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Experimental study: coolant viscosity's impact on Inconel 600's surface roughness measured using a refractometer

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ABSTRACT

This paper presents an experimental study on the impact of coolant viscosity on the surface roughness of Inconel 600 material processed using a lathe. This research employs sequential experimental methods, encompassing a coolant viscosity test, specimen machining with a lathe, and surface roughness test. The standard for the roughness grade number is defined by ISO 1302. The study effectively demonstrates the use of a refractometer as a reliable and practical alternative for determining coolant quality in % Brix units, which strongly correlates with coolant viscosity. The research findings reveal that an increase in coolant viscosity results in a smoother surface roughness of the workpiece, while a decrease leads to an increase in surface roughness. Specifically, the average viscosity of 8%, 10%, and 13% Brix coolant results in an average surface roughness of Ra 11.83 µm, Ra 10.09 µm, and Ra 7.23 µm, respectively. The average roughness grade number based on this study is N9 - N10. However, the study also identifies the need for further mathematical calculations to establish a link between coolant concentration, % Brix, and coolant viscosity. This opens up an intriguing avenue for future research and holds the potential to significantly enhance our understanding of the relationship between these variables.

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1. Introduction

As the demand for optimal thermal efficiency in aeronautics and steam turbines of energy power plants grows, applications where aluminum and steel would fail due to creep caused by thermally induced crystal vacancies are turning to nickel-based alloys [1], [2], [3], [4]. These alloys have proven to be an excellent choice for high-temperature operations [5], [6], [7], [8]. Ni-Cr-Fe superalloys, commonly known as Inconel (a registered trademark of the International Nickel Company of Delaware and New York) are materials that resist oxidation, corrosion from caustic and high-purity water, and stress-corrosion cracking [9]. They are ideal for use in harsh environments under high mechanical loads and have a wide range of applications and characteristics [10]. One of the Inconel frequently used in the industrial world is Inconel 600. This alloy is suggested for utilization in components of furnaces and equipment for chemical processing [11]. Furthermore, due to its stable crystalline structure in applications that would lead to permanent deformation in other alloys, Inconel 600 is also efficiently employed in the food industry and nuclear engineering [12].

The turning process, which involves rotating and cutting the workpiece using a chisel, is a machining method used to produce cylindrical machine components. Several important factors in this process include cutting speed, cutting time, cutting depth, and cutting angle. The heat increase that often occurs during the turning process can affect the surface roughness of the workpiece, which must be considered because it has a significant impact on product quality. The most commonly measured surface roughness is the arithmetic average roughness, which has twelve levels (N1 to N12) according to ISO 1302:1992[13].

Coolant, a substance used to mitigate heat and friction during machining processes, plays a crucial role in maintaining the sharpness of cutting tools. By preventing overheating, it reduces tool wear, leading to an improved surface finish in machining operations. It also enhances chip removal from the tool-workpiece interface and prevents the formation of built-up edges on the cutting tool's surface [14]. The effect of coolant on the surface roughness and tool wear in hard turning of AISI 52100 steel using coated carbide inserts has been investigated. The article compares the performance of dry, wet, and minimum quantity lubrication (MQL) conditions. The article reports that MQL provides the best surface roughness and tool wear results, followed by wet and dry conditions [15]. Another study evaluates how material hardness and high-pressure coolant jet affect surface roughness and cutting temperature in hard turning using the Taguchi method analyzes the experimental data using various statistical tools and identifies the most significant factors for both responses. The result shows that a high-pressure coolant jet improves surface quality and reduces cutting temperature[16].

Before the introduction of cutting fluids, dry machining was the prevalent method for material removal, offering cost savings by eliminating the need for metal-working fluids. However, the advent of cutting fluids brought about various delivery methods such as flooded cooling, high-pressure coolant, solid coolant, cryogenic cooling, and minimum quantity lubrication (MQL). These coolants can be composed of different materials, including synthetic oil, vegetable oil, or natural vegetable oil. They serve to cool the workpiece and tool, slow down the tool's wear rate, and affect the roughness and hardness of the workpiece surface. As a result, the use of coolant can significantly improve machining performance, surface quality, and tool life across various metals and alloys. In Addition, the empirical research conducted by another researcher elucidates the efficacies of various coolant lubricants that enhance the machinability of Inconel 718, focusing on parameters like surface roughness and tool wear. The study uses a CNC milling machine for experimentation with ceramic inserts. It summarizes various cooling techniques, including hybrid cooling, flood emulsion cooling, minimum quantity lubrication, and cryogenic cooling. As a result, the hybrid cooling technique is highlighted as the most effective, providing longer tool life and a smoother surface finish [17].

Viscosity indicates how much a fluid resists moving, due to the friction between fluid layers. The movement of fluids is relevant for many fields, such as medicine (artery blood flow, medicine delivery), the food industry (pumping systems), transportation industries (oil and machine damage, electric car batteries), and the oil industry [18]. The properties of a cutting fluid depend largely on its viscosity. The fluid lubricates better when it has higher viscosity, but it cools less effectively. The fluid cools better and removes solid particles more easily when it has a lower viscosity. However, this can cause insufficient lubrication between the edge of the tool and the workpiece, especially at high production speed. This can result in poor surface quality and more tool wear. Therefore, viscosity influences the speed at which the liquid reaches the contact zone between the cutting tool and the workpiece, and the liquid film thickness. Measuring viscosity helps to achieve a trade-off between the highest possible machine parameters and the best possible surface quality of the workpiece [19].

According to the report revealed by Anton Paar Group, the viscosity and density of metal cutting fluids were measured using SVM™ 3001 or SVM™ 4001 Viscometer, which can produce other parameters such as viscosity index and Saybolt viscosity. The viscometer is developed, produced, distributed and supported by the Anton Paar Group, a leading company in analytical instruments for research, development and quality control. Two types of cutting fluids: Jokisch Monos Atos N3S and Castrol Honilo 980 were tested. The measurement results were compared with the typical values from the product data sheet and show that SVM™ 3001 is suitable for determining the viscosity of cutting fluids [19].

Furthermore, another study investigated the properties of nanofluids containing Al_2O_3 nanoparticles in a car engine coolant, such as thermal conductivity and viscosity. The study used a Brookfield programmable viscometer (model: LV DV-II-Pro) connected to a PC-controlled Julabo Temperature Controlled Bath to measure the viscosity of nanofluids, which affects the lubrication and cooling performance of the fluid. The study also measures the thermal conductivity of nanofluids, which depends on the volume fraction of nanoparticles and the temperature. The research compares the results with various theoretical models and suggests that the Brownian motion of nanoparticles is an important factor in the heat transfer and rheological behaviour of nanofluids. It concludes that the nanofluids based on car engine coolant have potential applications in improving the cooling performance and efficiency of automobile engines [20].

Conversely, the machining of Inconel 718, a heat-resistant superalloy, under the influence of high-pressure coolant, has been simulated using a Finite Element Method (FEM) program. This research introduces a predictive Finite Element Model specifically designed to estimate the distribution of tool temperature during the turning process of Inconel 718. The study underscores the pivotal role of temperature in determining the efficacy of machining performance, demonstrating that the pressure of the coolant exerts a significant impact on temperature, with elevated pressures contributing to enhanced cooling and lubrication. Furthermore, the research broaches the subject of sustainability in manufacturing, spotlighting innovative techniques such as Minimum Quantity Lubrication (MQL) that aim to curtail the usage of cutting fluid. The empirical findings of the research indicate that the application of high-pressure coolant can precipitate a substantial reduction in tool temperature, a factor that proves advantageous for the machining of challenging materials such as Inconel 718 [21].

Another research investigates the impact of alumina nanoparticles on the thermal conductivity and viscosity of engine coolant. The study reveals that these nanoparticles can enhance the coolant's heat transfer efficiency and flow resistance. The goal is to find the optimal nanoparticle concentration that boosts coolant performance, thereby improving engine efficiency and lifespan. The research concludes that alumina nanofluids, due to their excellent thermal properties and suitable viscosity, could potentially outperform traditional coolants, paving the way for more efficient engine cooling systems [22].

A refractometer is a simple optical device that is used to measure the concentration of aqueous solutions[23][24]. This device only requires a few drops of liquid and is often used as laboratory equipment in various industries, such as food, agriculture, chemistry, and manufacturing. The principle of refractometer is to utilize the phenomenon of refraction, which is the change of direction of light when entering a liquid substance. The refractometer measures the angle of refraction of light and connects it with the refractive index (nD) value that has been established. With this value, we can determine the concentration of solutions. For example, solutions have different refractive indices depending on their concentration.

Table 1. % Brix in some sample fluids [25]

Sample Fluid	% Brix
Cutting Oil	0 to 8
Oranges	4 to 13
Carbonated beverages	5 to 15
Apples	11 to 18
Grapes and Wines	14 to 19
Concentrated Juices	42 to 68
Condensed Milk	52 to 68
Jams and Jellies	60 to 70

The % Brix scale shows the percentage of concentration of dissolved solids in a sample of aqueous solution. Dissolved solids are the total of all substances that are dissolved in water, starting from sugar, salt, protein, acid, and so on. The measurement reading value is the total value of all those substances. The Brix scale is calibrated with the amount of cane sugar contained in 100 g of water [25]. When measuring a sugar solution, the % Brix reading should match the actual concentration. One example of using a refractometer is to test the quality of cooking oil. It explains how a refractometer can be used for this purpose based on the principle of light refraction and the refractive index value. It also presents data from experiments using various types and brands of cooking oil [24].

A detailed study on the use of a critical angle refractometer for analyzing heavy water (deuterium oxide) was also investigated. The authors describe the design and functioning of the refractometer, which is specifically tailored for heavy water analysis. They emphasize the instrument's precision and reliability in measuring the refractive index of heavy water, a parameter that is crucial for various applications in nuclear facilities. The refractometer's capability to provide accurate measurements contributes significantly to the control and monitoring of heavy water quality, ensuring the safe and efficient operation of nuclear reactors where heavy water is used as a moderator and coolant [26].

Drawing upon the research spearheaded by Jeanne W. George in the field of veterinary science, it has been established that refractometers possess the capability to quantify the concentration of total solids predicated on specific gravity. The utility of refractometers is particularly pronounced in the determination of urine-specific gravity in veterinary samples, attributed to their requirement for relatively diminutive sample volumes. Specific gravity persists as the most prevalent unit for the reporting of total solids concentration. However, it is noteworthy to mention that certain solutes, such as acetone, may induce erroneous elevations in specific gravity as measured by refractometry. This phenomenon occurs due to their ability to augment refraction, despite being less dense than water [27].

Heidemann et al.'s research is the first to explore using a refractometer to measure mineral oil viscosity. They focus on the production of diesel injector nozzles, which require precision and the use of an abrasive fluid to shape micro-holes. This fluid's viscosity can change during the grinding process, affecting the outcome. The research investigates using the oil's refractive index to monitor viscosity during grinding. They create a calibration curve using two different mineral oils and test it with 45 oil samples from the grinding process. The results suggest refractometry could be used for real-time grinding efficiency control by tracking viscosity changes [28].

A refractometer is a simple optical device used to measure aqueous solution concentration. On the other hand, a viscometer is a laboratory device that is used to measure the viscosity of a liquid. Viscosity is a property of a liquid that describes how thick or viscous it is. This property is very important in various industrial applications. The measurement of the viscosity of a liquid, in this case coolant, in some scientific journals is done using a viscometer. The use of a refractometer in measuring the viscosity of coolant and connecting its effect with the surface roughness of the material is a new method. This present study examines the effect of the viscosity of coolant measured by a refractometer on the surface roughness of Inconel 600 material processed by a lathe.

2. Method

This research used a sequential experimental method as shown in Fig. 1. The research process consists of several stages, namely: (1) literature study from scientific journals, papers, and articles related to coolant viscosity, surface roughness, and turning process; (2) preparation of coolant solution by mixing coolant and water with a ratio of 1:3; (3) testing the viscosity of coolant that has been mixed with water using a refractometer with variations of 8% Brix, 10% Brix, and 13% Brix, and adjusting the water content if the coolant viscosity exceeds or is less than the desired value; (4) turning process using coolant that has been tested for its viscosity; (5) testing the surface roughness of the workpiece that has been turned using a surface roughness tester; and (6) comparing the results of surface roughness testing with the established standards.

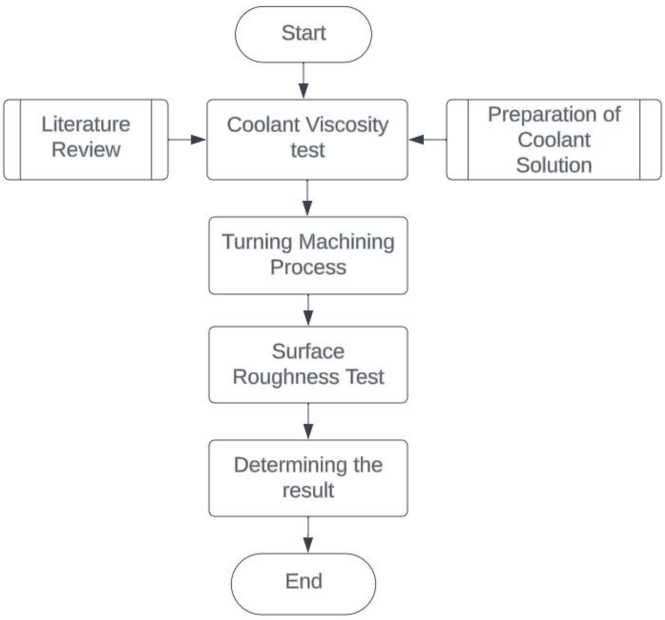

Fig. 1. Research's flow chart

This research focused on Inconel 600, a nickel-based alloy used in the aviation industry. The material composition of Inconel 600 can be seen in Table 2. The advantages of Inconel 600 include high strength and oxidation resistance at extreme temperatures, extraordinary corrosion resistance, and the ability to prevent stress corrosion cracking. By this research, these superior properties in aviation industry applications can be understood and utilized.

Table 2. Limiting chemical composition, % [29]

Nickel (plus Cobalt)	72.0 min
Chromium	14.0 – 17.0
Iron	6.0 – 10.0
Carbon	0.15 max
Manganese	1.00 max
Sulfur	0.015 max
Silicon	0.50 max
Copper	0.50 max

The lathe process was carried out using the ISCAR 2020 cutting tool. The operational parameters used were a feed rate of 0.0002 mm/minute and a spindle speed of 200 rpm. The cutting time required was 2 minutes and 50 seconds. The workpiece specimen met the expected standards. The finished workpiece specimen can be seen in Fig. 2. The outer diameter, thickness, and width of the specimen are 0.565 inch, 0.010 inch, and 0.125 inch, respectively.

Fig. 2. Workpiece specimen

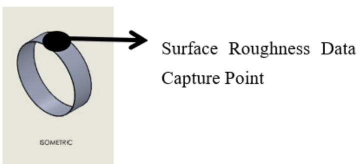

Fig. 3. Location of data collection point

The coolant used in this research is Blasocut 2000 CF. It's a versatile, water-miscible, chlorine-free, mineral oil-based cutting fluid. It's designed for machining a variety of materials including cast iron, steel, and aluminium alloys. Detailed properties and performance data can be found in Table 3. The surface roughness of the material was quantified by the surface variations that deviate from its ideal shape, which consist of roughness (the irregularities of the surface profile), waviness (the deviations of the surface profile from a mean line), direction (the predominant orientation of the surface profile), and defects (the discontinuities or flaws of the surface).

Table 3. Physical and chemical data of Blasocut 2000 [30]

	Concentrate	**Emulsion**
Color	Green	Milky, Green
Mineral Oil Content	65%	
Water Content	4%	
Density at 20º C	0,94 gr/cm^3	
Viscosity at 40º C	43 mm^2/s	
Flash Point	144ºC	
PH value		8.5 – 9.2
Refractometer Factor		1.0

The roughness test was performed after the machining process was completed. A single workpiece was selected for this research, and its roughness level was measured on one side. Three experimental runs were conducted to measure the effect of coolant viscosity on the workpiece quality. The locations of the data collection points are shown in Fig. 3. The roughness level was measured using the surface roughness tool, which uses the arithmetic mean deviation of the surface profile (Ra) as the unit of measurement. The test results were then converted into the standard of surface roughness of the material based on ISO 1302:2002, which is displayed in Table 4.

Table 4. Comparison of arithmetical mean deviation Ra and roughness grade numbers (Table C.1 of ISO 1302:1992) [31]

Roughness Value Ra		**Roughness Grade Number**
µm	**µin**	**(Given in the previous Edition of ISO 1302)**
50	2000	N12
25	1000	N11
12.5	500	N10
6.3	250	N9
3.2	125	N8
1.6	63	N7
0.8	32	N6
0.4	16	N5
0.2	8	N4
0.1	4	N3
0.05	2	N2
0.025	1	N1

The ISO 1302 standard provides a method for indicating the surface texture of a material through a roughness grade number. This number is represented by the letter ‘N’ and a number ranging from 1 to 12. A grade of N1 signifies the smoothest surface, while N12 indicates the roughest. The roughness grade number aligns with the arithmetic mean roughness value, Ra, measured in micrometres. Ra is calculated as the average of the absolute differences between the surface profile and its centre line. A table typically illustrates the correlation between the roughness grade number and the Ra value.

3. Results and Discussion

Surface roughness is one of the indicators of surface quality of the material that is influenced by the turning process. Surface roughness can be defined as the geometric variations of the surface that consist of four components, namely: roughness, waviness, lay, and flaws. Roughness is the deviation of the surface profile from the center line that is measured in micro scale. Waviness is the deviation of the surface profile from the center line that is measured in macro scale. Lay is the dominant orientation of the surface profile. Flaws are the discontinuities or deficiencies of the surface that are caused by factors such as tool damage, vibration, or operational errors. To measure the surface roughness of the material, the author uses the Surface Roughness Tester tool that operates on the principle of electromagnetic induction. The tool has a probe that moves along the surface of the material and produces an electrical signal that is proportional to the roughness of the surface. The tool can measure the surface roughness with the unit Ra, which is the arithmetic average of the absolute values of the deviation of the surface profile from the center line. The results of the surface roughness measurement of the material for each experimental condition, namely the variation of coolant viscosity, are presented in Table 5.

Table 5. Surface roughness result test on specimen

Experiment	**Coolant’s Quality 8% Brix**		**Coolant’s Quality 10% Brix**		**Coolant’s Quality 13% Brix**	
	Ra (μm)	**Grade Number**	**Ra (μm)**	**Grade Number**	**Ra (μm)**	**Grade Number**
1	9.97	N9 - N10	8.91	N9 - N10	6.90	N9 - N10
2	11.38	N9 - N10	8.75	N9 - N10	7.08	N9 - N10
3	14.15	N10 - N11	12.62	N10 - N11	7.70	N9 - N10
Average	**11.83**	**N9 - N10**	**10.09**	**N9 - N10**	**7.23**	**N9 - N10**

The research results shown in Table 5 reveal several important findings. First, the highest arithmetic mean value (Ra) is shown at a coolant fluid quality of 8% Brix, with a surface roughness value reaching Ra 11.83 μm. This indicates that the quality of the coolant fluid significantly affects the level of surface roughness. On the other hand, the minimum Ra value is shown at a coolant fluid quality of 13% Brix, with a Ra value of 7.23 μm. This suggests that an increase in the quality of the coolant fluid can reduce the level of surface roughness. However, it should be noted that although the average roughness grade number is generally N10, there are exceptions in some cases. For example, in test 3 with a coolant fluid quality of 8% Brix and 10% Brix, the roughness level reached N10 - N11. This indicates that there are other factors besides the quality of the coolant fluid that affect the level of roughness.

For comparison as shown in Fig. 4, in a parallel experiment executed by V Vasu and Reddy, the Inconel 600 material was subjected to a turning process with a cutting speed of up to 60 m/min, a feed rate of up to 0.16 mm/rev, and a depth of cut of 1.2 mm, all in the absence of coolant. This process resulted in a surface roughness of 0.91 µm, falling within the N7 range. However, with the introduction of a coolant (Minimum Quantity Lubrication + 6% Al_2O_3), the surface roughness was observed to decrease to 0.81 µm, thereby situating it within the N6 range.

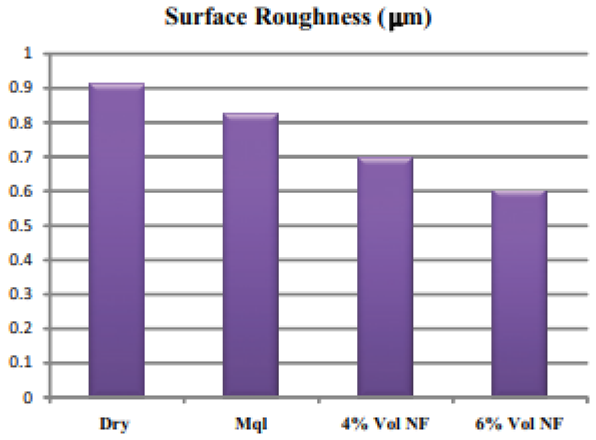

Fig. 4. Result graph on surface roughness research by Vassu and Reddy [32]

Surface roughness, measured using a specific instrument in this study, significantly affects product performance and can lead to early failure. The use of a coolant composed of 6% Al_2O_3 nanofluid was found to reduce surface roughness compared to other conditions, due to the high temperatures and stresses during dry cutting. Furthermore, using MQL and adding 6% Al_2O_3 nanofluid to it further improved the surface finish.

Meanwhile, in the research conducted by Ranjit and Sonawane with parameters almost similar to what the author did (spindle speed 500 rpm, feed rate 0.71 mm/rev, and depth of cut 1.5 mm) without coolant and accompanied by machine vibration 0.586 m/s^2, the resulting surface roughness is 10.08 mm, as shown in Table 6.

Table 6. Experimental results on Inconel 600 conducted By Ranjit and Sonowane [33]

No	Spindle Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Vibration (m/s2)	Ra (µm)
1	135	0.22	0.5	0.44	2.86
2	135	0.40	1.0	0.196	6.78
3	135	0.71	1.5	0.222	9.08
4	215	0.22	0.5	0.501	3.80
5	215	0.40	1.0	0.276	6.58
6	215	0.71	1.5	0.402	8.70
7	500	0.22	0.5	0.572	3.75
8	500	0.40	1.0	0.635	8.67
9	500	0.71	1.5	0.586	10.08

Their investigation discerns that turning parameters, such as speed, depth of cut, and feed, exert a substantial influence on the surface roughness of the workpiece. This effect is partially modulated by induced vibration, which is found to be directly proportional to these parameters. Several factors affect the level of surface roughness of the workpiece during the turning process, both technical and human factors. Technical factors include tool geometry, where the cutting tool's shape and angle significantly impact the resulting surface roughness. Cutting speed also affects the level of roughness, where different cutting speeds will produce different levels of roughness. In addition, feed rate, feed motion, cutting depth, and machine vibration during the cutting process also become factors that affect the level of surface roughness.

On the other hand, human factors also play an important role in this process. Machine operators are responsible for determining and setting process parameters such as cutting speed, feed rate, and cutting depth by entering G-Code into the CNC machine program screen. Operators also have the responsibility to set the zero point, which must be done manually. Errors in setting these parameters or the zero point can produce geometric shapes with low precision and affect the level of surface roughness. Therefore, even though CNC machines have a high level of precision and can operate automatically, the operation and setting of machine parameters by operators remain very important. Thus, both technical and human factors play an important role in determining the level of surface roughness of the workpiece during the turning process.

4. Conclusion

Lathe machine parameters such as speed and depth of cut significantly influence the surface roughness of Inconel 600. The application of coolant during machining can reduce this roughness. This study has shown that a refractometer can effectively measure the quality of the coolant in % Brix units, which correlates strongly with the coolant's viscosity. Although this does not directly measure viscosity, it is a reliable and practical alternative. The study found that the surface roughness of the workpiece decreases as the % Brix (and thus the quality) of the coolant increases. This implies that a higher % Brix leads to a smoother workpiece surface, while a lower % Brix results in a rougher surface. However, further research is needed to establish a mathematical relationship between coolant concentration, % Brix, and coolant viscosity. This could significantly enhance our understanding of these variables and their impact on surface roughness.

References

[1] B. Ghiban, C. F. Elefterie, C. Guragata, and D. Bran, "Requirements of Inconel 718 alloy for aeronautical applications," *In AIP Conference Proceedings*, vol. Vol. 1932 No 1, no. AIP Publishing, Feb. 2018.

[2] S. Qadri, G. Harmain, and M. Wani, "Influence of Tool Tip Temperature on Crater Wear of Ceramic Inserts During Turning Process of Inconel-718 at Varying Hardness," *Tribol. Ind*, vol. 42, pp. 310–326, 2020, doi: DOI: 10.24874/ti.776.10.19.05.

[3] H. Nomoto, *Development in materials for ultra-supercritical and advanced ultra-supercritical steam turbines. In Advances in Steam Turbines for Modern Power Plants*, 2nd ed. UK: Woodhead Publishing: Sawston, 2022.

[4] M. E. Kassner, *Creep Fracture. In Fundamentals of Creep in Metals and Alloys*, 3rd ed. Boston: Butterworth-Heinemann: , 2015.

[5] M. F. Ashby, "Materials Selection in Mechanical Design," *Elsevier Science: Amsterdão, Paises Baixos*, 2006.

[6] Lin Liu, Taiwen Huang, Min Qu, Gang Liu, Hengzhi Fu, and Jun Zhang, "High thermal gradient directional solidification and its application in the processing of nickel-based superalloys," *J Mater Process Technol*, vol. 210, no. 1, pp. 159–165, Jan. 2010.

[7] J. H. Weber and M. K. Banerjee, "Nickel and Nickel Alloys: An Overview. In Reference Module in Materials Science and Materials Engineering," *Elsevier: Amsterdam, The Netherlands*, 2019.

[8] M. E. Kassner, *Nickel-Based Superalloys. In Fundamentals of Creep in Metals and Alloys*, 3rd ed. Boston: Butterworth-Heinemann, 2015.

[9] H. Dai *et al.*, "Effects of elemental composition and microstructure inhomogeneity on the corrosion behavior of nickel-based alloys in hydrofluoric acid solution," *Corros Sci*, vol. 176, no. 108917, Nov. 2020.

[10] D. Deng, *Additively Manufactured Inconel 718: Microstructures and Mechanical Properties. Licentiate Thesis, Comprehensive Summary*. Linköping, Sweden: Linköping University Electronic Press, 2018.

[11] K. Vinod, Udaya Ravi, and N. Yuvaraja, "A Study of Surface Morphology and Wear Rate Prediction of Coated Inconel 600, 625 and 718 Specimens," *Int. J. Sci. Acad. Res. (IJSAR)*, vol. 3, pp. 1–9, 2023.

[12] M. Dhananchezian, "Influence of variation in cutting velocity on temperature, surface finish, chip form and insert after dry turning Inconel 600 with TiAlN carbide insert," *Material Today: Proceeding*, vol. 46, pp. 8271–8274, 2021.

[13] S. B. Ruggayah, "Analisa Pengaruh Cairan Pendingin Terhadap Tingkat Kekasaran Permukaan Pada Proses Pembubutan Baja ST 42," *Makassar: Universitas Negri Makassar: unpublished*, 2020.

[14] G. W. A. Wong, S. Islam, M. M. Reddy, N. Khandoker, and V. L. C. Chen, "Recent progress and evolution of coolant usages in conventional machining methods: a comprehensive review," *The International Journal of Advanced Manufacturing Technology*, vol. 119, no. 1–2, pp. 3–40, 2022.

[15] K. A. Alharbi and T. Alotaibi, "THE INFLUENCE OF COOLANT TYPES ON SURFACE ROUGHNESS IN THE TURNING PROCESS," *The American Journal of Interdisciplinary Innovations and Research*, vol. 04, pp. 93–112, Nov. 2022.

[16] M. Mia and N. R. Dhar, "Optimization of surface roughness and cutting temperature in high-pressure coolant-assisted hard turning using Taguchi method. ," *Int J Adv Manuf Technol*, vol. 88, pp. 739–753, 2017.

[17] P. Sivadasan, G. S., Sharma, I. S. Rout, and P. Pal Pandian, "A Review on Influence of Cutting Fluid on Improving the Machinability of Inconel 718," *Springer Proceedings in Materials*, vol. 8, 2020.

[18] L. Y. Beaulieu, E. R. Logan, K. L. Gering, and J. R. Dahn, "An automated system for performing continuous viscosity versus temperature measurements of fluids using an Ostwald viscometer," *Review of Scientific Instruments*, vol. 88, no. (9), pp. 95–101, 2017.

[19] Anton Paar GmbH., "Viscosity of Metalworking Fluids in Cutting Processes Determined with SVM™ 3001 or SVM™ 4001 Viscometer." Accessed: Jan. 31, 2024. [Online]. Available: https://www.anton-paar.com/corp-en/services-support/document-finder/application-reports/viscosity-of-metalworking-fluids-in-cutting-processes-determined-with-svm-3001-or-svm-4001-viscometer/1

[20] M. Kole and T. K. Dey, "Thermal conductivity and viscosity of Al2O3 nanofluid based on car engine coolant," *J Phys D Appl Phys*, vol. 43, no. (31), 315501, 2010.

[21] D. D'Addona and S. Raykar, "Thermal Modeling of Tool Temperature Distribution during High Pressure Coolant Assisted Turning of Inconel 718," *Materials*, vol. 12, no. 3, p. 408, Jan. 2019, doi: 10.3390/ma12030408.

[22] M. Kole, T. K. Dey, A. Pratap, and N. S. Saxena, "Experimental Investigation On The Thermal Conductivity And Viscosity Of Engine Coolant Based Alumina Nanofluids," 2010, pp. 120–124. doi: 10.1063/1.3466537.

[23] H. Contreras-Tello, S.-P. C. O., A. García-Valenzuela, R. Márquez-Islas, and Vázquez-Estrada, "Understanding the performance of Abbe-type refractometers with optically absorbing fluids," *Measurement Science and Technology*, , vol. 25, no. 7, 2014.

[24] N. Rohmah, "Analysis of the utilization of refractometer tools to test the quality of cooking oil. ," *SAINSTEK: Jurnal Sains dan Teknologi*, , vol. 14, no. (1), pp. 41–45, 2022.

[25] Antylia scientific blog team, "Understanding your lab equipment: How a refractometer works. ," Cole-Parmer. Accessed: Jan. 31, 2024. [Online]. Available: from https://www.coleparmer.com/blog/2013/09/20/understanding-your-lab-equipment-how-a-refractometer-works/

[26] D. V. Udupa, R. P. Shukla, and M. V. Mantravadi, "A critical angle refractometer for heavy water analysis," *Journal of Optics*, vol. 40, no. 3, pp. 107–113, Sep. 2011, doi: 10.1007/s12596-011-0043-z.

[27] J. W. George, "The Usefulness and Limitations of Hand-held Refractometers in Veterinary Laboratory Medicine: An Historical and Technical Review," *Vet Clin Pathol*, vol. 30, no. 4, pp. 201–210, Dec. 2001, doi: 10.1111/j.1939-165X.2001.tb00432.x.

[28] B. R. Heidemann, G. Scherpinski, L. Fabris, M. Muller, J. L. Fabris, and G. Pintaude, "Assessing Viscosity in Hydro-Erosive Grinding Process via Refractometry," *SAE Int J Fuels Lubr*, vol. 12, no. 3, pp. 04-12-03–0012, Aug. 2019, doi: 10.4271/04-12-03-0012.

[29] "SPECIAL METALS INCONEL ALLOY 600," *Alloy Digest*, vol. 69, no. 4, Apr. 2020, doi: 10.31399/asm.ad.ni0758.

[30] MSDS.com, "Blasocut® 2000 CF." Accessed: Feb. 05, 2024. [Online]. Available: https://www.blaser.com/fileadmin/user_upload/SDS/DE/Blasocut_2000_CF_DE.pdf

[31] British Standard, "Geometrical Product Specifications (GPS) —Indication of surface texture in technical product documentation," May 16, 2002

[32] V. Vasu and G. Pradeep Kumar Reddy, "Effect of minimum quantity lubrication with Al_2O_3 nanoparticles on surface roughness, tool wear and temperature dissipation in machining Inconel 600 alloy," *Proceedings of the Institution of Mechanical Engineers, Part N: Journal of Nanoengineering and Nanosystems*, vol. 225, no. 1, pp. 3–16, Mar. 2011, doi: 10.1177/1740349911427520.

[33] Shinde Ranjit and S. A. Sonawane, "Effect of Speed, Feed, Depth of Cut on Vibration and Surface Roughness during Turning Operation," *International Journal of Mechanical and Production Engineering Research and Development*, vol. 8, no. 4, pp. 819–826, 2018, doi: 10.24247/ijmperdaug201884.