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RESEARCH

Multi-Response Optimization of Parameters in Turning of DSS-2205 using Hybrid (Al_2O_3+CuO) Nano Cutting Fluid with MQL

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A B S T R A C T

Duplex stainless steel (DSS)-2205 offers high strength compared to normal steels; however, currently need for rapid production of high-quality parts in bulk quantities has led to high competitiveness. So characterizations of machining process parameters of DSS-2205 are essential. This paper focuses on finding the optimum turning parameters for cutting force(CF), cutting temperature(CT), and surface roughness(SR) in turning of DSS-2205 using hybrid(Al_2O_3+CuO) nano cutting fluid under minimum quantity lubrication technique. The experiments were conducted based on the face-centered composite design (CCF) in three levels of four factors, namely volume concentration of nanoparticles, Cutting speed, feed rate, and Depth of Cut (DOC). The analysis of variance (ANOVA) was used to inspect the most significant turning parameters on responses. The feed rate is the most influential parameter for cutting force & surface roughness and DOC for cutting temperature. Multi-response optimization was carried out under the desirability function approach (DFA). The optimum turning parameters for minimizing the responses are volume concentration of nanoparticles 0.3 %, speed 50 m/min, feed rate 0.051 mm/rev and DOC 0.4 mm.

1. INTRODUCTION

Turning is one of the essential machining processes in the manufacturing industry to remove material to get the final size and shape of the component. Nowadays, several new steel materials have developed; these materials have excellent mechanical properties but poor in machinability. Among these, one of the material duplex stainless steel-2205 includes a combined microstructure of austenite and ferrite with the same proportions allowing an aggregate of brilliant mechanical properties and excessive corrosion resistance [1].Currently, those steels are getting used in replacement of austenitic stainless steel in numerous industrial packages like piping, valves, heat exchangers, fittings, fasteners, vessels & construction materials. The machining of DSS-2205 is very poor and 10-20% slower than for other steel alloys due to high strain hardening, low thermal conductivity, heat concentration on the cutting edges and high toughness [1-3]. Hence, towards enhancing the machinability of these materials, selecting proper cutting parameters, lubrication fluids, tool selection, and fluid application is essential. Common methods of evaluating machinability in turning operations based on performance characteristics such as cutting force, cutting temperature, surface roughness, tool wear rate, a life of the tool, and material removal rate. In traditional turning, these performance traits are strongly correlated with cutting parameters such as cutting speed, feed rate, depth of cut, and cutting fluids [2]. The applications of cutting fluids in any machining operations to reduce friction among the tool and workpiece, temperature developed in the machining zone, and it acts as a lubricant and improves the surface finish of the components [4-5]. The selection of cutting fluid plays a vital role. Many factors to be considered during selection, such as the category of material, the form of tool, and the nature of the operation. Water primarily based cutting fluids are used in machining heat resistant and difficult-to-cut steel alloys because of the involvement of superior temperature in the turning zone. Sulphur additional oils are used in machining stainless steel, which produced stains over the machined surface [6-7]. Cutting fluids having more advantages and also extra drawbacks fluids have been initiate to cause health and social harms for workers related to lubricant use and correct disposal of fluids [7]. Therefore, several other technologies have been advanced in modern years to remedy of these problems. Sharma et al. [8] explored different cooling procedures they are flood cooling, cryogenic cooling, MQL(minimum quantity lubrication), excessive stress coolants, stable lubricants, compressed air coolants as far as controlling the temperature in the cutting zone. Dry machining and MQL machining have become the focal point of consideration for specialists and professionals in the field of machining. However, several researchers are working on MQL. The MQL is a method of cutting fluid broken into small debris with the compressed air known as an aerosol in the system. This aggregate of fluid and air is applied to the cutting region with excessive pressure in the form of the jet through a nozzle. The exhibition of the MQL method can be improved by the utilization of specific cutting liquids having excellent properties in which nanofluids gives a promising solution [8]. Nanofluids are nanoparticles suspended in base fluid with its particle size ranging between 1 to 100 nm. The addition of nanofluids coolant to the base fluid can increase and augment the base fluids thermal conductivity since the thermal conductivity of a metal is many orders of magnitude higher than the base fluid [9]. Enhancement of thermal conductivity was affected by a few factors such as temperature condition, the shape of nanoparticles, the size of nanoparticles, the type of nanoparticles, and the type of base fluids [10-11].Islam et al. [12] have reported thermal conductivity increases with increasing the concentration of nanoparticles. The nano-cutting fluids have a high thermal conductivity, heat transfer coefficient and withstand a very high temperature in the machining zone compare with those of base liquids. Nanofluids are incredible potential applications in numerous fields [13]. S. Khatai et al. [14] studied applications of Al_2O_3, CuO, Fe_2O_3, TiO_2 SiO_2 metal-oxide based nanofluids in turning and grinding operations, and given a suggestion for selection of nanoparticles based on their nature and properties. Soumikh et al. [15] a detailed review on the role of vegetable oil, mineral oil, synthetic oil and nanofluids in the enhancement of the machining aspects such as surface quality, machining temperature, tool wear and life of the cutting insert found that performance of nanoparticles-based machining fluid was superior as compared to conventional machining fluid under MQL technique. Ramanuj Kumar et al. [16] experimented on the hard turning of AISI D2 steel through Al_2O_3 water and TiO_2 water nanofluids. The TiO_2 nanofluids in spray impingement cooling hard machining can be very promising for a practical manufacturing concern. Min Yang et al. [17-18] studied the effect of friction coefficient on chip thickness in grinding of zirconia ceramics under dry, MQL using palm oil and MQL with MOS_2 nanofluid a developed predictive model for minimum chip thickness. Usha M et al. [19] experimented on Al_2O_3 nanofluid to find optimum parameters under the genetic algorithm and effect of speed, feed, DOC & MQL flow rate on responses. Teng G et al. [20] evaluation of Surface morphology with nanofluid MQL grinding, NMQL obtained a better result than flood cooling. Sakinah et al. [21] an attempt is made to enhance the tribological behaviour and thermal properties of lubricant by hybrid particles (CNC+CuO) into SAE40 oil, obtained very improved results for hybrid nanofluids. Akhtar et al. [22] analyze the thermal conductivity, viscosity, and stability of titanium dioxide (TiO_2)-multi-walled carbon nanotubes (MWCNTs) nanofluid. The thermal conductivity of nanofluid increases as increasing the concentration of nanoparticles and also shows enhancement results compared to the base fluid. Jamil et al. [23] used hybrid nanofluids (Al_2O_3 +MWCNT) to look at the performance traits of Ti–6Al–4V.The outcome has been compared with the cryogenic cooling technique. The improved results are obtained for tool life, cutting force, and surface roughness with nano MQL cutting conditions. Yanbin Zhang et al. [24] studied the effects of the MoS_2/CNT nanofluid on the force, coefficient of friction, and workpiece surface quality for Ni-based alloy are analyzed under MQL in grinding. The results show that more improvement in hybrid fluids. Zhang et al. [25] examine the execution of Al_2O_3-SiC enriched nanofluid through MQL grinding of Ni-based alloy opined that the Al_2O_3-SiC enhanced fluids yield better surface quality compared with lone nanoparticle. Rabesh Kumar et al. [26] conducted experiments using hybrid nanofluid (Alumina-Graphene) with different volume concentrations in turning 304 steel under MQL. The author reasoned that using hybrid nanofluid with MQL extensively reduces the surface roughness compared to alumina nanoparticles mixed with deionized water. Many researchers are proposing that nanofluids application through MQL better improvement in machining. Few researchers also recommend that choice and optimization of parameters are very critical in any machining technique; they are using various strategies to locate response optimization [19-22]. The vast majority of them took a shot at desirability function analysis (DFA). The DFA is one of the most generally utilized strategies in the industry for the optimization parameters [27-31]. Singh et al. [27] exploited Taguchi and Response surface methodology (RSM) of comparative study. The creators found that optimization by way of the DFA was very close to the optimal solutions furnished via the Taguchi method. Walid Azizi et al. [28] examines the impact of cutting parameters & material hardness on surface roughness and cutting force in finish turning of 52100 steel with a coated tool. The optimization of parameters was accomplished via DFA to reduce the responses. Aouici et al. [29] conducted an experiment on turning with CBN tool for roughness and force, respectively, in which the multi-objective optimization is carried out by using DFA. Zerti et al. [30] is conducted experiments to optimize parameters through DFA. Sathishkumar et al. [31] performed optimization responses under DFA.

It is evident from the above literature review the following literature gaps were identified:

1. Numerous beneficial works have been completed in the past in the region of nanoparticles enriched cutting fluid. As it may, restricted work was accounted for the utilization of hybrid nanofluids as a cutting fluid in turning operation [24-27].
2. DSS-2205 has doubled the strength of ordinary steel alloys very less literature available to study the machining effect and its tribological behaviour.
3. Constrained work was accounted for in the turning of duplex stainless steel-2205 under dry machining. Still, there is no turning work detailed with the utilization of hybrid nano cutting fluid under MQL technique and optimization of cutting parameters through desirability function analysis.

In the current work, the experimentation was conducted based on the central composite face-centered design (CCF) in turning of DSS-2205 under MQL with a PVD layered carbide tooltip. Hybrid nanofluids were prepared (50:50) proportions of aluminium oxide (Al_2O_3) and copper oxide (CuO) particle size of 30-50nm. The impact of volume concentration, speed, and feed, depth of cut on cutting force, cutting temperature, and surface roughness were examined through ANOVA. Finally, optimum parameters were obtained through the DF approach.

2. EXPERIMENTAL DETAILS

2.1 Material, Cutting tool, and holder

The material selection for turning is DSS-2205, having a wide variety of industrial applications but poor machinability. Table 1 shows the element composition DSS-2205. The size of the material for turning is 300mm length and 40 mm diameter. The Cutting tool used for experimentation was TNMG 160404 MS PR-1535 Kyocera makes carbide inserts having a physical vapour deposition multi-layer coating with Titanium+Aluminum+Nitride material. The holder was Kennametal makes MTJNR1616H16 used during turning operation.

Table 1. Element Composition of DSS-2205.

Element	% in wt
C	0.029
Si	0.283
Mn	1.63
Cr	22.1
Ni	4.5
Mo	2.9
P	0.030
S	0.020
Fe	68.508

2.2 Preparation of hybrid nano cutting fluid

The Hybrid nano cutting fluids are set up by utilizing two-step approaches. The aluminum oxide (Al_2O_3) and copper oxide (CuO) nanoparticles of size 30-50 nm are purchased from nano research lab Jamshedpur Jarkand. The required weight proportion was measured using the rule of mixture Formula 1. Figure 1 shows the preparation of nano cutting fluids.

$$\%volume\,concentration = \frac{WAl_2o_3}{\dfrac{WAl_2o_3}{\rho Al_2o_3} + \dfrac{Wbf}{\rho bf}} \quad (1)$$

The Initial step is to take the required amount of base fluid deionized water and blend the surfactant of sodium dedycyl benzene sulfonate (SDBS) and continuously stirring with the help of a magnetic stirrer around 20 min after that, add both nanoparticles continue the stirrer for another 20 min. The following step is to sonicate this mixture by utilizing an ultrasonicator of 20 kHz around 90 min for uniform dispersion of the nanoparticles alongside the base liquid. During nanofluid preparation, the stirrer is required to mix up the liquids every 30 minutes after sonication to stay away from the settling of nanoparticles into the bottom. Evaluated the thermal conductivity using KD2 pro thermal properties analyzer and dynamic viscosity from Brook field digital viscometer of the prepared nanofluids in Karunya University, Coimbatore values are given in below Table 2.

Fig. 1. Preparation of Hybrid nano cutting fluids.

Table 2. Conductivity and viscosity values.

Fluids	% of volume Conc.	Thermal conductivity (W/m-K)	Dynamic viscosity (cP)
DI water+ (Al_2O_3+CuO) nano fluid	0.3	0.662	1.6
	0.5	0.686	2.2
	0.7	0.725	2.6
DI water		0.601	1.2

2.3 Experimental conditions

Based on a face-centered composite (CCF) design for four factors and three levels, the 30 experiments are designed.

Table 3. Experimental factors and Levels.

Notations	Factors	Symbol (unit)	Level 1 (-1)	Level 2 (0)	Level 3 (1)
A	volume conc.	C (%)	0.3	0.5	0.7
B	Speed	V_C(m/min)	50	70	90
C	Feed	f (mm/rev)	0.051	0.128	0.205
D	DOC	d(mm)	0.4	0.8	1.2

This consists of 16 fractional factorial points, 8 axial/star points, and 6 center points. Table 3 shows the Levels of experiments and factors. Table 5 shows the order of the experiments and their response values.

2.4 Experimentation

The turning operation was carried out using MAGNUM-SSM 1430 precision variable lathe machine. Figure 2 shows the experimental setup with MQL and response measuring devices.

In every 40 mm length of turning, the output response CF, CT, and SR were measured. The cutting force is measured using lathe Kistler dynamometer, which is preset to the lathe post, and forces are measured using dynoware software. Temperature and Surface roughness was measured using a digital thermometer of K type and Taylor Hobson surtronic-S128. Each separate workpiece turned three times the average values were tabulated.

2.5 Supply parameters of MQL

The MQL system is purchased from KENCO Company from Hubli the supply parameters are given in Table 4.

Table 4. Supply parameters of MQL.

Company	KENCO
MQL Flow Rate	10ml/min
Air pressure	6 bar
MQL nozzle distance from contact zone	20mm
Angle of the nozzle from base	α=45°
Tank capacity	5liters

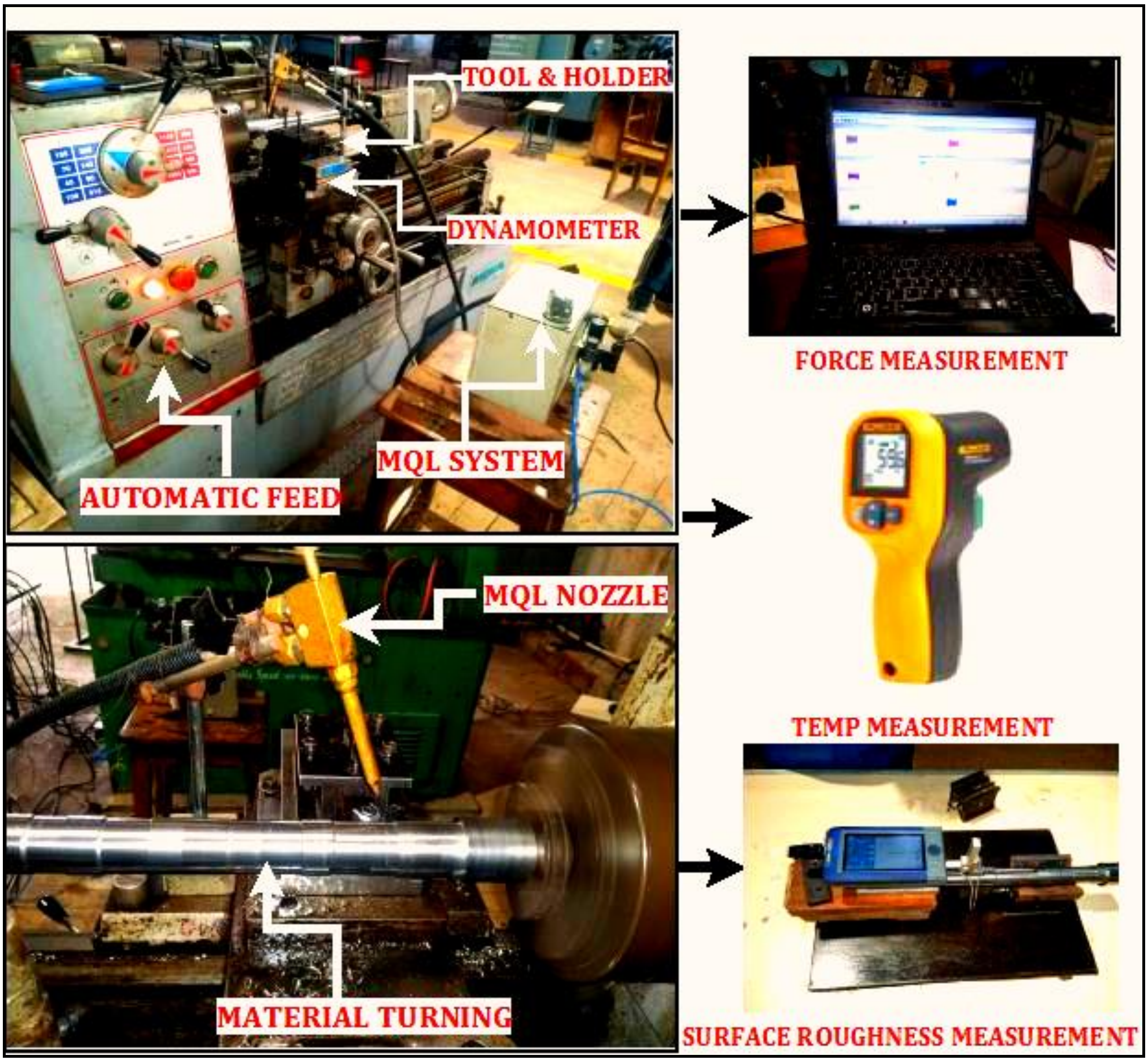


Fig. 2. Experimental setup with MQL system.

Table 5. Experimental order and Response values.

		Control variables				Response variables		
Ex No	Std order Run	Volume con. (%)	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Cutting force (N)	Temperature (^{0}C)	Surface roughness (μm)
1	28	0	0	0	0	270	68	1.93
2	15	-1	1	1	1	570	63	3.9
3	2	1	-1	-1	-1	45	31	1.33
4	14	1	-1	1	1	550	55	4.3
5	18	1	0	0	0	284	61	1.96
6	22	0	0	1	0	420	58	3.76
7	16	1	1	1	1	560	54	3.63
8	27	0	0	0	0	250	70	1.93
9	5	-1	-1	1	-1	235	38	3.33
10	24	0	0	0	1	438	76	2.13
11	20	0	1	0	0	288	64	1.9
12	11	-1	1	-1	1	174	85	1.23
13	4	1	1	-1	-1	81	34	1.03
14	9	-1	-1	-1	1	171	48	1.1
15	23	0	0	0	-1	158	62	1.98
16	3	-1	1	-1	-1	64	59	1.03
17	8	1	1	1	-1	230	37	4.1
18	26	0	0	0	0	278	78	1.7
19	21	0	0	-1	0	158	67	1.06
20	30	0	0	0	0	258	70	1.96
21	10	1	-1	-1	1	132	47	2.12
22	29	0	0	0	0	260	72	1.96
23	19	0	-1	0	0	255	44	1.9
24	7	-1	1	1	-1	185	42	4.13
25	17	-1	0	0	0	265	68	1.53
26	1	-1	-1	-1	-1	69	35	0.62
27	25	0	0	0	0	277	70	1.83
28	13	-1	-1	1	1	623	48	3.7
29	6	1	-1	1	-1	235	39	3.5
30	12	1	1	-1	1	192	64	1.33

3. RESULTS

3.1 Discussion

Figure 3 shows the cutting force (Fz) for an experimental run. It has been observed that maximum force obtained 623 N during low Conc. 0.3 % high feed 0.205 mm/rev, high DOC 1.2 mm, and low-speed 50 m/min. When increasing the Conc. of particles to 0.7 %, force is reducing to 550 N due to high concentration of nanoparticles leads to a high heat dissipation rate, which protects the cutting edge from the thermal softening effect, and also less friction and a decrease in the formation of built-up edges leads to decreases cutting force, but some inconsistent behavior is perhaps due to the interaction effect [33]. When high volume Concentration of particles superior lubricating performance obtained due to more particles deposited over the tool and a workpiece to produced rolling effect of nanoparticles instead of sliding friction rolling contact obtained in machining zone overall results cutting forces are reduced [34].

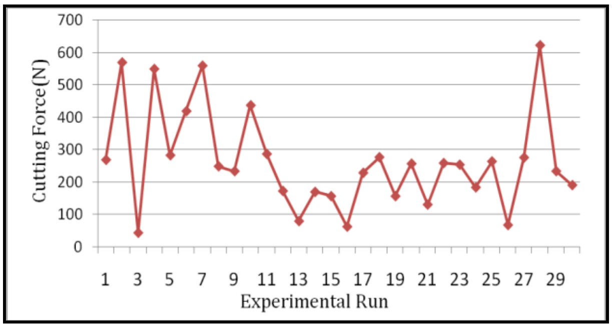


Fig. 3. Experimental run versus cutting force.

Figure 4 shows Cutting temperature for experimental run maximum temperature 85 ^{0}C is observed when high speed, high DOC & low Conc. of particles, but increasing in Conc. of particles temperature reduces to 64 ^{0}C. When increasing Conc.of nanoparticle temperature reduces the reason behind these nanoparticles having more thermal conductivity and high heat transfer coefficient to absorb the heat generated in the machining zone [35].

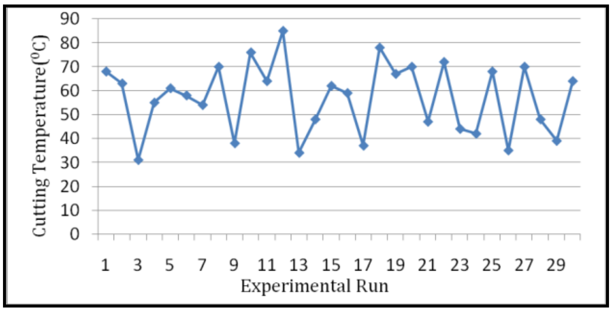


Fig. 4. Experimental run versus temperature.

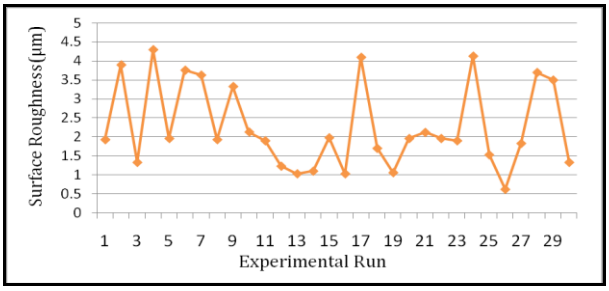


Fig. 5. Experimental run versus surface roughness.

Figure 5 shows the Surface roughness with an experimental run. It has been seen that the lower value of surface roughness obtained for lower Conc. of particles, low speed, low feed& DOC. When increasing the Conc. of nanoparticles in the base fluid increases, the collision, and impedance among the particles, the surface quality will reduce [34], but when we reduced the feed rate, surface roughness reduces; large concentration of nanoparticles exhibits the effect on the reduction of cutting forces but causes the negative effect on surface roughness.

3.2 Analysis of variance (ANOVA)

Anova is a powerful tool to understand the factors that influence the response. The significance level of 5 % and a confidence level 95 % are achieved in ANOVA. The significance of a given hypothesis test P-values under 0.0500 demonstrates model terms are significant [35-44]. Table 6, 8 and 10 is shown the ANOVA for force, temperature, and surface roughness. The developed models were significant. It is seen from the Table 7 C, D, AB, AD, BC, BD and B^2 are significant terms. The feed is the most significant factor for cutting force, followed by DOC and interaction factors Vol concentration*speed, Vol concentration*DOC, speed*feed and Speed*DOC. Table 9 A, B, C, D, AB, AC, BC, BD, B^2 and C^2 are critical model terms for cutting temperature. The DOC is the primarily affected parameter followed by speed, feed, and Volume Conc and affected by interaction and square factors. The Table 11 indicates A, C, D, AB, AC, BC, BD, CD, C^2 and D^2 are the significant terms. The feed is the most significant factor contribution for surface roughness followed by volume concentration, particles, DOC and speed.

Table 6. ANOVA for cutting force.

Model	Sum of squares	df	Mean square	F	Sig.
Regression	672155.94	7	96022.27	331.4	0.00
Residual	6374.222	22	289.737		
Total	678530.16	29			

Table 7. Estimated coefficients for cutting force.

variable	Parameter Estimate	Standard Error	t	Sig.
Constant	276.33	4.914	56.237	0.000
C	140.11	4.012	34.923	0.000
D	117.11	4.012	29.190	0.000
AB	12.875	4.255	3.026	0.006
AD	-8.875	4.255	-2.086	0.049
BC	-12.000	4.255	-2.820	0.010
BD	63.000	4.255	14.805	0.000
B^2	-17.500	6.344	-2.759	0.011

Table 8. ANOVA for cutting temperature.

Model	Sum of squares	df	Mean square	F	Sig.
Regression	6013.67	10	601.36	42.47	.000
Residual	269.026	19	14.159		
Total	6282.70	29			

Table 9. Estimated coefficients for temperature.

variable	Parameter Estimate	Standard Error	t	Sig.
Constant	69.355	1.138	60.966	0.000
A	-3.556	.887	-4.009	0.001
B	6.500	.887	7.329	0.000
C	-2.000	.887	-2.255	0.036
D	9.056	.887	10.210	0.000
AB	-3.938	.941	-4.186	0.001
AC	2.813	.941	2.990	0.008
BC	-4.063	.941	-4.319	0.000
BD	2.438	.941	2.591	0.018
B^2	-14.629	2.027	-7.215	0.000
C^2	-6.129	2.027	-3.023	0.007

Table 10. ANOVA for Surface Roughness.

Model	Sum of squares	df	Mean square	F	Sig.
Regression	35.436	10	3.544	222.95	0.00
Residual	0.302	19	0.016		
Total	35.738	29			

Table 11. Estimated coefficients for roughness.

variable	Parameter Estimate	Standard Error	t	Sig.
Constant	1.867	0.038	48.989	0.000
A	0.153	0.030	5.160	0.000
C	1.304	0.030	43.880	0.000
D	0.134	0.030	4.524	0.000
AB	-.171	0.032	-5.414	0.000
AC	-.083	0.032	-2.637	0.016
BC	0.094	0.032	2.994	0.007
BD	-.167	0.032	-5.295	0.000
CD	-.079	0.032	-2.518	0.021
C^2	0.507	0.068	7.465	0.000
D^2	0.152	0.068	2.239	0.037

Table 12 indicates the value of R^2 is near to 1 shows that the model is significant. Predicted R^2 is in reasonable agreement with the adjusted R^2. The distinction is less than 0.2 Adeq Precision measures the signal to noise ratio. A ratio of more than 4 is appropriate. Adeq Precision suggests good enough for all three models.

Table 12. Model summary.

Response	R^2	Adjusted R^2	Predicted R^2	Adeq Precision
CF	0.991	0.988	0.9661	41.61
CT	0.957	0.935	0.8635	20.71
SR	0.992	0.987	0.9571	41.31

3.3 Regression equations

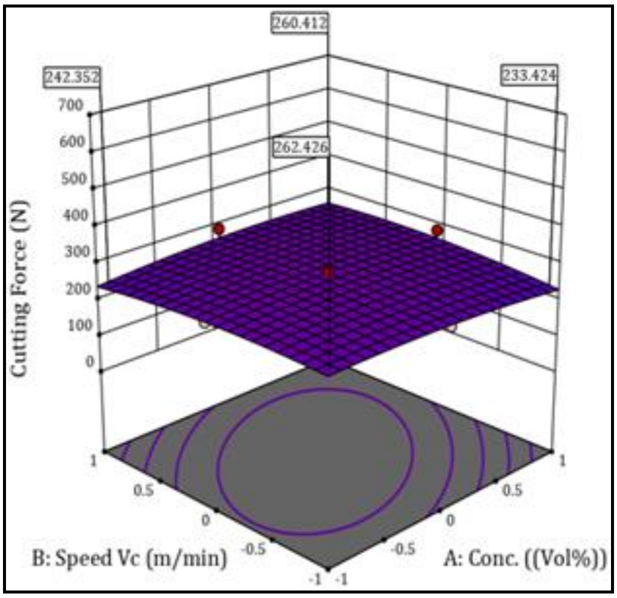
$$\textbf{CF}=276.3+140.1*f+117.1*d+12.8*C*V_C-8.87*V_C*d-12*V_C*C+63*V_C*d-17.5V_C^2 \quad (2)$$

$$\textbf{CT}=69.35-3.55*C+6.50*V_C-2.00*f+9.05*d-3.93*C*V_C+2.81*C*f-4.06*V_C*f+2.43*V_C*d-14.6*V_C^2-6.12*f^2 \quad (3)$$

$$\textbf{SR}=1.86+0.153*C+1.304*f+0.134*d-.171*C*V_C-0.083*C*f+0.094*V_C*C-0.167*V_C*d-0.079*f*d+0.507*f^2+0.152*d^2 \quad (4)$$

3.4 Influence of parameters on cutting force

Figure 6 (a to f) indicates the three dimensional surface plots for cutting force feed is the maximum influential factor followed by DOC, Conc. of nano particles and speed.



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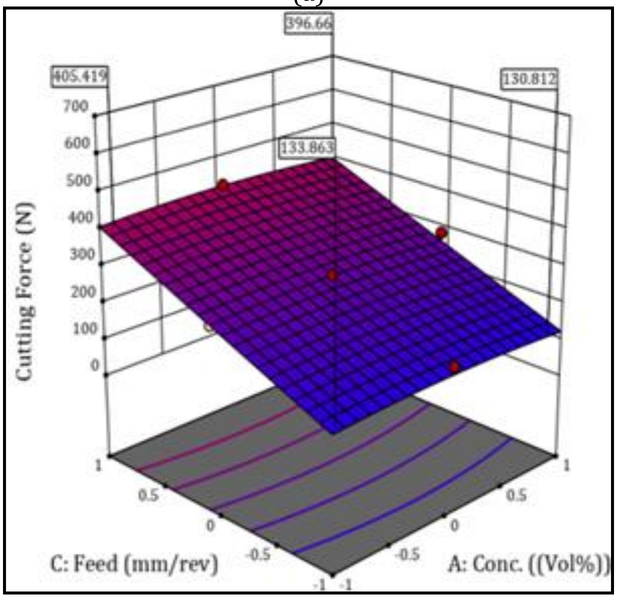

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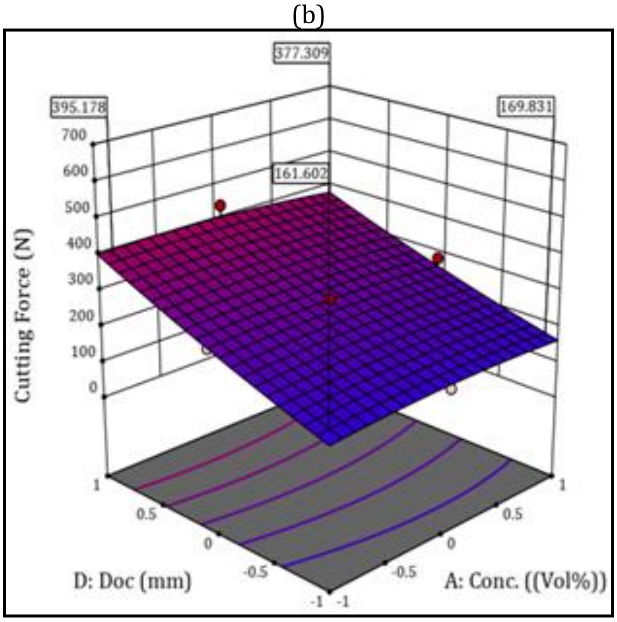

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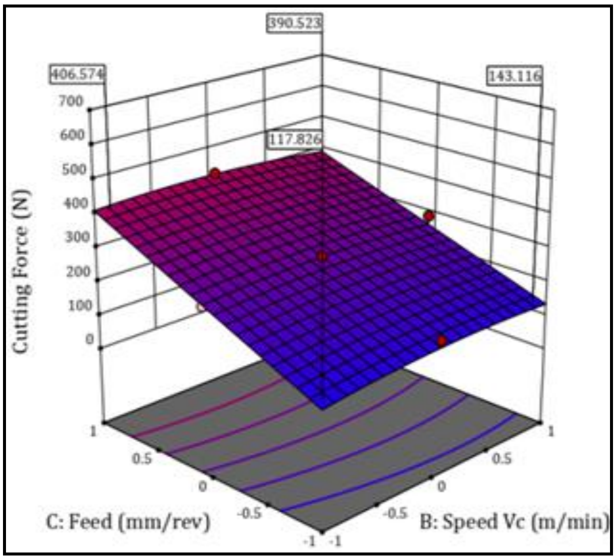

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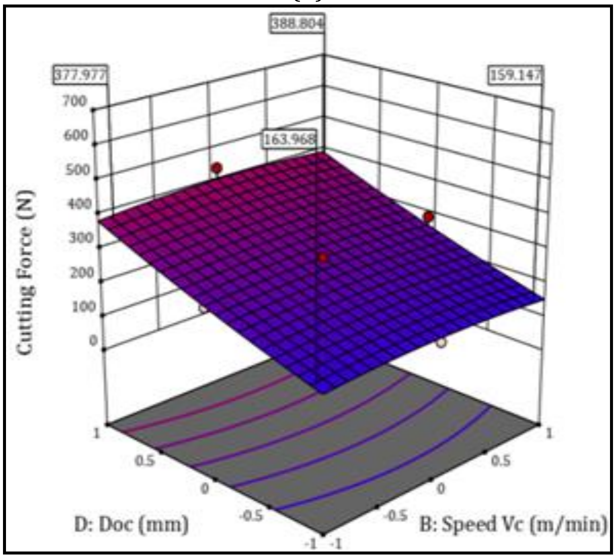

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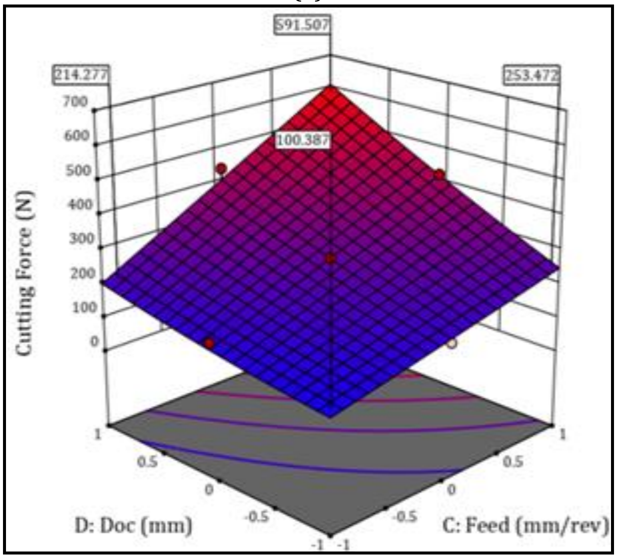


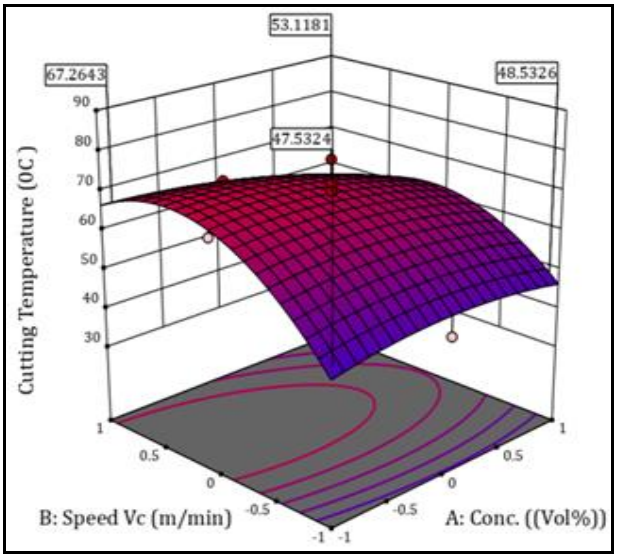
(f)

Fig. 6. Three-dimensional response surface graphs for cutting force.

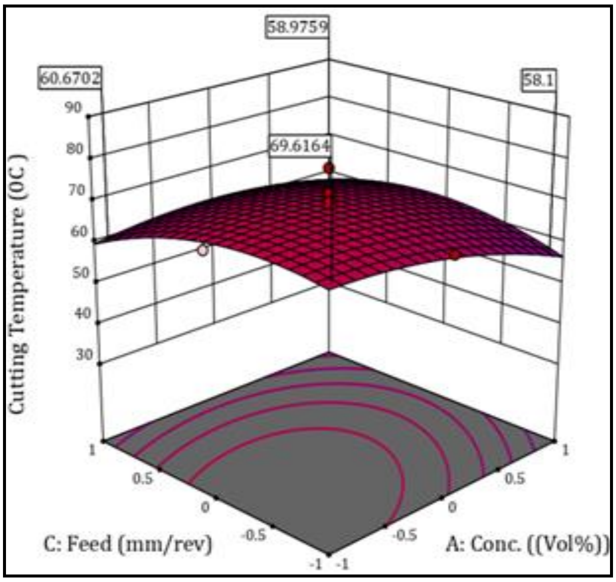
When raising the feed, cutting forces are increases simultaneously increases the Conc. of nanoparticles with high feed rate forces are decreases, as shown in Figure6b. The feed and DOC are influential factors at a minor level of these factors forces are reduced, as shown in Figure6f. When increasing the Conc. of particles, forces are reduced, but some inconsistent behavior is perhaps due to the existence of interaction effect [45]. When particle concentration increases, better lubricating performance is obtained due to the rolling effect of nanoparticles instead of sliding friction rolling contact obtained in the machining zone. [46] Another possibility is higher cutting speed also influences to reduce the chip thickness, but more shearing action leads to increases cutting force.

3.5 Influence of parameters on cutting temperature

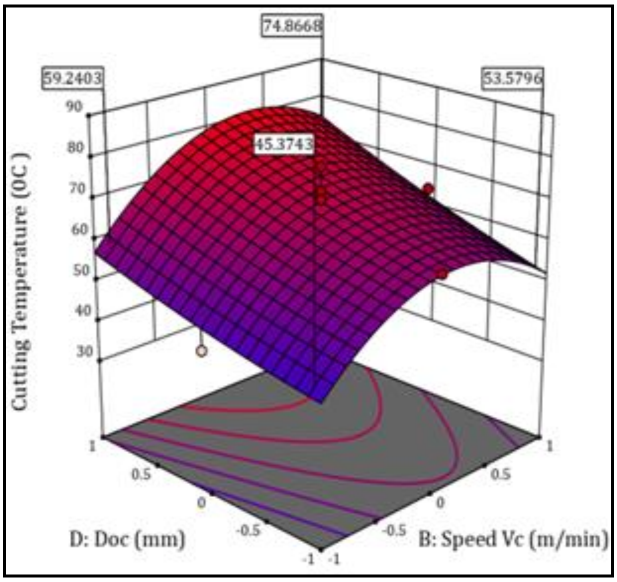
Figure 7 (a to f) shows the three-dimensional surface plots for cutting temperature DOC is the major influential factor, followed by speed, the concentration of nanoparticles, and feed. When raising the DOC temperature increases at the same time nanoparticles Conc. increases, the temperature reduces, as shown in Fig. 7c. When increasing in the DOC, additional contact among tooltip and work leads to the formation of a higher thickness of chips owing to this friction among the tooltip and work are increases, causes the temperature to increase.



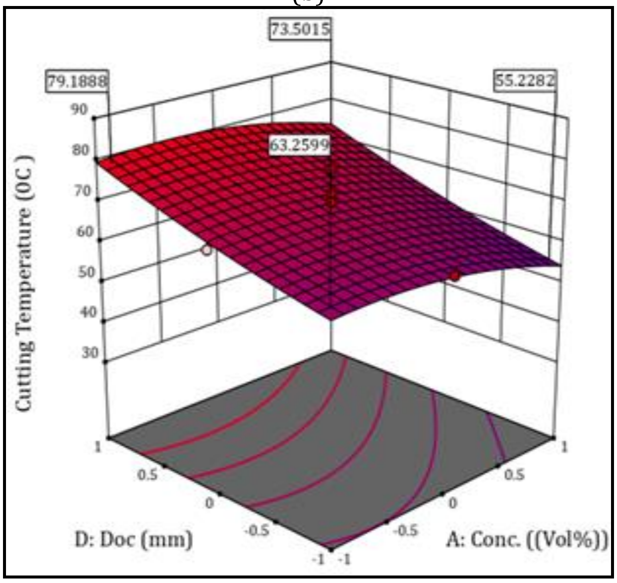
(a)



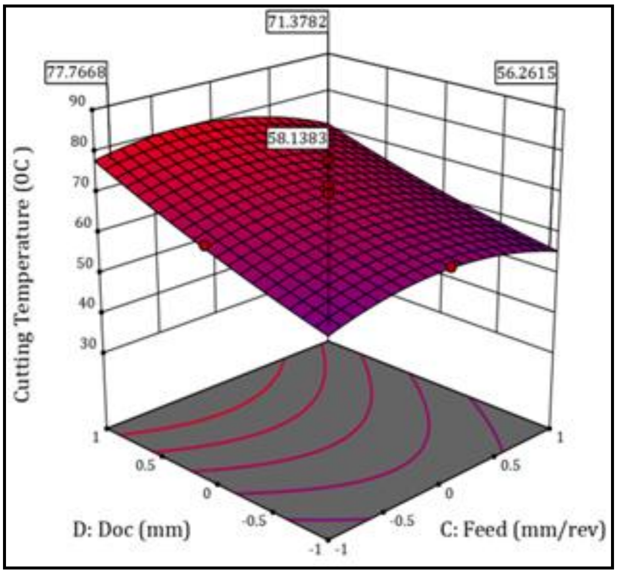
(b)



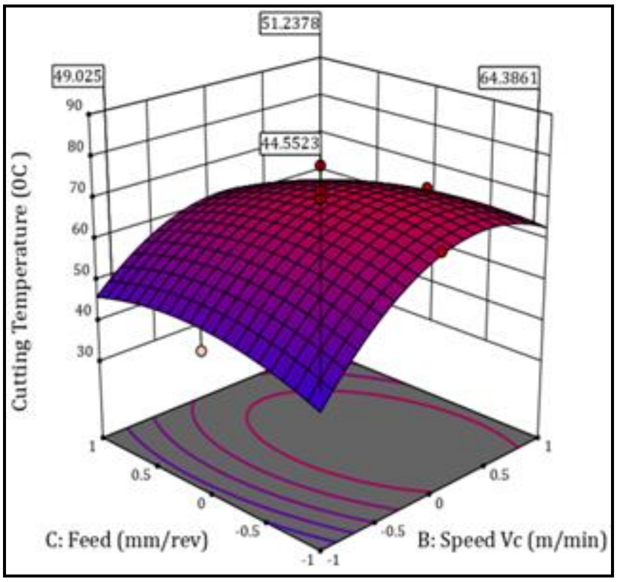
(e)



(c)



(f)



(d)

Fig. 7. Three dimensional response surface graphs for Cutting temperature.

While increasing the concentration of nanoparticles, form a thin film layer over the workpiece and tool, reducing the temperature since the nanofluids have high thermal conductivity and heat carrying capacity from the cutting zone.

3.6 Influence of parameters on surface Roughness

Figure 8 (a to f) indicates the three-dimensional surface plots for surface roughness feed is the maximum influential concern observed with the aid of concentration of nanoparticles, DOC, and speed. It has been noted that feed increases the roughness also increases.

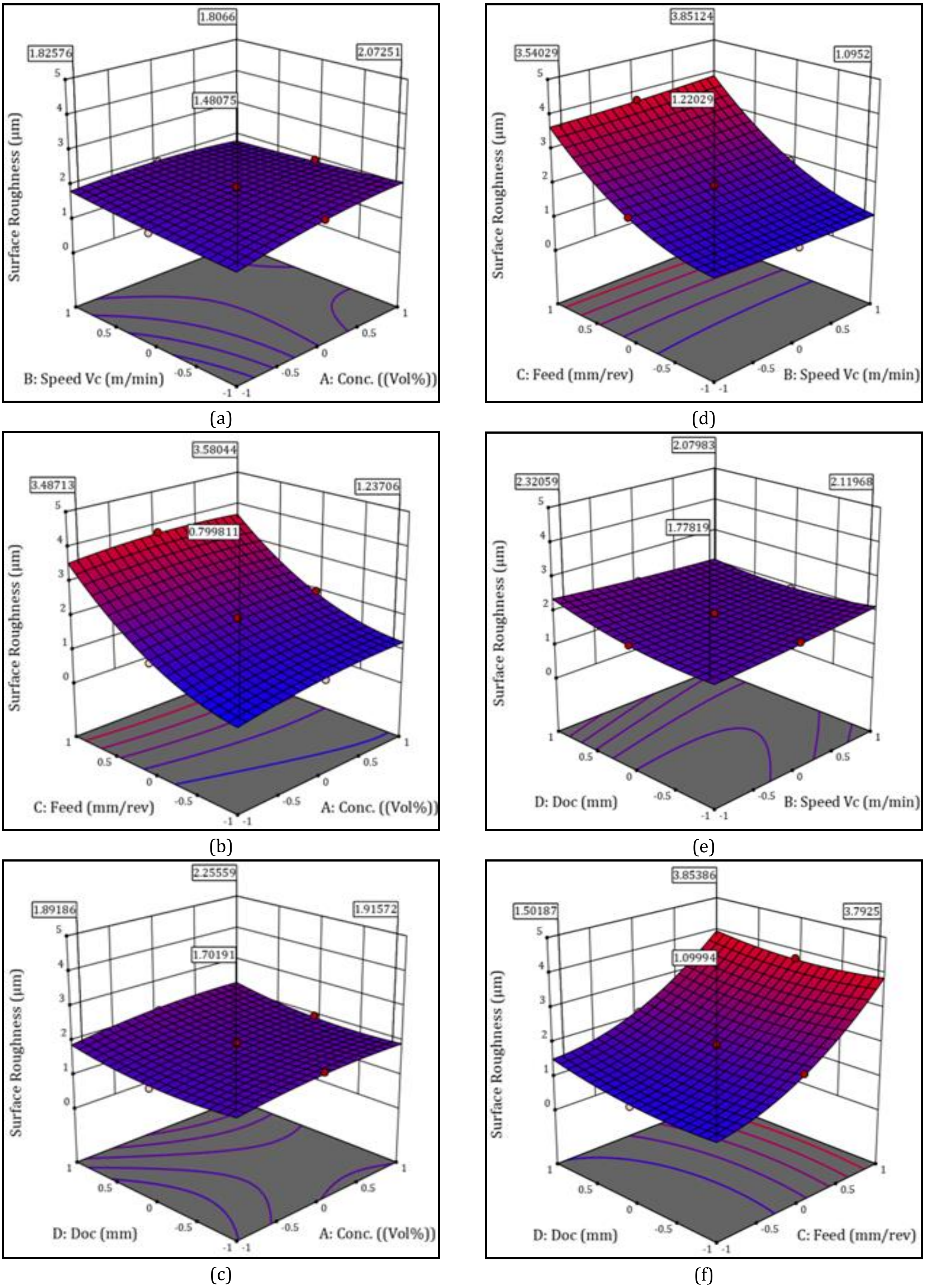


Fig. 8. Three-dimensional response surface graphs for Surface Roughness.

When feed increases, the tool carriage will move faster than usual, and extra friction between the tool and workpiece leads to a rough surface on the work. When increasing the attention of nanoparticles reduce the roughness as shown in Fig. 8b. The nanofluid is deposited like a thin layer on the surface, which reduces the rubbing action of a tooltip with work, temperature, and friction in the turning zone. This will leads to the formation of the fine surface end. In the Fig. 8f shows that low-level depth of cut and feed roughness reduces, and increasing depth of cut roughness will increase. High depth of cut results in the formation of high temperature and heat-affected region poor finish of the workpiece.

3.7 Desirability function approach (DFA)

The DFA is one of the maximum widely used techniques in the industry for response optimization. It is based on the idea that the quality of a process that has more than one quality characteristics. Derringer and suchi [45] proposed a helpful class of DFA. There are three forms of the desirability functions according to response characteristics larger-the better, nominal-the better & smaller-the better [37].

The goal is to maximize response (larger-the better) the individual desirability is defined as:

$$d_i(Y_i) = 0 \ if \ Y_i(x) \le L_i$$
$$d_i(Y_i) = \left[\frac{Y_i(x) - L_i}{U_i - L_i}\right] if \ L_i \le Y_i(x) \le U_i \quad (5)$$
$$d_i(Y_i) = 1 if \ Y_i(x) \ge \mathrm{U}_i$$

The Y_i exceed a particular criteria value, which can be viewed as the requirement the desirability value equals to 1, if the Y_i is less than a particular criteria value, which is unacceptable, the desirability value equals to 0.

The goal is to target response (nominal-the better) the individual desirability is defined as:

$$d_i(Y_i) = 0 \ if \ Y_i(x) \prec L_i$$
$$d_i(Y_i) = \left[\frac{Y_i(x) - L_i}{T_i - L_i}\right] if \ L_i \le Y_i(x) \le T_i \quad (6)$$
$$d_i(Y_i) = \left[\frac{Y_i(x) - U_i}{T_i - U_i}\right] if \ T_i \le Y_i(x) \le U_i$$

The value of Y_i is required to achieve a particular target T. When the Y_i equals to T, the desirability value equals to 1 if the Y_i excesses a particular range from the target, the desirability value equals to 0.

The goal is to minimize response (smaller-the better) the individual desirability is defined as

$$d_i(Y_i) = 1 \ if \ Y_i(x) \le L_i$$
$$d_i(Y_i) = \left[\frac{U_i - Y_i(x)_i}{U_i - L_i}\right] if \ L_i \le Y_i(x) \le U_i \quad (7)$$
$$d_i(Y_i) = 0 \quad if \ Y_i(x) \ge U_i$$

When, the Y_i is less than a particular criteria value, the desirability value equals to 1 if the Y_i exceeds a particular criteria value, the desirability value equals to 0.

Where U_i= maximum obtained response
L_i= minimum obtained response
$Y_i(x)_i$= current run order response

The overall desirability value:

$$D = (d_1(Y_1)\, d_2(Y_2) ... d_k(Y_k))^{(1/k)} \quad (8)$$

Where K=number of responses

3.8 Multi-response optimization

In the current work, numerical multi-response optimization was carried out underneath the DF approach using Design expert-12 software. In the numerical optimization phase, we requested design expert software to minimize (smaller-the-better) of Force (CF), Temperature (CT), &Roughness (SR) to find out the optimum parameters in turning of DSS-2205. For this study, all the variables were set in range by keeping force, temperature, and roughness value at a minimum. Table 13 indicates the constraints for turning parameters, and Table 14 indicates the optimal solutions are reported in order of decreasing desirability value.

Table 13. Constraints for optimization of parameters.

Name	Goal	Low Limit	High Limit	Importance
Vol Conc.	Is in range	0.3	0.7	3
Speed	Is in range	50	90	3
Feed	Is in range	0.051	0.205	3
Doc	Is in range	0.4	1.2	3
CF	minimize	45	623	3
CT	minimize	31	85	3
SR	minimize	0.62	4.3	3

Table 14. Optimal solutions.

No	Conc.-C (Vol %)	Speed-Vc (m/min)	Feed- f (mm/rev)	DOC- d (mm)	Cutting Force (N)	Cutting Temperature (°C)	Surface Roughness (μm)	Desirability	
1	0.3	50	0.051	0.4	59.543	34.965	0.541	0.967	Selected
2	0.301	50	0.051	0.4	59.722	34.996	0.547	0.966	
3	0.3	50	0.051	0.41	60.706	35.110	0.541	0.965	
4	0.3	50	0.051	0.418	61.407	35.195	0.540	0.964	
5	0.3	50.08	0.051	0.422	61.869	35.394	0.541	0.963	
6	0.3	50.04	0.051	0.428	62.481	35.413	0.540	0.962	
7	0.313	50	0.051	0.426	63.461	35.516	0.580	0.961	
8	0.3	50	0.051	0.455	66.153	35.772	0.543	0.958	
9	0.349	50.02	0.051	0.400	63.887	35.694	0.683	0.954	
10	0.3	50.04	0.051	0.501	70.340	36.354	0.544	0.951	

Table 15. Confirmation experiment results.

CUTTING FORCE (N)				
Exp no	Predicted values	Actual values	Error	% Error
1	59.54	64.15	4.61	7.18
2	59.72	65.33	5.61	8.59
3	60.70	62.56	1.86	2.97
4	61.40	63.55	2.15	3.38
5	61.86	65.81	3.95	6.00
CUTTING TEMPERATURE (°C)				
1	34.96	36.51	1.55	4.25
2	34.99	37.2	2.21	5.94
3	35.11	34.15	0.96	2.81
4	35.19	36.2	1.01	2.79
5	35.39	36.12	0.73	2.02
SURFACE ROUGHNESS (μm)				
1	0.541	0.572	0.031	5.41
2	0.547	0.584	0.037	6.33
3	0.541	0.591	0.05	8.46
4	0.540	0.558	0.018	3.22
5	0.541	0.581	0.04	6.82

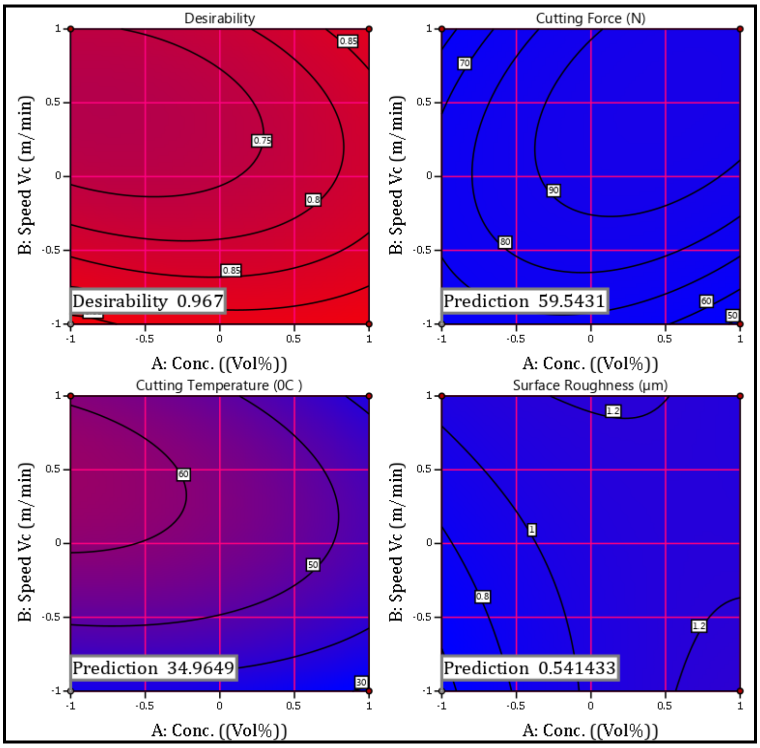


Fig. 9. Desirability value and optimal solutions for responses.

3.9 Confirmation test

To validate the developed mathematical model, a verification experiment was performed. The expected and actual experimental values were compared, and the proportion of error became calculated and as shown in the Table 15.

Figure 9 shows the selected desirability values and optimal solutions for cutting force, cutting temperature, and surface roughness in turning of DSS-2205. The overall desirability obtained 0.967. The overall desirability value near to 1 is acceptable [37] and prediction values for Cutting force 59.543 N, temperature 34.96 ^{0}C, and surface roughness value0.541 μm.

4. CONCLUSION

In the current work, the response optimization was carried out underneath the DF approach in turning of DSS-2205 with hybrid (Al_2O_3+CuO) nanofluid under MQL technique. Experimental outcomes of CF, CT, and SR had been analyzed. The following conclusions were drawn.

1. The analysis of variance (ANOVA) for the experimental outcomes revealed that the feed is the most influential factor for cutting force, followed by the depth of cut, the concentration of nanoparticles, and speed.
2. The depth of cut is the most influential factor for cutting temperature, followed by speed, the concentration of nanoparticles, and feed. For surface roughness, feed is a significant factor, followed by the concentration of nanoparticles, depth of cut, and speed.
3. Response optimization was carried out under desirability function analysis (DFA) the optimum turning parameters for minimizing the responses are volume concentration of nanoparticles (0.3 %), speed (50 m/min), feed (0.051 mm/rev) and DOC (0.4 mm).
4. Confirmation experiments were conducted for the first five optimal solutions obtained from DFA. The average percentage of error obtained for predicted and actual values are acceptable range 5.62 %, 3.56 %, and 6.04 % respectively for cutting force (CF), cutting temperature (CT), and Surface roughness (SR). It tends to be said that experimental models created were genuinely well.
5. In the current study turning operation was conducted with hybrid nanofluids of 50:50 proportions. In future work, we can vary the proportions, concentration of nanoparticles and MQL flow rate, this will helps to analyze the material behavior and evaluate the other response like a tool wear rate also since DSS-2205 having more toll wear rate.

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Nomenclature

CCF	Central composite face centered
CF	Cutting force
CT	Cutting temperature
SR	Surface roughness
DOC	Depth of cut
Conc.	Concentration
RSM	Response surface Methodology
DFA	Desirability function analysis
DSS	Duplex stainless steel
MQL	Minimum quantity lubrication
DI water	Deionized water
V_C	Cutting speed
DOE	Design of experiments