Experimental Investigation for Enhancement of CNC Turning Tool for a Different Quenchants

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Abstract: Machining procedures are used in many manufacturing industries. One of the most basic cutting techniques used in metalworking is turning. Surface polish and dimensional tolerance are two important characteristics of a turned product that are used to assess and establish its quality. In this research, experimental work has been investigated in order to increase the quality output of CNC turning operations by the optimization of input parameters. Applications of Heat Treatment techniques are crucial for increasing tool life and improving quality in a variety of industries. The practice of precisely heating and cooling metals to alter their mechanical and physical properties without changing the material's shape. This technique can be used to increase hardness.

Keywords: Turning operation, Heat Treatment Process, Surface Roughness, PXD185941.

I. INTRODUCTION

The machining process that creates cylindrical pieces is called turning. It is the machining of an exterior surface in its most basic form: 1. With the work piece revolving. 2. With a single-point cutting tool, and • With the cutting tool feeding at a distance that will remove the work's outer surface while remaining parallel to the work piece's axis. Turning is done on a lathe that has the power to feed the cutting tool at a certain rate and depth of cut and to turn the work piece at a specific rotating speed. Thus, in a turning operation, three cutting parameters—cutting speed, feed, and depth of cut—need to be established. The performance and wear of the mating parts are significantly influenced by the quality of the mating components whenever two machined surfaces come into contact with one another. Numerous factors, including the following, affect the height, form, arrangement, and direction of these surface flaws on the work piece: A) The machining parameters, such as feed and cutting speed. c) Cut depth. d) Cutting tool wears, and e) A number of additional factors Applying heat treatment procedures to CNC tool inserts can greatly improve their strength and usefulness.

1.1 Increased Hardness: The hardness of the CNC tool insert can be increased by heat treatment techniques including quenching and tempering. The high heat and stresses that are present during machining operations like turning are better tolerated by harder inserts. Longer tool life and less wear are the results of this improved hardness.

1.2 Improved Wear Resistance: The CNC tool insert may develop a harder surface layer as a result of heat treatment procedures like carburizing or nitriding. Longer tool life and improved performance are the results of this hardened layer's exceptional resistance to abrasive wear and frictional pressures experienced during machining processes.

1.3 Enhanced Toughness: Maintaining sufficient toughness is just as important as hardness in order to avoid tool chipping or fracture during milling. The CNC tool insert can attain a balance between toughness and hardness with appropriate heat treatment and tempering, guaranteeing that it can tolerate the impacts and stresses experienced during cutting.

1.4-Dimensional Stability: By reducing internal tensions, heat treatment enhances the dimensional stability of the CNC tool insert. This guarantees that the insert will precisely keep its size and shape

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An easy way to comply with the Journal paper formatting requirements is to use this document as a template and even after extended use, producing accurate and reliable machining results.

1.5 Optimized Microstructure: The CNC tool insert material's microstructure can be precisely controlled through heat treatment. Manufacturers can improve the microstructure to increase mechanical qualities like strength, toughness, and wear resistance by adjusting the heating and cooling processes. This produces a tool insert that is more resilient and long-lasting.

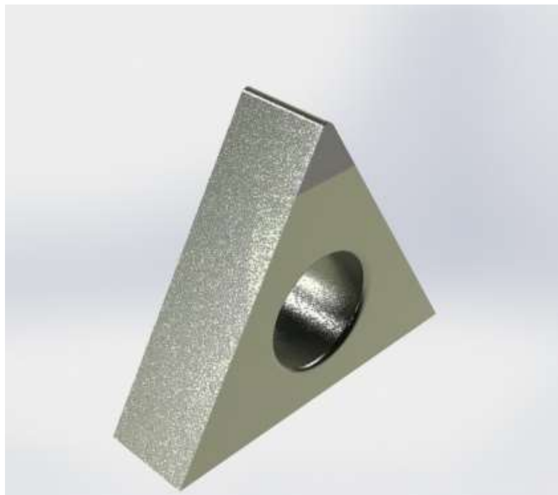

Fig. 1 PXD-18594Z

II. LITERATURE REVIEW

Induction hardening enhanced the microstructure and machining-induced residual stresses of hardened AISI 4340 steels, according to W. Jomaa et al. (2016). Cutting circumstances were observed to have an impact on the distribution of residual stresses; more particularly, a higher cutting speed (202 m/min) causes tensile residual stresses on the surface [01]

AISI 52100 steel hard turning's machinability properties, including surface roughness, tool wear, and chip morphology, were evaluated by A. Panda et al. (2018) using a multilayered coated carbide tool. Researchers noticed a significant improvement in surface roughness quality in the higher feed rate range due to the vibration created during the hard turning process. The high machining temperature generated during dry hard turning at the chip-tool and tool-work piece interfaces affects the surface integrity of AISI 52100 steel. The machining zone's high temperature generation is decreased by efficient cooling and lubrication. Traditional flood cooling has several drawbacks, such as expensive processing costs, pollution from inappropriate disposal, and hazardous odors for workers. [02]

Using a CBN cutting tool, M. Bicek et al. (2012) examined the machinability of hardened and normalized AISI 52100 steel under dry, flood, and cryogenic chilling environments. It has been demonstrated that cryogenic cooling has less micro hardness variation and a thinner white layer than dry and flood cooling. [03]

V. Derflinger and colleagues (1999) investigated the benefits of cooling lubricants in machining operations. But the cost of using, maintaining, and discarding coolant lubricant is substantial. Investigations have shown that using coolant lubrication can sometimes be far more expensive than the tool itself. The deposition of a hard/lubricant coating on cutting tools seems to be a very interesting alternative to remove the large amounts of cooling emulsion in metal cutting and to function with little to no lubrication in a range of applications. Possible uses include alloyed steel machining, cast iron, and aluminum alloys [04].

The machining of AISI-304 steel was assessed by S. Berkania et al. (2015) in terms of surface roughness, specific cutting force, power consumption, and force development. The findings showed that the key factor impacting surface roughness was feed rate. However, the depth of cut has a major effect on cutting power and force, respectively. [05]

In their study of 2013, M. Kaladhar et al. examined how machining parameters affected flank wear, surface roughness, and performance indicators when turning AISI 304 austenitic stainless steel. The results showed that cutting speed influences both surface roughness and tool flank wear. [06]

The RSM approach is used by P. Saini et al. (2014) to determine the ideal machining parameters that result in the least amount of surface roughness during the turning process. [07] A 2009 study by M. Nalbant et al. examined AISI 1030 steel machining without the use of cooling solutions. Research has been done on the effects of feed rate, cutting speed, coating substance, and coating procedure on the work piece's surface roughness. The findings showed that compared to an untreated tool, a coated tool offers better surface roughness values. [08]

The surface roughness results of hardened AISI D2 steel in hard turning using a coated carbide tool were investigated by Sahoo (2014). Because BUE formation vanished and chip-tool contact length shrank, the researcher found that higher cutting rates led to less surface roughness. [09] The method of creating white and black layers during hard machining of AISI 52100 steels was investigated by Zhang et al. (2018). After machining, researchers found that a white coating is produced by a rapid transition in the austenite phase with a quenching effect brought on by the combined action of plastic deformation and phase changes. However, the combined effects of high temperature and plastic deformation on the tempering process resulted in the black layer [10].

III. DESIGN OF EXPERIMENT & METHODOLOGY

Tungsten carbide is a typical material used for CNC (Computer Numerical Control) tool inserts due to its high hardness, wear resistance, and thermal conductivity. CNC tool inserts, also known as carbide inserts, are replaceable cutting tips that are brazed, clamped, or mechanically secured to the tool body. Tungsten carbide inserts are ideal for CNC machining operations such as turning, milling, drilling, and threading in a variety of materials, including metals, alloys, composites, and some non-metallic materials. These inserts are extremely adaptable and can be adapted to specific machining applications by adjusting their geometry, coating, and tungsten carbide grade. The qualities of tungsten carbide inserts can be improved by adding elements such as cobalt, titanium, and tantalum, among others, to improve toughness, resistance to thermal deformation, and overall performance. When choosing tungsten carbide CNC tool inserts, cutting speed, feed rate, depth of cut, workpiece material, and surface finish requirements must all be taken into account to achieve optimal performance and tool life. Overall, tungsten carbide CNC tool inserts are popular in modern machining due to their durability, precision, and cost-effectiveness.

TABLE I:
MATERIAL TESTING REPORT

T9215		
Elements	**Result**	**Test Method**
% Carbon	5.40	LDM_01_B:2020
%Sulphur	0.011	
%Phosphorus	0.014	
%Manganese	0.85	
%Nickel	0.001	
%Chromium	0.09	
%Molybdenum	0.010	
%Copper	0.02	
%Titanium	1.65	
%Cobalt	11.80	(WET PROCESS)
%Aluminum	0.01	
%Niobium	1.50	
%Antimony	0.07	
%Tantalum	0.41	
%Iron	0.80	
%Tungsten	77.31	

TABLE II:
MATERIAL TESTING REPORT

CNMG190612		
Elements	**Result**	**Test Method**
% Carbon	5.85	LDM_01_B:2020
%Sulphur	0.009	
%Phosphorus	0.010	
%Manganese	0.007	
%Nickel	0.01	
%Chromium	0.04	
%Molybdenum	0.010	
%Copper	0.02	
%Titanium	2.10	
%Cobalt	11.00	(WET PROCESS)
%Aluminum	0.01	
%Niobium	1.60	
%Antimony	0.02	
%Tantalum	2.00	
%Iron	0.025	
%Tungsten	78.22	

TABLE III:
MATERIAL TESTING REPORT

CNMG120408		
Elements	**Result**	**Test Method**
% Carbon	5.32	LDM_01_B:2020
%Sulphur	0.010	
%Phosphorus	0.012	
%Manganese	0.015	
%Nickel	0.01	
%Chromium	0.01	
%Molybdenum	0.02	
%Copper	0.02	
%Titanium	2.00	
%Cobalt	10.75	(WET PROCESS)
%Aluminum	0.01	
%Niobium	0.58	
%Antimony	0.05	
%Tantalum	1.80	
%Iron	0.13	
%Tungsten	79.19	

TABLE IV:
MATERIAL TESTING REPORT

PXD-18594Z		
Elements	**Result**	**Test Method**
% Carbon	5.52	LDM_01_B:2020
%Sulphur	0.010	
%Phosphorus	0.013	
%Manganese	0.035	
%Nickel	0.025	
%Chromium	2.30	
%Molybdenum	0.010	
%Copper	0.02	
%Titanium	1.90	
%Cobalt	11.70	(WET PROCESS)
%Aluminum	0.09	
%Niobium	1.62	
%Antimony	0.06	
%Tantalum	0.41	
%Iron	2.13	
%Tungsten	74.14	

3.1 Heat Resistance: Tungsten carbide has exceptional heat resistance, making it a popular choice for applications that need high temperatures, such as cutting tools in machining processes. Here are some important features of tungsten carbide's heat resistance.

High melting point: Tungsten carbide has an extremely high melting point of roughly 2,870°C (5,198°F), allowing it to survive the intense temperatures found in many industrial processes without melting or deforming.

Thermal conductivity: Tungsten carbide has a high thermal conductivity as compared to other materials, which aids in heat dissipation during cutting or machining operations. This feature is critical for maintaining cutting tool integrity and avoiding heat damage.

Thermal expansion: Tungsten carbide has a low thermal expansion coefficient, which means it expands minimally when subjected to heat. This property aids in maintaining dimensional stability and precision in cutting tools even at high temperatures.

Oxidation resistance: Tungsten carbide is highly resistant to oxidation, which means it can maintain its properties even in high-temperature environments where oxygen exposure is prevalent. This resistance to oxidation contributes to the longevity and performance of tungsten carbide cutting tools.

Retention of hardness: Tungsten carbide is highly resistant to oxidation, therefore it can preserve its qualities even in high-temperature situations where oxygen is present. This resistance to oxidation improves the longevity and performance of tungsten carbide cutting tools.

Overall, tungsten carbide's great heat resistance makes it an excellent choice for a wide range of applications, including cutting tools, wear parts, and components that are exposed to high temperatures.

3.2 Heat Treatment: The experimental work was carried out using the heat treatment settings, which were based on Research Paper [04] These parameters, which included things like temperature, holding time, cooling rate, and environment, had a big impact on the material's mechanical and microstructural characteristics.

Tungsten carbide composed with cobalt (90-10% wt) that is treated by quenching in an oil bath with annealing by heating to 800°C for four hours is the most appropriate material utilized in cutting tool applications due to its high hardness and ultimate strength compared with other samples. The heat treatment procedure described entails heating a material to 800 degrees Celsius for four hours before quenching it in oil. This procedure is popularly known as quenching and tempering, and it is frequently used to improve the mechanical characteristics of metals, especially steel.

1. Heating to 800 degrees Celsius: The first step in the heat treatment technique is to heat the material to a specific temperature. In your situation, the temperature is 800°C. For a set period of time, the material is kept at this temperature to allow its microstructure to undergo the appropriate alterations.

2. Soaking for 4 hours: The material is heated to 800 degrees Celsius for four hours. This extended soaking period allows for the requisite atom diffusion inside the material's microstructure and ensures that the material achieves thermal equilibrium in its entirety.

3. Oil quenching: After soaking, the material is swiftly cooled by being immersed in oil. Quenching is the process of immersing a hot material in a quenching media (such as water, oil, or polymer) to rapidly reduce its temperature. This fast cooling alters the material's microstructure, typically increasing hardness and strength.

The material's composition, initial microstructure, and cooling rate all influence the precise microstructure changes that occur throughout the quenching and tempering processes. Quenching and tempering can improve the material's hardness, strength, toughness, and wear resistance, making it suitable for a wide range of applications in industries such as manufacturing, aircraft, and cars.
It is critical to recognize that the efficacy of the heat treatment technique is dependent on the proper regulation of temperature, duration, and rate of cooling, as well as the suitable choice of quenching medium. When the recommended specifications are not followed, undesirable outcomes such as excessive hardness, deformation, or cracking may occur. To achieve the specified material qualities, heat treatment processes must be properly designed and carried out.

3.3 L9 Method:

When using the L9 approach with a CNC turning machine, experimental design concepts can be used to optimize the machining process. The L9 approach can be adapted as follows for usage with CNC turning.

TABLE V:
INPUT PARAMETERS

Sr. No	Speed (RPM)	Feed Rate (mm/min)	Depth of Cut (mm)
1	800	0.17	0.4
2	950	0.2	0.2
3	950	0.15	0.4
4	1100	0.17	0.2
5	950	0.17	0.6
6	800	0.15	0.2
7	800	0.2	0.6
8	1100	0.2	0.4
9	1100	0.15	0.6

3.4 Surface Roughness

Surface roughness values on completed work pieces were measured using the Mitutoyo Surface Roughness Tester SJ-201 in accordance with the proper protocol. The Mitutoyo Surface Roughness Tester SJ-201 is a gadget that uses a mechanical stylus to gently drag across a surface. To collect data, the sample is moved beneath the surface roughness tester's diamond-tipped stylus. An LVDT detects the stylus' vertical movements, digitizes them, and saves the information in the instrument's memory. Its output is a digital display of the measured surface roughness value Ra, as well as additional features. Surface roughness was measured according to ISO standards. The ambient temperature was 32 ± 1◦C. In this study, we measured surface roughness (Ra).

3.5 Work Flow:

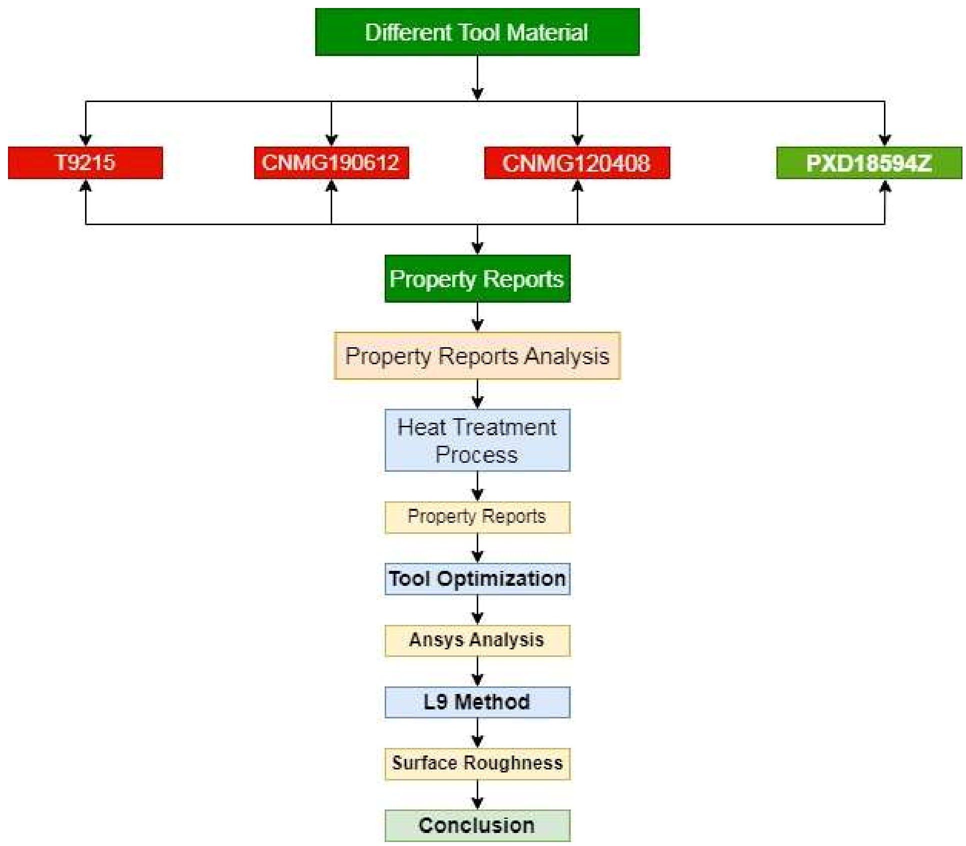

Fig. 2 Work Flow

IV. EXPERIMENTAL SETUP & MEASUREMENT

4.1 Heat Treatment Process

A muffle furnace is a type of oven that uses controlled conditions to heat materials to high temperatures. It contains an insulated compartment. In metallurgy, this apparatus is commonly used for a variety of heat treatment operations. Inside the muffle furnace, the tungsten carbide tool was precisely heated to 800°C. This temperature is significant because it most likely corresponds to the annealing or transformation temperature that tungsten carbide should have. In addition, the material was heated for four hours, allowing it to reach thermal equilibrium and undergo any desirable microstructural changes.

The goal of heating the tungsten carbide tool to 800°C for 4 hours was to cause specified changes in its microstructure or property. Annealing, sintering, and stress relieving are examples of high-temperature heat treatment methods that can be used to affect the characteristics of materials such as tungsten carbide. These treatments can increase hardness, toughness, dimensional stability, and other desirable properties.

The objective of quenching in oil after four hours of heating at 800°C is most likely to improve a certain tungsten carbide tool feature. Rapid cooling after exposure to high temperatures can change the microstructure of a material, giving it additional dimensional stability, wear resistance, or hardness.

Fig. 3 Muffle Furnace

Fig. 4 CNC Insert

4.2 Microhardness Testing

Examine the micro hardness profiles of several measurements taken in different locations or depths of the material to determine changes in hardness within the tungsten carbide tool. Variations in microhardness can reveal differences in material qualities induced by variables such as composition, microstructure, or processing conditions.

4.3 Optimization of Tool

PXD-18594Z has a greater micro hardness rating than the other evaluated tools, indicating that it may have better hardness properties. This could indicate changes in material composition, processing background, or heat treatment conditions.

4.4 CNC Lathe Machine Setup

The Cartesian coordinate system is the basis for CNC motion. A CNC machine cannot be properly operated unless the definitions of coordinate systems in CAM and CNC machines, as well as how they interact, are understood.

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The Input Parameters are in Table 3.5

Fig. 5 CNC Programming

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V. RESULT AND DISCUSSION

5.1 Heat Treatment

TABLE VI:

Location	Micro Vickers Hardness Value (HV)
Test Force (kgf.)	HV 1
Result 1	1195
Result 2	1183
Result 3	1117
Avg.	1165.00

Results:

- The observed increase in hardness after heat treatment.
- Phase transformations.
- Comparison of hardness values obtained at different testing locations on the sample.

5.2 Ansys Analysis

5.2.1 Total Deformation

Total deformation load applied to the model during analysis, with data showing maximum and minimum deformation values. Here is how you can interpret these results.

Total Deformation: The phrase "total deformation" refers to the model's overall displacement or distortion due to the applied load. It illustrates the combined effects of all deformation modes, such as rotation, translation, and elemental deformation.

The maximum deformation value of 0.014628 mm is the most deformation seen across the model. This value can be used to identify potential sources of concern or excessive stress levels. It signifies a key spot where the deformation is most pronounced.

The minimum deformation value of 0.0016253 represents areas of the model with minimal or minor distortion. This number can be used to find areas where the applied load causes the least amount of displacement or deformation

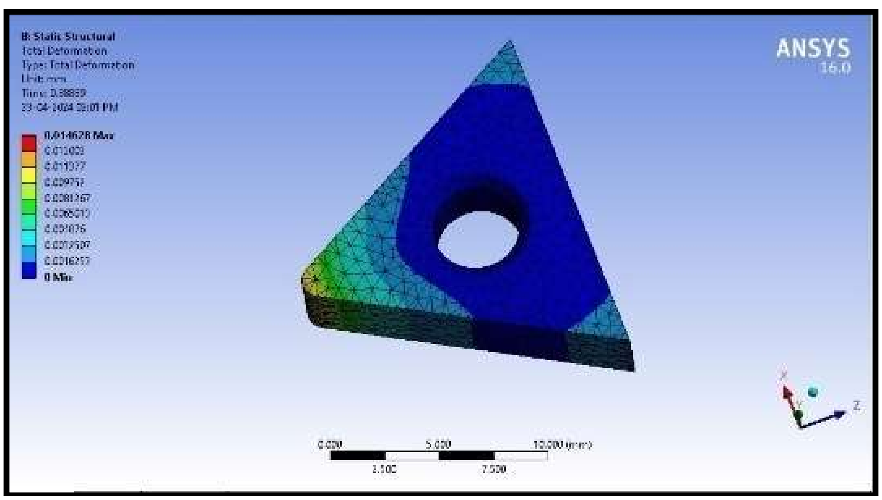

Fig. 6 Total Deformation

5.2.2 Equivalent (von- Mises) Stress

During the Ansys stress study of the CNC insert, a maximum von Mises stress of 987.64 MPa was observed. This value represents the maximum amount of stress that the material has experienced when loads are applied.

According to this data, the CNC insert is highly stressed in some regions, which may have an impact on the device's structural integrity and operation. More analysis and interpretation of these data is required to determine any necessary design changes or optimization strategies, as well as to understand the precise variables causing the reported stress levels.

Ansys' stress analysis results provide crucial insights into the mechanical behavior of the CNC insert, which can aid in the assessment and improvement of design and performance parameters.

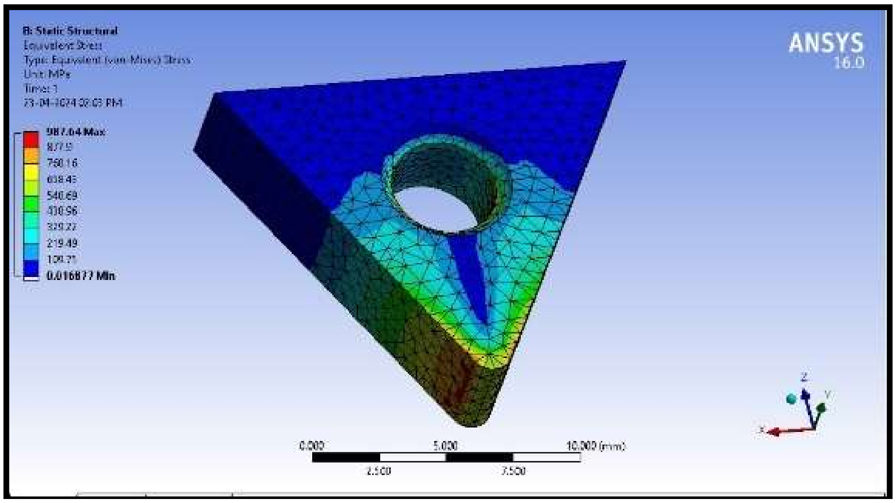

Fig. 7 Equivalent (von- Mises) Stress

5.2.3 Total Heat Flux

To compute the total heat flow, consider the distribution of heat flux across the entire model surface. You can use this maximum value if the heat flux over the surface remains constant. If the heat flux changes over the surface, you may need to conduct further analysis to calculate the overall heat flux.

In my ANSYS simulation, the maximum heat flux result was 25.33 W/mm², indicating the highest heat flux observed in your model during the simulation.

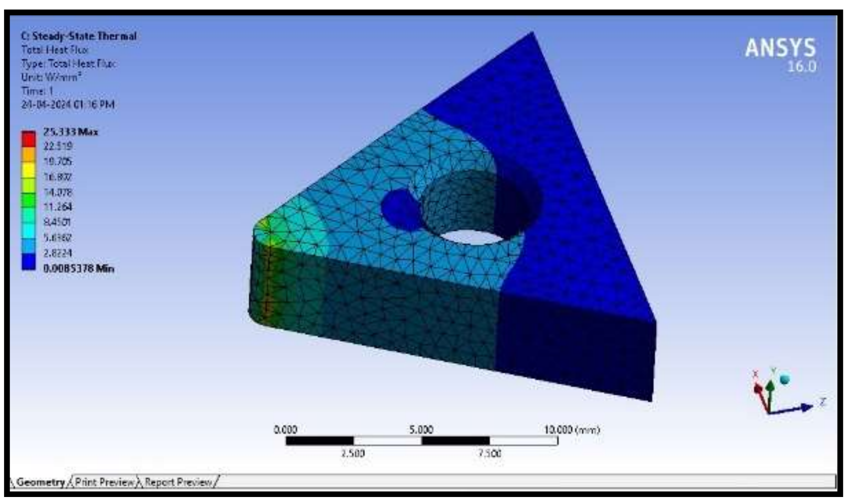

Fig. 8 Total Heat Flux

5.2.4 Temperature

ANSYS simulation produced a maximum temperature of 815.55°C, which represents the highest temperature ever recorded in my model during the simulation. To interpret this conclusion correctly, I must first understand the context of my simulation as well as the physical significance of the temperature distribution in my model.

Determine whether the maximum temperature exceeds any material or safety thresholds. If so, consider using additional thermal management strategies such as insulation, heat sinks, or active cooling.

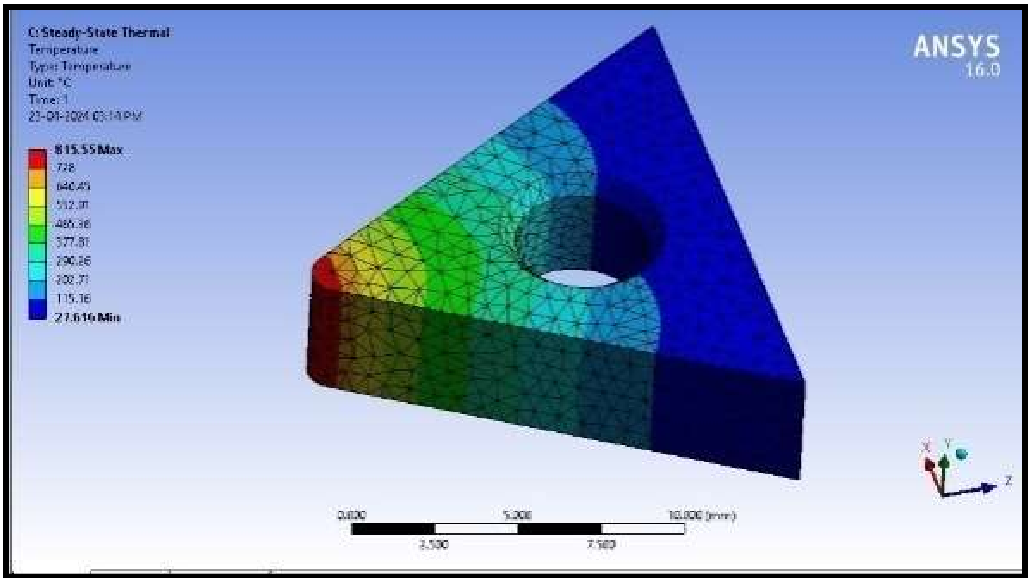

Fig. 9 Temperature

5.3 L9 Surface roughness results

TABLE II:

Sr. No	Speed (RPM)	Feed Rate (mm/min)	Depth of Cut (mm)	Surface roughness (µm)	S/N Ratio
1	800	0.17	0.4	3.260	-10.2644
2	950	0.2	0.2	2.97	-9.45513
3	950	0.15	0.4	3.06	-9.71443
4	**1100**	**0.17**	**0.2**	**0.53**	**5.514483**
5	950	0.17	0.6	3.18	-10.0485
6	800	0.15	0.2	4.648	-13.3453
7	800	0.2	0.6	5.594	-14.9544
8	1100	0.2	0.4	0.580	4.73144
9	1100	0.15	0.6	0.52	5.679933

5.3.1 Response Table for Signal to Noise Ratios

TABLE III:

Level	Speed	Feed Rate	Depth of cut
1	-12.855	-5.793	-5.762
2	-9.739	-4.933	-5.082
3	5.309	-6.559	-6.441
Delta	18.163	1.627	1.359
Rank	1	2	3

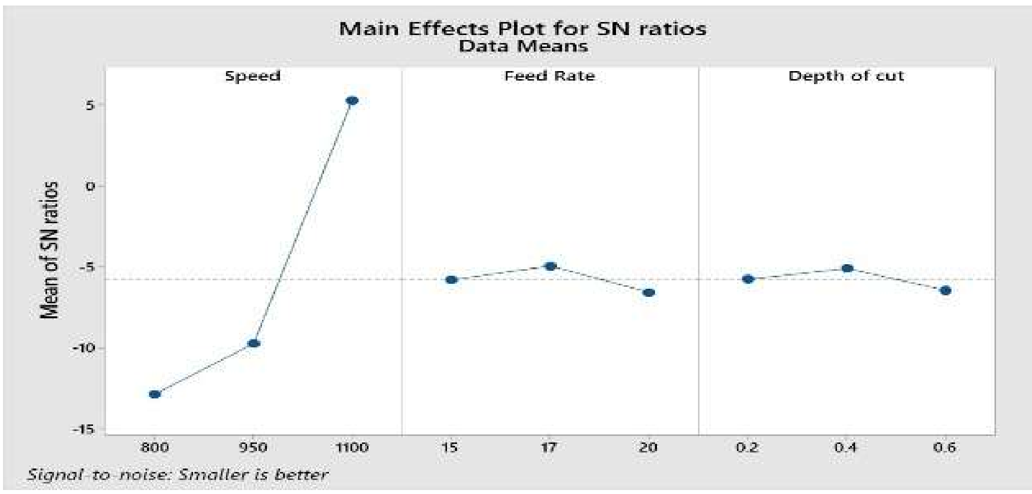

Fig. 10 Signal to Noise Ratios

Based on the experiment results, there are several implications and things to consider moving ahead, including the fact that the optimal parameter combinations for speed, feed rate, and depth of cut were 1100 rpm, 0.17 mm/min, and 0.2 mm, respectively. This yielded a surface polish of 0.53 µm.

5.4 Optimization Refinement

Even if the chosen parameter combination yielded promising results, surface finish may still require more optimization and refinement. To achieve an even better surface finish, fine-tune parameters within a small range of the identified values.

By considering these consequences as well as future issues, manufacturers can increase surface finish quality, optimize machining techniques, and achieve greater performance and efficiency in precision machining operations

VI. CONCLUSIONS

Furthermore, the addition of tungsten carbide to tool PXD-18594Z has significantly improved surface quality, hardness, and heat resistance. All of these enhancements work together to optimize machining operations, increase productivity, and ensure dependable production outcomes, ultimately contributing to the tool's superior performance and extended lifespan in industrial applications.

While the experiment results reveal that tungsten carbide integration improves tool performance, heat treatment operations can be viewed as complementing techniques that increase tool finishing precision and overall performance in machining applications.

The best solution should be chosen based on the machining process's unique requirements, materials, and operating conditions.

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