DOI: https://doi.org/10.24425/amm.2025.152553

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INVESTIGATION ON MACHINING PARAMETERS OF TITANIUM ALLOY IN NMQL ENVIRONMENT

Vegetable oil-based nano particle is a realistic alternative lubrication used in standard cutting fluids. In this research, turning operations are done on titanium alloy utilizing cemented carbide inserts with nano minimum quantity lubrication (NMQL). A response surface methodology is employed to optimize the machining variables such as cutting speed, feed, and depth of cut to anticipate the ideal surface roughness, cutting forces, and tool tip temperature. Moreover, an experimental study is conducted to evaluate the performance of NMQL with the different machining factors. According to the findings, NMQL with nano aluminum oxide particles added with coconut oil is an effective lubricant which provides lowering cutting forces, surface roughness, and tool wear. The novelty of work is to analyze the machined surface using atomic force microscopy and tool wear patterns were analyzed by using SEM image. Result was compared with the experimental observations. The most ideal solution for the reduction of surface roughness, cutting force, and tool tip temperature was reached at cutting speed of 60 m/min, a feed rate of 0.04 mm/rev, and a depth of cut of 0.05 mm. The greatest roughness value of 1.62 microns obtained.

Keywords: MQL; tool wear; titanium alloy; Nano particles; surface roughness; tool wear; surface morphology

1. Introduction

Titanium and its alloys are widely demanded in the industrial sectors due to their qualities like a high strength-to-weight ratio and maximum corrosion resistance. At the same time, it was extensively employed in aviation industries owing to its high strength characteristic [1]. Most of the components are fabricated from titanium alloy in the form of round cross section. Turning is the most effective technique to turn any shape into a circular one. As a consequence of this, considerable wear may take place on the cutting tool, which results in a poor surface quality on the work material and also affects the production rate. Use of multi-hole nozzle hybrid cryogenic MQL in machining boosts the production rate up to 50% [2-3]. The great performance an assessment in the machining of titanium alloy was achieved by employing the cryo-MQL technique. Two distinct cooling approaches, such as minimal quantity lubrication and the cryo-MQL method, were selected for this investigation. These two strategies were combined to form a hybrid cooling system that was efficiently applied in this study. Surface roughness and micro hardness were evaluated and comparative study of dry, MQL, and Cryo-MQL was also explored. Cryo-MQL effects greater concentration to lower the surface roughness and machining forces by 46% and 27%, respectively, compared with a dry machining environment. In addition to provide a superior surface finish on the workpiece by lowering the surface roughness value by 32% to 46% in comparison to a dry machining environment. The quenching impact of liquid nitrogen over the workpiece also contributed to the improvement of the surface finish [4] attempted to reduce the tool wear and enhance the tool life and surface polish in the milling of titanium alloy by utilizing cryogenic LN_2, MQL, and dry machining conditions. In this investigation, it was discovered that the Co_2 snow effect creation in the cryo system excelled well in lowering the surface roughness value and improving the tool life by 50%. Co_2 snow generation in the cryo lubrication system was well suited to milling tools with a 420° helix angle, and improved machining conditions were attained while down milling with a 30° helix angle. Under the up-milling condition, a high energy efficiency of 30.72 percent was reached at a cutting speed of 110 m/min and a helix angle of 30° in the cryo LN_2 cooling mode. The sustainability measure was also remarkable with the CO_2-snow cooling condition [5]. Turning test was performed in titanium alloy by employing a laser-textured tool aided by vegetable oils.

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Machining conditions were carried out in three distinct settings, such as dry, MQL, and nano MQL systems. The purpose of this research is to minimize cutting forces, friction coefficient, contact length, and tool wear. In the textured tool, the curling radius was limited to lessen the heat production during the turning operation. Fine dispersion of droplets in MQL and nano MQL appears to be useful in the lowering of cutting forces. The friction coefficient plays a critical function in MQL conditions to lower the cutting and thrust forces in the machining of titanium alloy. In another work [6], the authors evaluated the surface roughness, micro hardness, and subsurface deformation in the drilling of titanium alloy. The machining condition was properly designed using the MQL attachment. MQL conditions were carried out with the use of synthetic ester and palm oil. It functioned as the MQL system's lubricant [7]. A multi-CI method was designed to anticipate the ideal value of input variables such as cutting force, tool wear, and surface roughness. Initially, the MQL approach was utilized in the machining of titanium alloy, and then the multi-CI algorithm and particle swarm optimization technique were adopted to forecast the ideal parameter. Comparing PSO and MCI procedures, MCI gives the greatest results, which minimize 42% in tool wear, 8% in the cutting force, and 15% in surface roughness compared with the particle swarm optimization methodology [8]. The environment's safety in the machining of titanium alloy was investigated with different parameters. Ranque-Hilsh vortex tube (RHVT) was effectively utilized in the MQL method to decrease surface roughness, cutting force, and tool wear. In the arrangement of RHVT, which conducts hot and cold air via the vortex tube into the nozzle to produce cooling in the MQL condition, ANOVA, PSO bacterium foraging optimization, and teaching learning-based optimization were utilized to assess the response variables by employing algorithms. In this research, speed, feed, depth of cut, and machining time were considered the input factors. Four machining conditions, such as dry, chilling with liquid nitrogen, MQL with LN_2 and RHVT with MQL, were applied. Average flank wear was steadily rising with the cutting speed, but specific cutting energy was substantially dropping in the N_2 with MQL environment owing to an increase in the dependability of the cutting tool. In the same instance, surface roughness was observed to be negligible compared with other machining conditions. Surface roughness was observed to be significantly low in the N_2 with MQL condition. The micro hardness of the specimen reduced progressively with the depth of the machined surface. It was regularly noticed in all machining environments [10] investigated the surface study on the machining of titanium alloy. The MQL approach was applied to increase the surface finish by employing CBN inserts. Air flow rate, lubricant flow rate, and input pressure were the input elements considered in this investigation. It was a highly successful way to link the relationship between the cutting factors and their output characteristics [11] attempted to make an effort to analyze the surface quality of the titanium alloy in machining using least amount lubrication and cooling technology. Polytetrafluoroethylene combined with synthetic oil, 15% graphite enhanced with demineralized water, a flood lubrication system, and a dry machining environment was incorporated. Due to the dynamic viscosity of the PTFE particles used in MQL environments, tool nose wear is reduced, and at the same time, solid lubricant assists MQL, resulting in the best results in part in reducing the surface roughness value and increasing the surface finish by up to 39% compared with dry machining and 29% with MQL. Overall, MQC with 15% graphite boosted surface quality and increased the dependability of the cutting tool [12]. Two alternative ways were applied in cryogenic air combined with the MQL method such as external oils on water (EOW) and internal oils on water. This study examined the comparative examination of cutting force in the feed and radial directions by utilizing the cryogenic air mixed with oil technique and the cryogenic air minimal quantity lubrication system (CAMQL). In this turning procedure, chips look to be extremely short and spiral in the EOW technique. Surface roughness appears to be quite high in CAMQL compared with EOW and IOW techniques. In all three procedures, flank wear increased with cutting distance. In terms of superior surface quality, the IOW approach was rated the best way along with other methods. The wiper geometry insert employed in the machining of titanium alloy was studied [13]. LB 8000 was utilized as the lubricating oil in the MQL system. Skewness and kurtosis values were largely evaluated in this research. These characteristics were most critical to examine the surface behavior of the machined surface. Feed rate has a vital function in minimizing the surface roughness of the machined item. Particularly when utilizing a wiper insert tool in the MQL system, lower Rz by 40% in dry machining and by 43% in the MQL system. Owing to the potential of oil mist, the production of cracks and valley profiles was reduced, and a smooth surface was given with the assistance of the wiper insert tool [14]. Explored a novel approach in the milling of titanium alloy that tends to focus on the dependability of the cutting tool was investigated. Cold air electronic minimum grade lubrication was employed in this experiment. Cutting length in milling operations substantially increased with tool flank wear. The four various systems, such as a MQL or an electrostatic MQL, A cold air MQL and cold air emission MQL system were utilized to evaluate the wear behavior of milling tool cutting. The cold air emission MQL system lessens the friction between tool and workpiece, which concurrently reduces flank wear [15] developed an ANN model to forecast the cutting force in the machining of titanium alloy, while a genetic method was adopted to predict the ideal parameters that lower cutting forces. The evolutionary algorithm was largely appropriate for examining various solutions, and ANN is highly suited to forecast the response factor in this investigation [16]. The performance of turning experiment in the machining of Ti-6AL-4V alloy was analyzed. Canola combined with graphene and sulfur-based EP additives was efficiently employed in this experiment. Three forms of MQL procedures were engaged in this investigation; compared with these three types of techniques, canola oil, graphene, and EP additives helped with the MQL method offered superior outcomes [17]. Linear regression, random forest, and support vector machine approaches were used to anticipate the optimal value. In this work, alumina nanoparticles with diameters ranging from 30-40 nm were selected. Surface roughness was adequately decreased in the experimental procedure with 40 nm particle size compared with 30 nm particle size. Many researches are working on the nano MQL machining condition to boost productivity and improve the surface quality [18-25].The purpose of this work is to establish a green manufacturing environment by employing nanofluid enriched with coconut oil. A nanofluid-assisted minimal amount lubrication system was efficiently employed to minimize the responses. Speed feed and depth of cut were regarded the input factors, while surface roughness, tool tip temperature, and cutting force were considered the results of this experiment. The SEM research for the tool was fully examined, and the surface morphology of the machined surface was clearly explored by an atomic force microscope image.

2. Materials and methods

Nano particle sizes of 30-40 nm for aluminium oxide particles were acquired from outside sources, and the SEM image of the particles was captured using a SEM to confirm the particle size displayed in Fig. 1. The nanofluid-MQL approach is utilized on an all-geared lathe for performing tests. In this experimental work, nanofluid production was the major goal, and it was created by employing a magnetic stirrer and the sonification process. The magnetic stirrer was applied in nanoparticles with 5% of weight was combined with coconut oil. The stirring procedure was efficiently employed to agitate the nanoparticles in the base fluid to produce a homogenous combination of aluminum particles in the coconut oil. Following the stirring process, it was placed into the sonicator to accomplish the sonification process. By utilizing an ultrasonic method, the nanoparticles were pushed and evenly disseminated in the base fluid to obtain aluminium oxide with coconut oil-based nano fluid. In this research, titanium alloy was selected owing to its demand in an industrial area. The dimension of the solid rod of the titanium alloy was chosen as 120 mm by 30 mm in diameter, as referred to in the literature research [26]. The chemical composition of the titanium alloy was clearly mentioned in TABLE 1. During the experiment, the tool tip temperature was estimated using an infrared thermometer with 2% accuracy and a temperature measurement range of –20°C to 2200°C. The average of three temperatures measured from the workpiece was taken as tool tip temperature. In this experimental approach, the statistical technique of response surface methodology was combined to identify the ideal value of speed, feed, and depth of cut. As per the recommendations referredto in the literature research, 15 runs were completed, and the combination of speed, feed, and depth of cut was generated using RSM. The tests were done, and the findings were noted in the TABLE 4. Nano particles added with coconut oil tends to reduce high amount of temperature in between the cutting tool and workpiece in NMQL which was additionally used to reduce friction and wear of the cutting tool and to enhance the surface finish of the work material.

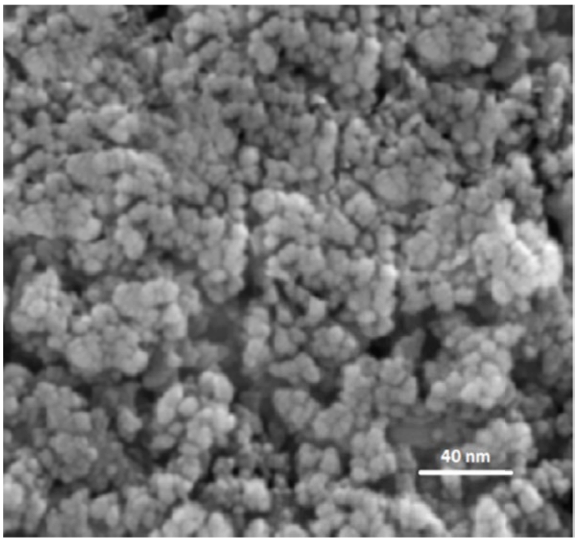

Fig. 1. SEM image of the aluminum oxide Nano particles

TABLE 1

Alloying elements

Material	Al	V	C	O	N	Fe	Ti
Weight %	6	4	0.1	0.2	0.05	0.25	89.4

3. Experimental work

Owing to the hardness and difficult-to-cut behavior of titanium alloy, cemented carbide with TiAlN (PVD coating) tool material was used for the cutting tool insert material. The cutting tool parameters are clearly indicated in TABLE 2. For performing tests, cutting parameter values and inputs were set as per the literature research [20]. The value of input variables and their levels were clearly indicated in TABLE 3.

TABLE 2

Cutting tool specification on cemented carbide coated with TiAlN (PVD coating)

Corner radius	Clearance angle	Rake angle	Cutting edge length	Position angle
0.8 mm	0°	6°	13 mm	45°

TABLE 3

Input variables and their levels

Input variables	Level 1	Level 2	Level 3
Cutting Speed (m/min)	60	75	90
Feed (mm/rev)	0.04	0.08	0.12
Depth of cut (mm)	0.05	0.1	0.15

From the literature study the factors and their values were selected. The experimental design layout was clearly depicted in Fig. 2. The fifteen experimental input runs were structured by using response surface methodology. TiAlN PVD coated tool has better thermal stability, low coefficient of friction, excellent wear resistance and high heat carrying capacity, compared with other type of coated tool. For each experiment fresh 15 cutting tool was used to calculate the tool wear. AlN was coated on the cemented carbide due to minimize the tool wear and thermal failure of the cutting tool [27]. Nanofluid was created using the mixture of coconut oil as a base fluid and enhanced with Al2O3 Nanoparticles were preferred for the MQL method. This approach was selected to lessen the human danger concern and, at the same time, lower the machining and fluid expenses. The use of nanofluid helps to enhance the mechanical and surface behavior of the cutting tool and workpiece. In this configuration, a compressor was utilized to deliver compressed air to the oil tank, which stores the nanofluid, and the outflow was linked to the mixing chamber, which is also connected to the nozzle. The highly compressed air combines air with nanofluid and is sent directly onto the MQL nozzle, which concentrates on the contact zone on the tool and workpiece during machining processes. Due of the high pressure of the compressed air, nanofluid and air mixed together and formed an atomization process, resulting in a flow rate of 100 ml/hr at the site of contact. The infrared thermometer was fastened to the tool post, its focal point calibrated and corrected to the machining zone, and it went along with the tool post during machining. It was used to measure the tool tip temperature. Following each operation, the old tool was measured with the use of an optical microscope to compute the tool wear, and it was recorded. The machining length for each operation was judged to be 75 mm.

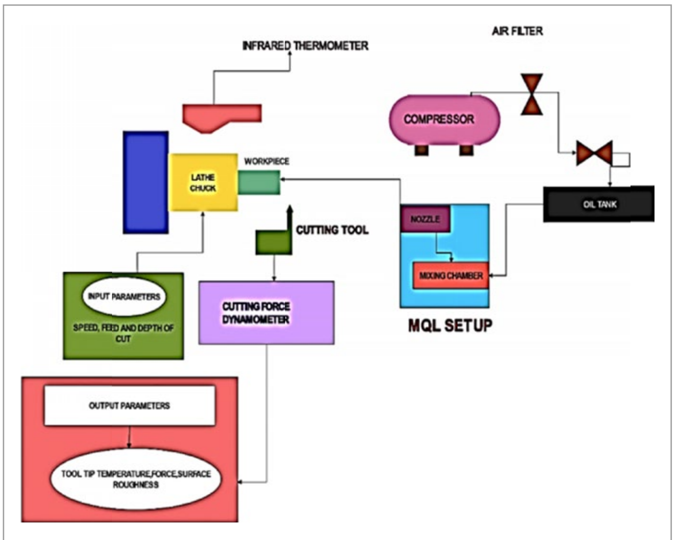

Fig. 2. Schematic layout of experimental setup

4. Results and discussion

The purpose or goal of this investigation is to minimize the response factors. For this reason, it was very much essential to compute the desirability value of the output response. TABLE 4 displays the value of output responses by applying an experimental approach. The speed plays a major role in predicting the cutting force. As the speed rises, the force likewise increases, and vice versa. It indirectly demonstrates that there is a contribution from an interaction between the feed and depth of cut in the prediction of cutting force. As the speed and feed rise, the tool tip temperature likewise increases, and at the lowest speed and feed, the temperature would be approximately 200°C. At the same time as speed and feed are raised, the tool tip temperature hits 291°C due to the rubbing motion between the tool and workpiece.

TABLE 4

Experimental output results

Exp. No.	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Cutting force (N)	Tool tip temperature	Surface roughness (microns)
1	75	0.08	0.1	128	266	1.31
2	60	0.04	0.05	85	200	0.75
3	75	0.12	0.1	131	278	1.21
4	75	0.08	0.1	132	265	1.31
5	75	0.04	0.1	122	245	1.31
6	75	0.08	0.05	115	256	1.07
7	60	0.12	0.15	117	260	1.06
8	75	0.08	0.1	127	262	1.25
9	90	0.12	0.05	141	289	1.33
10	90	0.04	0.15	160	291	1.78
11	90	0.08	0.1	152	288	1.62
12	75	0.08	0.15	138	278	1.42
13	75	0.08	0.1	127	262	1.23
14	75	0.08	0.1	126	261	1.2
15	60	0.08	0.1	103	231	0.92

4.1. Tool wear investigation

Fig. 3 depicts the wear development of the cutting tool insert, a cemented carbide insert coated with TiAlN. Fig. 3(a-e) depicts the wear profile of the cutting tool with varied wear patterns. In this experimental study severe wear was increases with an increase in the cutting speed and it was clearly illustrated in the Fig. 3. Various sorts of wear patterns such abrasion wear, attrition, chipping, cracking, sticking of particles, and chipping off were developed on the tool during machining, which resulted in a poor surface quality on the workpiece. The cause for the wear creation is simply related to the friction and heat behavior. Fig. 3(a) depicts the tool wear profile, which was obtained by the SEM picture at a 2× magnification. Tool wear was achieved under machining settings of 60 m/min, 0.04 mm/rev, and a depth of cut of 0.05 mm. These three input parameters were connected to low-level values, which were listed in TABLE 4. Surface roughness and tool tip temperature values are very briefly reported in the same table. The cutting tool with the usual wear failures of abrasion markings and built-up edge was formed in the tool profile due to the cutting motion. Fig. 3(b) depicts the tool that underwent pitting, chipping, and abrasion markings under the machining settings of 75 m/min, 0.08 mm/rev, and a depth of cut of 0.15 mm. Owing to the highest depth of cut, the tool tip temperature was determined to be at its maximum, and the friction plays a critical part in the creation of pitting and chip-

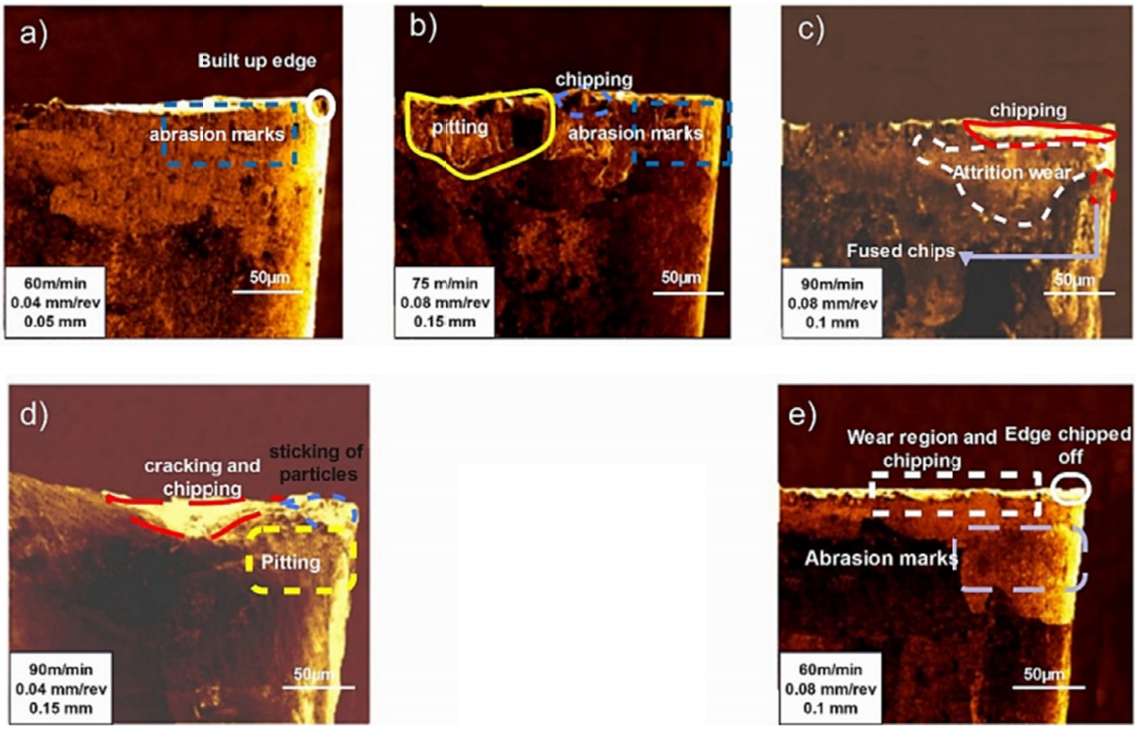

Fig. 3. Tool wear profile on cutting tool under various speed, feed and depth of cut

ping on the tool. This was only achievable because a high tool tip temperature of 278°C was achieved during the machining. Fig. 3(c) illustrates the wear profile contains chipping, attrition wear, and fused chips that also attach to the tool's flank surface.

The temperature was found to be greatest in the cutting zone owing to the maximum cutting speed of 90 m/min. Because to the high speed, the coated surface of the tool was delaminated from the cutting tool, a phenomenon called attrition wear, and chipping was also detected. Owing to the greatest temperature, chips are fused and stick over the flank face on the tool surface, which was also seen. The similar phenomena were also addressed [28]. Fig. 3(d) depicts the wear profile on the tool under the operating condition of 90 m/min, a feed rate of 0.04 mm/rev, and a depth of cut of 0.15 mm. In this scenario, the increased level of cutting speed and depth of cut propagates the fracture on the tool flank surface, and chipping of the tool surface was also seen. A maximum temperature of 291°C generated on the cutting zone. In the nose area, tool pitting was also seen owing to the highest cutting speed. Similar incident was happening [26]. Fig. 3(e) reveals the tool wear profile was obtained under the following conditions: 60 m/min, 0.08 mm/rev, and a 1 mm depth of cut. Under these settings, highly frequent wear profiles such as chipping and abrasion marks are created.

4.2. Surface morphology

Surface morphology is characterized as the surface texture of the machined surface evidenced by the defects such as pit and valley profile. In this study, atomic force microscope analysis was performed to give the 3D image of the machined titanium alloy surface. It was extremely vital to study how the surface profile was formed. For this investigation, wire-cut EDM machining was carried out to cut the machined surface to the dimension of 100 by 100 microns for the AFM study. Following the cutting process, the specimen was cleaned with an acetone solution before it underwent the AFM examination. Fig. 4 illustrates the 3D surface image of the machined surface. Fig. 4(a) depicts the profile of the machined surface machined at 60 m/min, a feed rate of 0.04 mm/rev, and a depth of cut of 0.05 mm. From these circumstances, smooth surface finish happened and was supported by TABLE 4. As a consequence, there were fewer pit and valley forms. Fig. 4(b) reveals a larger number of pit and valley formations were detected. As a consequence of these conditions, the work surface was determined to contain abrasion marks of the highest size. That was justified by the greatest roughness value of 1.62 microns obtained in TABLE 4. Fig. 4(c) demonstrates that pits and cavity development were seen at two spots. That was owing to the maximum depth of cut, and it was obvious from the surface roughness value indicated in the output data. Surface morphology was used to investigate the surface pattern of the workpiece. Surface roughness was measured at three places on the circumference of the work piece and the average values were taken for the research study. Fig 4(d) illustrates that the bulky peak profile was localized in one spot. A hill like, spiky shape was noted due to the highest speed and depth of cut. Pits and valley formation indicates the surface roughness of the workpiece. It was replicated in TABLE 4 with a roughness value of 1.78 microns. Fig 4(e) displays the AFM picture of the machined surface, and it was quite fascinating to see that there is no pit and valley creation owing to the minimum cutting speed and depth of cut.

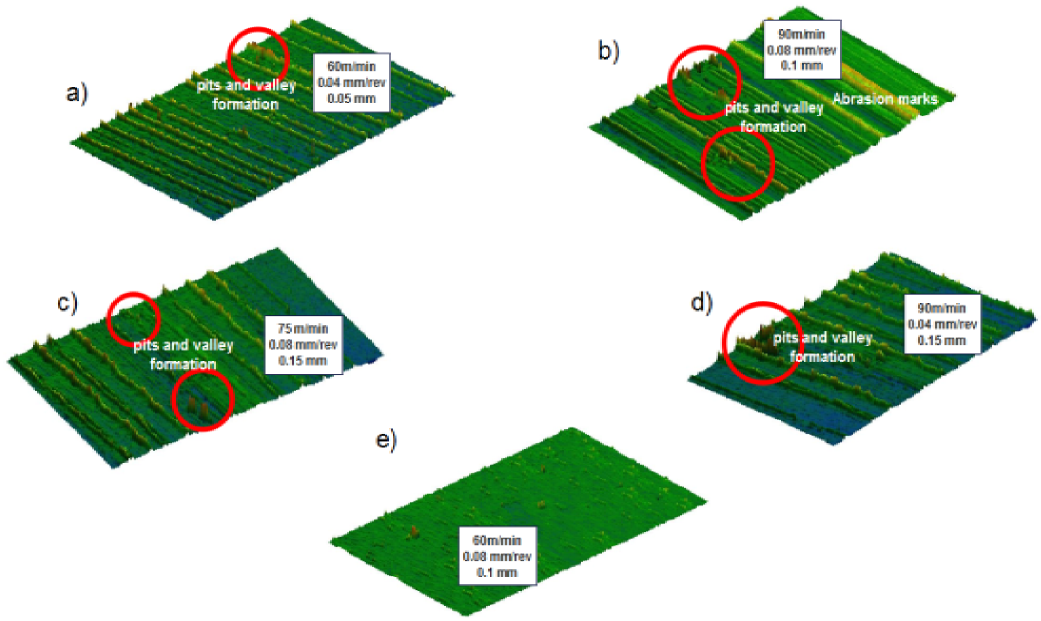

Fig. 4. AFM image of the machined titanium surface

6. Conclusion

In the past, a few researchers have centered on using the nano-minimum amount lubrication system to assess the mechanical and surface study of the titanium alloy. In this work, a unique way of employing coconut oil based on nano sized Al_2O_3 particles was employed to investigate the surface morphology. AFM technology was adopted to pick out the peak and valley profiles related with the experimental outcomes.

- Response values are evaluated based on the input constraints and their level.
- The wear pattern of the tool was explored using the experimental findings, and the wear patterns were readily detected with the SEM image.
- In this analysis, abrasion and attrition wear were regularly detected in all the tool flank profiles under the wear analysis.
- All response variables, such as surface roughness, tool tip temperature, and cutting force, demonstrate that cutting speed alone only plays a critical role compared with feed and depth of cut.
- The most ideal solution for the reduction of surface roughness, cutting force, and tool tip temperature was reached at a cutting speed of 60 m/min, a feed rate of 0.04 mm/rev, and a depth of cut of 0.05 mm.
- An atomic force microscopic investigation was successfully done on the machined surface to identify the surface characteristics and emphasize the peak and valley forms.

Future direction and limitations

The experiment will be done based on nano minimum quantity lubrication with different metal oxides. The improper selection and high level of machining parameters may damage the surface morphology of the material.

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