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INVESTIGATION AND MODELLING OF NANO-MWCNT DIFFUSED CUTTING FLUID IN MILLING PROCESS ON Ti-6Al-4V ALLOY

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The milling process is a machining process widely used in recent days in the field of automobile, biomedical, tool and die industries and aerospace. In this research, the influence of the cutting parameters on the cutting temperature and surface roughness were investigated in the milling of Ti-6Al-4V alloy. Cutting speed, cutting feed, axial depth of cut and concentration of multiwall carbon nanotubes (MWCNT's) nano-fluid are selected as the control factors. Response surface methodology (RSM) based desirability function analysis (DFA) approach was used in the optimization of the cutting parameters for cutting temperature (Ct) and surface roughness (Ra). The analysis of variance (ANOVA) is used to analyze the contribution percentages of the cutting parameters. According to the statistical analysis results, it was determined that cutting speed influences at maximum for cutting temperature and nanoparticles MWCNTs concentration influences at maximum for surface roughness compare to all other cutting parameters. From the observations, it is clear that percentage of added nanoparticles MWCNTs concentration directly influences cutting temperature (Ct) and surface roughness (Ra). The interactive plots reveal that MWCNT nano-fluid improves the results in terms of surface quality. Also the optimal results confirm that 2% of MWCNTs concentration reduces the cutting temperature and improves the surface finish.

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Keywords: Ti-6Al-4V, MWCNT, RSM, Ct, Ra, ANOVA etc.

1. Introduction

Titanium and their alloys have more number of enormous properties including temperature resistance, light weight, high strength to weight ratio and corrosion resistance. Due to titanium's better biochemical and electrochemical properties, it is a trendy material for marine, medical industries and aerospace(Y. Houchuan et al 2015, S. L. M Ribeiro Filho et al 2019 and R. S .Revuru et al 2018). Ti-6Al-4V is the most broadly used titanium alloy especially in the aerospace industry. Although, Ti-6Al-4V machining is very difficult due to heat resistance, inherent chemical properties and springiness and also processing time is high and manufacturing costs are very expensive while using conventional methods to machine it (K. H. Hashmi et al 2016 and). Due to its special and enormous properties compare to other materials, titanium alloys are broadly used in several industrial applications like automotive, aerospace and medical (S. Pervaiz et al 2019).

Ti-6Al-4V is an alloy ($\alpha + \beta$) which is the most widely used titanium alloy, with α phase stabilizing 6% aluminum and β phase stabilizing 4% vanadium. In room temperature, Ti-6Al-4V microstructure primarily consists of α phase with a minimal retained β phase (J. Li et al 2015). It is therefore suitable for use in a variety of applications and conditions. It was noted that inducing of reduced tool yield strength by high machining temperature in combination with continuous tool surface effect the pressure can guide to increase the tool wear (Gupta, M.K et al 2016). Processing parameter consequences on surface topography and machining performance has been the concentrated and the purpose of research to predict the tool failure and extends the tool life within

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a basic method (M. Miranda et al 2018). In conventional machining operation, cutting parameters like feed, depth of cut, and speed are plays a major role (Z. Ren et al 2019). The productivity is also largely dependent on the cutting parameter values. Cutting speed is the most important variable among the cutting parameters (N. E .Karkalos et al 2016 and D. Yang et al 2015). Due to heat production in the machining zone during dry machining, the cutting velocity value is maintained at certain limit and this heat also affecting the sharpness and hardness of the cutting tools and before time breakage (J. Ren et al 2018). So, to reduce the production of temperature during dry machining the suitable coolant is necessary to introduce in the machining zone (T. Singh et al 2018). Coolant's primary function is to cool and lubricate the cutting tool-workpiece interaction and wash off the chips from the machining area (R. S. Revuru et al 2018 and Eltaggaz et al 2018). With an excellent combination of an attractive cost and mechanical properties, it is no wonder that such nano additives have a broad range of applications. Nano additive's enormous properties are stiffness, hardness, high strength, excellent thermal conductivity and wear resistance. So, introducing of nano-cutting fluids helps to defeat the challenging the dissipation of heat during cutting processes as it provide a highly observed thermal conductivity value relative to the base lubricants (V. K. Pasam et al 2018).

In addition, because of its excellent heat removal capabilities, that nano cutting fluids have excellent cooling properties. As per some previous presented studies, nano cutting fluids have shown positive feedback on the characteristics of cutting performances through various cutting operations like grinding, turning and milling (H. Hegab et al 2018 and K Sharmaet al 2017). Particularly when machining the materials are tough to cut to develop the MQL's (Minimum quantity of lubrication) efficiency, that MQL nano cutting fluid is one of the recommended techniques. As per previous studies, the highly significant factor in enhancing the functions of cooling (K. Sharma et al 2016) and lubricant in the MQL method is the use of some cutting fluids, like as nano-fluid, which would improve its aspects of wettability, conduction and convection. From the open literature it is found that MWCNTs (Multi-Walled Carbon Nanotube) obtained positive results in the conventional cutting fluid as a nano-additive; nevertheless only few studies have studied its effects on various machining operations (H. Hegab at al 2018). There is a research gap from the literature review in investigating the effects of nanofluid technology by cutting titanium alloys. To provide better surface performance, it is important to choose the optimum machining parameters. In addition, to apply the most important factors for processing parameters, a systematic approach should be used. Therefore, to reduce the number of experiments, advanced design of experiment (DOE) method is needed (K. H. Hashmi et al 2016). To reduce the number of repetitions that powerful DOE method has been introduced. For engineering applications, Box – Bohen (BBD), Taguchi and central composite design (CCD) have been commonly used. These methods are suitable for providing a cost-effective experimental design. Metaheuristic algorithms like simulated annealing (SA), particle swarm optimization (PSO) and genetic algorithm (GA) have been used to various engineering and machining problem in the recent years (J. Li et al 2015 and N. E .Karkalos). In addition, to optimize the machining parameters that design of experimental (DOE) with metaheuristic algorithms has become popular method

2. Proposed methodology

It can be concluded from the available literature that Ti-6Al-4V machining is a significant challenge due to poor surface quality and high temperatures. To cool the machining area that cutting fluids are conventionally applied with high pressure in flood condition. Though, due to atmosphere affair that cutting fluid utilization is limited. Cutting fluids with micro-nano particles is an excellent alternative with the recorded benefits compared to traditional flood lubrication. Though, in the machining of titanium alloys, there is a small amount of work to be done to formulate and testing of supportable cutting fluids.This study examines the machining efficiency of milling titanium alloys under MWCNT's nano-fluid lubricating conditions and then further determines the optimum cutting parameters (Cutting speed, cutting feed, axial depth of cut and concentration of multiwall carbon nanotubes (MWCNT's) nano-fluid. In this work numbers of various cutting conditions were considered. RSM design of experiments was selected to decrease the replications of experiments. Desirability function analysis is adopted to solve multi objective optimization problems. The Fig.1 shows the flowchart of research work carried out.

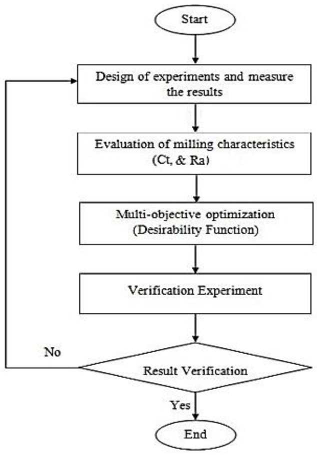


Fig. 1.Research flowchart.

3. Experimentation

3.1. Materials and methods

3.1.1.Preparation of MWCNT-diffused cutting fluid

The diffused multi-wall nano carbon tube (MWCNT) cutting fluid is prepared from mixture of base oil, deionized water and MWCNTadditive.In this research work, MWCNT is utilized size less than 100 nm nanotubes. Fig.2 has illustrated the few nanotubes of MWCNT structure. Industrial cutting fluid 'S' servo cut oil was selected as the base oil for the MWCNT-dispersed cutting fluids.The base fluid is prepared with mixture of base oil and deionized water (Metalworking Fluid Standards). The diffused MWCNT cutting fluids are prepared using a two-step process, i.e. nanoparticles preparation and cutting fluids diffused by nanoparticles are not performed simultaneously. Initially, the MWCNT-diffused cutting fluids were stirred utilized by a magnetic stirrer (for 30 min.) and then diffused using an ultrasonic dispersion instrument (40 kHz, 80 W) (for 1 hour) during the diffusion process. This process of diffusion was repeated multiple times until the 'S' servo cut oil diffused with MWCNT nanoparticles uniformly. During the whole experiment process there is no agglomeration was observed and the MWCNT -diffused cutting fluids were stable. The Energy-dispersive X-ray spectroscopy (EDS) for MWCNT shown in Fig.3. The EDS figure shows the presence of carbon element which confirms the pure form of MWCNT at energy level of 20 cps/eV. For machining lubrication, three samples of cutting fluids were prepared. The samples of cutting fluids preparation are given in Table 1 (for 100 ml MWCNT -diffused cutting fluids). The scanning electron microscopy (SEM) analysis of different samples of cutting fluids (Normal cutting fluid, 1 wt% of MWNCT diffused with cutting fluid and 2 wt% of MWNCT diffused with cutting fluid) is shown in Fig.4(a-c)

Table 1.Samples of cutting fluids preparation.

Sl.no	Sample-1	Sample-2	Sample-3
1.	95 ml of deionized water + 5 ml of 'S' servo cut oil	95 ml of deionized water + 5 ml of 'S' servo cut oil + l wt% of MWCNT	95 ml of deionized water + 5 ml of 'S' servo cut oil + 2 wt% of MWCNT

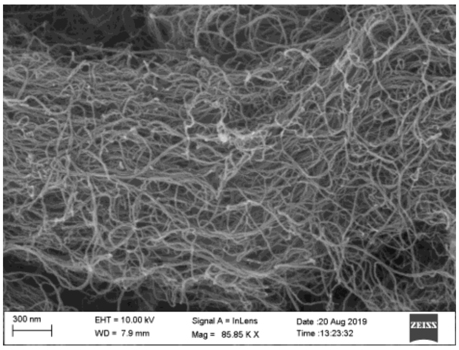


Fig. 2.Nanotubes of MWCNT structure.

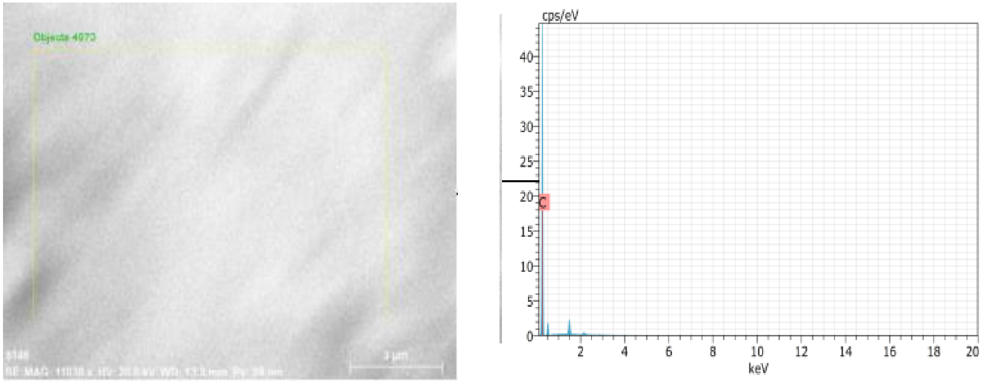
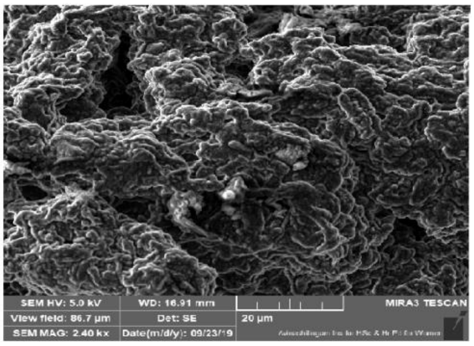
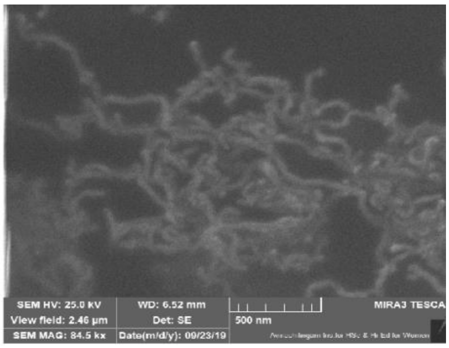
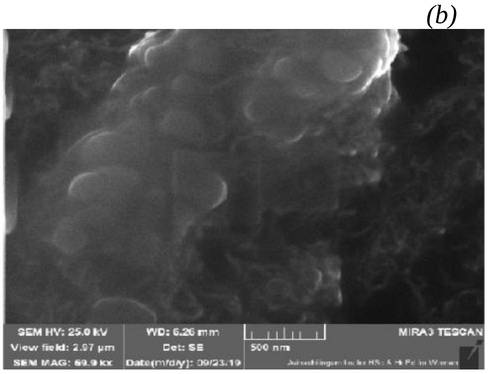


Fig. 3.Energy-dispersive X-ray spectroscopy for MWCNT.





a) *(b)*



(c)

Fig. 4. Different samples of cutting fluids a) Normal cutting fluid b) 1 wt% of MWNCT diffused with cutting fluid c) 2 wt% of MWNCT diffused with cutting fluid.

4. Experimental setup and procedure

Ti-6Al-4V alloy was chosen as the workpiece in this research due to its enormous mechanical properties.Ti-6Al-4V alloy is used in the biomedical industry and is gaining increased interest in medical field. In this study, experiments were performed based on DoE of response surface methodology (RSM). The DoE was developed using design expert software version.11. The DoE design was generated based on face centered central composite design. Face centered design is simple and easy to conform the experimentations due to the ranges of limits assigned will not exceed. The ranges of milling parameters and design of experiments are given in Table 2 and 3. Titanium alloy Ti6Al4V square pieces (length 50 mm, breadth 50 mm and 25 mm width) is selected to conduct slotting experiments using Haas VF- 3-Axis CNC vertical machining. Slotting operation was performed using power radius End Mill MSXH440R (MSXH440R) cutter. Surface roughness measurement device (SJ210) is used to measure the reading of roughness value on milled surface. Cutting temperature measurement device (K Type Thermocouple Temperature - TEL96-9001) is used to measure cutting temperature.

4.1. Measurement of cutting temperature and surface roughness

The machining performance and surface integrity of workpiece is remarkably affects by the parameter of milling temperature. The surface integrity can be enhanced in milling performances by lowering the cutting temperatures. Milling temperature measurement with different machining parameters under lubrication conditions was carried out using the temperature measurement method. The strategy of temperature measurement is illustrated in Fig.5. To measure the surface temperature, K-type thermocouple was inserted into below the workpiece about diameter of 5 mm hole. The peak temperature was noted during the milling operation is considered as cutting temperature for each experiments are given in Table 3. The roughness of machined surface is an important indicator to determine the characteristics of quality of machined surface, and a small surface roughness value is analytic of better workpiece service efficiency. Hence, desirable surface roughness value is smaller.

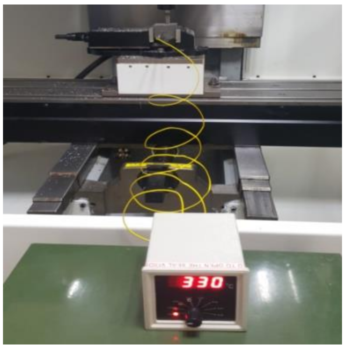


Fig.5.Cutting temperature measurement setup.

Table 2.Limits of machining parameters.

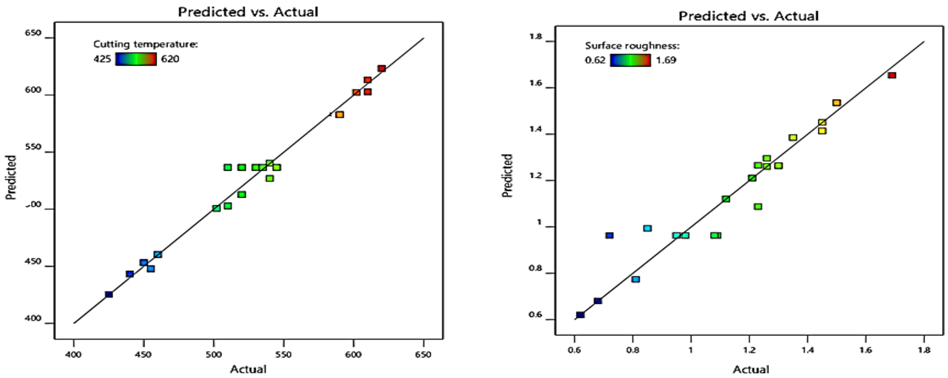
Machining Parameters	Units	-1	0	1
Cutting speed	m/min	80	120	160
Cutting feed	mm/rev	0.08	0.14	0.2
Axial depth of cut	mm	0.5	1	1.5
Nanoparticles MWCNTs concentration	wt%	0	1	2

Table 3.Experimental values.

Sl.no	Cutting speed (A)	Cutting feed (B)	Axial depth of cut (C)	Nanoparticles MWCNTs concentration (D)	Cutting temperature (Ct)	Surface roughness (Ra)
	m/min	mm/rev	mm	wt%	° C	µm
1	120	0.14	1	1	520	0.95
2	80	0.08	1.5	0	450	1.5
3	120	0.08	1	1	510	1.45
4	160	0.2	1.5	0	610	1.23
5	80	0.2	1.5	2	440	1.35
6	80	0.08	0.5	0	460	1.45
7	120	0.14	1.5	1	540	1.23
8	120	0.2	1	1	590	1.21
9	80	0.2	0.5	2	425	1.3
10	120	0.14	1	0	610	1.26
11	160	0.08	0.5	2	540	1.69
12	120	0.14	0.5	1	502	0.85
13	120	0.14	1	1	510	0.98
14	120	0.14	1	2	520	0.62
15	80	0.14	1	1	455	1.12
16	120	0.14	1	1	535	1.08
17	160	0.2	0.5	0	602	0.81
18	120	0.14	1	1	545	0.72
19	120	0.14	1	1	530	1.09
20	160	0.08	1.5	2	620	1.26
21	160	0.14	1	1	590	0.68

4.2. Statistical analysis

The analysis of variance (ANOVA) is used to analyze the contribution percentages of the cutting parameters. According to the F- statistical values, for cutting speed (33.75882), cutting feed (11.85495), axial depth of cut (6.357587) and concentration of MWCNT's (15.00392), it was determined that cutting speed influences at maximum for cutting temperature. The statistical analysis values observed for surface roughness is cutting speed (0.088231), cutting feed (0.309812), axial depth of cut (0.368851) and concentration of MWCNT's (0.025353). From the F-values, it was determined nanoparticles MWCNTs concentration influences at maximum for surface roughness compare to all other cutting parameters. The R^2 values for cutting temperature (97 %) and surface roughness (91 %) shows the good relationship between the experimental and predicted cutting conditions. The predicted versus experimental Fig.6(a-b) shows the minimum error occurrence of predicted analysis.



a) *(b)*

Fig.6. (a) Predicted Vs. Actual for Ct, (b) Predicted Vs. Actual for Ra.

4.3. Response surface methodology

A tool of Response surface methodology (RSM) is used to examine the effective parameters on a response. To determine the effective factor, RSM method is an efficient method. This method is a statistical based approach; it also examines the correlations between the effective variables which are not feasible in a traditional experimental design. Furthermore, few experimental studies are the benefits of this method of design. The use of visual methods, data analysis is implemented and examined all the level of combinations than conventional experimental design that is one-variable-at-a-time (OVAT). To enhance the mathematical models are another beneficial of this method of design. In this research, RSM based face central composite design (CCD) is utilized to determine the optimal conditions for the cutting speed, cutting feed, depth of cut and Nanoparticles MWCNTs concentration. The regression equation is developed from the experimental readings given in equations. The regression equations 1 and 2 are used to understand the relationship between the input and output data's as well used to predict the optimal parameters.

Cutting temperature:

$$-37.31509+5.29273*A+2137.27884*B+148.95106*C-212.54140*D-13.69792*A*B+0.518750*A*C+0.978125*A*D-195.83333*B*C-118.75000*B*D+24.25000*C*D-0.013268*A^2\ 1741.86129*B^2-90.91720*C^2+21.27070*D^2 \quad (1)$$

Surface roughness:

$$+1.04254+0.026879*A-11.92534*B-0.727725*C+0.178944*D-0.165104*A*B-0.000687*A*C+0.000781*A*D+3.54167*B*C-2.39583*B*D-0.212500*C*D-0.000039*A^2+102.11430*B^2+0.310446*C^2-0.022389*D^2 \quad (2)$$

5. Result analysis

5.1.Interactive effects on cutting temperature and surface roughness

The inappropriate selection of cutting conditions and cutting fluid causes the surface integrity which may result in poor surface finish. The nanoparticle structure plays a vital role to enhance the nanofluid efficiency. Nanofluids efficiency is enhanced by the synergic effect of MWCNT nanoparticles due to liquid tribo-film formation of nano-cutting fluid between the sliding surfaces; the coefficient of friction is decreased. Furthermore, wettability of nanofluids enhanced by the mixer of MWCNT -diffused cutting fluids.

Fig. 7(a) portrays the response surface 3D plot that relates to interaction plot integrates with cutting speed and cutting feed. From the interaction Fig.7(a), it has been noticed that if the cutting speed and cutting feed increases, the cutting temperature increases. The higher cutting temperature will lead to reduce the quality of machined surface. This is due to the major reason that the higher cutting speed and cutting feed increases the friction between the workpiece and tool. The higher friction leads to generate the higher cutting temperature. Fig.7(b), depth of cut interaction effects acts directly proportional to cutting speeds and feeds. The higher depth of cut increases the cutting temperature. This is due to the reason that higher depth of cut increases the amount of removal of material which causes to increase the shearing forces. The higher shearing forces will stressed up the interface between tool and workpiece leads to increase the cutting temperature. From Fig.7(c), it can be observed that increase of concentration of MWNCT which increases the cutting temperature. This is owing to the reason that titanium alloy has poor thermal conductivity due to reduced heat dissipation. The higher concentration of MWNCT leads to carry the cutting temperature through the cutting fluidsalso increases the thermal conductivity. Also it has been observed that the absence of MWNCT reduces the performance of cutting fluid because nanofluid's has property of higher wettability between the sliding surfaces and at the machining area. This could be beneficial in two ways; first, due to the nano-ball bearing effects of the nanoparticles, the coefficient of friction may have been decreased at the tool work piece interface during machining. In Fig.7(c) illustrated the remarkable reduction in the cutting temperature with use of nano sized MWCNT diffused cutting fluid and thus prove to be the better-quality lubricant over normal base fluids. In Fig.7(c) illustrates that the temperatures dropped significantly when nano cutting fluids were applied. This can be related to lubricating film creation at the interface, thus reducing cutting temperatures and friction. Lower temperatures have been reported while using nano fluids than in microfluids, because the layer between tool-work interfaces in nanofluids is more stable and stronger than in microfluids, In addition, nano-particles have better heat transfer properties than micro-particles attributable to their larger surface region. On comparison, reducing temperatures in nanofluids reduced normal cutting fluids respectively. The interaction effect analyses revealed that, nano-MWCNT nano-fluid has stronger cooling action than normal fluids; this might be related to nano-MWCNT fluid capability to accelerate the film formation at higher temperatures, resulting in increased fluid heat transfer efficiency.

It is also observed from the Fig.7(f), when normal cutting fluid used without diffusion of MWCNT, the roughness of surface values increased on Ti-6Al-4V alloy, it may be due to higher cutting temperature occurred due during the machining operation. It is clear from Fig.7(d) the interaction effects of cutting parameters have greater influence on surface roughness, lower cutting speed and cutting feed resulting in poor machined surface quality and higher tool wear rate, this is due higher feed rate would lead to overload of contact between the workpiece and tool, which would reduce the quality of surface finish. The Fig.7(e) shows the higher depth of cut increases the surface roughness, this may be owing to the reason the higher depth which causes to strain in removing the higher material thus increase in cutting forces. The capability of lubrication of the coolant, which is used with MWCNTmachining, compared to without diffusion of MWCNT and lower Ra value was measured in 2% of MWCNT diffused cutting fluids. Due to greater lubrication and great heat dispersion on the rake and flank face under MWCNT diffused cutting fluids; a minimum Ra value was recorded in Fig.7(f). Ti-6Al-4V alloy surface finish under 2% of MWCNT diffused cutting fluids milling is better than normal cutting fluids during machining process.

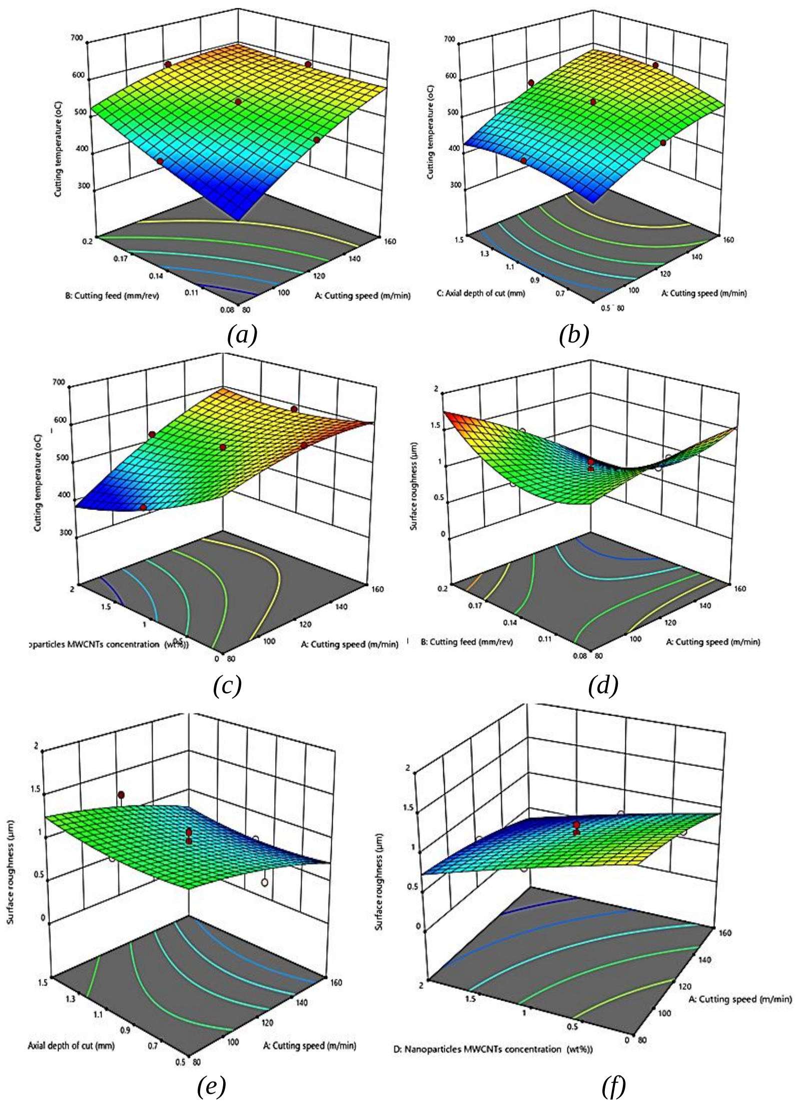


Fig.7.Interactive figure of machining parameters (a) A, B Vs. Ct, (b) A, C Vs. Ct, (c) A, D Vs. Ct, (d) A, B Vs. Ra, (e) A, C Vs. Ra, (f) A, D Vs. Ra.

5.2. Multi objective optimizationusing Desirability Function Analysis (DFA)

For Multi objective optimization, DFA is one of the most broadly used methods in engineering applications. According to this method, each expected response's determined performance characteristics are converted into a desirable dimensionless value. The function values are between 0 and 1. The value of d_i increases as the subsequent answer becomes more desirable. In this research, Smaller-the-better quality characteristic was chosen to transform the value of surface roughness. Hence, equation 3 is chosen. The value of target is denoted as T of the i^{th} response, y_i, Weight is denoted as W, upper limit of acceptable value is denoted as U, and lower limit of acceptable value is denoted as L, for this response.

$$d_i = \begin{cases} 1 & y_i < T \\ \left(\frac{U-y_i}{U-T}\right)^{\omega} & T \le y_i \le U \\ 0 & y_i > U \end{cases} \quad (3)$$

Minimum cutting temperature and least surface roughness will be effectively obtained in optimizing of milling parameters while machining of Ti-6Al-4V alloy. The gap of variation of the weights, cutting conditions and the significance accorded to each one when optimizing the minimum cutting temperature and least surface roughness. The conditions applied for desirability function analysis is shown in Table 4. The both Ct and Ra weight importance is given equal as 5. From the Fig.8, it has been analyzed that the optimum cutting conditions are attained A = 91.84 m/min, B = 0.13 mm/rev, C = 1.196 mm and D = 2 %. In the result, the responses were predicted with least 'Ct' value is equal to 424.998 °C and Ra = 0.713 µm at desirability value of D = 0.955. Further the predicted results were validated and found that the values predicted falls with less than 2.8 % for cutting temperature and 3.6 % for surface roughness.

Table 4.Conditions applied for desirability function analysis.

Milling parameters	**Goal**	**Lower**	**Upper**	**Lower**	**Upper**	**Importance**
A:Cutting speed	range	80	160	1	1	3
B:Cutting feed	range	0.08	0.2	1	1	3
C:Axial depth of cut	range	0.5	1.5	1	1	3
D:Nanoparticles MWCNTs	range	0	2	1	1	3
Cutting temperature	minimize	425	620	1	1	5
Surface roughness	minimize	0.62	1.69	1	1	5

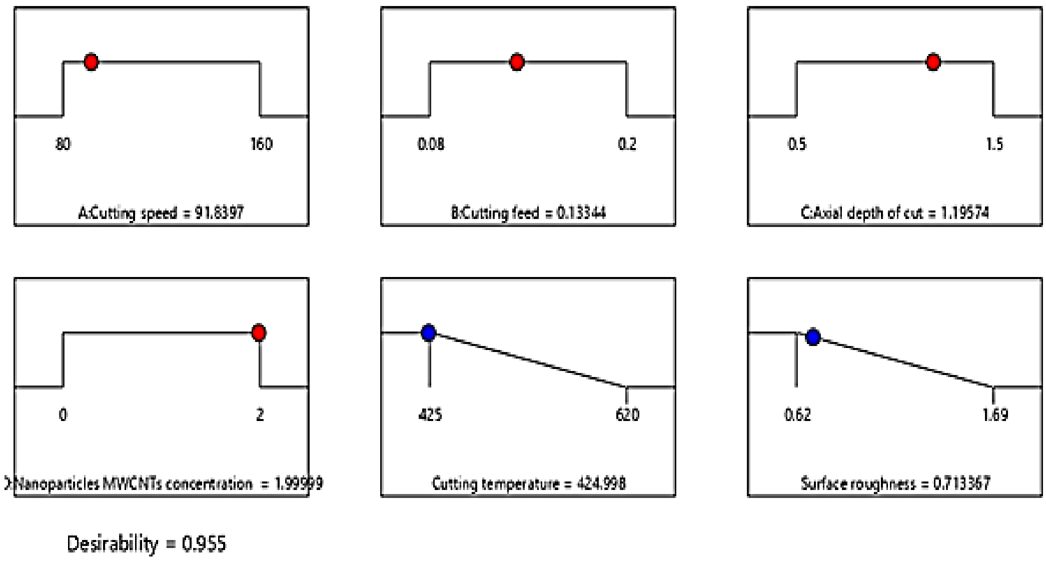


Fig.8.Ramp graph of optimized and predicted values.

6. Conclusions

During the Ti–6Al–4V machining process, multi wall carbon nano-tubes (MWCNT) nano-fluid was used to research their effect on cutting temperature and surface roughness reduction. The conclusions of the study were as follows:

The percentage of added multi wall carbon nano-tubes (MWCNT) nano-fluid has been shown to be a significant variable in design influencing both cutting temperature and surface roughness reduction using ANOVA. The R^2 values for cutting temperature (97 %) and surface roughness (91 %) shows the good relationship between the experimental and predicted cutting conditions.

Multi wall carbon nano-tubes (MWCNT) nano-fluid has been reported to give better results in terms of cutting temperature and surface roughness related to experiments conducted without nano-additives. The capability of lubrication of the coolant, which is used with MWCNT machining, compared to without diffusion of MWCNT and lower cutting temperature and surface roughness value was measured in 2% of MWCNT diffused cutting fluids.

Based on the range of design variables studied, two mathematical models were established to describe the researched cutting responses, and reasonable average accuracy was achieved for each proposed system. Multi objective optimization results shows the better machining performance with selection of optimum cutting conditions (A = 91.84 m/min, B = 0.13 mm/rev, C = 1.196 mm and D = 2 %).

Cutting temperature and surface roughness were predicted with least 'Ct' value is equal to 424.998 °C and Ra = 0.713 µm at desirability value of D = 0.955. Future research needs to focus on the nano-fluid size with various reinforcement soft particles and effects of nano-additive concentration.

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