameters significantly impacts the machining process's performance, efficiency, and quality, particularly spindle speed (revolutions per minute or RPM), cutting speed, and depth of cut.These parameters regulate the interaction between the cutting tool and the workpiece, influencing material removal rate, surface finish, tool wear, and overall machining stability. It is essential to optimize these parameters to achieve the intended machining results, reduce tool wear, and ensure cost-effective manufacturing.

RPM (Revolutions Per Minute) indicates the rotational speed of the spindle and, by extension, the workpiece. It is crucial in determining the relative speed between the cutting tool and the workpiece. RPM is derived from the desired cutting speed and the workpiece diameter; higher RPMs are better suited for smaller workpiece diameters as they help maintain an optimal cutting speed. In contrast, larger workpieces require lower RPMs to avoid overheating and to maintain machining stability. Proper selection of RPM directly affects tool longevity, surface quality, and the potential for workpiece distortion. Incorrect RPM settings can cause chatter, poor surface quality, or accelerated tool wear.

Cutting speed is the linear speed at which the tool's cutting edge interacts with the material, expressed in meters per minute (m/min). This speed is influenced by the material characteristics of both the workpiece and the cutting tool. Hard materials like hardened steel or titanium alloys generally need lower cutting speeds to avoid rapid tool wear, whereas softer materials such as aluminum can be processed at higher speeds for enhanced productivity. The cutting speed is directly related to heat generation during the machining process. Excessively high cutting speeds can lead to tool failure due to thermal stress, while too low speeds may result in inefficient material removal and poor surface finish. This parameter is vital for calculating the material removal rate (MRR) and is measured in millimeters (mm). Increasing the depth of cut raises MRR, allowing for quicker machining, but also exerts greater cutting forces and thermal loads on the tool and workpiece. This can lead to tool deflection, vibration, and thermal distortion of the workpiece, especially in applications requiring high precision. Conversely, a shallower depth of cut ensures superior surface finish and reduces tool stress, although it may necessitate multiple passes, thereby increasing machining time.

The relationship between these parameters greatly influences machining results. For instance, high RPM paired with a significant depth of cut can result in chatter and diminished tool life, while a low RPM with a high cutting speed may detract from the surface finish. To attain optimal outcomes, these parameters must be meticulously balanced based on the material being machined, the attributes of the cutting tool, and the desired surface finish and dimensional precision. Furthermore, additional factors like coolant use, tool geometry, and machine rigidity also contribute to ensuring these parameters achieve the needed performance.

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Table 3 Parameters Table of Dry Machining, MQL, LNB Methods.

RPM	CUTTING SPEED	DEPTH OF CUT
2500	235.61	0.25
2500	259.18	0.50
2500	282.60	0.75
2750	235.61	0.50
2750	259.18	0.75
2750	282.60	0.25
3000	235.61	0.75
3000	259.18	0.25
3000	282.60	0.50

III. RESULT AND DISCUSSION

This tables (4.1, 4.2, 4.3) shows the impact of RPM, cutting speed, and depth of cut on surface roughness. Increasing depth of cut generally increases roughness, while RPM and cutting speed show fewer clear trends.

- *Dry Machining*

Table 4 Surface Roughness Values for Dry Machining.

S.NO	RPM	CUTTING SPEED (m/min)	DEPTH OF CUT (mm/min)	SURFACE ROUGHNESS (μm)
1.	2500	235.61	0.25	3.25
2.	2500	259.81	0.50	3.162
3.	2500	282.60	0.75	3.19
4.	2750	235.01	0.50	2.85
5.	2750	259.18	0.75	2.93
6.	2750	282.60	0.25	3.01
7.	3000	235.61	0.75	3.25
8.	3000	259.18	0.25	3.012
9.	3000	282.60	0.50	3.12

- *Minimum Quantity Lubrication (MQL)*

Table 5 Surface Roughness Values for (MQL)

S.NO	RPM	CUTTING SPEED (m/min)	DEPTH OF CUT (mm/min)	SURFACE ROUGHNESS (μm)
1.	2500	235.61	0.25	1.123
2.	2500	259.81	0.50	1.268
3.	2500	282.60	0.75	1.392
4.	2750	235.01	0.50	1.369
5.	2750	259.18	0.75	1.426
6.	2750	282.60	0.25	1.187
7.	3000	235.61	0.75	1.493
8.	3000	259.18	0.25	1.168
9.	3000	282.60	0.50	1.52

- *Liquid Nitrogen Bath (LNB)*

Table 6 Surface Roughness Values for (LNB)

S.NO	RPM	CUTTING SPEED (m/min)	DEPTH OF CUT (mm/min)	SURFACE ROUGHNESS (μm)
1.	2500	235.61	0.25	1.5
2.	2500	259.81	0.50	1.63
3.	2500	282.60	0.75	2.01
4.	2750	235.01	0.50	1.71
5.	2750	259.18	0.75	2.11
6.	2750	282.60	0.25	1.669
7.	3000	235.61	0.75	2.184
8.	3000	259.18	0.25	2.252
9.	3000	282.60	0.50	2.3

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A. *Mean Effective Plot Graphs*

Surface finish quality plays a significant role in machining processes, particularly when dealing with materials such as EN19, which is a high-strength alloy steel frequently utilized in the automotive, aerospace, and manufacturing sectors. Enhancing the surface finish of EN19 can improve its resistance to fatigue and corrosion, as well as its overall performance. Several methods, including Dry Machining, Minimum Quantity Lubrication (MQL), and Liquid Nitrogen Bath (LNB), have been investigated to improve the surface finish during machining tasks. Effective plot graphs serve as a valuable resource for visualizing the correlation between various machining parameters and the surface quality attained through these techniques. This paragraph explores the utilization of such graphs to evaluate and refine the surface finish on EN19 using a CNC lathe.

Dry machining, characterized by the absence of cutting fluids, has gained traction for its environmental and cost-effective advantages. Nonetheless, if not meticulously controlled, it can lead to increased tool wear and subpar surface finish. Plot graphs that contrast cutting speed, feed rate, and depth of cut against the resultant surface finish prove especially beneficial in dry machining. These visual representations assist in pinpointing optimal ranges for each parameter, ensuring maximum surface quality while reducing tool wear. Typically, surface roughness (Ra) values are positioned on the y-axis, while cutting parameters such as cutting speed (m/min), feed rate (mm/rev), and depth of cut (mm) are laid out on the x-axis. This arrangement enables operators to comprehend how changes in these aspects influence surface quality. For instance, a plot graph similar to fig 4.1 may indicate that higher cutting speeds yield smoother surfaces until a specific threshold is reached, beyond which the surface quality declines due to excessive heat production and tool wear.

On the other hand, MQL entails applying a minimal quantity of lubricant directly to the cutting zone. This method considerably decreases friction, resulting in lower cutting temperatures, diminished tool wear, and enhanced surface finish. When employing MQL, effective plot graphs usually illustrate the effect of varying lubricant flow rates on surface finish. The x-axis may denote the MQL flow rate (ml/min), while the y-axis represents surface roughness (Ra). Another graph, equivalent to fig 4.2, might incorporate cutting parameters at different cutting speeds and feed rates while treating the lubricant flow rate as a variable. These graphs can reveal the optimal flow rates that maximize the advantages of MQL concerning surface finish, frequently demonstrating a significant reduction in surface roughness as lubrication improves, but eventually plateauing at elevated flow rates. Such evaluations assist in determining the ideal MQL configuration for specific machining conditions.

When assessing all three techniques—Dry Machining, MQL, and LNB—integrating their impacts into a unified plot graph can deliver a thorough insight into their comparative benefits. For example, a multi-line plot could represent surface roughness on the y-axis and cutting speed or feed rate on the x-axis, with distinct lines corresponding to dry machining, MQL, and LNB. This format facilitates a direct juxtaposition of the efficacy of each approach under varying machining conditions. By recognizing the areas where each technique excels, operators can select the most suitable method based on the specific demands of the machining operation. For instance, LNB might be most effective at high cutting speeds, while MQL might yield better results for medium to low-speed tasks.

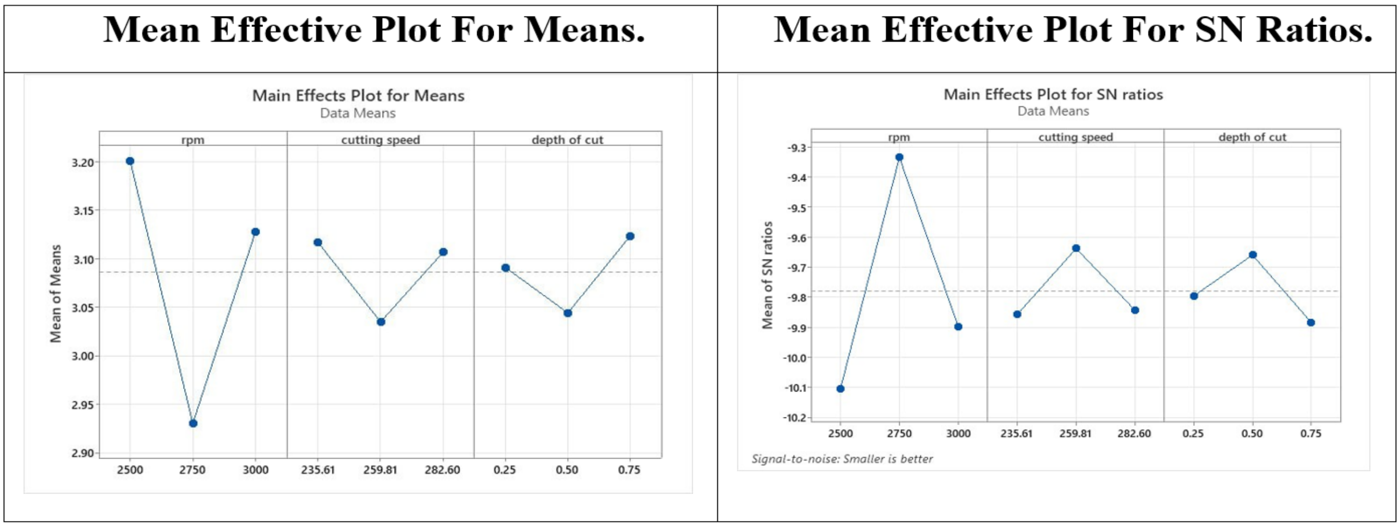

Fig 7 Dry Machining Mean Effective Plot Graphs.

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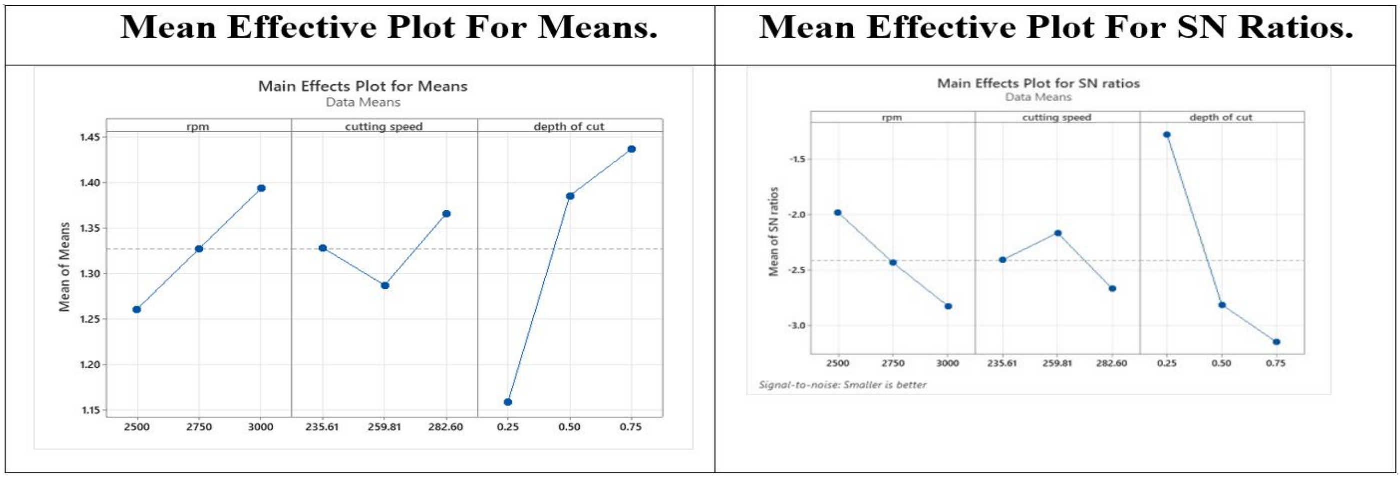

Fig 8 MQL Mean Effective Plot Graphs.

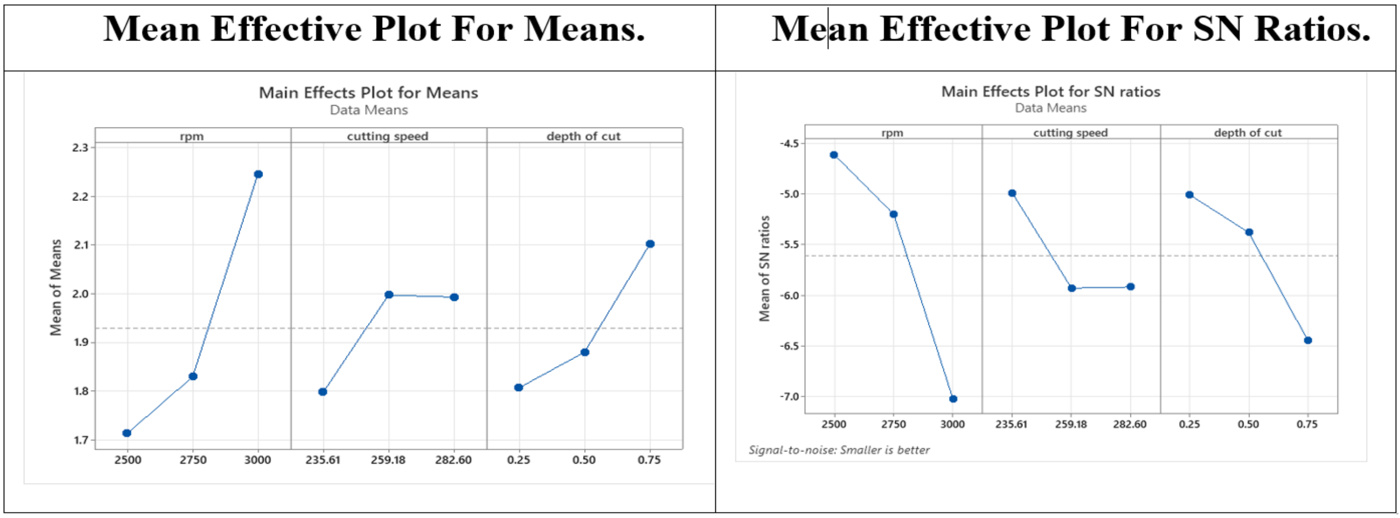

Fig 9 LNB Mean Effective Plot Graphs.

B. *Response Table for Signal to Noise Ratios (S/N Ratios)*

The Signal-to-Noise Ratio (S/N ratio) is a fundamental statistical concept utilized in experimental design and process enhancement, especially in areas such as manufacturing and quality assurance. This metric is crucial for evaluating how the variability ("noise") in a process contrasts with the desired outcome ("signal"). The S/N ratio offers valuable insights into the stability and reliability of a process, with a higher S/N ratio signifying a more consistent process that exhibits less variability in output. In manufacturing or machining contexts, the S/N ratio is generally employed to assess the link between process parameters (the signal) and the resulting variations in product quality (the noise). A response table for S/N ratios functions as a method to analyze and contrast the effects of various factors on a specific output, such as surface roughness in machining, tensile strength in materials, or yield in chemical processes.

The S/N ratio calculation is often performed to evaluate how different process variables (inputs) influence the variation in the output. The calculation formula for the S/N ratio varies based on the specific performance characteristic being optimized. Generally, it can be characterized as follows: where it represents the measured value of the output (such as surface roughness or tensile strength) for each experimental iteration, and is the total number of observations. The objective is to achieve the highest possible S/N ratio, which indicates that the desired output (signal) is maximized while keeping variability (noise) to a minimum.In practical scenarios, a response table for S/N ratios acts as an overview of experimental outcomes, displaying the correlation between different process parameters and their effect on the output. This table usually comprises several columns:

- *Factors (Process Parameters):*

  These denote the input variables or parameters that are systematically adjusted during the experiment. In machining, examples may include cutting speed, feed rate, depth of cut, and cooling method.

- *Levels of Each Factor:*

  Each factor undergoes testing at multiple levels, such as high, medium, and low, representing the various settings or values the factor can assume during the experiment.

- *Observed Responses (Output):*

  These are the output measurements or values (e.g., surface roughness, tensile strength) recorded for each combination of factor levels.

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➢ *S/N Ratio:*

For every combination of factor levels, the respective S/N ratio is computed, reflecting the robustness of the process under those specific conditions.

After completing the experiments, the response table is filled with the S/N ratios for each factor combination and their respective levels. This table's aim is to determine the optimal combination of factors that maximizes or minimizes the output while reducing variability. The S/N ratio serves as an indicator of process stability, with factor combinations yielding the highest S/N ratios deemed most favorable.

Response tables for S/N ratios find extensive application across industries such as manufacturing, automotive, aerospace, and materials science. In machining, for instance, the goal may be to reduce surface roughness, where the S/N ratio aids in identifying cutting conditions that produce the smoothest surfaces with minimal variability. Similarly, in product design, this approach is employed to pinpoint optimal conditions for maximizing product strength, yield, or efficiency while minimizing defects or deviations. In chemical processes, the response table can help elucidate the relationship between process variables and product quality.

Table 7 Dry machining Response Table for Signal to Noise Ratios

S.No.	Level	RPM	Cutting speed	Depth of cut
1.	1	-10.104	-9.857	-9.795
2.	2	-9.335	-9.638	-9.660
3.	3	-9.899	-9.843	-9.884
4.	Delta	0.769	0.220	0.224
5.	Rank	1	3	2

Table 8 MQL Response Table for Signal to Noise Ratios

S.No.	Level	RPM	Cutting speed	Depth of cut
1.	1	-1.981	-2.406	-1.282
2.	2	-2.433	-2.165	-2.809
3.	3	-2.822	-2.666	-3.145
4.	Delta	0.841	0.502	1.864
5.	Rank	2	3	1

Table 9 (LNB) Response Table for Signal to Noise Ratios

S.No.	Level	RPM	Cutting speed	Depth of cut
1.	1	-4.610	-4.989	-5.007
2.	2	-5.198	-5.927	-5.379
3.	3	-7.024	-5.916	-6.445
4.	Delta	2.414	0.938	1.437
5.	Rank	1	3	2

C. Optimization Graphs for Surface Roughness

Optimization graphs from figures 4.4, 4.5, and 4.6 are essential tools for examining and illustrating the connections between input variables and output responses across various domains, such as engineering, manufacturing, economics, and logistics. These graphs enable researchers and practitioners to discover the most favorable conditions or parameter adjustments that can either maximize or minimize a particular objective, like cost, efficiency, or performance, while maintaining minimal variability. In the realms of manufacturing and engineering, optimization graphs are frequently employed to depict the impacts of various process parameters on system performance, aiding in enhanced decision-making and more streamlined operations. By graphing the correlations between variables and performance outcomes, optimization graphs create a straightforward and intuitive method for grasping how modifications in input factors affect results, thus simplifying the process of determining ideal operating conditions.

In any optimization scenario, one or more objective functions are generally being optimized—either maximized or minimized—according to specific criteria. In manufacturing, these criteria might encompass product quality, production speed, or energy consumption, whereas in economics, they could pertain to maximizing profit or reducing costs. As visual representations, optimization graphs illustrate how different inputs influence these goals. Frequently utilized alongside techniques like Design of Experiments (DOE), regression analysis, or machine learning models, these graphs play a crucial role in comprehending both linear and non-linear interactions between process parameters and outputs.

A commonly encountered type of optimization graph is the response surface plot, which is particularly advantageous when examining the effects of multiple variables on a specific outcome. This plot typically displays two independent variables on the x- and y-axes, with the dependent response (e.g., surface finish, yield, or cost) represented by the z-axis or as a color gradient. Such three-dimensional plots offer an in-depth perspective on how changes in input parameters affect the output, assisting engineers and operators in identifying the best combination of variables that either maximizes or minimizes the desired outcome. Response surface plots are especially useful for investigating complex, non-linear correlations among factors, where the impact of altering one variable may depend on the levels of others.

Another common optimization graph is the contour plot, which serves as a two-dimensional version of the response surface plot. Contour plots convey the same information as response surface plots but illustrate lines of constant response instead of a three-dimensional surface. Here, the contours on the graph indicate varying levels of the output variable, such as product quality or cost, for distinct combinations of input variables. These contour lines assist in visualizing areas of optimal performance, demonstrating where the objective function reaches maximum or minimum values across various combinations of the independent variables. This is particularly beneficial for pinpointing regions of interest within the parameter space that may require further refinement.

Pareto charts are another crucial resource in the realm of optimization, especially when addressing multiple factors or causes that influence a process or system. A type of bar chart, Pareto charts display the frequency or impact of different factors in order of importance or contribution to a specific issue. In optimization, these charts help identify the most influential variables on system performance, thereby guiding prioritization for improvements or interventions.

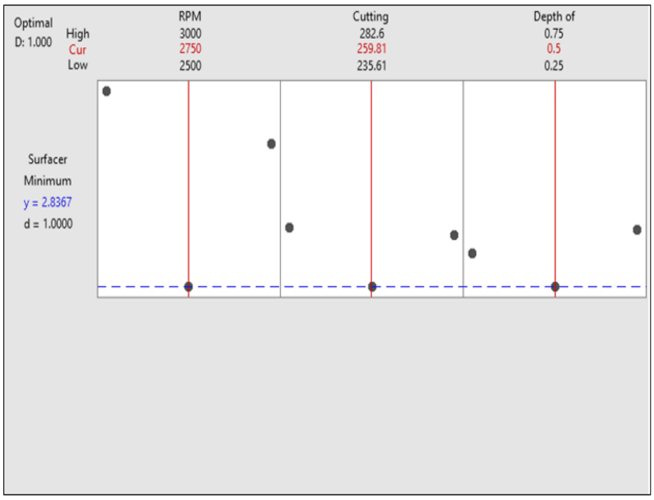

Fig 10 Dry Machining Optimization Graph

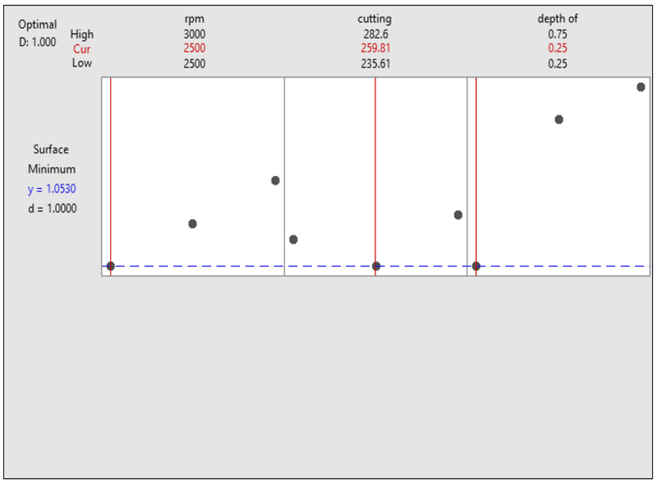

Fig 11 MQL Optimization Graph

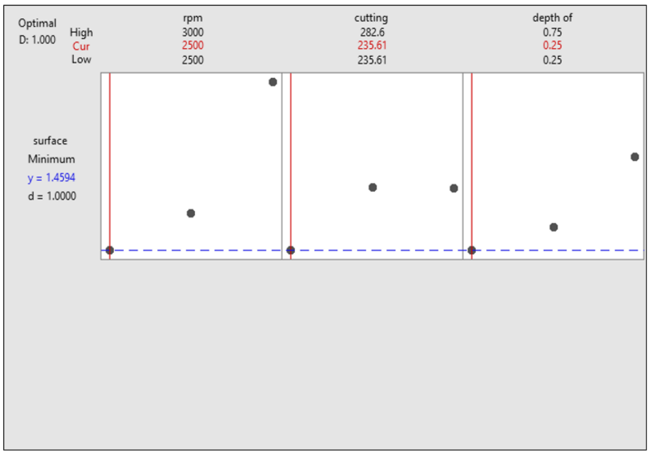

Fig 12 LNB Optimization Graph

D. Interaction Plots for Surface Roughness

Interaction plots serve as an essential instrument for examining the impacts of two or more factors on a designated response variable within experimental design, particularly when investigating how different process parameters affect outcomes like surface roughness in machining tasks. Surface roughness is a key measure of product quality in manufacturing processes, influencing performance attributes such as wear resistance, fatigue lifespan, and visual appeal. When processing materials such as metals or alloys, operators strive to reduce surface roughness to enhance these qualities. Interaction plots are particularly beneficial for identifying and illustrating how various machining parameters—like cutting speed, feed rate, depth of cut, and tool material—interact to affect the resulting surface finish. By analyzing these interactions, manufacturers can gain insights into complex relationships among factors and refine their processes to improve surface quality.

In the realm of surface roughness, interaction plots illustrate how the combination of two variables affects the outcome, which may not be apparent when evaluating each variable separately. For example, varying one factor, such as cutting speed, can impact surface roughness differently depending on the level of another factor, like feed rate. Interaction plots facilitate the visualization of these combined effects, pinpointing where one factor's influence varies with the level of another. Comprehending these interactions equips operators to make knowledgeable choices about optimal parameter settings to minimize surface roughness and enhance machining efficiency.

Typically, an interaction plot features two independent variables on the x-axis and the response variable—in this scenario, surface roughness—on the y-axis. Each line within the plot signifies a different level of one of the factors, while the slope or orientation of the line illustrates how that factor impacts the response across varying levels of the other factor. If the lines in the plot run parallel, it suggests that there is no significant interaction between the factors, indicating that each factor influences surface roughness independently. Conversely, if the lines intersect or separate, it implies a notable interaction between the factors, where one factor's effect on surface roughness is altered by the level of the other factor.

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Depth of cut is another variable frequently analyzed in interaction plots concerning surface roughness. In turning operations, for instance, the depth of cut can affect both the volume of material removed and the cutting forces encountered by the tool. Interaction plots involving depth of cut along with cutting speed or feed rate can assist in determining the ideal combination of these parameters. For instance, while a greater depth of cut may initially boost productivity, it could also raise surface roughness due to increased cutting forces. An interaction plot might reveal that, at higher cutting speeds, the influence of depth of cut on surface roughness is less significant, but at lower speeds, a greater depth of cut may result in considerably poorer surface finishes.

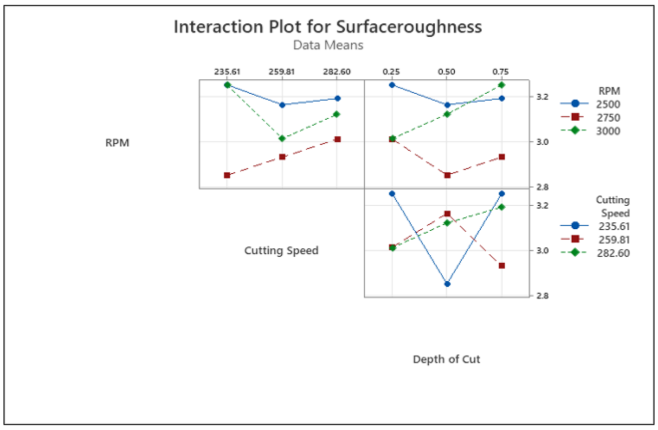

Fig 13 Interaction plots of Dry machining

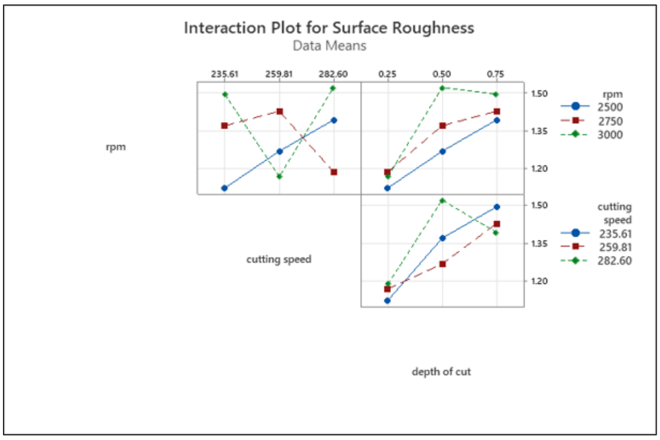

Fig 14 Interaction plots of MQL

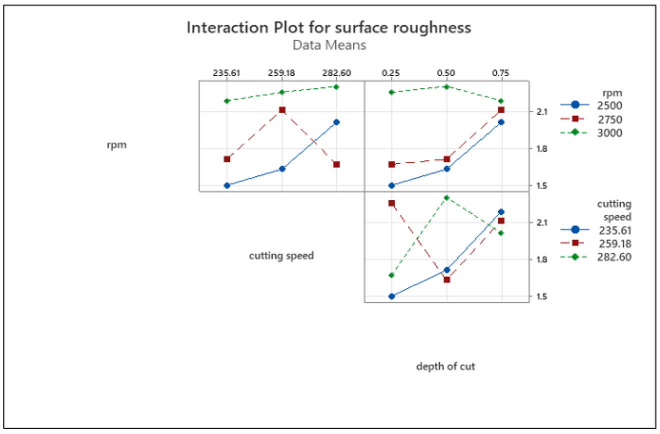

Fig 15 Interaction plots of LNB

IV. CONCLUSION AND FUTURE SCOPE

The following are the conclusions drawn after conducting the experimental investigation with three different Machining Processes with varying cutting parameters to optimize the results. From the analysis of results of the signal-to-noise ratio (S/N) approach, Taguchi's minimization technique, and Analysis of variance (ANOVA) the following conclusions are obtained

- The surface finishing is mainly affected by feed rate and cutting depth. If the feed rate increases the surface roughness increases gradually.
- If spindle speed, feed rate, and cutting depth gradually the metal removal rate also increases.
- In the process of Dry machining, the optimum value for the surface finish is 3.01 µm and the parameter values are:
- Spindle speed -3000 rev per min Cutting speed – 259.18 mm/rev Depth of cut - 0.50 mm
- In the process of Minimum Quantity Lubrication, the optimum value for the surface finish is 1.123 µm and the parameter values are:
- Spindle speed -2500 rev per min Cutting speed – 235.61 mm/rev Depth of cut - 0.25 mm
- In the process of Liquid Nitrogen Bath, the optimum value for the surface finish is 1.5µm and the parameter values are:
- Spindle speed -2500 rev per min Cutting speed – 235.61 mm/rev Depth of cut - 0.25 mm

The potential for improving the surface finish on EN19 steel through innovative machining techniques such as dry machining, Minimum Quantity Lubrication (MQL), and Liquid Nitrogen Bath (LNB) is extensive and holds considerable promise for creating more efficient, sustainable, and cost-effective manufacturing practices. EN19 is a high-strength alloyed steel widely utilized in critical applications like automotive components, aerospace parts, and heavy-duty machinery. The surface finish of EN19 plays a vital role as it directly affects the material's performance, including its fatigue strength, wear resistance, and overall durability. Therefore, the advancement of modern machining methods that enhance surface quality while reducing tool wear, energy consumption, and environmental impacts is highly advantageous. Regarding dry machining, we are likely to witness ongoing progress in cutting tools and machining techniques that lessen the reliance on conventional coolants. As industries strive for more sustainable solutions, dry machining becomes increasingly appealing since it avoids the use of cutting fluids, which can create disposal problems and raise environmental issues. The future landscape of dry machining for EN19 will probably feature the incorporation of high-performance coatings on cutting tools to decrease friction and heat generation during the machining process. The implementation of advanced sensor technologies and AI-driven adaptive control systems may further fine-tune the cutting operation in real-time, providing greater control over surface finish and minimizing result variability. Furthermore, high-speed machining along with laser-assisted machining technologies could enhance surface quality while ensuring energy efficiency.

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Minimum Quantity Lubrication (MQL) is a promising field with significant future opportunities. MQL entails the precise application of minimal amounts of cutting fluids at the machining site, providing an environmentally sustainable and economical alternative to traditional flood cooling methods. Future research will probably concentrate on refining MQL systems by enhancing fluid delivery techniques, investigating new lubrication fluids, and incorporating smart sensors to adjust lubrication according to real-time conditions. Additionally, progress in additive manufacturing and hybrid machining techniques may facilitate the creation of specialized MQL systems that focus on specific areas of the cutting tool and workpiece, further improving surface quality. The use of MQL allows for the machining of EN19 at greater speeds and feeds, boosting productivity while achieving superior surface quality in comparison to traditional methods.

The incorporation of Liquid Nitrogen Bath (LNB) cooling presents an innovative and relatively new method for improving surface finish, especially on difficult materials like EN19. Utilizing liquid nitrogen as a cooling agent provides multiple benefits, including decreased tool wear, lower machining temperatures, and enhanced surface integrity. The future will likely see broader implementation of LNB cooling, particularly in precision machining contexts. Researchers might concentrate on optimizing process parameters related to LNB, such as immersion depth, cooling rate, and the compatibility of tool materials, to attain the finest surface finish possible. Moreover, the creation of more effective cryogenic systems and automation technologies could render LNB cooling more economical and simpler to apply on a larger scale. When used alongside other advanced cooling techniques, LNB has the potential to significantly improve the machinability of EN19, particularly in high-performance applications.

In the future, combining these technologies—dry machining, MQL, and LNB—presents exciting opportunities for hybrid machining processes that incorporate various cooling and lubrication techniques. For example, merging LNB with MQL could combine the advantages of cryogenic cooling and reduced fluid consumption, resulting in improved surface finish, extended tool life, and greater process efficiency. Furthermore, machine learning and AI could be utilized to predict and optimize machining conditions in real time, thereby enhancing the surface finish of EN19 steel. The integration of these technologies with Industry 4.0 principles could lead to highly automated and intelligent manufacturing processes that are not only more efficient but also adaptable to different material characteristics, cutting conditions, and surface quality standards.

To sum up, the future potential for improving the surface finish on EN19 through CNC lathe operations via dry machining, MQL, and Liquid Nitrogen Bath is extensive. With ongoing technological advancements, such as enhanced cutting tools, lubrication systems, cooling techniques, and automation, it is expected that machining processes for EN19 will become more efficient.

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