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Comparative Study of the Effect of Dry, Mineral Oil, and TiO_2 Nano-Lubricant on Tool Wear During Face-Milling Machining of Ti-6al-4v-Eli Using Carbide Tool Insert

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ABSTRACT

Titanium alloys are valuable materials in the manufacturing industry. They are applied to develop major parts in the aerospace, automobile, and aeronautic industry**.** The major challenge faced by the manufacturer is the ability to cut Titanium alloys to the specific shape desired. The influence of nanoparticles as an additive to the mineral oil is vital in the machining of Titanium alloys to reduce vibration and friction, leading to high wear in the cutting tool. The quest for a sustainable and reliable method to minimize tool wear and increase efficiency has led to the nano-lubricants application during metal machining. Therefore, this research focus on the impact of three machining cutting conditions on TI-6AL-4V-ELI during face-milling operations. The Taguchi experimental design method was employed to study the machining factors effects on the tool wear by varies the machining factors, such as Cutting speed: 2000 rpm, 2500 rpm, and 3000 rpm, Feed rate: 150 mm/min, 200 mm/min, 250 mm/min, Depth of Cut: 0.3 mm, 0.6 mm, and 0.9 mm and the cutting conditions: dry, mineral oil and Titanium Oxide ($TiO_{2)}$ nano-lubricant to study their effects on the Carbide Insert cutting tool wear minimization for improving workpiece's machinability. This research also studies the interactions of the machining factors on the tool wear under the three lubrication cutting conditions. The findings confirm that the state of TiO_2 nano-lubricants decreased the tool wear for all the experimental runs. The signal-to-noise ratio results from the Taguchi design show that the cutting condition has a significant role in having 5.794. The cutting speed of 2.145, the feed rate of 0.789, and the depth of cut were 0.724. Furthermore, the generated model could predict the cutting tool wear rate with 97%, proving that the experimental result is viable for application in the manufacturing industry.

1. INTRODUCTION

In recent years, the use of titanium alloys has grown dramatically in businesses, particularly in aeronautics and aviation companies, where about 80 percent of titanium production is used [1]. This is primarily because titanium alloys have numerous uses due to their fantastic mechanical properties, such as high tensile strength, the high-strength-to-weight ratio, for lightweight titanium alloys, high corrosion resistance, and cost-effectiveness [2]. Titanium is utilized in automobile applications, for example, compressor blades, rotors, nacelles, and hydraulic framework parts of an airplane, autos, maritime boats, shuttle, and rockets. This is due to their high ratio of tensile strength to mass, high corrosion resistance, and ability to withstand relatively high temperatures without the need for slippage. Titanium is also used in motorsports, where weight reduction is essential while retaining rigidity and high strength [3]. Regardless of all these remarkable characteristics, machining measures on these alloys are as yet a test. Subsequently, tool wear is a huge factor to ponder. Tool wear essentially impacts production expenses and influences the part's surface finishing [4]. Along these lines, cutting tool choice is a fundamental factor while machining Ti-based composites. The machining process should increase resistance to wear, high quality and strength, high hardness at high temperatures, chemical stability, and thermal shock resistance. Hence, cemented Carbide appears to be an ideal fit. They fit machining at high speeds with excellent wear resistance, notwithstanding their fantastic quality and sturdiness [5].

Thus, the expansion of nanoparticles was recently reported to reduce friction to about 70% and the wear volume in the limit additive field by 75% [6, 7]. However, the total nanoparticles in a base oil are the bottleneck for an additional turn of events. A steady suspension of nanoparticles is essential; the total number of nanoparticles restricts their ability to lubricate the contact zone [8]. Furthermore, nano-lubrication in machining limits the use of fluids and prevents corrosion or pollution [9].

Tool life is an essential factor for many manufacturing organizations [10]. The cutting tools are essential for machining various materials used in factories. Hence, tools and tool inserts are commonly used and are, therefore, susceptible to wear over time [11]. Hence, it is common for machine operators to replace tools and tool inserts regularly to avoid producing defective parts. In machining processes, the majority of the mechanical energy used to machine the material becomes heat. This heat causes a high temperature in the cutting area at that point. Examinations show that the higher the cutting speed and feeding, the faster heat energy is produced [12-16]. The new issue in machining is to utilize high cutting speed to expand profitability. This problem occurs more for titanium and its alloys because of their low heat conductivity, as 80% of the heat generated in the cutting zone goes to the cutting apparatus and causes tool wear [17]. An et al. [18] carried out a face milling machining operation on Ti-6242S and Ti-555 alloys. Study the tool performance between CVD-Ti(C, N) + Al_2O_3 + TiN, PVD-(Ti, Al)N + TiN-coated and uncoated cutting tool. The Ti-555 alloy causes a lot of tool wear, which was affected by adhesive and diffusion wear. Due to the coatings' effect, the PVD-(Ti, Al)N + TiN coated has a high resistance to wear rate. Therefore the authors recommended PVD-(Ti, Al)N + TiN coated cutting tool for face milling operations. In machining, the problem arises due to power-efficient and pollution-prevention to reduce the force needed.

Arif et al. [19] affirmed that as the Gr (Graphene) focus increments in the Aluminum composites, the wear opposition expanded. The outcomes demonstrated that the composites' wear opposition expanded by adding Gr particles up to 6 wt%. The improvement in wear obstruction was ascribed to the accompanying reasons; (a) during sliding movement, the graphene framed a flimsy greasing up movie which forestalls direct metal contact, (b) nanoparticles granted hardness to the delicate aluminum lattice, (c) graphite diminished the odds of warm relaxing, which lessens the odds of interfacial debonding of network and fortifications. Talib et al. [20] found that the mix of vegetable oil with nanoparticles brings about fantastic tribological conduct, which decreased the apparatus wear rate and surface harshness. Also, the study of Kishawy et al. [21]; Yi et al. [22]; Azman et al. [23], and Khandekar et al. [24] worked on nanoparticle implementation in base oil during machining processes. In machining, the problem arises for power-efficient and pollution-preventing methods to reduce the force needed to conquer the friction segment in machining measures for less fuel utilization and contamination. Therefore, improving the lubricating system arises; hence, investigating and implementing Nano-lubricants saves cost, time, and power and is very environmental-friendly.

Nanoparticles of various shapes and sizes have shown certain levels of wear and friction reduction. [25-29]. This nanoparticle is composed of base oil to form nano-fluids. However, the total nanoparticles in a base oil are the bottleneck for an additional turn of events. A steady suspension of nanoparticles is essential; the total number of nanoparticles restricts their ability to lubricate the contact zone when mixed with the cutting oil. Furthermore, nano-lubrication in machining limits the use of fluids and prevents corrosion [9].

In the study of Sahin et al. [30], a simple lattice mixture methodology is utilized to optimize the nano-additives particle segment. This cubic experimentation was vital in showing the effects of tool wear properties on AISI 4140 steel. 3-D models used the desirability function to output single-response optimization, which also meticulously defined optimal values and desirability region for every input parameter. Nanoparticles mixture displayed effectiveness in reducing wear when compared to other individual results. Therefore, the ideal combination for the nano-fluid additive preparation was a mixture of ZnO of 67.4% and CNTs of 32.6%. A confirmatory experiment was done. The results showed a prediction rate of 95% confidence level, which corroborates the model's accuracy. When related to the non-oil additive, there was an enhancement of 77.81% in wear profile of cross-sectional area. These results show that optimization of nanoparticle preparation can be achieved with a mixture design methodology.

McPherson et al. [31] reviewed a design of an experiment comprising 4 to 5 factors and three-level parameters done in Minitab. This experimentation allows the study of the effects of solubility on individual factors. Although, 2-way analysis or greater factor relations are not permitted due to limited experiment runs. Munawar et al. [32] used a distinct DOE technique to analyze every parameter's impact at various levels by finding the average S/N ratios for every level. The method proved vital in calculating response values for tensile strength and standard deviation.

After a critical review of the literature in the machining process with the nano-lubricant and experimental design procedure, this research aims to study the tool wear analysis during machining Ti-6al-4v-Eli with face milling machining under different cutting conditions with cemented carbide-cutting tool. Also, the study employed Tanguchi's experimental design to carry out the experimental analysis to achieve the aim and the objectives of this study.

2. METHODOLOGY

2.1 Materials

Titanium dioxide nanoparticles (TiO_2), also known as nanocrystalline titanium dioxide or ultrafine titanium dioxide, are simply particles with diameters less than 100 nm. The main difference between TiO_2 particles and TiO_2 nanoparticles is that they are transparent, and the normal TiO_2 is white. TiO_2 possesses strong Ultraviolet (U.V.) absorption characteristics and is hence used to produce sunscreens. TiO_2 is one of the three most-produced nanoparticles, SiO_2 and ZnO. The white mineral oils are refined with colorless, odorless, transparent, and non-fluorescent hydrocarbon blends. They are a product of refining crude petroleum. They are used in the food industry and are ideally used to dissolve nanoparticles.

The wedge shape responsible for the removal of excess material from the workpiece is the cutting tool. The most commonly used tool inserts are cemented carbide inserts. It represents about 80-90 percent of all cutting tool inserts due to its unique blend of wear resistance and toughness properties and its ability to form complex shapes. Cemented Carbide is a tungsten carbide (W.C.) composite and a metallic cobalt (Co) profuse binder. In Table 1, the chemical composition of the cutting insert can be seen.

The choice of the Ti-6AL-4V-ELI in this research is due to the excellent material combination of corrosion resistance, good biocompatibility, strength, and high fatigue resistance. The property makes it an excellent material used for aerospace and automobile application. The titanium cylindrical block has been machined in diameter and length. The alloy's chemical composition, mechanical and physical characteristics can be seen in Tables 2 to 4, respectively.

Table 1. Chemical composition of Milling Carbide Insert tool

Elements	Co	TaC	NbC	WC
Weight%	9.1	1.23	0.30	89.37

Table 2. Chemical composition of Ti-6AL-4V-ELI

Elements	Ti	Al	V	O_2
Weight%	89.69%	6%	4%	0.13%

Table 3. Mechanical Properties of Ti-6AL-4V-ELI

0.2%Yield Strength Rp ≥ N/mm^2	Tensile Strength Rm N/mm^2	Elongation A5 ≥%	Modulus of Elasticity KN/mm^2
760	825-860	8-10	110

Table 4. Physical Properties of Ti-6AL-4V-ELI

Density g/cm^3	Specific Heat Capacity J/kg K	Thermal Conductivity W/m K	Electrical Resistivity Ω mm^2/m
4.45	560	6.9	1.71

2.2 Method for preparation of nano-lubricants

TiO_2 nanoparticles are utilized in this investigation, and the arrangement and security are of the most extreme significance in this work. Mineral oil is utilized as grease oil because of its simple openness and predominant quality. The Ultrasonic vibration technique is utilized in the trial to balance out the scattering of the nanoparticles. The different stages engaged with the readiness of the nano-greases is as per the following:

- The authors measured the TiO_2 nanoparticle utilizing an advanced electronic equilibrium. The estimation scope is 10 mg to 210 mg, and a most extreme blunder of 0.1 mg was permitted.
- The TiO_2 nanoparticles are added to the mineral oil.
- A homogenized mixture is obtained by vibrating the arrangement for 3 hours in a Branson ultrasonic shower. The surfactant is not added to the blend as it was quickly used in the tests because it can also decrease the thermal conductivity and nano-fluid execution.

The point of use of the Nano-lubricant is free from sedimentation.

2.3 Procedure employed for the implementation of the machining operation

The CNC machine is a motorized machine that performs machining operations using automated controls. It is a programmable machine fully capable of autonomously performing its operations. Many materials, including metals, composites, plastics, and wood, are well suited. XM1060 VMC model CNC machine was used in this study, having a maximum cutting speed of 10000 rpm, rated power of 21 K.W., power supply of 400V-50Hz-3PH. The experimental setup is shown in Figure 1.

Different steps were taken in this study to implement the nano-lubricant in face milling machining operations; the steps are as follows:

i. Preparation of the vertical XM1060 CNC Machine for performing the machining operation.

ii. The authors fixed the 80 mm diameter face-milling cutting tool of Carbide on the machine's spindle taper.

iii. The Titanium alloy workpiece is mounted on top of the machine's table, clamped on the vice.

iv. The CNC software is then used to determine the cutting tool's travel path along the axes X, Y, and Z.

v. Before carrying out the face milling operation, machining variables like cutting speed, feed rate, and depth of cut are introduced into the machine.

vi. The metal is first machined, with the lubricant being mineral oil. Then the nano-lubricants are used to machine the TI-6AL-4V-ELI.

vii. After machining, the cutting tool insert is taken to the Dinolite Digital Microscope (Tool wear analyzer). The Dino-lite AM4113T-1.3MP USB digital microscope with optical magnification of 10x-220x was used to analyze the tool wear and wear rate under the specified machining variables. The cutting tool is placed under the Dino-lite with a magnification of 20x, and the hexagonal measuring tool is used to measure the tool wear area to obtain the tool wear of each sample after the machining process.

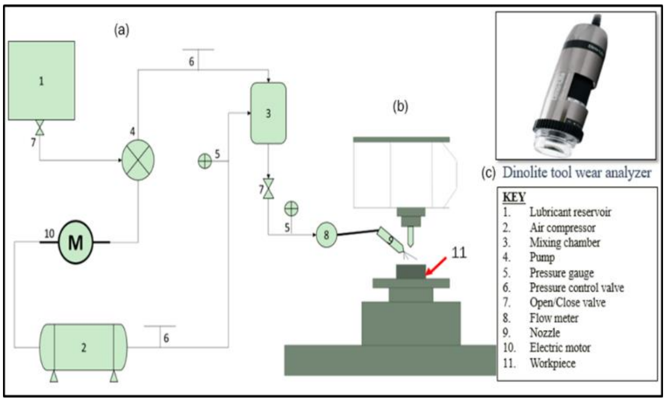

Figure 1. The Schematic Diagram of the experimental setup (a) the MQL system, (b) the Milling Machining process, (c) the tool wear measurement system

2.4 Design of experiments and mathematical methods

The experiment's design parameters are as follows: Cutting speed: 2000 rpm, 2500 rpm, and 3000 rpm, Feed rate: 150 mm/min, 200 mm/min, 250 mm/min, Depth of Cut: 0.3 mm, 0.6 mm, and 0.9 mm. The Taguchi experimental design method was utilized in this analysis. The Taguchi method is a proficient and compelling technique for planning tests. It gives a precise way to deal with upgrade plans for execution and quality. Most Taguchi tests are worried about the enhancement of a solitary quality trademark. Enhancing numerous quality attributes in assembling measures is not regular. It has gotten next to no consideration among the Taguchi professionals. A few businesses have utilized the Taguchi technique to improve items and cycle exhibitions throughout the long term. The technique is vigorous for the plan or creation stage to deliver more excellent items at a lower cost and less time. Numerous specialists utilizing Taguchi techniques have utilized unadulterated designing judgment when managing various assembling measure enhancement attributes.

This investigation utilized the Taguchi strategy and standard symmetrical cluster to distinguish three elements and three levels before choosing the ideal blend of cutting boundaries. The three degrees of cutting boundaries are low, medium, and high. Semantic measurement was then used to decide the objective cutting qualities. The device wear was isolated into five classes (most noteworthy, enormous, moderate, minor, and negligible). The term 'signal' speaks to the desired value (mean) for the Taguchi method's yield trademark. The term 'noise' speaks to the undesired value (S.D.)

for the yield trademark. The S/N proportion, therefore, refers to the measure of variety present in the quality mark. The S/N ratio is the proportion of S.D.'s intent. To quantify the quality mark straying from the ideal value, Taguchi uses the S/N proportion. The proportion μ of the S/N is explained as shown in Eqns. (1) to (3):

$$\mu = -10 \log(\text{MSD}) \quad (1)$$

where, MSD = mean-square deviation.

The desired objective here is to obtain a lower estimate of the wear of the cutting tool. In this way, the information, the lower-the-better sort of S/N proportion μ, is given in Eq. (2):

$$\mu = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (2)$$

$$\bar{\mu} = \mu_m + \sum_{i=1}^{k}(\bar{\mu}_i - \mu_m) \quad (3)$$

For the lower-the-better case, where μ = the S/N ratio, y_i= the characteristic of the measured quality for the repetition of ith and, N = the number of trial repetitions. When the ideal degree of the plan boundaries has been chosen, the last advance is to foresee and check the quality trademark's improvement utilizing the plan boundaries' ideal level. In order to achieve minimum tool wear results during the machining process.

3. RESULTS AND DISCUSSION

Experiments are carried out following the previously mentioned experimental procedure. Table 5 shows the measured value of the tool's wear and the cutting parameters. The effects of the various cutting parameters on the titanium alloy's tool wear under dry cutting, lubricants, and nano-lubricants during machining. The workpiece was machined at three cutting speeds for all the cutting conditions. The speed was changed after three subsequent experiment runs (2000 rpm, 2500 rpm, and 3000 rpm). Data is analyzed using the Signal-to-noise (S/N) ratio to identify the best possible combinations of control factors based on the experiment's data.

Table 5. Tool wear results

Exp. Runs	Cutting Speed (rpm)	Feed Rate (mm/min)	Depth of Cut (mm)	Cutting Condition	Tool wear (mm)
1	2000	150	0.3	Dry	0.41
2	2000	200	0.6	Lubricant	0.35
3	2000	300	0.9	Nano-lubricant	0.25
4	2500	150	0.6	Nano-lubricant	0.22
5	2500	200	0.9	Dry	0.47
6	2500	300	0.3	Lubricant	0.31
7	3000	150	0.9	Lubricant	0.26
8	3000	200	0.3	Nano-lubricant	0.18
9	3000	300	0.6	Dry	0.38

Table 6. Response analysis for signal to noise ratios

Level	Cutting Speed (rpm)	Feed rate (mm/min)	Depth of Cut (mm)	Cutting Condition
1	9.635	10.979	10.937	7.569
2	9.961	10.190	10.225	10.444
3	11.780	10.206	10.213	13.362
Delta	2.145	0.789	0.724	5.794
Rank	2	3	4	1

The S/N ratio was calculated using Taguchi L9 Orthogonal Array runs in the Minitab software are shown in Table 6. The values, as stated earlier, are at their lowest when in the optimum condition. A higher value corresponds to better performance in the case of the S/N ratio. Table 6 (in the form of a Delta) shows the difference between the maximum and minimum values of the S/N ratio (main effect). For better representation, Table 6 is plotted in Figure 2 below. Let us assume that the cutting speed is factor N, feed rate (factor F), depth of cut (factor D), and condition of cutting (factor C). Therefore, it can be concluded that the maximum value for factor N occurs at level 3 with an S/N ratio of 11.780. Also, factor F and factor D occur at level 1 with an S/N ratio of 10.979 and 10.937.

Besides, factor C happens at level 3 at an S/N proportion of 13.362. Subsequently, the ideal tool life's combined parameters can be seen at levels N3, F1, D1, and C3 (3000 rpm, 150 mm/min, 0.3 m, and nano-lubricant cutting conditions). The result in Table 2 shows that the cutting condition is the factor most affected by the tool's wear, individually trailed by cutting speed, feed rate, and cutting depth. The delta value and the slope in the model in Figure 2 also clearly demonstrate that the prevailing variable affecting tool wear estimation is the cutting condition. Due to the increase in temperature, friction between the cutting tool and the workpiece causes the cutting tool to wear over the long haul.

In order to analyze the critical influence, the actual mean effect plot is employed in Figure 3, where the dry, lubricant and Nano-lubricant machining are represented with 1, 2, 3. The trend of the graph shown in Figure 3, that the dry machining operations have the highest tool wear due to the friction caused by the contact of the cutting tool with the workpiece. However, since the Titanium alloy has high hardness, it increases the vibration and friction since there was no lubrication during the machining operations. The cutting condition shows a constant decrease in tool wear when the lubricant was implemented in the machining. Also, the nanoparticles added to the lubricant increased the nano-lubricant performance, and much more reduction was observed. This research has proven the significance of nanoparticles in the machining of difficult-to-cut materials like Titanium alloy.

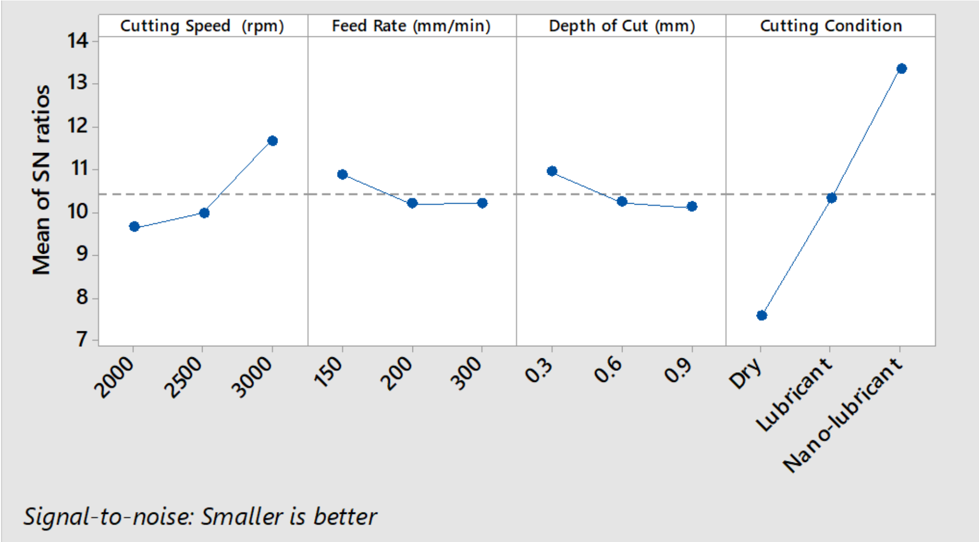

Figure 2. Signal to noise ratio for tool wear

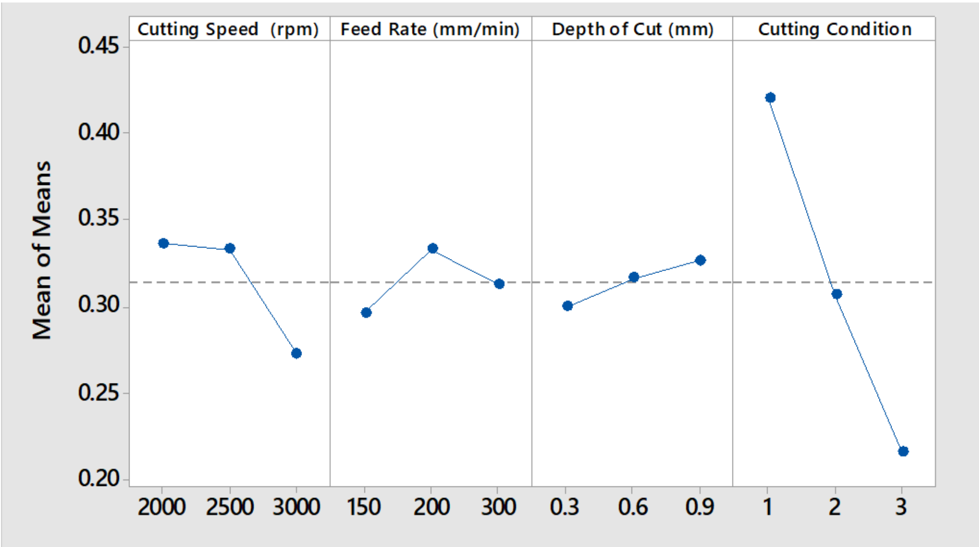

Figure 3. Mean effects of the cutting parameter and cutting conditions on the cutting tool wear

The tool wear is principally brought about by constant contact between the workpiece and front lines. This wear is due to specific variables, such as workpiece hardness, cutting limits, liquid/coolant cutting properties, and low material thermal conductivity. Due to more minor softening of the material, the TI-6AL-4V-ELI low thermal conductivity material is difficult to machine. Therefore, the use of coolant in tool wear assumes a fundamental function. The nano-lubricant is responsible for the ideal tool wear value due to improved thermophysical characteristics. The dry cutting condition is responsible for increasing the tool wear value. Figure 4 shows the four-in-one graph from the Minitab 16 used in this analysis. The normal probability plot from the model predicting the tool wear with the cutting parameters, the histogram showing the frequency of occurrence with the residual plot, and residual against the observation runs.

Table 8 shows the analysis of the prediction of the cutting tool wear rate during the machining operation. The developed model can predict the response parameters with 94.04%, denoted by the R.sq prediction rate.

Table 7. Analysis of variance for tool wear

Source	DF	Seq SS	Cont. %	Adj S.S.	Adj MS	F-Value	P-Value
Regression	5	0.070861	97.04%	0.070861	0.014172	19.67	0.017
Cutting Speed (rpm)	1	0.006017	8.24%	0.006017	0.006017	8.35	0.063
Feed Rate (mm/min)	1	0.000156	0.21%	0.000156	0.000156	0.22	0.674
Depth of Cut (mm)	1	0.001067	1.46%	0.001067	0.001067	1.48	0.311
Cutting condition	1	0.062017	84.93%	0.062017	0.062017	86.09	0.003
$(\text{Cutting Speed})^2$ (rpm)	1	0.001606	2.20%	0.001606	0.001606	2.23	0.232
Error	3	0.002161	2.96%	0.002161	0.000720		
Total	8	0.073022	100.00%				

Table 8. Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
0.0268397	97.04%	92.11%	0.0203161	72.18%

Table 9. Coded Coefficients

Term	Coef	S.E. Coef	95% CI	T-Value	P-Value	VIF
Constant	0.3339	0.0155	(0.2844, 0.3834)	21.48	0.001	
Cutting Speed (rpm)	-0.0317	0.0110	(-0.0665, 0.0032)	-2.89	0.063	1.00
Feed Rate (mm/min)	0.0050	0.0108	(-0.0292, 0.0392)	0.46	0.674	1.00
Depth of Cut (mm)	0.0133	0.0110	(-0.0215, 0.0482)	1.22	0.311	1.00
Cutting condition	-0.1017	0.0110	(-0.1365, -0.0668)	-9.28	0.003	1.00
Cutting Speed (rpm)*Cutting Speed (rpm)	-0.0283	0.0190	(-0.0887, 0.0321)	-1.49	0.232	1.00

Table 9 presents the Coded Coefficients of the interaction parameters with T-value, F-value, and Variance inflation factor (VIF). The result of VIF having 1 shows that the interaction between the parameters is no multicollinearity. This result means that the model has moderately correlated with good collinearity. The tool wear regression model is shown in Eq. (4).

$$\text{Tool wear} = -0.054 + 0.000503\,N + 0.000067\,F + 0.0444\,D - 0.1017\,C - 0.000000N^2 \quad (4)$$

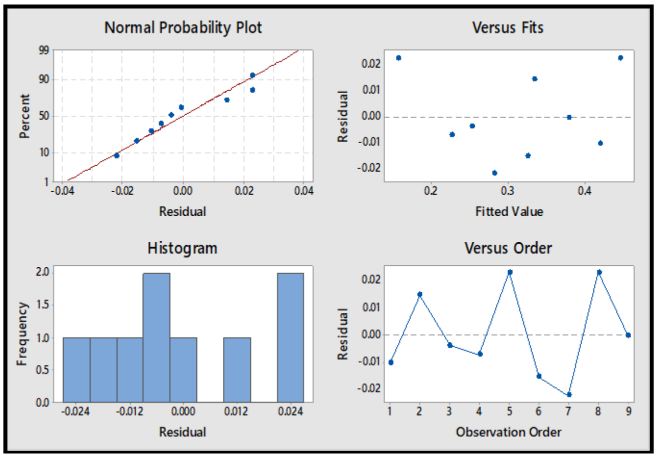

Figure 4. Residua, fitted value, histogram, and residual vs. observation order plots for the tool wear

3.1 Effects of individual machining parameters on tool wear

The study in Figure 2 shows the influence of the cutting conditions at the different cutting speeds on the tool wear. During dry cutting, it can be shown that the highest value of tool wear is reported. The lowest wear of the tool is seen through nano-lubricants that show their superior cooling properties at a higher cutting speed of 3000 rpm. In Table 7, the ANOVA data model indicates each parameter's contribution to the effects of the wear rate on the cutting tool. Cutting conditions at 84.93 percent, cutting pace at 8.24 percent, cutting depth at 1.46 percent, and feed rate at 0.21 percent are the cutting parameters with the highest contribution. This also shows that tool wear on the cutting tool is most affected by the cutting environment. The F-Value also provides a similar definition. From Figure 5, the effect of the cutting speed on the tool wear for the three cutting conditions shows that as the cutting speed increase from 2000 to 3000 rpm, the tool wear decreases. In this study, it can be concluded that the increase of the cutting speed assists the machining process to be free from the chips falling back to the cutting region. The higher F-Value demonstrates that the cutting condition parameter is the most relevant. The relation between tool wear and feed rate is shown in Figure 6. The lowest tool wear value was reached at a 200 mm/min feed rate with the nano-lubricant cutting condition. The highest tool wear value was obtained during the dry cutting condition is at 200 mm/min feed rate and 2500 rpm cutting speed. These results indicate that the feed rate value is more affected by the cutting condition and speed.

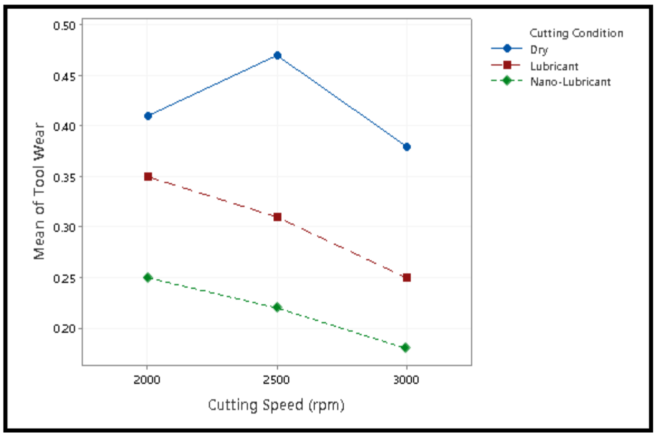

Figure 5. Graph of mean tool wear vs. cutting speed

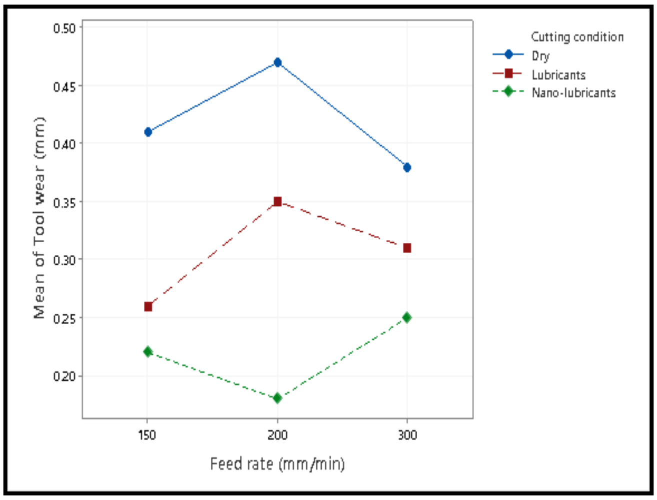

Figure 6. Graph of mean tool mean wear vs. feed rate

The relationship between tool wear and the depth of cut is shown in Figure 7. The study concluded that using the lowest value of cut depth (0.3 m) under nano-lubricant cutting conditions, the optimal (lowest) tool wear value was achieved. However, the highest value for tool wear is achieved using the maximum value of cut depth (0.9 m) under the cutting conditions. This study is in line with the observation made by Okokpujie et al. [33]. The authors study the various cutting parameters on vibration during machining operations. They observed that the depth of cut increases the vibrations, which causes a high rate of tool wear. The authors' study recommended a nano-lubricant study to reduce vibration and tool wear, which has been diligently studied in this research. Liu et al. [34] confirmed the significance of machining factors in the cutting tool wear rate. The authors studied the tool wear monitoring process, and the cutting forces analysis was also studied. Relatively depth of cut is a significant parameter that significantly affects tool wear of any cutting tool materials.

Tian et al. [35] study the optimization of machining factors on cutting tool wear. The study shows that the machining factors affect the cutting tool wear when it varies. Furthermore, the authors concluded that the study of various cutting conditions with the machining factors is highly needed to optimize the machining factors properly. Moreover, this study has carried out a machining experiment with three machining conditions and employed the machining factors during the study under the dry, mineral oil, and TiO_2 nano-lubricant. Moreover, it is worth noting that the addition of the TiO_2 nanoparticles to the base oil improved the thermal properties and assisted in the lubricity of the mineral oil. This results from the minimum tool wear observation during the experimental study.

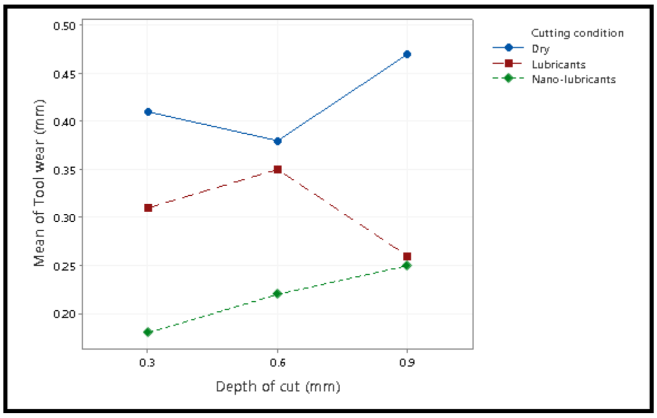

Figure 7. Graph of mean tool wear vs. depth of cut

3.2 Interactions study of the cutting parameters on tool wear

Figure 8 shows the relationship between the effects of the cutting parameters on the tool wear can be inferred from the interaction plots. The interaction plots confirm that cut parameters' feed rate and depth improve tool wear value under the TiO_2 nano-lubricant. Also, the study indicates an inversely proportional relationship between the parameters and tool wear. The TiO_2 nano lubricants have the lowest tool wear values for the cutting condition under the cutting parameters. The study concluded that the low tool's wear value is often connected to TiO_2 nano lubricants' effect irrespective of the other's value cutting parameters [36-38]. The feed rate and the depth of cut are the most interacted machining parameters with the cutting conditions. This result is supported by the study of [39, 40].

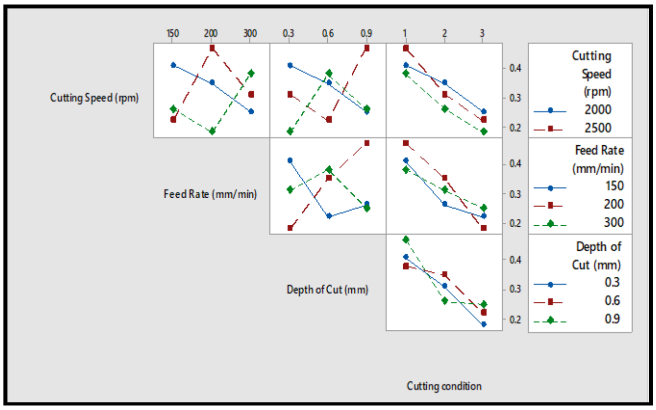

Figure 8. Interaction Plot for the Cutting Parameters and cutting condition on Tool wear

4. CONCLUSION

The effect of three machining cutting conditions on face milling of Titanium alloys machining (TI-6AL-4V-ELI**)** was carried out under dry, mineral oil, and TiO_2 nano-lubricants to study the cutting tool wear rate. The study employed the Taguchi L9 design of the experiment. Also studied the interactions of the machining factors with the cutting conditions. The results prove that TiO_2 nanoparticles performed excellently well as an additive to the mineral oil due to the percentage reduction of the tool wear compared with dry machining and mineral oil. Furthermore, the following conclusion was drawn out:

i. The analysis of variance (ANOVA) results showed that the cutting condition primarily affects the cutting tool wear by 84.93 percent. This result is followed by cutting speed at 8.24 percent, then cutting depth at 1.46 percent, and feed rate at 0.21 percent.

ii. Furthermore, the nano-lubricants produced the lowest value for tool wear under all cutting parameters, hence, confirming its remarkable cooling endowment in this study. A cutting speed of 3000 rpm, a feed rate of 150 mm/min, cut depth of 0.3 mm. The TiO_2 nano-lubricant cutting condition has the optimum combination of parameters for the best tool life for machining TI-6AL-4V-ELI.

Therefore, machining factories and industries can apply the optimum parameters from this study under the additive of TiO_2 nano-lubricant to manufacture mechanical parts. Hence the implementation of minimum quantity nano-lubricants machining operations will reduce the cutting fluid consumption, reduce production costs, and promote sustainable production.

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