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# Augmenting Inconel 718 Super Alloys CNC Machining During Finish Cuts with WCO/$TiO_2$ Nanofluids

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## Abstract

Nanofluids are extensively utilized in metal machining operations. In contemporary times, there has been a notable surge in the utilization of challenging-to-cut materials. This trend is primarily driven by the need to enhance the dependability of critical products operating under elevated temperatures, while also minimizing wear and maximizing strength. Traditionally, the machining of such materials necessitated the implementation of specialized machining processes. However, the process of mass production is characterized by its time-consuming nature and its propensity to significantly escalate manufacturing expenses. To address these challenges, the present study has opted for the utilization of computer numerical control (CNC) machining, specifically focusing on CNC turning centres. The cooling process assumes a crucial role due to the high cutting velocity and utilization of much harder tools in this specific procedure. In this study, the utilization of preferred refined waste cooking oil as the primary fluid and the incorporation of titanium dioxide ($TiO_2$) nanoparticles as additives to enhance cooling effects were examined. Additionally, other crucial factors such as spindle speed, tool feed rate, and depth of cut were taken into account to optimize material removal rate that is maximize material removal rate during the finishing process of the components. The Taguchi method was utilized. The findings indicated that the process parameters that yielded the best results were a spindle speed of 3000 rpm, a low feed rate of 0.05 mm per revolution, a depth of cut of 0.02 mm, and a refined waste cooking oil (WCO) with a $TiO_2$ concentration of 0.75 wt.%.

## Keywords

Coolant, CNC turning, Waste cooking oil, Nanofluids, Nanoparticles

## Introduction

The utilization of nickel-based alloys, such as Inconel 718, has experienced an upward trend within the aerospace sector. This can be attributed to the enhanced mechanical properties, commendable weldability, and notable resistance to oxidation and corrosion exhibited by these alloys. Inconel 718 is utilized in the production of various components in aviation and land-based turbine engines, as well as rings and casings for liquid-fueled rockets [1]. The utilization of Inconel alloy 718 is also observed in cryogenic tankage, which functions under conditions of significantly low temperatures. In accordance with existing literature, Inconel 625 is widely acknowledged as a challenging material to machine owing to its relatively low thermal conductivity, propensity to generate built-up edges, and heightened inclination to adhere or fuse to cutting edges.

Inconel 625 exhibits a relatively low heat transfer coefficient, resulting in a significant portion of the cutting energy being converted into heat, which persists at the tool-workpiece interface for an extended duration during the machining process. The generation of heat in the machining region results in elevated localized temperatures. Consequently, the tool material undergoes softening and experiences rapid wear. This, in turn, diminishes the lifespan of the tool and compromises the integrity of the machined surface. The resolution of these issues can solely be achieved through the application of cutting fluids. The majority of traditional machining fluids consist of hazardous chemicals that present potential health hazards to workers, contribute to soil and water contamination upon disposal, and have adverse environmental impacts. Furthermore, it is worth noting that a mere 8% of the overall machining cost can be attributed to the expenditure on tools, while the remaining 17% is allocated to the cost of cutting fluids. There have been multiple endeavors aimed at reducing the usage of cutting fluids in order to promote environmentally sustainable material removal processes [2]. The predominant challenge encountered by the metalworking industry pertains to enhancing the caliber and efficiency of machined goods. Consequently, there has been a heightened emphasis on closely monitoring each stage of the material removal procedure. Dry cutting, also known as machining without the utilization of cutting fluid, presents a feasible approach for the production of environmentally sustainable products. Nevertheless, it has been observed that Inconel exhibits a high affinity for the material removal rate and tool surface during the process of dry machining, resulting in untimely tool deterioration and inadequate surface characteristics. In the absence of a coolant, the machining of Inconel is characterized by the manifestation of adverse residual stresses, material removal rate, surface imperfections, and burning/overheating in the cutting region, owing to the material's robust mechanical strength and limited thermal conductivity. The material removal rate of a machined product can impact several factors, including gentle friction, heat generation, lubricant distribution and retention, wear, surface roughness, material removal rate and fatigue resistance of the material. Dry cutting necessitates the utilization of cutting tools composed of specialized materials such as ceramic, polycrystalline diamond, or polycrystalline cubic boron nitride, in addition to precise geometries and meticulously selected coatings. Hence, it is common practice to employ wet cutting conditions when machining these adhesive alloys in order to improve heat dissipation at the tool-chip interface. However, this approach incurs substantial manufacturing expenses, raises occupational safety concerns, and presents notable environmental challenges. The unique inherent qualities and biodegradability of vegetable oils have positioned them as a potential substitute for mineral oils [3].

Vegetable oils are considered more advantageous compared to mineral oils due to their superior characteristics, including a higher flash point, viscosity index, and lubricity, coupled with a lower evaporative loss. The process of extracting oil involves applying pressure to the relevant part of a plant. Various methods can be employed to extract oils from plants, encompassing the dissolution of plant constituents in water, distillation of the oil, or infusion of plant components with a base oil. This applies to both edible and non-edible plant varieties. Multiple research studies have demonstrated the efficacy of coconut oil, palm oil, soybean oil, and canola oil as environmentally sustainable lubricants in machining processes. The novelty of this study is based on the underlying assumption that productivity is influenced by the interaction of three key factors: product quality, resource utilization, and operational efficiency. In this study, the input variables considered are cooling/lubrication conditions and depth of cut. Over the past decade, there has been significant attention directed towards the utilization of nanoparticles in various base fluids. Nanoparticles dispersed within a water medium have the potential to enhance thermal conductivity, rendering it a highly suitable heat transfer medium, particularly in the context of solar collectors. Since the beginning of the 21st century, scholars have conducted investigations on the potential advantages of nano-coolants, which involve the dispersion of nanoparticles in water or ethylene glycol, in addressing practical issues. The antifriction and anti-wear properties of the lubricant are thought to be derived from the incorporation of nanoparticles.

The enhanced properties, in this case, are contingent upon the intrinsic characteristics of the nanoparticles, including their morphology, dimensions, and abundance. Furthermore, there have been assertions regarding the augmentation of the antifriction and anti-wear characteristics of lubricating oil through the incorporation of an appropriate quantity of nanoparticles. The lexicon of manufacturing encompasses various terms such as surface roughness, material removal rate, and spindle vibration. These terms are commonly utilized throughout the manufacturing process. The optimization of reactions is achieved by fine-tuning constructive process parameters, such as feed speed and cutting depth. The utilization of the Taguchi Design of Experiments is employed to optimize the system as a whole, considering the potential variability in the response based on the input parameters. The aim is to optimize the input parameters in order to generate outcomes that are both beneficial and durable. Taguchi's Design of Experiment is widely regarded as a highly effective optimization tool due to its notable ease of use and efficacy. The Taguchi method is a valuable approach for ascertaining the optimal combination of control variables that effectively mitigates the impact of noise factors. In order to maintain cost efficiency in manufacturing processes, it is imperative to minimize tool expenses.

Superalloys, alternatively referred to as high-performance alloys, constitute a category of metallic materials that exhibit remarkable resistance to thermal creep deformation, robust resistance to corrosion and oxidation, and elevated strength at high temperatures. Inconel 718 is classified as a nickel-based superalloy due to its composition, which includes substantial quantities of niobium and molybdenum, in addition to nickel, chromium, and iron. The inclusion of niobium in the alloy results in age-hardening, which imparts enhanced strength and fatigue resistance to the material. Inconel 718 is classified as a high-temperature resistant superalloy, belonging to the category of High-temperature resistant superalloys. It exhibits exceptional mechanical properties, retaining its structural integrity even when exposed to elevated temperatures surpassing 700 °C. The alloy's distinctive combination of characteristics enables a wide range of applications, including turbine engines, cryogenic tankages, aircraft components, and liquid rockets. The welding characteristics of Inconel 718, including its exceptional resistance to post-weld cracking, are unparalleled. This alloy exhibits enhanced mechanical properties owing to its austenitic face-centered cubic crystal structure. Inconel 718 possesses various applications; nevertheless, its suboptimal machinability represents a significant drawback. This substance belongs to the category of abrasive materials. Inconel 718 exhibits exceptional retention of its mechanical strength even under elevated temperature conditions. The alloy exhibits a rapid rate of work hardening and is highly susceptible to strain rate, resulting in accelerated tool wear. The presence of hard carbide particles within its microstructure renders it highly abrasive, resulting in the occurrence of abrasion wear on the cutting tool. The cutting zone temperature of Inconel 718 is notably elevated, reaching temperatures as high as 1200 °C, primarily as a result of its relatively low thermal conductivity, which measures at 15 W/m/K. Inconel 718 exhibits diffusion wear as a result of its notable chemical affinity towards tool materials and co-binders [4].

Phenomena such as chip welding, adhesion, notching, and pull out of tool material contribute to the necessitation of alterations in tool geometry. The high-temperature strength of Inconel 718 leads to the development of substantial cutting forces, resulting in the generation of excessive vibration (known as chatter) in the machine tool. Consequently, this vibration adversely affects the surface quality of the machined work component material removal rate. The practice of machining without the utilization of cutting fluid is subject to criticism, particularly in the context of machining challenging materials. However, it is worth noting that conventional dry machining offers several advantages, including cost-effectiveness, environmental sustainability, and adherence to occupational health and safety regulations. In wet machining, the utilization of cutting fluid serves to enhance the efficiency of the process through the provision of cooling and lubrication to the workpiece. Several distinct wet cooling methods can be identified, namely flood cooling, minimum quantity lubrication (MQL), and nanofluid MQL (NFMQL). The utilization of flood cooling has been identified as a viable alternative for machining operations conducted at reduced cutting speeds, as it leads to improved tool life due to the relatively low temperature maintained in the cutting zone.

The coolant's flushing mechanism effectively eliminates debris from the machining area while also providing a protective barrier against corrosion for the final product. In instances where both cutting speed and temperature are elevated, it is common for the cutting fluid to undergo evaporation, resulting in the formation of a steam barrier that restricts the sufficient influx of fluid into the cutting zone. One potential approach to address this problem involves the implementation of a high-pressure coolant injection system into the cutting area. This system would generate a hydrodynamic wedge at the interface between the tool chip and the tool work, resulting in the removal of the chips from the rake face of the tool. The relationship between tool life and the efficiency of cutting fluid penetration into the material being cut is directly proportional. Notwithstanding the advantages mentioned, flood cooling exerts a detrimental impact on the environment and entails substantial coolant consumption, thereby leading to escalated production expenses. Hence, it appears that the MQL method presents itself as a viable choice. In the context of MQL, a cutting fluid is applied to the cutting zone in conjunction with compressed air, forming an air-oil mist. However, it is important to note that this application is limited to minute volumes, typically ranging from 10 to 100 ml/h. In the realm of machining, MQL presents an economically viable and environmentally friendly cooling and lubrication alternative. The utilization of vegetable oil based MQL is restricted due to its inadequate thermal conductivity, despite its advantageous characteristics such as reduced toxicity, environmental friendliness (biodegradability), and cost-effectiveness. The literature suggests that incorporating nano-sized additives into a base cutting fluid is recommended as a strategy for addressing these challenges.

The production of nanofluid involves the combination of a base cutting fluid with nano-sized particles of metals, ceramics, or carbon nanotubes in a suitable proportion. The utilization of a base fluid incorporating nanoparticles offers numerous advantages. The dispersion stability of a base cutting fluid is enhanced when nanoparticles experience Brownian motion. Nanoparticle dispersions have been found to exhibit enhanced heat transmission capabilities due to their heightened specific surface area. The enhancement of thermal conductivity and wettability of a fluid can be achieved by dispersing nanoparticles throughout the base fluid.

The available literature provides ample evidence to support the notion that nanofluid exhibits enhanced thermal conductivity compared to conventional cutting fluid. Based on a study conducted by [5], it has been observed that the thermal conductivity of a nanofluid, created through the dispersion of graphene oxide in water, exhibits a noteworthy enhancement of 48.15% when compared to the thermal conductivity of the base fluid, which is water. The introduction of nanoparticles $SiO_2$, ZnO, $TiO_2$, MgO, and $Al_2O_3$ to the base fluid, ethylene glycol, resulted in an observed enhancement in the thermal conductivity of the nanofluids. A notable enhancement of 40.6% in thermal conductivity was observed in nanofluids formulated with MgO as the base material [5]. The study conducted by [6] revealed a notable improvement in the thermal property of nanofluid, specifically multiwall carbon nanotubes dispersed PAO6.

This study aims to investigate the existing research gap pertaining to the machining of Inconel 718 using $TiO_2$ nanofluid in conjunction with refined WCO within a flood cooling environment, with the objective of enhancing the material removal rate. The objective of this investigation is to synthesize nanofluid with varying concentrations of $TiO_2$ nanoparticles. In order to determine the range of variables, multiple trial runs will be conducted using the L16 orthogonal array experimental design. In order to enhance the material removal rate, it is necessary to optimize the parameters, including the concentrations of nanoparticles. In order to verify the accuracy of the predicted process parameters, confirmation experiments were conducted.

## Materials and Method

The standard work materials were acquired from Chennai metals, located in Tamil Nadu, India. The work pieces should be cut into lengths of 40 mm. The diameter of the rod measured 16 mm. The cutting process was conducted using a wire cut electric discharge machine. The process of preparing the nanofluid consisted of combining refined WCO with $TiO_2$ nanoparticles at varying concentrations, namely 0.25 wt.%, 0.5 wt.%, 0.75 wt.%, and 1 wt.%. Therefore, four distinct cutting fluids were prepared. A quantity of 1 kg of refined WCO is utilized for the production of each type of nanofluid. The experiments were conducted using a CNC turning center. Several preliminary trials were conducted in order to address the multitude of variables. Table 1 presents a comprehensive display of the various variables, their respective ranges, and levels.

In this investigation, the L16 orthogonal array was utilized to manipulate four factors, specifically the coolant grades, which were varied at four distinct levels in ascending order. Table 2 presents the Taguchi experimental design. The flow rate of the coolant was established at a rate of 4 L/min. The decision was made considering non-fuming conditions, with the aim of ensuring the effective removal of machined chips and providing lubrication to enhance the shearing process. The nanofluids exhibited satisfactory homogeneity, as evidenced by the absence of significant sedimentation after a storage period of 48 h in the beaker. The experiments were conducted at the CNC turning center, as depicted in figure 1. The average material removal rate while machining each specimen was observed and the corresponding values were recorded subsequent to the machining process. The final column of table 2 displays the recorded observations for each experiment. Material removal rate is equal to loss of weight of material divided by density. Where loss of weight of material was found from the difference of weight before machining and weight after machining, and density of the work material is 8.17 g/cc.

**Table 1:** The range and levels of variables to test machinability if Inconel 718 work materials.

| Factor | Levels | Values |
|---|---|---|
| Spindle speed (rpm) | 4 | 1200, 1800, 2400, 3000 |
| Feed rate (mm/rev) | 4 | 0.05, 0.10, 0.15, 0.20 |
| Depth of cut (mm) | 4 | 0.01, 0.02, 0.03, 0.04 |
| $TiO_2$ concentration (wt.%) | 4 | 0.25, 0.50, 0.75, 10.00 |

**Figure 1:** CNC turning center at SIMATS University.

**Table 2:** Experimental design and material removal rate observations on Inconel 718.

| Exp. No. | Spindle speed (rpm) | Feed rate (mm/rev) | Depth of cut (mm) | $TiO_2$ concentration (wt.%) | Material removal rate | FITS | SNRA6 |
|---|---|---|---|---|---|---|---|
| 1 | 1200 | 0.05 | 0.01 | 0.25 | 0.104 | -0.04846 | -19.7693 |
| 2 | 1200 | 0.1 | 0.02 | 0.5 | 0.15 | 1.23870 | 1.1346 |
| 3 | 1200 | 0.15 | 0.03 | 0.75 | 0.16 | 2.16215 | 6.7498 |
| 4 | 1200 | 0.2 | 0.04 | 10 | 0.23 | 3.26659 | 10.1074 |
| 5 | 1800 | 0.05 | 0.02 | 0.75 | 0.075 | 2.48116 | 7.6626 |
| 6 | 1800 | 0.1 | 0.01 | 10 | 0.165 | 1.36028 | 2.7551 |
| 7 | 1800 | 0.15 | 0.04 | 0.25 | 0.16 | 4.32714 | 12.5226 |
| 8 | 1800 | 0.2 | 0.03 | 0.5 | 0.34 | 3.84304 | 12.0286 |
| 9 | 2400 | 0.05 | 0.03 | 10 | 0.11 | 4.41522 | 12.7017 |
| 10 | 2400 | 0.1 | 0.04 | 0.75 | 0.083 | 5.29673 | 14.7246 |
| 11 | 2400 | 0.15 | 0.01 | 0.5 | 0.13 | 2.38152 | 7.2968 |
| 12 | 2400 | 0.2 | 0.02 | 0.25 | 0.112 | 3.39024 | 10.6378 |
| 13 | 3000 | 0.05 | 0.04 | 0.5 | 0.109 | 6.69087 | 16.5265 |
| 14 | 3000 | 0.1 | 0.03 | 0.25 | 0.12 | 5.47427 | 14.6628 |
| 15 | 3000 | 0.15 | 0.02 | 10 | 0.08 | 4.51222 | 13.3740 |
| 16 | 3000 | 0.2 | 0.01 | 0.75 | 0.108 | 3.62247 | 10.9390 |

## Results and Discussion

The experiments were conducted following the Taguchi experimental design in the form of an orthogonal array. The average material removal rate was observed as the response variable. To analyze the results, Taguchi analysis was employed. The collected data was inputted into the statistical software program Minitab 18. The results of the Taguchi analysis on the observation of material removal rate are presented in table 3. In table 3, the factors that contribute to the influence of machining feed rate on high delta-value, resulting in a value of 14.3200, were ranked no. 1. In a similar vein, the ranking of the depth of cut was found to be 2 (Delta = 13.1648), while the concentration of nanofluids ranked 3 (Delta = 6.6478), and the spindle speed ranked 4 (Delta =5.5055). The observed signal to noise ratios in table 3 exhibit a positive relationship, indicating that smaller values are preferable. The machining time was 15 sec.

**Table 3:** Taguchi analysis results on the observation material removal rate while machining surface of Inconel 718.

| Level | Spindle speed (rpm) | Feed rate (mm/rev) | Depth of cut (mm) | $TiO_2$ concentration (wt.%) |
|---|---|---|---|---|
| 1 | -0.4444 | 4.2804 | 0.3054 | 4.5135 |
| 2 | 8.7422 | 8.3193 | 8.2022 | 9.2466 |
| 3 | 11.3402 | 9.9858 | 11.5357 | 10.0190 |
| 4 | 13.8756 | 10.9282 | 13.4703 | 9.7346 |
| Delta | 14.3200 | 5.5055 | 13.1648 | 6.6478 |
| Rank | 1 | 4 | 2 | 3 |

In figure 2, a higher signal is considered advantageous, thus making a high signal-to-noise ratio the preferred choice for optimal parameters. Based on the findings, it can be observed that the spindle speed has a significant impact on the enhancement of material removal rate. Specifically, the material removal rate experiences a rapid decrease when the spindle speed is set at 1800 rpm. However, it should be noted that the material removal rate subsequently increases significantly when the spindle speed is further increased to 3000 rpm. The optimal speed is 300 rpm. Likewise, a feed rate of 0.05 mm per revolution was determined to be the optimal feeding condition. The optimal conditions were found to be a depth of cut of 0.04 mm and a concentration of 0.75 wt.%.

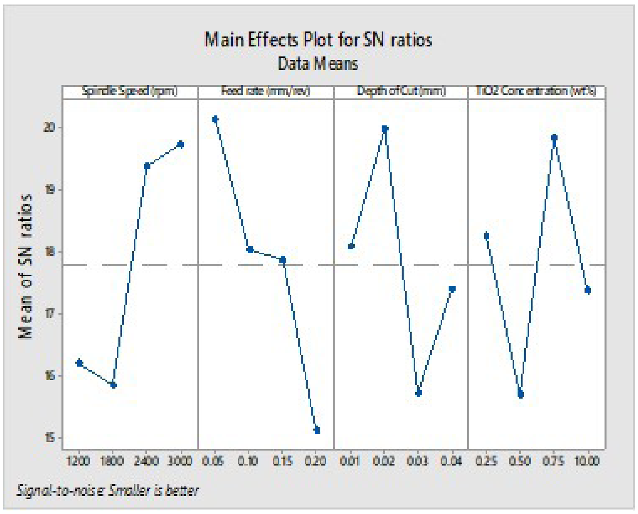

**Figure 2:** Taguchi analysis results in terms of effects of means of singal-to-noise ratios yielded by the different factors and their levels for the material removal rate observations.

The effects of means of material removal rate is demonstrated in the figure 3. Here the mean material removal rate is maximum is better. According to this higher rpm of spindle speed recorded minimum mean material removal rate that is 3000 rpm. Similarly, 0.05 mm per revolution feed rate, 0.04 mm depth of cut and 0.75 wt.% concentration was optimal processing condition.

Analysis of variance (ANOVA) results are two kinds such as for factors and their levels. Table 4 shows the results of ANOVA for the material removal rate observations for factors. the F values shows the contribution factors and p-values shows the level of significance. The F-values for spindle speed (rpm), feed rate (mm/rev), depth of cut (mm) and $TiO_2$ concentration (wt.%) are 0168.08, 0.63, 142.37

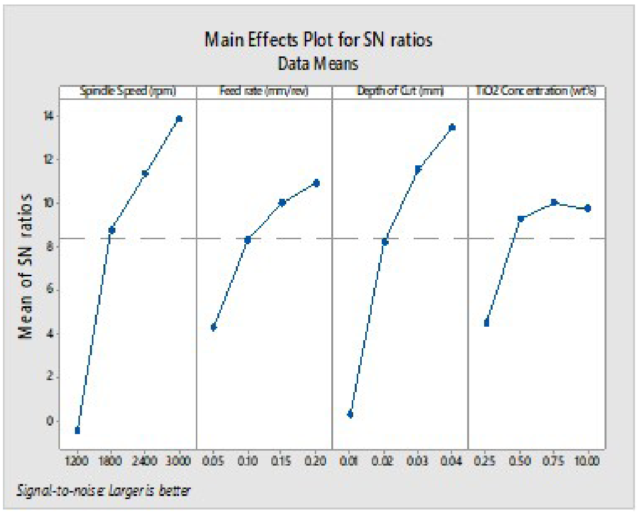

**Figure 3:** Taguchi analysis results in terms of effects of means of material removal rate observations at the different factors and their levels.

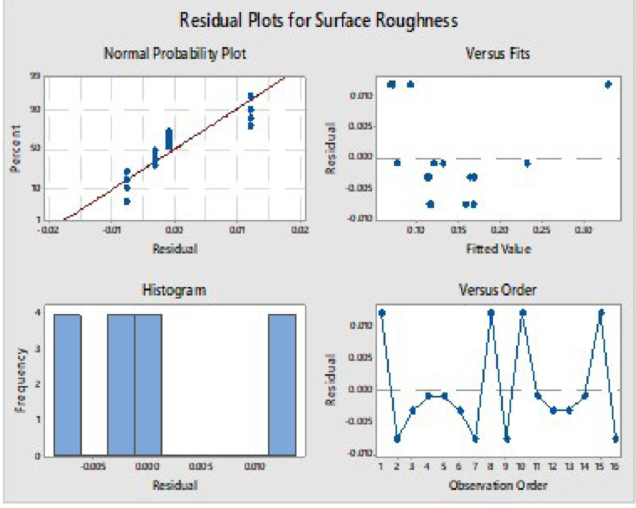

**Figure 4:** The residuals of material removal rate observations.

**Table 4:** Results of ANOVA for the of material removal rate observations at the different factors.

| Source | DF | Adj SS | Adj MS | F-value | p-value |
|---|---|---|---|---|---|
| Spindle speed (rpm) | 3 | 24.9234 | 8.30779 | 168.08 | 0.001 |
| Feed rate (mm/rev) | 3 | 0.0941 | 0.03138 | 0.63 | 0.042 |
| Depth of cut (mm) | 3 | 21.1110 | 7.03700 | 142.37 | 0.001 |
| $TiO_2$ concentration (wt.%) | 3 | 0.1298 | 0.04326 | 0.88 | 0.034 |
| Error | 3 | 0.1483 | 0.04943 | | |
| Total | 15 | 46.4066 | | | |

and 0.88, respectively. The p-value greater than 0.1 are said to be in significant and p-value which secure less that 0.05 is significant. Hence the p-values for spindle speed (rpm), feed rate (mm/rev), depth of cut (mm) and $TiO_2$ concentration (wt.%) are 0.0001, 0.034, 0.001 and 0.042, respectively. As all p-values are less than 0.05 the model is good.

Table 5 shows results of ANOVA for the of material removal rate observations at the levels of different factors. The p-value greater than 0.1 are said to be in significant and p-value which secure less that 0.05 is significant. Hence the p-values for spindle speed of 1200 rpm, 1800 rpm and 2400 rpm and feed rate (mm/rev) of 0.05, 0.10 and 0.15, depth of cut (mm) of 0.01, 0.02 and 0.03 and the $TiO_2$ concentration (wt.%) of 0.25, 0.50 and 0.75 are 0.000, 0.026, 0.016, 0.877, 0.587, 0.607, 0.000, 0.014, 0.009, 0.031, 0.024, 0.022 in which all parameters were insignificant. These values and omitted levels in the tables shall not considered for better material removal rate. Equation 1 is mathematical model to predict the material removal rate.

Material removal rate = 3.4009 – 1.7461 Spindle Speed (rpm)_1200 – 0.3980 Spindle Speed (rpm)_1800 + 0.4700 Spindle Speed (rpm)_2400 + 1.6741 Spindle Speed (rpm)_3000 – 0.0162 Feed Rate (mm/rev)_0.05 – 0.0584 Feed Rate (mm/rev)_0.10 – 0.0551 Feed Rate (mm/rev)_0.15 + 0.1297 Feed Rate (mm/rev)_0.20 – 1.5719 Depth of Cut (mm)_0.01 – 0.4953 Depth of Cut (mm)_0.02 + 0.5728 Depth of Cut (mm)_0.03 + 1.4944 Depth of Cut (mm)_0.04 – 0.1151 $TiO_2$ Concentration (wt.%)_0.25 + 0.1376 $TiO_2$ Concentration (wt.%)_0.50 – 0.0103 $TiO_2$ Concentration (wt.%)_0.75 – 0.0123 $TiO_2$ Concentration (wt.%)_10.00 (1)

**Table 5:** Results of ANOVA for the of material removal rate observations at the levels of different factors.

| Term | Coef | SE Coef | T-value | p-value | VIF |
|---|---|---|---|---|---|
| Constant | 3.4009 | 0.0556 | 61.19 | 0.000 | |
| Spindle speed (rpm) | | | | | |
| 1200 | -1.7461 | 0.0963 | -18.14 | 0.000 | 1.50 |
| 1800 | -0.3980 | 0.0963 | -4.13 | 0.026 | 1.50 |
| 2400 | 0.4700 | 0.0963 | 4.88 | 0.016 | 1.50 |
| Feed rate (mm/rev) | | | | | |
| 0.05 | -0.0162 | 0.0963 | -0.17 | 0.877 | 1.50 |
| 0.10 | -0.0584 | 0.0963 | -0.61 | 0.587 | 1.50 |
| 0.15 | -0.0551 | 0.0963 | -0.57 | 0.607 | 1.50 |
| Depth of cut (mm) | | | | | |
| 0.01 | -1.5719 | 0.0963 | -16.33 | 0.000 | 1.50 |
| 0.02 | -0.4953 | 0.0963 | -5.14 | 0.014 | 1.50 |
| 0.03 | 0.5728 | 0.0963 | 5.95 | 0.009 | 1.50 |
| $TiO_2$ concentration (wt.%) | | | | | |
| 0.25 | -0.1151 | 0.0963 | -1.20 | 0.031 | 1.50 |
| 0.50 | 0.1376 | 0.0963 | 1.43 | 0.024 | 1.50 |
| 0.75 | -0.0103 | 0.0963 | -0.11 | 0.022 | 1.50 |

Figure 4 provides a means to ensure the observation and validation of the model. The display illustrates the residuals of the observed data points. The graph indicates that all observations are satisfactory, and no errors have been identified. The model produced an R-squared value of 98.70%, surpassing the threshold of 95%. Therefore, it is appropriate to utilize the model within the solution domain. The statistical model demonstrates a high level of reliability. The prediction model exhibits a high level of concordance with empirical findings. Confirmation validation is not necessary.

## Conclusions

The present study involved the preparation of nanofluids intended for utilization as cutting fluids in the machining of Inconel 718 work material within a CNC turning center. A total of 16 samples were subjected to machining processes, utilizing different combinations of input parameters. The resulting material removal rate were then evaluated to determine the average material removal rate. Taguchi analysis is a statistical technique employed for the purpose of optimization. The following statements can be considered as conclusions.

- An experimental investigation was conducted to explore the feasibility of machining Inconel 718 under flood cooling conditions.
- The material removal rate exhibits a significantly high level of material removal rate.
- The parameters examined in this study, including spindle speed, feed rate, depth of cut, and $TiO_2$ concentration, have a significant impact on material removal rate. Specifically, the feed rate and depth of cuts were found to be notably influenced, as indicated by their p-values being less than 0.05.
- The observations exhibited statistical validity and were devoid of errors.
- The mathematical model that was developed for prediction exhibited a high level of concordance with the experimental findings.

## Acknowledgements

None.

## Conflict of Interest

None.

### References

1. Dhokia V, Newman ST, Imani-Asrai R. 2012. An initial study of the effect of using liquid nitrogen coolant on the surface roughness of Inconel 718 nickel-based alloy in CNC milling. *Procedia CIRP* 3: 121-125. https://doi.org/10.1016/j.procir.2012.07.022
2. Deshpande YV, Andhare AB, Padole PM. 2019. Application of ANN to estimate surface roughness using cutting parameters, force, sound and vibration in turning of Inconel 718. *SN Appl Sci* 1(1): 104. https://doi.org/10.1007/s42452-018-0098-4
3. Aruna M, Dhanalaksmi V. 2012. Design optimization of cutting parameters when turning Inconel 718 with cermet inserts. *World Acad Sci Eng Technol* 61: 952-955.
4. Chaurasia A, Wankhede V, Chaudhari R. 2019. Experimental investigation of high-speed turning of INCONEL 718 using PVD-coated carbide tool under wet condition. In Deb D, Balas V, Dey R (eds) Innovations in Infrastructure. Advances in Intelligent Systems and Computing. Springer, Singapore, pp 367-374.
5. Rahman M, Seah WKH, Teo TT. 1997. The machinability of Inconel 718. *J Mater Process Technol* 63(1-3): 199-204. https://doi.org/10.1016/S0924-0136(96)02624-6
6. Saravanakumar K, Kumar M, Dawood A. 2012. Optimization of CNC turning process parameters on Inconel 718 using genetic algorithm. *Int J Sci Technol* 2(4): 532-537.